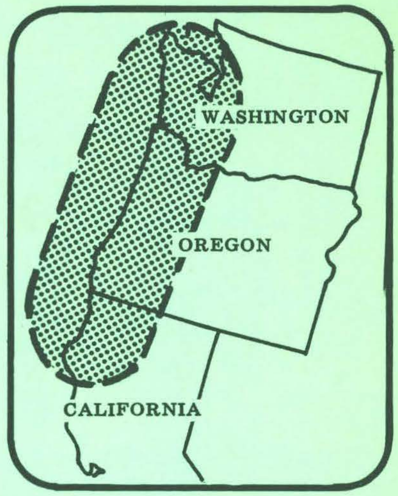
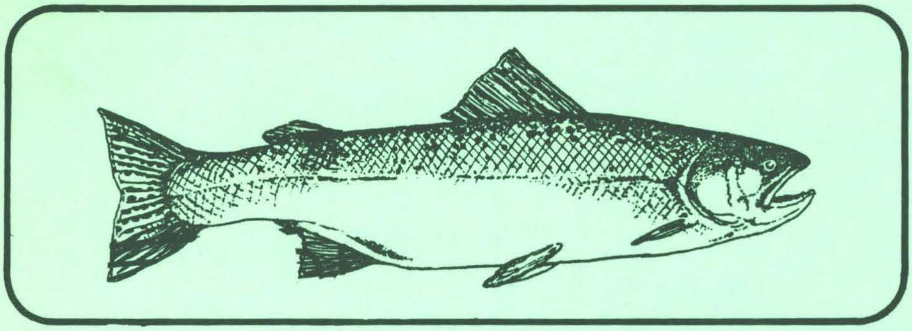
Biological Services Program

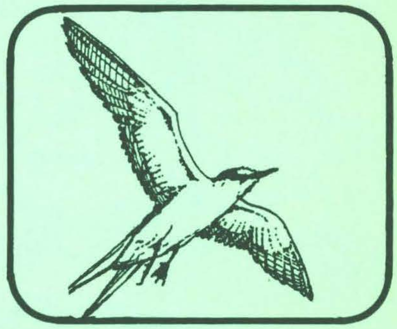
FWS/OBS-79/12
July 1980

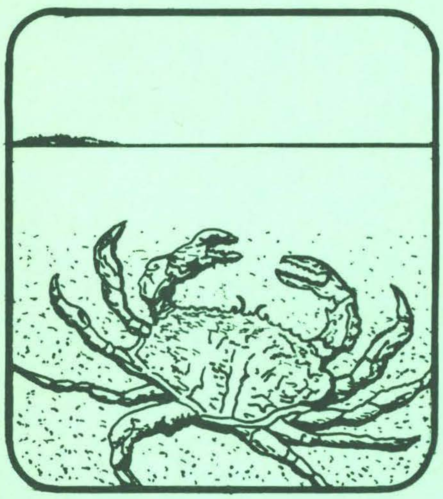
An Ecological Characterization of the Pacific Northwest Coastal Region

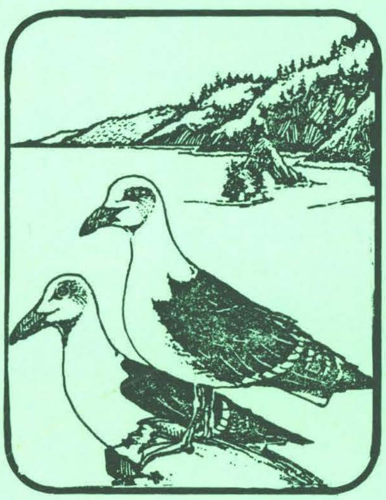
VOLUME 2
CHARACTERIZATION ATLAS-REGIONAL SYNOPSIS

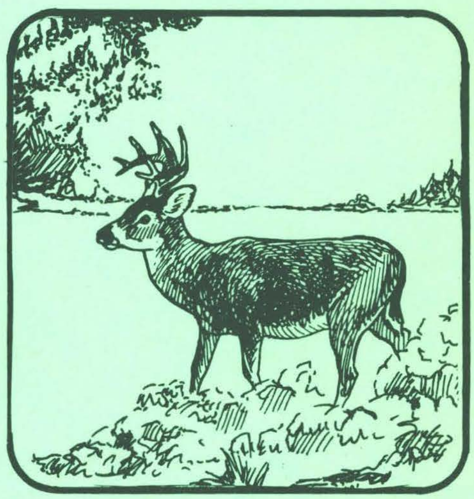












Interagency Energy-Environment Research and Development Program

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
AND
Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.

- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.

- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process to prevent or minimize the impact of development on fish and wildlife. Research activities and technical assistance services are based on an analysis of the issues a determination of the decisionmakers involved and their information needs, and an evaluation of the state of the art to identify information gaps and to determine priorities. This is a strategy that will ensure that the products produced and disseminated are timely and useful.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; geothermal, mineral and oil shale development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; and systems inventory, including National Wetland Inventory, habitat classification and analysis, and information transfer.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Staff, who provide a link to problems at the operating level; and staff at certain Fish and Wildlife Service research facilities, who conduct inhouse research studies.

FWS/OBS-79/12
JULY 1980

AN ECOLOGICAL CHARACTERIZATION
OF THE PACIFIC NORTHWEST COASTAL REGION

VOLUME TWO

CHARACTERIZATION ATLAS -
REGIONAL SYNOPSIS

Prepared by
Charles M. Proctor, Project Manager
John C. Garcia, Technical Director
David V. Galvin, Technical Editor
Gary C. Lewis
Lincoln C. Loehr
Alison M. Massa, EDAW

Ryckman, Edgerley, Tomlinson & Associates, Inc.
a division of Envirodyne Engineers, Inc.
100 116th Avenue Southeast
Bellevue, Washington 98004

U.S. Fish and Wildlife Service
Contract No. 14-16-0009-77-019

Project Officer
Jay F. Watson
Office of Biological Services - Region 1
U.S. Fish and Wildlife Service
Lloyd 500 Building, Suite 1650
500 N.E. Multnomah Street
Portland, Oregon 97232

Performed for
National Coastal Ecosystems Team
Office of Biological Services
Fish and Wildlife Service
U.S. Department of the Interior

PREFACE

The concept and organization of deliverable reports for this study gradually evolved during the first year of the project. In the early stages, the Conceptual Model was to contain a considerable amount of regional data plus the zone and habitat descriptions and habitat-specific models. The early drafts, 3 June 1977 and 23 November 1977, had that structure.

After completion of the Pilot Study (report of 23 November 1977 and exhibits) it became evident that the reporting structure was unsatisfactory for two reasons. First, the sheer physical bulk of material for the Conceptual Model would exceed any convenient size to be bound within one cover and would need to be divided into two or more books for ease of handling. Second, and more important, it became apparent that much of the material that was in the Conceptual Model of November 1977 really belonged in the Characterization Atlas. The structure of reports was therefore changed, in February 1978, to the form described in Section iii of the Introduction and Users' Guide which follows this Preface.

The general framework for organizing the Ecological Characterization is contained in the Conceptual Model (Volume 1). The Model now forms the basis for organization and synthesis of data to provide, in this Regional Synopsis, an ecological overview of the Pacific Northwest Coastal Region.

The Characterization Atlas then continues with Zone and Habitat Descriptions and models, and with specific data for the Watershed Units in the next two volumes.

Questions or requests for this publication should be addressed to:

Information Transfer Specialist
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
NASA-Slidell Computer Complex
1010 Gause Blvd.
Slidell, Louisiana 70458

This report should be cited:

Proctor, C. M., et al. 1980. An ecological characterization of the Pacific Northwest coastal region. 5 vol. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-79/11 through 79/15.

TABLE OF CONTENTS

CHAPTER AND SECTION	PAGE

CHAPTER AND SECTION | PAGE

CHAPTER AND SECTION	PAGE

CHAPTER AND SECTION	PAGE

PART 3. REFERENCE DATA

LIST OF FIGURES

FIGURE NUMBER PAGE

INTRODUCTION

PART 1. REGIONAL CHARACTERIZATION

FIGURE NUMBER		PAGE

FIGURE NUMBER		PAGE

FIGURE NUMBER		PAGE

FIGURE NUMBER		PAGE

LIST OF TABLES

TABLE NUMBER		PAGE

Region

TABLE NUMBER		PAGE

TABLE NUMBER		PAGE

TABLE NUMBER		PAGE

TABLE NUMBERS		PAGE

TABLE NUMBER		PAGE

PART 2. SPECIES OF CONCERN

LIST OF CONTRIBUTORS

Contributors are listed by name, affiliation, and contribution to this volume. RETA/Envirodyne Engineering, Inc. personnel are identified by RETA. Faculty consultants are identified by institution and department - SPU, Seattle Pacific University; UW, University of Washington. Graduate students are identified by institution only. Subcontractor personnel are identified by EDAW for EDAW, Inc., San Francisco, CA, who prepared Chapter 4. Independent consultants are identified by the word Consultant. The act of contributing does not necessarily constitute endorsement. The responsibility for this document rests with RETA, Bellevue.

Baergen, Arlene, RETA: Secretary; document makeup and typing coordination

Barnes, Dr. Clifford A., UW Oceanography: review oceanographic text

Brown, Dr. George W., Jr., UW Fisheries: bibliographic system

Caple, Kathleen, RETA: Graphics illustrator

Cole, Dr. Dale W., UW Forestry: review old growth ecosystem model

Collias, Eugene E., UW Oceanography: review oceanographic text

Crew, Martha E., RETA: Graphics Coordinator; cartography

Galvin, David V., RETA: Technical Editor; general biology, ecosystem summaries, soils, document management

Garcia, John C., RETA: Technical Director; old growth and emergent vegetation ecosystems, succession, species and areas of concern

Gessel, Dr. Stanley P., UW Forestry: review old growth ecosystem model and notes, terrestrial succession

Hoth, Margaret L., RETA: Graphics Coordinator; species of concern, models

Joyner, Dr. Timothy, RETA: physical-chemical descriptions

Lewis, Gary B., RETA: eelgrass, unprotected beach, and euphotic pelagic ecosystem

Loehr, Lincoln C., RETA: oceanography, physical-chemical descriptions and models, unprotected beach and euphotic pelagic ecosystems

Massa, Alison M., EDAW: Manager; socioeconomic text

Phillips, Dr. Ronald C., SPU Biology: review eelgrass ecosystem model and notes

Proctor, Dr. Charles M., RETA, Project Manager: project and model concepts and development, review, editing, regional summary

Schreuder, Dr. Gerard F., UW Forestry: review socioeconomics in early draft

Silver, Larry D., EDAW: socioeconomic analysis

Stednick, John D., UW: forest hydrology

The following people provided technical/editorial assistance. FWS indicates Fish and Wildlife Service and BLM stands for Bureau of Land Management, both of the U.S. Department of the Interior.

Bunce, Elaine: FWS

Byrne, John: FWS

Hedgepeth, Joel: Consultant

Jamison, Dave: State of Washington, Department of Ecology

Jensen, William: Consultant

Johnston, James: FWS

Keene, Don: BLM

Kline, Gary: FWS

Kroger, Richard: FWS

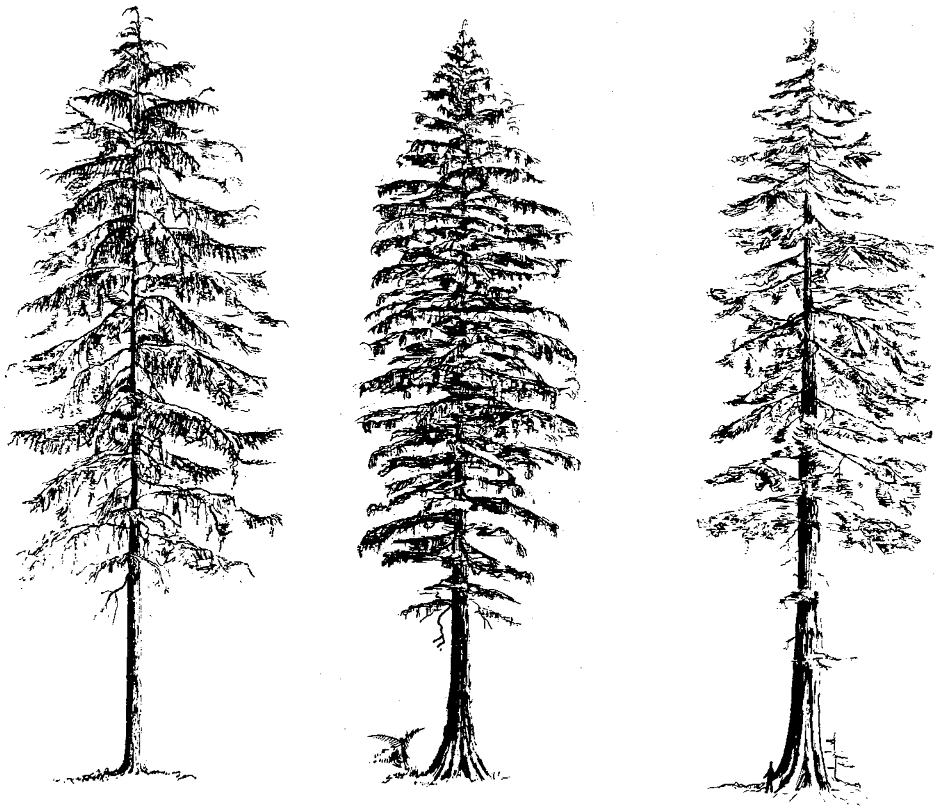
Watson, Jay: FWS

Willet, Charlotte: Consultant

Yoshinaka, Marvin: FWS

Young, Martha: FWS

Barbara Carney and Daisy Singleton, FWS, provided clerical assistance in preparing the camera-ready document.



THREE OF THE BIG TREES OF THE PACIFIC NORTHWEST COASTAL REGION. From left to right they are: western hemlock, Port Orford cedar, and redwood, drawn the same size for better comparison of shape. Discussion will be found in Part 2, Species of Concern.

INTRODUCTION AND USERS' GUIDE

i. Introduction and Objectives of the Study

The Ecological Characterization of the Pacific Northwest Coastal Region is one of four similar projects of the Fish and Wildlife Service to characterize key coastal areas of the United States in order to provide the means of assessing and minimizing impacts of human activities on important fish and wildlife habitats.

When decisions must be made in land use planning and resource development matters, administrators and planners need an integrated overview of the ecosystems in the locale which may be affected, including the influences of man's activities. This overview must identify the important components of the ecosystem, the interrelationships of these components, how the ecosystem functions and changes, both seasonally and over the long term, and information that is missing. The scientist also needs to know the status of present ecological knowledge in the area.

The ecological characterization is intended to serve the needs of both these groups: to aid decision-makers by supplying an integrated body of information in such form as to enable impact assessment and analyses, and to make apparent research needs to complete the data base.

The ecological characterization compiles and integrates information currently available concerning ecosystems of the study area, but does not claim to include all the data needed for detailed assessments of impacts. The characterization should enable decision-makers to ask the right questions.

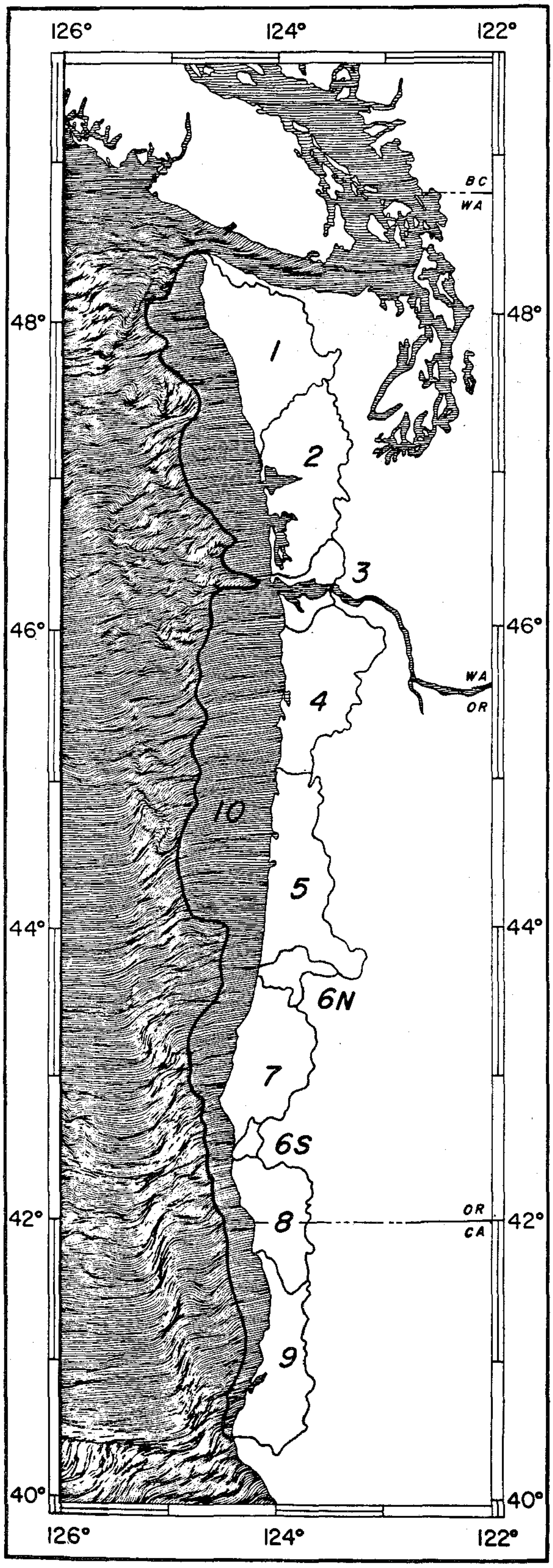
The specific objectives of the Study, as stated in the Request for Proposal, are:

1. To obtain and synthesize available environmental data which identify and describe important resources, ecological processes, and their interrelationships within the study area and to provide an analysis of their functional relationships.
2. To identify additional information that may be required to more completely characterize the study area and recommend special studies to fulfill this need.
3. To present information obtained in the form of detailed reports, graphic illustrations, and descriptive models.

ii. The Study Area

The Pacific Northwest Coastal Region (Figure 1) extends from Cape Mendocino, California, on the south to Cape Flattery, Washington, on the north - a distance of about 900 kilometers (560 statute miles) - and encompasses the area between the crest of the coastal range and the 200 meter (600 foot) depth contour on the continental shelf - an average width of about 80 kilometers (50 miles). This expanse coincides with the Columbia Province of Cowardin et al. (1977). In Terrell's (1977) hierarchical regional classification: at Level I, the study area is H. Northwest Pacific, except for H.3. Puget Sound; at Level II, it is H.1. Pacific Northwest plus H.2. Columbia River Estuary to the tip of Puget Island.

This long, narrow coastal strip slopes steeply from east to west. The characteristics of plant and animal communities in the study area change rapidly with elevation change. Although the area extends over 8 degrees of latitude, variations in life forms usually associated with latitudinal effects on climate are minimized by the moderating influence of the North Pacific Current. General divisions of the coastal region by topography, land form, and human influence are shown in Figure 2 and further division into biological zones is shown in Figure 3-1 of Chapter 3.



PACIFIC NORTHWEST COASTAL REGION WATERSHED UNITS

1 Olympic Rainforest

2 Willapa - Grays Harbor

3 Columbia Estuary

4 Oregon North Coast

5 Oregon Mid Coast

6 Lower Umpqua and Lower Rogue

7 Coos - Coquille

8 Oregon - California Border

9 Redwood Coast

10 Continental Shelf

FIGURE 1. LOCATION OF THE STUDY AREA AND ITS DIVISIONS. Note that "Unit #10" - the Continental Shelf - is not a Watershed Unit as such, but is a distinct portion of the study area and is numbered to facilitate bibliographic and other reference to oceanic data. Table 1 has a brief description of each Watershed Unit. (Map based on McGary, 1971.)

TABLE 1. WATERSHED UNITS.

Number	Name	Description[a]
1	OLYMPIC RAINFOREST	NW and SW Olympic Peninsula, Areas 20 and 21
2	WILLAPA-GRAYS HARBOR	Willapa Bay and Grays Harbor and their tributaries except the upper Chehalis, this includes Areas 22 and 24, lower Chehalis and Willapa.
3	COLUMBIA ESTUARY	Columbia River and its tributaries west of Puget Island
4	OREGON NORTH COAST	North Coast, Area 1
5	OREGON MID COAST	Mid Coast, Area 18
6	LOWER UMPQUA AND LOWER ROGUE	The lower parts of Umpqua, Area 16, and Rogue, Area 15
6N	LOWER UMPQUA	The lower reach of the Umpqua River and its tributaries west of Scottsburg
6S	LOWER ROGUE	The lower reach of the Rogue River and its tributaries west of Agness
7	COOS-COQUILLE	South Coast, Area 17
8	OREGON-CALIFORNIA BORDER	Area 17A of Oregon and the Smith River of California (to Point St. George)
9	REDWOOD COAST	The California Coast from Point St. George to Cape Mendocino. Redwood and Bear Creeks are totally within the area; only the lower reaches of the Klamath, Mad, and Eel Rivers are included.
10	CONTINENTAL SHELF	The ocean and the atmosphere of the Pacific NW coastal region. Not a watershed unit, this area is treated in Volume 2 - the Regional Synopsis and is numbered for bibliographic and other reference purposes.

[a]Based largely on Water Resource Inventory Areas defined (and numbered) by the State of Washington Department of Water Resources and the State of Oregon Water Resources Board (PNRBC, V.2, Fig. 666, p. 780, 1970).

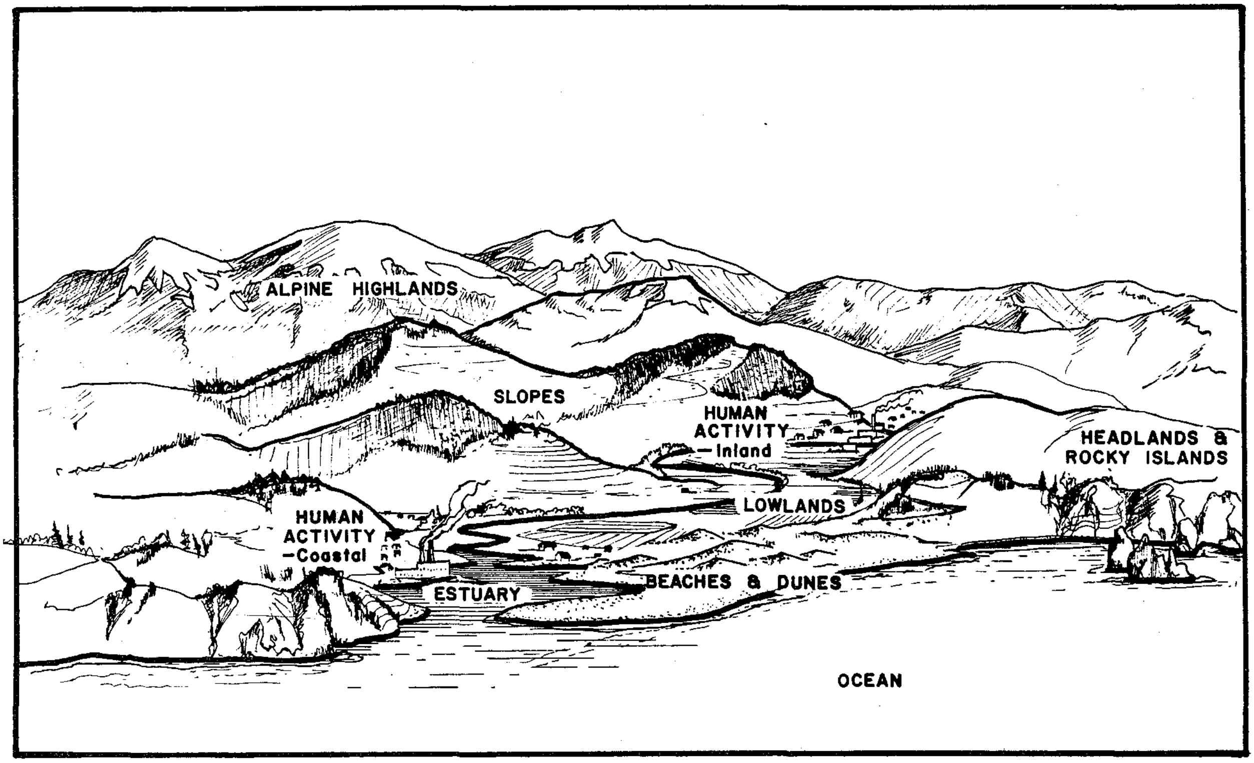


FIGURE 2. GENERAL DIVISIONS OF A COASTAL WATERSHED. Topography, land forms, and human influences are used to divide a region into gross areas of similarity, within which biological zones and their component habitats are delineated. (See Figure 3-1, in Chapter 3.)

Aside from elevation, the most profound effects on the zonation of life forms along the Pacific Northwest Coast are produced by the prevailing winds (as influenced by mountain masses) and the extent and configuration of the watersheds. To provide ecologically coherent subunits for the study, watersheds have been grouped along the general boundaries used in the Pacific Northwest River Basin Water Resources Study into nine Watershed Units having generally similar physiographic and hydrologic features, as shown in Figure 1 and listed in Table 1.

iii. Approach to the Study and Organization of Documents

To organize the collection, synthesis, and presentation of the data to be used for the ecological characterization of the study area, a Conceptual Model of the Pacific Northwest coastal ecosystems was developed. The Model was tested in the Pilot Study (Test Characterization of Coos-Coquille Watershed Unit 7) and was then extensively revised and reorganized. It now forms a comprehensive framework on which this Characterization is based.

The organization of documents for this study is illustrated in Figure 3. The Conceptual Model is Volume 1 of the Ecological Characterization of the Pacific Northwest Coastal Region. It is followed by Volume 2, Characterization Atlas - Regional Synopsis, which comprises the entire study area and, using the same outline and the models of Volume 1, includes information which is characteristic of the region as a whole and is not specific to the Watershed Units. The Regional Synopsis also includes detailed descriptions of species which are important to the Pacific Northwest for economic, ecological, and esthetic reasons. The modeling is continued and expanded in Volume 3, Characterization Atlas - Zone and Habitat Descriptions, which includes food web, community composition, succession, and ecosystem models for habitats in the biological zones of the region.

In Volume 4, Characterization Atlas - Watershed Unit Descriptions, specific data and/or references are given for each of the Watershed Units. This information is organized and presented primarily in the form of a summary and references, corresponding to sections of Volumes 1 and 2, rather than as an expanded independent document for each unit. Volume 5, Data Source Appendix, contains the Data Gap Report and an explanation of the Annotated Bibliography and Species Lists, computer tapes, programs, and print-outs of which will be on file with Region 1, U.S. Fish and Wildlife Service.

The same general chapter outline is used for the Model, the Regional Synopsis, and each of the Watershed Unit Descriptions in the Characterization Atlas. Thus Section 2.2.3 is Seismicity and Faults in each of these documents, ranging from a general description of the subject to a Pacific Northwest overview to a presentation of site-specific references.

iv. Development and Presentation of the Models

Environmental and ecological models are arranged to proceed from the simple to the complex and from the general to the specific. A detailed discussion of the modeling effort will be found in the Introduction to the Conceptual Model, Volume 1. Basic concepts are presented in Chapter 1 of that volume. Models of the physical-chemical environment are in Chapter 2, models of biological systems are developed in Chapter 3, and of man's activities in Chapter 4. The models are then applied in organization and preparation of this volume, the Regional Synopsis, in which a regional overview is given. Zone and habitat models are further developed in Chapter 3 of this volume and selected habitat models (food web, community composition, succession, environmental indices, and ecosystem) are incorporated into the Zone and Habitat Descriptions, Volume 3.

v. Access to Characterization Information - A Brief Users' Guide[1]

The foregoing discussion, figures, and tables present an introduction to the study area and the general structure of the Ecological Characterization. Organization of the reports is shown in Figure 3 and in the outline of Table 2. This introduction sets a logical sequence for familiarization of the reader with the study. The following paragraphs should further help the user to find specific information within these volumes.

Volume 1 - the Conceptual Model - should be read, or at least scanned, in its entirety before the other four volumes are used.

For many readers, the information presented in Volume 1 will be familiar, but a basic understanding of the outline, modeling approach and development, biological zonation, etc., used in this study is crucial to the usefulness of the other volumes. A user familiar with the contents and approaches of the Model will find easy access to the Characterization data of these other volumes. Volume 1 also serves to bring all readers, regardless of background, to a level of understanding of basic ecology and modeling, as related to the Pacific Northwest, that will enable them to use the models and data in the Atlas. The outline of Volume 1 is also followed in Volumes 2 and 4 for easy access to subjects, as described below.

Volumes 2, 3, and 4 - the Characterization Atlas - can be approached generally (in sequence) for an overall treatment of the Pacific Northwest Coastal Region, or selectively by subject following the common outline.

A brief overview and summary of significant facts about the study area is found in Chapter 1 of Volume 2, and about the Watershed Units in Chapter 1 of each Unit of Volume 4. Specific topics can be followed from general discussion and models (Volume 1) to regional characteristics (Volume 2) to general habitat descriptions (Volume 3) to watershed-specific references (Volume 4). Soils, for example, can be traced in this way by turning to Section 2.2.5 of Volumes 1 and 2 and each unit of Volume 4. In addition, soils that are characteristic of each biological zone are discussed briefly on the zone description pages in Part 2 of Volume 1 and in Volume 3.

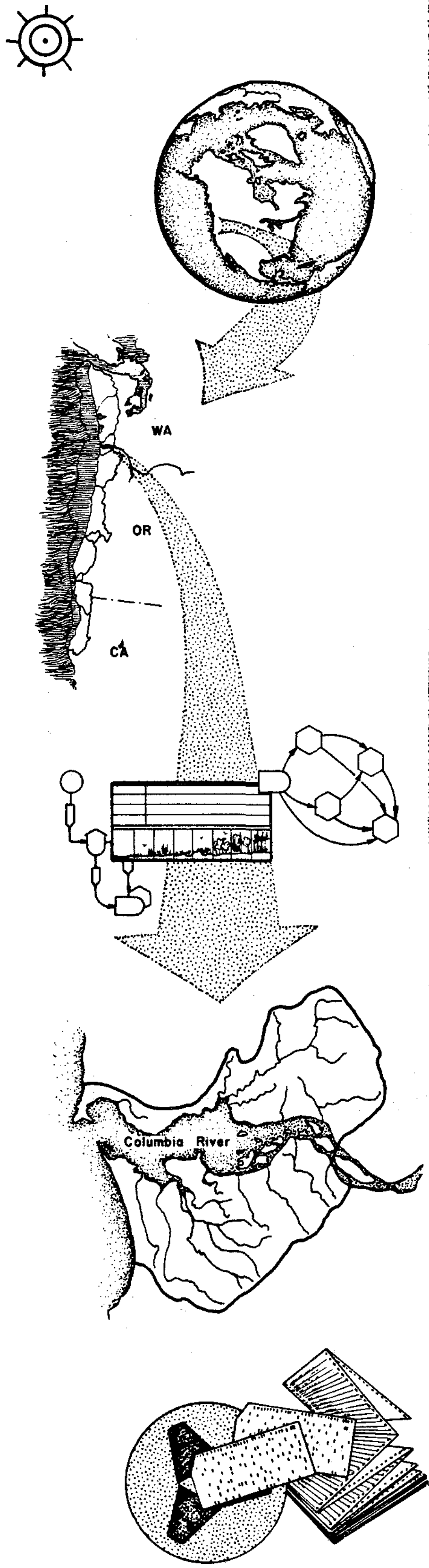
The Zone and Habitat Descriptions in Volume 3 contain models for the region including food web, community composition, succession, and ecosystem models for various biological zones and habitats.

The computer tape, programs, and print-outs of the Annotated Bibliography and Species Lists, on file at Region 1, USFWS in Portland, Oregon, can be used for machine or manual searching. Separate Lists of References were prepared for each volume; lists for the individual Watershed Units in Volume 4 are annotated. Community composition lists and food webs in Volume 3 were generated from the Annotated Species List.

Once the reader is familiar with these documents, it should be a fairly easy task to find specific data and to use the models to determine significant functional information. Specific approaches to this information include access by habitat, area, man's activity (potential impacts), species, and subject as outlined:

(1) Access by habitat. First determine the broad category - inland, coastal, oceanic, or human activity - of the type of area of concern, and then its location in the first level of breakdown within this category - slopes and lowlands, estuarine, coastal human activities, etc. - as

[1] Note: specific sources of user information are underlined in this section to make them stand out from the rest of the text.



VOLUME ONE

CONCEPTUAL MODEL

(General Ecosystem Modeling)

VOLUME TWO

CHARACTERIZATION ATLAS — REGIONAL SYNOPSIS

(Pacific Northwest Coastal Region Overview)

VOLUME THREE

CHARACTERIZATION ATLAS — ZONE & HABITAT DESCRIPTIONS

(Models and Descriptions)

VOLUME FOUR

CHARACTERIZATION ATLAS — WATERSHED UNIT DESCRIPTIONS

(Site Specific Data for 9 Units)

VOLUME FIVE

DATA SOURCE APPENDIX

(Data Tapes and Printouts)

FIGURE 3. ORGANIZATION OF THE ECOLOGICAL CHARACTERIZATION OF THE PACIFIC NORTHWEST COASTAL REGION. See the Introduction and Users' Guide of Volume 1 for more information.

TABLE 2. ORGANIZATION AND PRESENTATION OF THE DELIVERABLE REPORTS.

Title of Document Series:

AN ECOLOGICAL CHARACTERIZATION OF THE PACIFIC NORTHWEST COASTAL REGION

Titles of Volumes, Units, Parts:		Page Designator[1]
Volume 1	CONCEPTUAL MODEL	Model
Part 1	Ecological Modeling Introduction and Chapters 1 through 4	
Part 2	Zone and Habitat Classification Zone descriptions pages with, for each zone, a table of equivalent habitats in other classification systems	
Part 3	Reference Data Glossaries of symbols and terms, lists of abbreviations, English-metric conversions, and bibliographic references	
Volume 2	CHARACTERIZATION ATLAS - REGIONAL SYNOPSIS	Region
Part 1	Regional Characterization Introduction and Chapters 1 through 4	
Part 2	Species of Concern	
Part 3	Reference Data (Same as Volume 1)	
Volume 3	CHARACTERIZATION ATLAS - ZONE AND HABITAT DESCRIPTIONS	Habitat
Part 1	Classification and Modeling	
Part 2	Zone and Habitat Descriptions Descriptions and models of zones and habitats	
Part 3	Reference Data (Same as Volume 1)	
Volume 4	CHARACTERIZATION ATLAS - WATERSHED UNIT DESCRIPTIONS	
	Introductory and General Pages	Watersheds
Part 1	The Watershed Units	
Unit 1	Olympic Rainforest	1. Olympic
Unit 2	Willapa-Grays Harbor	2. Willapa
Unit 3	Columbia Estuary	3. Columbia
Unit 4	Oregon North Coast	4. OR-North
Unit 5	Oregon Mid Coast	5. OR-Mid
Unit 6	Lower Umpqua and Lower Rogue	6. Umpqua-Rogue
Unit 7	Coos-Coquille	7. Coos
Unit 8	Oregon-California Border	8. OR-CA Border
Unit 9	Redwood Coast	9. Redwood
	Each Unit contains a general summary chapter, topic outline with key to literature, and Unit-specific Annotated Bibliography.	
Part 2	Reference Data Same as Volume 1, with Annotated Bibliography applicable to <u>all</u> Watershed Units	Watersheds
Volume 5	DATA SOURCE APPENDIX - Reference Materials	Data
Part 1	Annotated Bibliography	Refs
Part 2	Annotated Species Lists	Species
Part 3	Data Gaps Report	Gaps
Part 4	Data Tape	Tape

[1] See Page Designation and Numbering, Section vi.

illustrated in Figure 2 and the lists given in Table 1-1 of Volume 1. Next, determine the biological zone in which the area is found by reading the zone description pages in Volume 3, and finally determine the habitat type within the appropriate zone by the same process, using the habitat description pages of Volume 3.

Models and data on the selected habitat type are presented in Volume 3 for the region and in Volume 4 for watershed-specific addenda to the regional information. Key example habitats from the various zones are discussed in further detail in Chapter 3 of Volume 2, especially in terms of the major processes and general characterizing data typical for that zone and habitat in the study region. These habitat models are keyed back to pertinent physical-chemical and socioeconomic models wherever appropriate.

If the habitat name is known in another classification system, it can be located with the aid of the tables in Part 2 of Volume 1. The zone description pages from Volume 3 are reproduced here with, facing each page, a table which lists the habitats that have been identified for that zone and the corresponding habitats in other, major classification systems.

(2) Access by area. Determine the point or area of concern in the Pacific Northwest coastal region, first by the study area key (Figure 1) in the Introduction in order to determine the Watershed Unit, then in the base map (Figure 1-1) of the appropriate Watershed Unit in Volume 4. (Oceanic data which is not pertinent to any single Watershed Unit is presented in Volume 2 and the Oceanic zones and habitats in Volume 3.)

Once the location of the area of concern is established, data for that location can be found in the appropriate Watershed Unit description in Volume 4 and, by referral from that volume, in the regional descriptions in Volume 2. Zone maps are found in each Watershed Unit description. From these and the process described above under "access by habitat," the zone and habitat of the area can be determined and these models and descriptions followed in Volumes 2, 3, and 4 as described above.

Bibliographic references pertaining to a point (e.g. Coos Bay), a Watershed Unit, or a State can be obtained easily by a computer search of the Annotated Bibliography's descriptor field. A printout of the Annotated Bibliography, with an Index by Key Words, is available at Region 1, USFWS in Portland, Oregon, (as Exhibits to Volume 5), making manual searching possible.

(3) Access by man's activities. Several approaches can be made to gain access to the complex interactions of human activities in the study area. The general socioeconomic models of Chapter 4 describe the structure and functions of economic and social/cultural factors in the industries and other major activities of man in the area. The user wishing to assess the potential impacts of a particular action on the natural environment should begin by studying the appropriate activity model and related discussion in Volumes 1, 2, and 4 for an understanding of the complex factors involved in this activity and its component activities (as well as for an understanding of the potential impacts of an action on purely socioeconomic parameters such as population, income, etc.).

The zone and habitat of concern should next be identified and the appropriate ecosystem model closely reviewed for the significant human activities involved in that particular ecosystem or in influencing the inputs, outputs, or internal processes of that system. Human activities acting as secondary regulating factors in these models should be noted as well as the major activities identified by processes and the human activity symbol (). The ecosystem model, in addition to identifying the diverse components and interconnecting processes involved in the system, serves to direct the user to the number of component models elaborated in other parts of the study. For example, the internal biological interactions in the community are addressed in the food web and community composition models for each habitat; the gains and losses of habitat are addressed in the succession models; the input and output of sediment is addressed in the appropriate sediment transport model.

Human actions that affect or influence any of the processes in these models should be addressed in a study of potential interactions and impacts to the system in question. The interactions identified by the use of these models also serve as feedback loops to the natural resource or related components of the socioeconomic models. It should be noted that the models in this study are aids to formulating the right questions, and as such do not pretend to be all-inclusive formulations of answers.

(4) Access by species. The Annotated Species List (ASL) is the key to approaching a particular species or group of species in this study. Computer search and sort capabilities allow an almost unlimited number of approaches, permutations, and combinations from the basic data entered in the ASL, as described in Section 3.3 of the Model (Volume 1) and in Part 2 of Volume 5. A printout of the ASL is on file with Region 1, USFWS, Portland, Oregon and can be searched manually. Community composition lists for several habitats were generated from the ASL (see Volume 3).

Approximately 30 plant and animal species of particular importance in the study area are described in detail in the Species of Concern accounts in Part 2 of Volume 2, following the population model format presented in Section 3.4 of the Model (Volume 1). These are cross-referenced in each community composition list in Volume 3.

(5) Access by subject. As described earlier, Volumes 1, 2, and 4 share a common outline in Part 1 (Chapters 1 through 4). Any subject of interest (e.g. estuarine sediment transport) can be followed from general descriptions and model (Volume 1) to Pacific Northwest regional characterization (Volume 2) to site-specific data (Volume 4) by turning to the same section number (for estuarine sediment transport, Section 2.6.3) in each volume. Zone and habitat descriptions and models in Volumes 3 and 4 have identical page numbering for quick cross-referencing between volumes.

The descriptor field in the Annotated Bibliography has hundreds of key words for rapid machine searching and sorting of references. Any combinations ("ands" or "ors") of these key words can be searched by computer and pertinent references obtained. The same can be done manually, using the Index by Key Words of the print-out (available at Region 1, USFWS) to find those references having the desired combinations of descriptors.

vi. Page Designation and Numbering

Page numbering in all volumes follows the system used in this Model, with page numbers in the lower outside corner and the Page Designator (see Table 2) in the lower inside corner. The numbers of pages, figures, and tables are generally in two parts, the first part being the number of the chapter, the second being the serial number of the page, figure or table within that chapter.

There are a few exceptions to this numbering system. Page numbers in the introductory part of each volume are in small Roman numerals; tables and figures in the Introduction have a single Arabic number. In Part 2 of this Volume, the species of concern accounts are divided into plants (P-page code) and animals (A-page code) and each account begins on a new tens digit (see the Introduction to Part 2 for more explanation). Figures and tables in these sections have single Arabic numbers and complete identification of them must include reference to the species number. The first part of Reference Data page numbers is a capital letter representing the kind of data: G for glossaries, R for reference, and so on.

ECOLOGICAL CHARACTERIZATION
OF THE
PACIFIC NORTHWEST COASTAL REGION

VOLUME TWO
CHARACTERIZATION ATLAS -
REGIONAL SYNOPSIS

Part One

REGIONAL CHARACTERIZATION

Chapters	Pages

Chapter One - THE REGIONAL ENVIRONMENT

Sections | Page

1.1 MAJOR FEATURES OF THE COASTAL ECOSYSTEM

The ocean and mountains bound the study area and determine its environment. Climate is moderated by the ocean and is usually mild. The coastal mountains are generally 3000 to 5000 feet (1000 to 1500 m), but Mount Olympus, in Washington, rises to 7900 feet (2400 m) and the coastal mountains are lower in Southwestern Washington where the Willapa Hills peak at 1000 to 2500 feet (300 to 800 m) and are flanked by the Columbia River and the broad valley of the Chehalis.

The dominant influence on the physical environment is the Pacific Ocean, and especially the California Current. This current moderates the weather, causing temperature to be rather uniform in time and space, i.e. throughout the year and from south to north throughout the region. At lower altitudes, the growing season typically lasts from April to November. The southwest winds of winter bring moisture-laden air from the Pacific which releases much of its load as rain as it moves toward the mountains. In summer, on the other hand, moisture for gardens, lawns, and pastures can be a problem during the peak of the growing season.

The Pacific Northwest Coastal Region contains some of the wettest areas on earth outside the tropic zone. Mean annual rainfall reaches 200 inches or more (over 500 cm) in the coastal mountains of Oregon just east of Lincoln City, and exceeds 250 inches (635 cm) high in the Olympic Mountains of Washington (see Sections 2.3 and 2.3.1). The annual rainfall is fairly uniform at sea level throughout most of the region: between 80 and 100 inches (200 to 250 cm), except around Coos Bay and parts of the Redwood Coast where it drops below 60 inches (150 cm) and around Humboldt Bay where it is 40 inches (100 cm) or less.

Even in the rainforests of the Olympics, heavy downpours are rare. Several inches of rain may fall in a day, but it will be a steady rain, not the violent storms of the Midwest where one or more inches of rain (or hail) may come down in an hour or two. An intermittent, light to moderate drizzle is typical of much of the area during the rainy (winter) season. A rainfall map of the region can be found in the next chapter (Figure 2-17 on page 2-32).

Seasonal variations of insolation are shown in Figure 1-1. The upper curve includes inland portions of the coastal states, plus Idaho and Montana. Cloud cover in the study area significantly reduces the total insolation, and explains most of the differences between the two curves. Also, wind-induced upwelling of cooler, deeper oceanic water nearshore produces coastal fog during the summer and further limits insolation. The two curves probably bracket mean values for the entire study area.

The moist, mild climate of the region supports dense coniferous forests which often extend right to the cliffs at the edge of the sea. These forests are among the most productive (in volume of timber) in the world and contain some of the largest trees in the world. The upwelling areas of the Pacific along the coast are very fertile and support large populations of fish, most notably salmon.

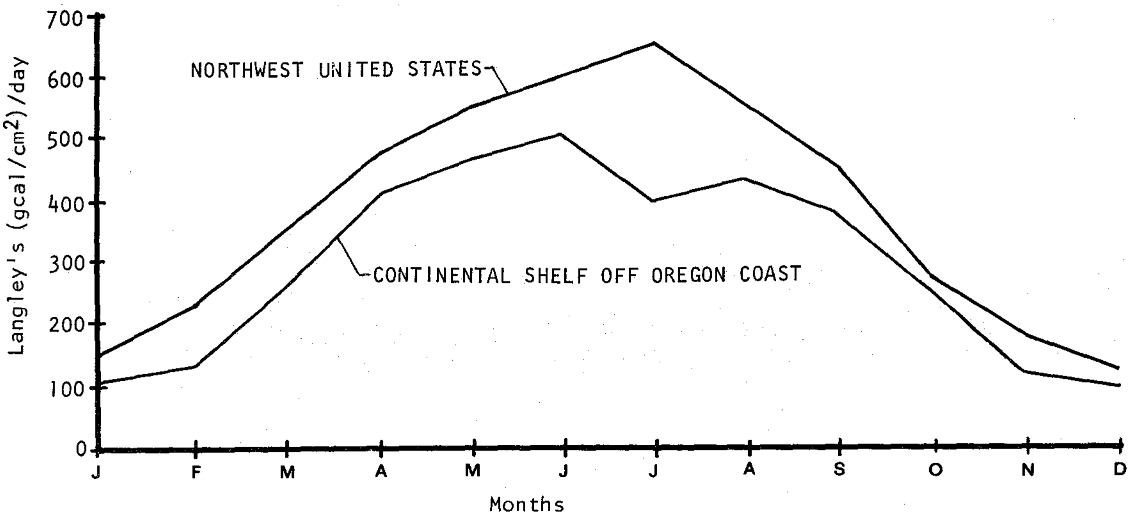


FIGURE 1-1. SEASONAL VARIATION IN INSOLATION. Monthly mean values of net solar radiation are shown for inland areas of the Northwest United States and for the continental shelf. The summer deficit in the coastal values is attributed to coastal fog. (Adapted from Reifsnyder and Lull, 1965, and Lane, 1965.)

The principal industries of the region are based on the wealth of natural resources found there. Agriculture, fishing, forestry, and recreation are the major socioeconomic activities, with forestry and forest products by far the dominant industry. The industries all tend to be seasonal and do not support a very large population.

The entire coastal area contains no major cities and no major seaports. Population is concentrated along the coast, especially near the estuaries where ports provide moorage for fishing vessels and shelter for handling commercial cargoes, primarily related to the forest industry. While Coos Bay is one of the largest wood and wood products handling points in the country (see Section 4.7.1.3), the port handles very little other cargo and the population of the whole Coos Bay-North Bend area is only about 35,000 (Loy et al., 1976). By far the largest part of the shipping, however, is handled by inland ports on Puget Sound (Seattle, Tacoma, Everett), the Columbia River (Portland, Vancouver), and San Francisco Bay. Shipping route distances between coastal ports in the study area, plus San Francisco, are shown in Figure 1-2.

Most of the counties are primarily coastal, i.e., the population and economic base are mainly on the west side of the Coastal Range (Figure 1-3). The four major exceptions - Clallam and Jefferson Counties in Washington, and Lane and Douglas in Oregon - have the county seat and major population areas on the east side of the Coastal Range, outside the study area.

The largest urban complexes in the region are Arcata-Eureka on Humboldt Bay, California, and Aberdeen-Hoaquiam on Grays Harbor, Washington; the population of each complex is not more than about 50,000. The largest city in the study region is Eureka, CA, with a 1970 population of 24,300 (not including tourists and summer visitors). Five other cities in the region had populations (in the 1970 census) of more than 10,000: Aberdeen, WA, 18,500; Coos Bay, OR, 13,500; Newport, OR, 12,300; Hoquiam, WA, 10,500; and Astoria, OR, 10,200.

1.2 THE PHYSICAL ENVIRONMENT

1.2.1 Lithospheric Features. Geologically recent orogenic activity and coastal subsidance have produced a picturesque coast. Rocky headlands and offshore rocks ("sea stacks") are common. They are interspersed with estuaries, dune areas, and sandy beaches.

Large scale tectonic processes over many millions of years have faulted, uplifted, and folded marine sedimentary deposits to form the Coastal Range. These mountains have been and are being shaped primarily by geo-hydraulic processes of erosion, transport, and accretion determined by gradient, snowmelt, precipitation, and runoff. Expansion of moisture in cracks due to freezing increases the breakdown of the rock at higher elevations. Wind erosion is of minor importance.

	San Francisco, Calif. 37°48.5'N., 122°24.0'W.	Eureka	Crescent City	Coos Bay	Gardiner	Florence	Newport	Depoe Bay	Garibaldi	Astoria	Longview	Vancouver	Portland	South Bend	Aberdeen
Eureka, Calif. 40°47.8'N., 124°11.2'W.	232														
Crescent City, Calif. 41°44.5'N., 124°11.4'W.	283	64													
Coos Bay, Oreg. 43°22.4'N., 124°12.5'W.	396	180	125												
Gardiner, Oreg. 43°43.9'N., 124°06.8'W.	411	195	140	42											
Florence, Oreg. 43°58.0'N., 124°06.3'W.	427	212	156	59	36										
Newport, Oreg. 44°37.8'N., 124°03.1'W.	459	244	188	92	69	43									
Depoe Bay, Oreg. 44°48.6'N., 124°03.6'W.	469	254	199	101	78	54	16								
Garibaldi, Oreg. 45°33.3'N., 123°55.1'W.	516	301	245	150	127	102	63	50							
Astoria, Oreg. 46°11.7'N., 123°50.0'W.	567	352	296	201	178	153	115	101	58						
Longview, Wash. 46°06.3'N., 122°57.7'W.	612	397	341	246	223	198	160	146	103	45					
Vancouver, Wash. 45°37.6'N., 122°41.3'W.	647	432	377	281	258	234	196	182	138	80	34				
Portland, Oreg. 45°33.0'N., 122°41.7'W.	652	436	381	285	262	238	200	186	142	85	39	13			
South Bend, Wash. 46°40.1'N., 123°47.5'W.	598	383	327	232	209	184	146	133	90	63	108	143	147		
Aberdeen, Wash. 46°58.4'N., 123°48.5'W.	610	395	339	244	221	196	158	144	102	75	119	155	159	53	
CAPE FLATTERY, WASH. 48°26.0'N., 124°47.0'W.	683	468	411	321	298	273	235	222	179	153	198	234	238	131	117

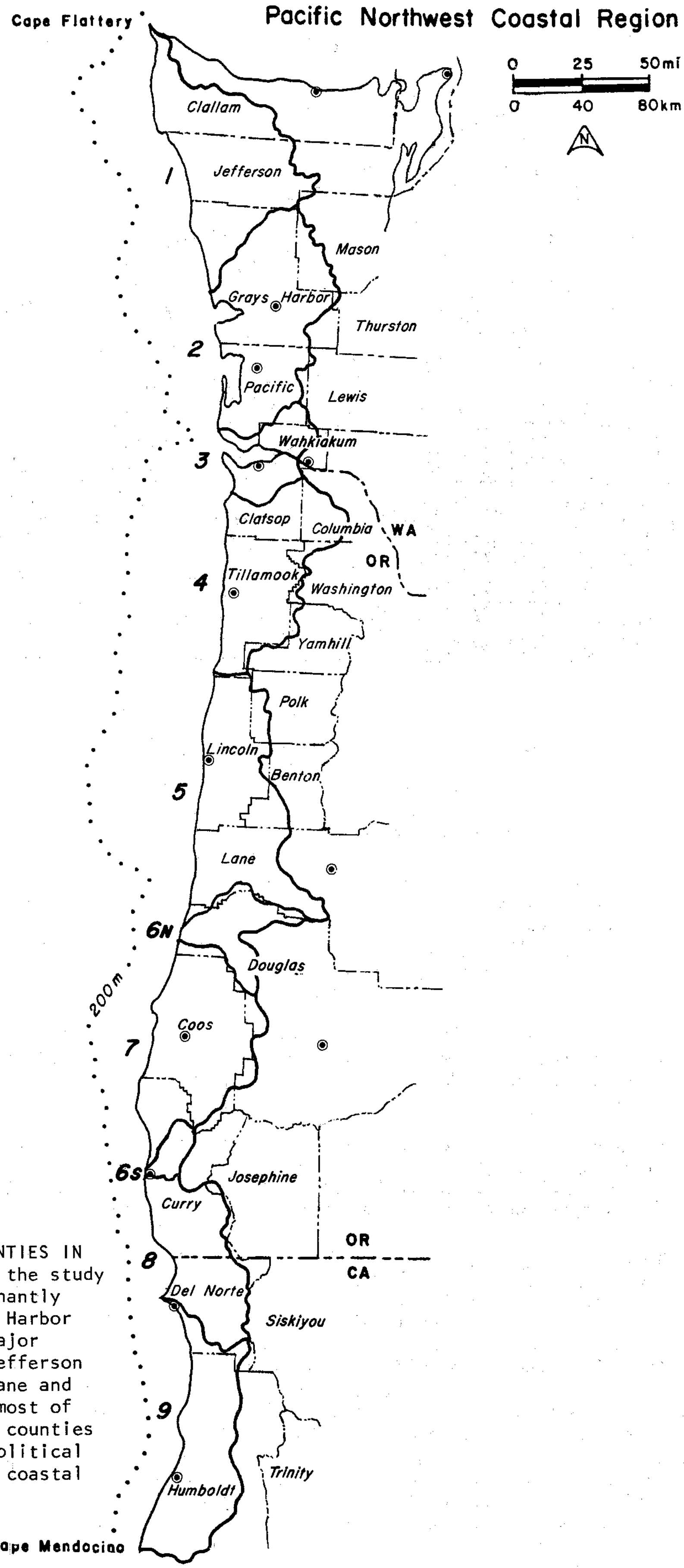
FIGURE 1-2. COASTAL SHIPPING DISTANCES BETWEEN MAJOR PORTS IN THE STUDY AREA. Distances are in nautical miles for the shipping routes between coastal ports of the Pacific Northwest. San Francisco, outside the study area, is provided for reference. (U.S. Department of Commerce, 1976.)

Glacial erosion, although not very significant today, carved large, characteristically "U" shaped valleys deep into the Olympic Mountains, setting the stage for the development of the rain forests. Flowing water and ice are the primary agents of geologic work in the region, with significant effects occurring within human lifespans. The rivers act as agents of erosion and also of transport and deposition of sediments. Deposition occurs in valleys and estuaries, with considerable sediment passing through to the Pacific Ocean, its beaches, the shelf, and beyond.

Although this region is seismically active, the major fault zones are offshore (see Figure 2-1) and damaging earthquakes are seldom felt along this coast, except in Northern California (see Figure 2-5), where the Mendocino Escarpment intersects the coast near the northern end of the San Andreas Fault.

Geological processes provide a wide range of forms and compositions - mountains and slopes, lowlands and wetlands, beaches and dunes, headlands and islands, streams and estuaries, and the ocean - which provide the physical substrates of the vegetative community and which, in turn, strongly influence the assemblage of animals, including man.

1.2.2 Atmospheric Features. The predominant air flow is from the north and west during the summer and early fall (about May through September), shifting to come from the southwest during the rest of the year. The southwest winds tend to be mild in temperature and moist, due to the marine influence. When drier, northerly winds occur, influenced by the land mass of Western Canada, they are cooler in winter, and warmer in summer than the marine influenced air. Compared to the non-maritime climates of the Midwest and the East Coast, the Pacific Northwest Coastal Region experiences very mild winters and summers, lacking lengthy hot or cold spells. Although the humidity is generally high, the combination of high temperature and high humidity that is common in the Midwest and the East seldom occurs here. The result is that the relatively cool summers are not "muggy." Because of the seasonal changes in the wind direction, rainfall is concentrated in the winter months, sometimes referred to by local people as the "monsoon season." This concentration of rain in the winter months differs from the Midwest pattern where it is wetter in summer, and the New England pattern where precipitation is distributed evenly throughout the year (Figure 1-4).



COUNTY BOUNDARIES

◉ **County Seats**

FIGURE 1-3. LOCATION OF COUNTIES IN THE COASTAL REGION. Most of the study area is contained in predominantly coastal counties (e.g. Grays Harbor County, Coos County). The major exceptions are Clallam and Jefferson Counties in Washington and Lane and Douglas Counties in Oregon; most of the population of these four counties and the major economic and political activities are inland of the coastal watershed boundaries.

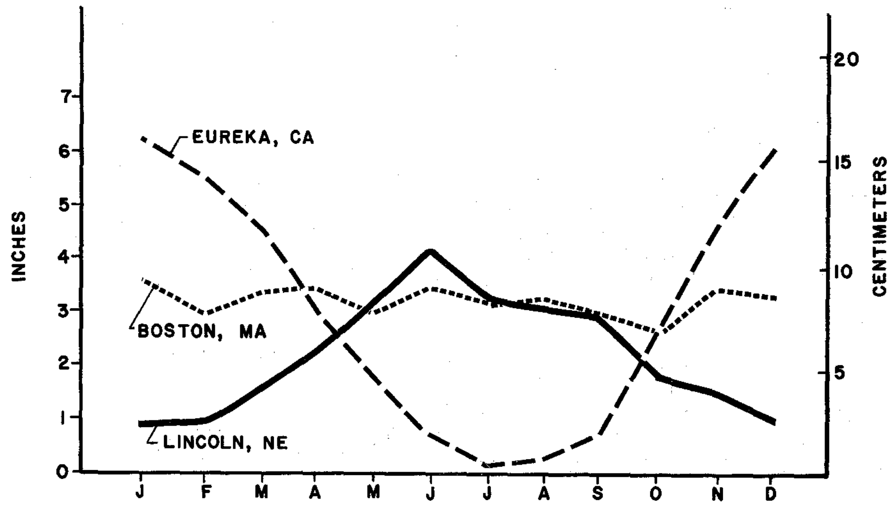


FIGURE 1-4. NORMAL MONTHLY TOTAL PRECIPITATION FOR EUREKA, CALIFORNIA; LINCOLN, NEBRASKA; AND BOSTON, MASSACHUSETTS. These patterns characterize the maritime Northwest, the Midwest, and the New England States. All stations are at approximately the same latitude. Eureka receives less precipitation than most of the Pacific Northwest study region, but the pattern of wet winters and dry summers characterizes the entire region. (Adapted from U.S. Department of Commerce, 1968.)

Mean temperatures at coastal stations are generally between about 40 and 70°F (5 and 20°C) the year around, with little variation from north to south within the region (see Section 2.3.1). However, with increasing elevation as one moves inland, the temperature ranges and extremes become somewhat wider. The coastal climate is only slightly less mild in the basins of Washington's Puget Sound and the Willamette Valley of Oregon. The maritime influence is weaker and the climate less moderate and drier in the mountains behind the Coastal Range in Northern California and Southern Oregon.

1.2.3 Hydrospheric Features. The large amount of precipitation in the study area produces a correspondingly high runoff to the ocean, and the numerous coastal rivers and streams reach the ocean by equally numerous coastal estuaries and lagoons. Many of the rivers have fairly small drainage basins due to the closeness of the crest of the coastal mountains. Their runoff peaks closely follow periods of peak precipitation. Several of the rivers, however, drain much larger inland basins; their peak flows still correlate with storm activity, but may be delayed longer.

The Columbia River is an exception. It is the dominant hydrological feature of the region, draining much of Oregon, Washington, and Idaho. Its drainage basin also includes portions of British Columbia, Alberta, Montana, Wyoming, Utah, and Nevada. The Columbia experiences a late spring peak in runoff that corresponds to peak snow melt. It is also a regulated flow, due to the large network of hydroelectric power dams. The high regional runoff of the Columbia produces a marked dilution of the surface oceanic waters. The plume of the Columbia is traceable at sea as far south as California in the summer, and north beyond Cape Flattery in the winter (see Figure 2-19).

The Fraser of British Columbia and the smaller rivers of Puget Sound drain largely through the Strait of Juan de Fuca, at the Canadian Border. They are a dominant influence off the coast of Washington in summer, as the Columbia outflow is farther south at that time of year.

In most of this area, the soils are deep and rich, due partially to erosion of the steep coastal range, but also to the accumulation of humus from annual litter contributions of the dense vegetation. Because of the nature of the rainfall patterns, steep slopes, and vegetation cover, organic and silt loading of the rivers occurs in pulses. The coastal streams typically rise quickly and become murky during storms, becoming clear again after the storm event has passed. A typical Northwest rain may have little or no observable effect on the streams, being absorbed by the soil and released slowly. This is not always true, however, if the soil is already at or near saturation, if the rain is persistent, or if the rain covers most, or all, of the watershed.

1.3 THE BIOLOGICAL ENVIRONMENT

1.3.1 Biological Zonation. Because of extensive altitudinal and microclimatic differences within the region, a diverse group of terrestrial communities has evolved. Changes in these inland communities are much more visible on a west-east transect than on a north-south transect where changes in community composition are slow and gradual. The rapid west-to-east changes in elevation and concomitant climatic and soil conditions establish these relatively rapid west-east changes in communities.

The steep western flanks of the Coast Range receive a high annual rainfall but also experience extended dry periods. It is here that the western hemlock community, dominated by Douglas fir, occurs. The lower slopes near the shore have less rain but are frequently shrouded in ocean fog during the dry summer months, making this area damper on the average than the upper slopes. This environment is conducive to the development of Sitka spruce forest, which occurs in dense stands, and coastal redwood groves.

For the inland areas of the coastal region in Washington and most of Oregon (Watershed Units 1 through 7), biological zonation is generally very similar and depends mainly on topography and altitude. The geology and soils are different in Southern Oregon and Northern California (Watershed Units 8 and 9), and rainfall is lower. The Western Hemlock Zone, which is dominant in the rest of the region, is replaced in turn by Mixed Evergreen and Redwood Zones in the Klamath Mountains and Northern California coastal lowlands, respectively. (A map of the distribution of inland biological zones is presented as Figure 3-1 of Chapter 3.)

The coastal zones (estuaries, beaches and dunes, and headlands and rocky islands) are determined by landforms, which are functions of the local geology, topography, and wind and water energies, and by differences in elevation with regard to tide. Estuarine zones (subtidal, intertidal, and above tide) develop in the mouths of nearly all of the streams and rivers along the coast. (A list and the locations of the region's estuaries are contained in Figure 2-24.) Beaches, dunes, headlands and rocky islands are found intermittently along the entire coast.

Zonation in the ocean over the shelf is determined by light penetration and relation to substrate (i.e. pelagic vs. benthic). The oceanic zones occur seaward of the Surf Zone along the coast out to the edge of the continental shelf, which approximates the 200 meter (600 ft) depth contour and which varies in width from about 15 to 65 kilometers (9 to 40 mi).

Zones of human activity occur within the inland and coastal zones and are determined by the changes in the environment that result from man's presence and activities. New and modified habitats are produced by earthmoving, pavement, building, and landscaping. Vehicle and pedestrian traffic and household pets have profound effects on the kinds of wildlife that occur in these zones. Proximity to the coast affects the micro-climate and the amount of salt in the air, both of which make differences in vegetation of otherwise similar habitats.

1.3.2 Species of Concern. The plants and animals of the region are of interest not only as components of dynamic zone and habitat ecosystems, but also for commercial, recreational, or conservation importance. The regional forests are among the most productive in the world and support the major industry - forestry and forest products - in the Pacific Northwest. The major commercial tree species are Douglas fir, western hemlock, redwood, western red cedar, Sitka spruce, and grand fir, with Douglas fir making up over sixty percent (by volume) of the timber harvested in the study area.

The fertile waters over the continental shelf, as well as the numerous rivers and streams of the region, support a large and diverse fishery. The most notable fish species of the region, both commercially and recreationally, are the salmonids, particularly chinook and coho. These salmon, which spawn in the coastal rivers, spend time as juveniles in the region's estuaries, maturing in the coastal Pacific Ocean, are harvested commercially at around 30 million pounds per year and for sport at around 5 to 7 million pounds per year in the coastal region. Other fish species of interest include the albacore (tuna), sole, and rockfish, which are harvested commercially over the shelf, and steelhead and cutthroat trout which are sought for sport in the coastal rivers.

Major game species in the study area include black-tailed deer, Roosevelt elk, black bear, and waterfowl. In addition, razor clams are harvested from some of the beaches in the region.

A number of species in the study area are classified as rare, threatened, or endangered by State and/or federal agencies, or are proposed for such classification. These include the Columbian white-tailed deer, Aleutian Canada goose, peregrine falcon, spotted owl, bald eagle, snowy plover, brown pelican, Karok Indian snail, Newcomb's littorine, Cape Mendocino snail, rocky coast snail, Siskiyou Mountain salamander, sea otter, wolverine, and seven whale species, as well as over one hundred vascular plants.

Section 3.4 of Chapter 3 and Part 2 in this volume discuss these species of concern in detail.

1.3.3 Areas of Ecological Concern. Many localities in the region are critical areas for the wildlife and other species of concern mentioned above, or represent unusual or unique landforms or habitat types. Olympic National Park in Washington includes a large part of one of the few temperate zone rainforests of the world, and Redwood National Park in California contains some of the last remaining virgin redwood groves in the world. In general, the region's estuaries are the areas of most critical concern because of the concentrations of human activities that occur in these areas of significant biological importance. Many specific areas in the region have been identified as critical or of special concern. These are discussed in Section 3.5 in this volume and in the Watershed Unit descriptions in Volume 4.

1.4 SOCIOECONOMIC ASPECTS

1.4.1 Human Activity - Population, Income, and Employment. The Pacific Northwest Coastal Region is relatively sparsely populated, with a concentration of urban centers along the coastal strip. The population is made up of a relatively high proportion of elderly people, most of whose income is from outside the region - from Social Security, pensions, and retirement funds. For this reason, and also due to limited employment opportunities, participation in the labor force tends to be lower than the average in each of the three states. Low labor force participation rates, high unemployment, and severe seasonal fluctuations in employment contribute to median family and per capita personal income levels significantly below state averages.

In the region to date, relatively little employment or income is derived from activities not directly linked to local natural resources. Most major sources of income are indirectly resource-related. They include a growing in-migration of retirees and seasonal residents and intervention of the federal government in the form of unemployment compensation, training, economic development programs, and regulation of land and ocean use. Population densities throughout the region are low compared with those of the highly developed Puget Sound and Willamette Valley regions. Unemployment and seasonal employment are more widespread than in those major urban areas, and income levels are generally lower. Thus the western, coastal, parts of Clallam and Jefferson Counties in Washington, and of Douglas and Lane Counties in Oregon are in sharp contrast with the more populous and prosperous eastern parts of the same counties.

1.4.2 Socioeconomic Environment - the Economic Base. The economic base of this coastal region rests on its economically and culturally valuable natural resources. With the exception of minerals, primarily sand and gravel, each of these resources is in demand by markets outside the study area. The largest of these markets is for forest products and this industry provided more than half the employment for basic industries on the Oregon coast in 1973 (see Section 4.9.1.1).

Economically valuable resources include extensive coniferous forests, estuarine and marine fish and shellfish, small areas of productive agricultural land, limited mineral deposits, and a shoreline suitable at several points for more extensive port development. Prospecting for oil on land and on the continental shelf of the region has not been encouraging.

The largely unspoiled natural areas, historic sites, fish, and wildlife are highly visible and valuable recreational and cultural resources. The region also contains ecological valuable and vulnerable resources, including particularly its estuaries, dunes, and beaches, that need to be used with care. Already the dominant economic importance of the forest resource is diminishing as old growth on private lands is harvested.

Agriculture has been declining in importance along the coast and recreation has been increasing; fishing and fish processing have also been increasing, but at a lower rate. These three industries, taken together with water transportation, employ almost as many people as forestry, roughly forty percent of the labor force in coastal Oregon in 1973. The remaining employment is for government and services (see Section 4.9).

1.4.3 Socioeconomic Activities in the Coastal Region. The region is relatively isolated from major population and industrial centers. Transportation routes are limited; fuel and power are mainly imported from outside the region; and the population density is low. Major sources of capital have tended to be national forest industry firms or local processors strongly dependent on them. Much of the region's economic activity is carried out by self-employed individuals in the agriculture, fisheries, and recreation industries who lack extensive capital resources. Participation in the labor force tends to be lower in the region than in the more urbanized areas of each state. This reflects the limited industrial employment opportunities but also represents a potentially valuable human resource.

The basic industrial activity of the region supports a relatively well developed service sector. The relationship between the basic and service sectors in terms of employment and income (the multiplier) is difficult to determine. This is largely because employment in agriculture, fisheries, and recreation, for several reasons discussed in Chapter 4, can only be estimated. In addition, some trade and service activities serve both the local population and tourists and so are partially basic.

Socioeconomic activity in the region is strongly influenced by the fluctuating demand for the products of its resource-based industries. Employment in the forestry and forest products, agriculture, and fisheries industries has been declining for a number of years and is expected to continue to decline as worker productivity increases. The long term outlook for forestry is the subject of debate depending upon assumptions regarding management of the industry. The economic effect of efforts to diversify industrial activity through increasing emphasis on recreation, aquaculture, and crop growing, although promising, do not yet appear to be significant.

Demand for all of the region's natural resources is increasing. At the same time, because of growing understanding both of the effects of over exploitation and of conflicts between uses, government limitations are being placed on resource extraction. Such limitations, and changes in policy regarding the manner in which resources should be used, lead to economic dislocations. Adjustment to such dislocations tends to be difficult and costly due to the region's lack of diversification and its population's traditional ties with a few basic industries. For the same reason, the region is also strongly affected by fluctuations, both cyclic and seasonal, in demand for its resources and products based on them.

Chapter 2 PHYSICAL-CHEMICAL ENVIRONMENT

Included in this chapter are descriptions of those physical and chemical processes that characterize the region. These include land, air, and water processes which create the physical environment that the plants and animals have adapted to. The physical processes are also what man must live with and to which he must adapt. In some cases, such as the damming of large rivers for hydroelectric power generation, these natural physical processes can be harnessed and have value as resources in themselves. In other instances of resource harvesting, such as forestry and fisheries, it is the physical processes that create the environment permitting the growth and development of these resources.

2.1 GENERAL FLOW OF MATERIALS

The environment of the Pacific Northwest Coastal Region is strongly influenced by its marine climate. The region is a moist one, with considerable precipitation released as the marine air blows over land. As the air rises against the western flanks of the coastal mountains, the precipitation increases, and the temperature decreases. Almost all precipitation along the coast occurs as rain, but snowfall is significant in the higher mountains, especially the Olympics. Snowfall inland of the coastal mountains is significant in supplying snowmelt and spring runoff to those rivers draining inland watersheds.

The precipitation exceeds the rate of evaporation and evapotranspiration, with the excess water flowing seaward as runoff and ground water. The highest levels of precipitation in the continental United States occur in this region; extensive rainforests occur in the Olympic Peninsula and precipitation near the peaks of the Olympics reaches 250 inches (635 cm) per year. The amount of runoff for the region is high, and the downhill flow of materials transported by the flowing water is high as well. Most all of the surface runoff enters the ocean via estuaries. Much material is deposited in the estuaries where the gradient is slight and tidal forces oppose the river flow. The runoff passes through the estuaries, combining with salt water in mixing processes important to estuarine circulation and flushing, finally reaching the ocean. The oceanic surface waters of this region are measurably diluted by the land runoff and by direct precipitation.

The ocean acts as a moderator of the regional climate. Temperatures along the coast are mild. Land forms affect the local precipitation and temperature patterns with significant increases in precipitation between the outer continental shelf, the coast, and the flanks of the coastal mountains.

Peak flows of the coastal streams and rivers are associated with peak winter storms. For watershed units with significant storage of water in snowpack or glacial ice, peak flows also occur in the spring due to melting (Watershed Units 1 and 3). Although the inland boundary of the study area is defined as the crest of the coastal mountain range, six rivers actually cut through the coastal range and drain larger inland basins. (A seventh, the Chehalis River in Watershed Unit 2, also extends inland of the selected boundary, but, because there is no significant mountain range in the small Chehalis basin, its overall runoff is relatively small compared to the other six rivers which extend inland of the Watershed Unit boundaries.) The figure showing the locations and sizes of the Watershed Units (Figure 1 in the Introduction) does not provide true representation of the size of these larger drainage basins. The six rivers that cut through the Coastal Range are the Columbia (Watershed Unit 3), the Rogue and the Umpqua (collectively called Watershed Unit 6), and the Klamath, Mad, and Eel Rivers (all in Watershed Unit 9). These rivers are the six largest in the study area; the Columbia River, whose discharge into the Pacific is three times that of all the other rivers in the study area combined, completely dominates the region. The flow of the Columbia is regulated by a large number of hydroelectric dams upstream that supply low cost electricity to the region. As a result, there is a lack of electrical generating stations along this coast (save a single nuclear power plant at Humboldt Bay), in sharp contrast to the coastal areas of the rest of the country.

Almost all of the land runoff of the region enters the ocean via coastal estuaries. Within the estuaries, gradient, tidal forces, and amount of runoff determine much of the estuarine characteristics. Tidal forces have daily, monthly, and seasonal variations; runoff has seasonal variations; and gradient for any given estuary remains essentially constant. Runoff and gradient differences between estuaries therefore account for most of the estuarine variety in the region.

The coastal estuaries are highly productive regions. They are also the avenues through which forest and agricultural products pass in trade, and through which anadromous fish pass enroute to spawning beds upstream. Estuaries also support large resident biological populations. They are the locations of settlement by man, and conflicts between different interest groups occur. The three major industries of forestry, fisheries, and agriculture all rely on and impinge on the coastal estuaries. The problems associated with this multiplicity of use are exemplified by Coos Bay, where there is considerable shipping, log storage, an airport built on fill, and a portion set aside to remain in its natural condition as the first "Estuarine Sanctuary" in the United States (established under the Federal Coastal Zone Management Act of 1972). The Estuarine Sanctuary is discussed later in this chapter, Section 2.6.

Seasonal shifts in wind direction significantly affect the oceanic conditions over the shelf, and in turn have climatic and biologic effects on the region. In the winter time, the winds have a northward component (coming from the southwest) and the Columbia River plume is held close to the Washington coast. In the summertime, the winds have a southward component (coming from the northwest) and the Columbia River plume moves southward. The Coriolis effect causes a moving body to be deflected to the right of its path in the northern hemisphere, and deflects the southward flowing plume such that it extends seaward to the southwest in the summertime. In the winter the Coriolis effect helps to push the north flowing plume onshore.

The summer time seaward flow of surface water (both plume and other) caused by the wind and the Coriolis effect is balanced by upwelling of deeper water near the coast. This deeper water is cooler and rich in nutrients. The continuing supply of nutrients promotes tremendous phytoplankton productivity which in turn supports higher trophic levels, including the commercially and recreationally valuable regional fisheries. The coolness of this upwelled water nearshore creates fog along the coast, further moderating the coastal climate. This climatic effect of coastal upwelling has probably contributed to discouraging dense coastal settlement and development by man which otherwise characterizes the shorelines of the United States.

Regional runoff carries with it considerable amounts of sediment both in suspended and bed loads, and to a lesser extent in dissolved load. The amount of sediment carried by the rivers varies with gradient and velocity. Velocity is dependent on the amount of runoff which varies seasonally and peaks with storm activity. Therefore, sediment discharge will vary with time. As the river flow slows, its capacity to hold sediment decreases and deposition occurs. This happens behind dams, in lakes, and in estuaries. In the estuaries, there is the added influence of tidal flows opposing the river flow. The estuaries are naturally depositional in nature, creating natural successions of habitats, and re-filling in man-made dredged navigation channels. For those estuaries with active shipping and trade, dredging is a never-ending maintenance process.

Fine sediments pass through the estuaries, and make their way seaward. Fine sands may contribute to beach formation, and be transported by wave action both on the beach face and in the surf zone. The Columbia River, for example, has provided the find sands that form Long Beach (18.5 mi or 30 km long) in Southern Washington. Finer sediments may remain in suspension and be transported over the shelf to be deposited on the continental slope or beyond. Deposition of fine sediments on the shelf is temporary, with severe winter wave activity resuspending them and continuing the seaward flow.

Inland, sediment is moved primarily by the downhill, gravity-induced flow of water. Along the shore, sediment is moved by wave action. On the continental shelf, sediment is resuspended, or kept in suspension by wave action, and transported with regional currents.

Dissolved material is transported to the ocean via the rivers and streams, and the estuarine tidal exchanges. Many materials that are dissolved and suspended in freshwater coagulate and precipitate out when mixing with salt water occurs in the estuaries. Estuaries as such can become sinks for heavy metals and other contaminants or pollutants, effectively preventing them from reaching the ocean. Dredging may return contaminants including toxic materials to the water column and eventually to the ocean, and may also reduce the capability of estuarine sediments to absorb and hold potentially toxic substances. A number of studies have been performed in Coos Bay on the effects of dredging on estuarine sediments (Oregon State University, 1977A,B,C).

2.2 LITHOSPHERIC FEATURES

In discussing the lithospheric features of the Pacific Northwest Coastal Region, it is necessary to understand the theory (or theories) of plate tectonics and the processes occurring in the northeast Pacific, beyond the boundaries of our immediate study area.

According to recent theories of plate tectonics (which include sea floor spreading and continental drift), the crust and upper mantle of the earth are subdivided into a series of semi-independent slabs or plates, each of which is moving laterally in response to deeper-seated activity within the earth. Boundaries between plates are characterized by sea floor rises in areas of divergence, trenches in areas of convergence, and transform faults in zones of parallel movement.

A relatively complex border zone has developed in the northeastern Pacific Basin between the Pacific Plate on the west and the North American Plate on the east. As the Pacific Plate moves northward relative to the North American Plate, a right lateral component of movement is experienced along the faults and rises separating the two plates. These areas include the Mendocino Escarpment, the Gorda Rise, the Blanco Fracture Zone, and the Juan de Fuca Rise. The Gorda and Juan de Fuca Plates are caught in the interaction between the North American and Pacific Plates and may be remnants of a once more extensive plate. Figure 2-1 presents the major bathymetric and topographic features of the continental shelf, slope, and deep-sea floor of the northeast Pacific Ocean and its adjacent land mass.

Subduction of oceanic crust occurs where plates converge, and the evidence suggests that subduction is, or was until recently, taking place along a line generally coinciding with the coast of North America between Vancouver Island and Cape Mendocino. The motion may be either slowed or presently inactive, however, since there is no oceanic trench along the plate margin, nor deep-seated earthquakes under the Plate Margin.

The interaction of the Juan de Fuca and Gorda Plates with the North American Plate is responsible for the structural formations that appear in the Klamath Mountains of Northern California and Southern Oregon, the Coastal Range Mountains of Oregon and Southern Washington, and the Olympic Mountains of Northern Washington. The structure of the continental shelf is less well known due to the difficulties of observation and sampling, but may be thought of as an extension of the onshore structural formations. Indeed, the processes of formation were the same.

The bedrock of the study area was bent, folded, fractured, and uplifted by the collision of the Juan de Fuca and Gorda Plates with the North American Plate. Volcanic deposits found in the area may also be attributed to the processes of plate tectonics, with global volcanic activity commonly occurring landward of subduction zones (and along the axis of spreading mid-ocean ridges).

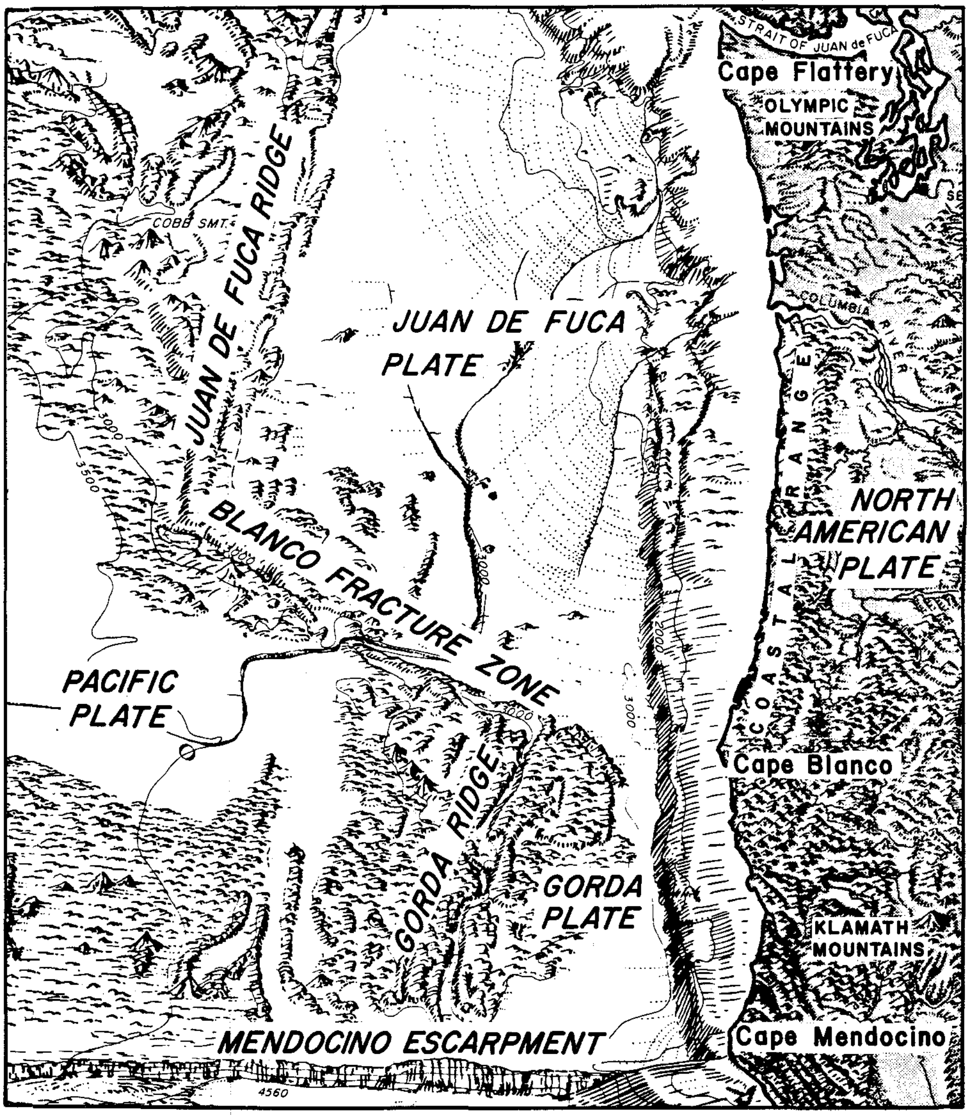


FIGURE 2-1 . TOPOGRAPHIC AND BATHYMETRIC FEATURES OF THE NORTHEAST PACIFIC AND THE WASHINGTON, OREGON, AND NORTHERN CALIFORNIA COASTS. The Mendocino escarpment is an identifiable feature of the north Pacific floor extending westward beyond Hawaii. The escarpment may be an extension of the San Andreas Fault in California. (Adapted from Menard, 1964.)

Regional earthquake activity is concentrated along the Mendocino Escarpment, an east-west trending transform fault which comes ashore at Cape Mendocino and marks the southern boundary of our study area. Offshore of Central and Southern Oregon, earthquake activity occurs along the Blanco Fracture zone, which is a transform fault similar to the Mendocino escarpment. Because the movements are mostly lateral along these faults, there have been no significant locally generated seismic sea-waves (tsunamis) generated by these earthquakes.

The uplifted formations produced by tectonic processes have been modified by weathering. The mountains and valleys in the study area have been and are still being shaped primarily by the erosive power of running water, although glacial erosion in the past has produced characteristic "U" shaped valleys in the Olympic Mountains of Washington. Glacial erosion is significant today only in the Arctic Alpine Zone occurring in Watershed Unit 1 (see Fig. 1). Riverborne sediment is deposited in valleys, estuaries, and beaches. Fine sediment is carried seaward and deposited on the shelf or beyond. The shelf, by contrast, was shaped by the erosive power of breaking waves, and the depth of the shelf edge corresponds to lower sea levels associated with periods of worldwide glaciation. Submarine canyons which incise the outer edge of the shelf in places are related to river drainage patterns at times of lower sea level, and in some cases (e.g. the Astoria and Eel Canyons), are related to existing river channels of today. The present shoreline is shaped by recent wave activity, tidal changes (which allow the waves to act over a wider zone), and resistance of headlands to erosion. These factors continue to alter the shoreline today. In recent years man has begun to influence the shape of the shoreline with jetties, breakwaters, mining of coastal sands, and building and protecting structures on the berm or backshore of beaches.

The boundaries of the study area extend inland to the crest of the coastal mountain ranges, and seaward to the edge of the continental shelf. The southern boundary is Cape Mendocino, where the Mendocino Escarpment meets the coast and the shelf is narrow. The northern boundary is Cape Flattery, where the Strait of Juan de Fuca meets the ocean. All study area boundaries are thus identifiable by lithospheric features, rather than the geologically (and biologically) insignificant, arbitrary, political and jurisdictional boundaries by which many studies and reports are bound.

The land area of the region is approximately 15,300 square miles (39,700 km^2) while the area of the shelf is approximately 13,000 square miles (33,000 km^2). Terrestrial features are more readily observed, and, hence, more detailed information is available for land areas than for the features of the shelf.

Considerable discussion of the lithospheric features of Washington and Oregon and their respective continental shelves is presented by the Oceanographic Institute of Washington (1977). Franklin and Dyrness (1973) more briefly discuss regional lithospheric features which include Northern California. Nearshore and coastal geologic features of the entire study area are briefly discussed by Oregon State University (1971). The OIW (1977) and OSU (1971) reports include extensive bibliographies.

2.2.1 Topography and Bathymetry. Figure 2-2 shows the land forms of the Pacific Northwest Coastal Region. The study area is divided into broad categories of beaches and dunes, open hills, tablelands, low mountains, high mountains, and crests and summits. The categories are based on elevation and percent of area that is gently sloping (defined as less than 8^{o}).

The Klamath Mountains (which include the Siskiyous) make up the coastal range in Northern California and Southern Oregon, and are high mountains in the figure. Crests and summits in Watershed Unit 9 show a strong linear orientation to the north-northwest and are indicative of regional fault structure. Major rivers in Watershed Unit 9 cut through the coastal range, also showing the north-northwest orientation (see Section 2.5). High mountains also occur in Northern Washington where the Olympics rise to greater than 7,000 feet in places. Most of the rest of the study area consists of low mountains, and includes Southern Washington and Northern and Central Oregon. Central Washington, around Grays Harbor and Willapa Bay, is the only significant region of open hills. The gentle gradient is a controlling factor in the size of these two coastal estuaries, which have the greatest amount of intertidal area of all the estuaries in the region (see Section 2.6).

The continental shelf extends from the coast seaward to where there is a definite change in slope at about the 600 foot (200 m) contour. Figure 1 in the Introduction presented a general view of the shelf in the study area. Off Cape Mendocino at the southern end of this study area, the continental shelf is only 10 miles (16 km) wide. To the north, the shelf widens to 20 miles (31 km) at the California/Oregon border and then narrows to 10 mi (16 km) again off Cape Blanco. Off Central Oregon, Stonewall and Heceta Banks extend the shelf out to over 40 mi (65 km). The shelf gradually narrows again to 16 mi (26 km) near Newport, Oregon, and then widens again to 36 mi (58 km) off Northern Oregon and Southern and Central Washington. Off Northern Washington, the shelf narrows to about 30 mi (48 km). The Juan de Fuca Canyon

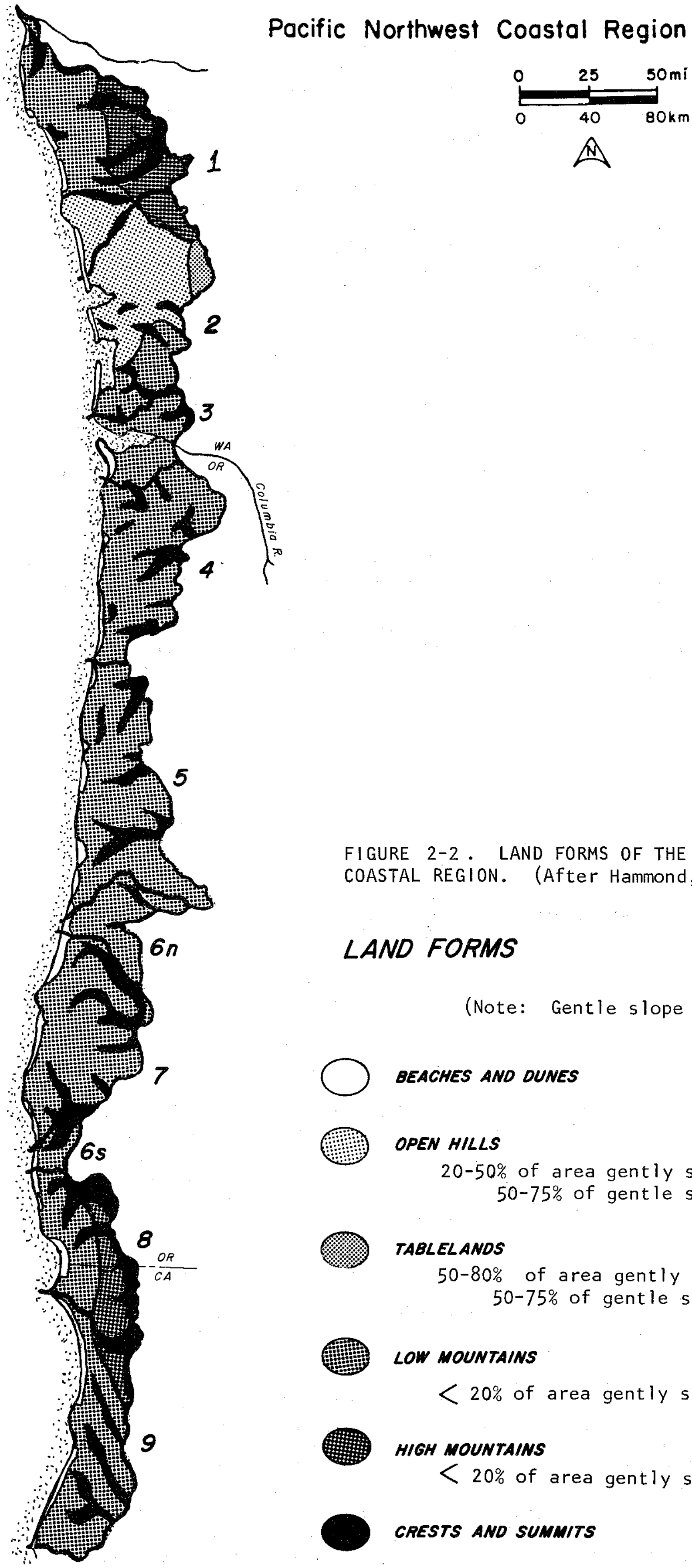


FIGURE 2-2. LAND FORMS OF THE PACIFIC NORTHWEST COASTAL REGION. (After Hammond, 1954.)

LAND FORMS

(Note: Gentle slope is defined as a slope $<8^{\circ}$)

BEACHES AND DUNES

OPEN HILLS
20-50% of area gently sloping; local relief, 300-500ft; 50-75% of gentle slope is in lowland

TABLELANDS
50-80% of area gently sloping; local relief, 300-500ft; 50-75% of gentle slope is on upland

LOW MOUNTAINS
$<$ 20% of area gently sloping; local relief, 1000-3000ft

HIGH MOUNTAINS
$<$ 20% of area gently sloping; local relief, 3000-5000ft

CRESTS AND SUMMITS

and the Strait of Juan de Fuca interrupt the shelf between Washington and Vancouver Island, with water deeper than 600 feet extending into the Strait of Juan de Fuca.

Submarine canyons cut into the continental slope and the outer edges of the shelf off Washington and Northern California. Large canyons are conspicuously absent off Oregon. The Juan de Fuca Canyon, Astoria Canyon, and Eel River Canyon come the closest to the coast of the study area, approaching to 5 mi (8 km), 15 mi (25 km), and 5 mi (8 km) offshore respectively.

The nearshore bathymetry, extending out to 3 miles (4.8 km) from the shore is presented in Figure 2-3. Significant variations occur throughout the region. The nearshore gradient is the smallest off Washington. Steep gradients in the first mile from shore are apparent off steep coasts and headlands. Figure 2-3 presents 12 representative profiles. The source document for this figure (OSU, 1971) presents an additional 15 profiles which follow the pattern presented here.

McManus (1964) describes the major bathymetric features near the coast of Oregon and Washington and presents the bathymetry for the Northeast Pacific from the Mendocino Escarpment to the northern end of Vancouver Island and seaward over 350 mi (550 km). Descriptions of Heceta and Stonewall Banks and Submarine Canyons off Washington pertain to the study area.

2.2.2 Bedrock Structure. The land area of the Pacific Northwest Coastal Region may be divided into three geologic provinces. North to south they are: 1) the Olympic Mountains, 2) the Coast Range, and 3) the Klamath Mountains. These provinces were presented in Figure 2-1. The offshore structure of the shelf may be considered as an extension of the onshore structure of these provinces.

Detailed discussion of the geological structures along the Oregon and Washington coast is summarized and presented by the Oceanographic Institute of Washington (1977). Offshore geologic structure of the Northeast Pacific is discussed by Dehlinger et al. (1970). The following general discussion of the three geological provinces is adapted from Franklin and Dyrness (1973). The geologic time scale is available in numerous references including dictionaries and is not repeated here.

> The Olympic Mountain Province is made up of two volcanic belts which encircle a large interior area containing sedimentary rocks. The volcanic belts bound the peninsula on the north and east sides, and as far west as Lake Quinault on the south. The outer belt, by far the thickest, is comprised of basalt flows and breccias (angular fragments embedded and consolidated in finer crushed material, formed by eruption of coarse fragments of cool lava or by fault action) of Eocene age. Between the two volcanic belts lies a generally thin band of argillite and graywacke (dark, fine-grained mud- and sandstones), also Eocene. The inner volcanic belt is very thin and discontinuous and consists of altered basalt, "pillow" lava (formed by flowing and cooling underwater) and flow breccia deposited late in the Mesozoic era or perhaps during the Paleocene epoch. The rugged interior of the Olympic Mountains is almost exclusively comprised of sedimentary rocks deposited late in the Mesozoic or very early in the Tertiary period. These rocks are largely graywacke, with some interbedded slate, argillite, and volcanic rocks. The broad, level areas along the western and southern margins of the peninsula are marine terraces and glacial outwash fans with Pliocene deposits.
>
> The Coast Ranges Province extends from the Middle Fork of the Coquille River in Oregon northward into Southwestern Washington where it includes the Willapa Hills. Geology south of the Salmon River (northern end of Watershed Unit 5) differs substantially from that to the north. Geologic history of the southern Coast Ranges began during early Eocene times with deposition of pillow basalts near the present town of Alsea (Watershed Unit 5). Later in the Eocene, the vast sedimentary beds of the Tyee formation, which make up by far the largest portion of this section of the Coast Ranges, were deposited under marine conditions. The Tyee formation, largely composed of rhythmically bedded, tuffaceous and micaceous sandstone, occurs throughout the southern Coast Ranges and is virtually the only rock present in the central portion. Also during the Eocene, other smaller marine sedimentary formations were laid down, mostly to the south and along the coast. Scattered igneous intrusions, largely gabbro, occurred during the Oligocene and cap many of the most prominent peaks. During the Miocene, localized depositions of both sedimentary and volcanic rocks occurred which are now exposed near Newport and Coos Bay (Watershed Units 5 and 7). Most of the spectacular coastal headlands are made up of Miocene basalt. The Pliocene epoch saw no new depositions, the principal activity at this time apparently being the rapid erosion of the tremendously thick beds of sediments. Pleistocene deposits, generally sandy in nature, were laid down along the coast during a period of rising sea level. This general rise of sea level, following the melting of glacial ice, also drowned the mouths of coastal rivers, forming the "drowned river" type estuaries characteristic of this province.

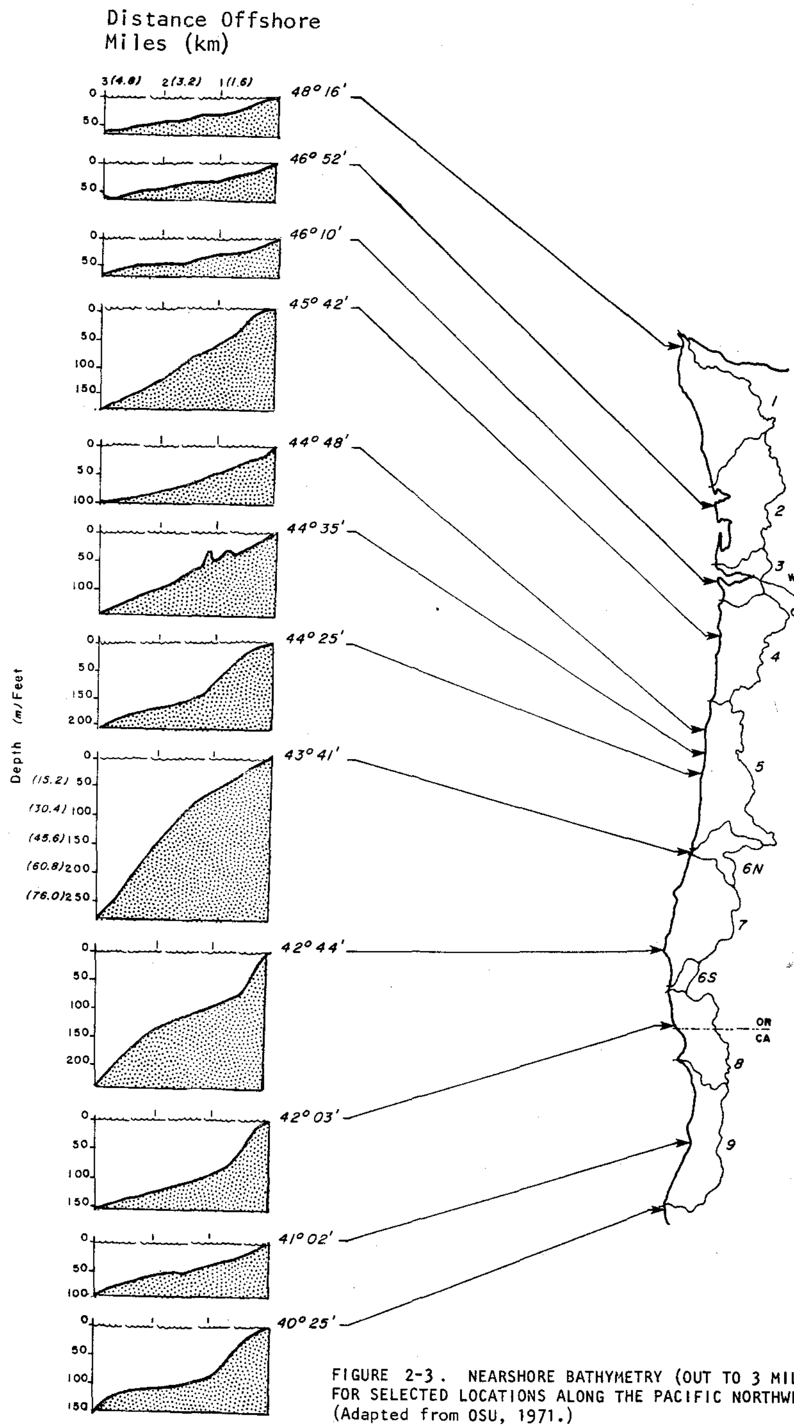


FIGURE 2-3. NEARSHORE BATHYMETRY (OUT TO 3 MILES OFFSHORE) FOR SELECTED LOCATIONS ALONG THE PACIFIC NORTHWEST COAST. (Adapted from OSU, 1971.)

As in the southern section, all rock formations in the northern Coast Ranges are Tertiary. Tertiary. Eocene formations are widespread and include both volcanic and sedimentary rocks. Eocene siltstone and sandstone are found along and to the south of the Siletz River (Watershed Unit 5), and in the Willapa Hills of Southwestern Washington. Eocene volcanic rocks, largely basalt with some tuffs (volcanic ash compacted into rock) and breccias, occupy extensive areas northeast of Tillamook and in the Willapa Hills, and to a lesser extent, between the Siletz and Salmon Rivers. Oligocene sedimentary formations, including siltstone, shale, and sandstone, are found along the Nehalem River, and to a limited extent, in the Willapa Hills. During the Miocene epoch, extensive basalt flows occurred in the most northerly section of the Oregon Coast Ranges and in the Willapa Hills. Near the Columbia River in Oregon, these flows are classified with the extremely widespread (inland) Columbia River Basalt. The Plio-Pleistocene was largely a period of erosion, with streams excavating their valleys as the ranges were slowly uplifted by regional tectonic processes.

The Klamath Mountains Province encompasses an area of old and geologically complex mountains in Southwestern Oregon and Northern California. The northern-most portion of the range in Oregon is also commonly identified as the Siskiyou Mountains. This region is logically set apart from the remainder of Southern Oregon by the boundary separating its pre-Tertiary rocks from Tertiary rock formations outside the area. The pre-Tertiary rocks of this province probably include the oldest in Oregon.

The geologic history of the Klamath Mountains began during the Paleozoic era with deposition of volcanic tuffs and sedimentary rocks which were subsequently metamorphosed, largely into schists. A period of erosion and folding followed until late in the Triassic period when a large series of volcanic and sedimentary rocks were deposited. These rocks have all undergone extensive metamorphism into various types of schists, gneisses, marbles, and other metavolcanic or metasedimentary rocks. (These rock types are extensive in the inland portion of Watershed Unit 8 in Southern Oregon and Northern California; some outcrops also exist east of Gold Beach in Watershed Unit 6S and at other scattered locations throughout the province.) During the Jurassic period, sandstones, siltstones, and shales were laid down along the coast and in a belt extending from the southwestern corner of Oregon across the province in a generally northeasterly direction and from the northwest corner of California extending in a generally south-southeasterly direction (through Watershed Units 8 and 9). This extensive formation is called the Dothan Formation in Oregon and the Franciscan Formation in California. Most of these deposits have undergone very little alteration. These rock strata were intruded with ultramafic rocks as peridotite and dunite during late Jurassic or very early Cretaceous times. The intrusions have largely been altered to serpentine which now appears in elongated, stringerlike outcrops, generally associated with fault zones. Other rocks which were intruded at approximately the same time include a variety of granitics such as diorite, quartz diorite, granodiorite, and granite. (Most of these intrusives are in the inland portion of Watershed Units 8 and 9 with some exposed near the coast between Cape Blanco and Gold Beach in Watershed Unit 7.) The early Cretaceous period saw additional depositions of sediments which now appear as grayish-green arkosic sandstone and siltstone near the Elk River in Oregon and Cape Mendocino in Northern California.

Rock strata within the province were greatly modified by folding and deformation during the middle Cretaceous period. Apparently, the Klamath Mountains were truncated and underwent peneplanation (end result of long term erosion of old mountains in which no mountains or high hills remain and a nearly level surface of large extent is formed). This peneplanation occurred during the Miocene and Pliocene epochs. Subsequent erosion and stream dissection have given rise to the mature topography which characterizes the area today.

(Geological maps for the individual Watershed Units are presented in Volume 4; and the data for these were obtained from maps prepared for and distributed by the respective states.)

Geologic structure and rock type are significant as the source of parent materials for soil formation and riverine, estuarine, and marine sediments. Basaltic headlands, resistant to erosion by waves, extend seaward along the coast, and act as boundaries for beaches and endpoints for drift sectors. Figure 2-4 presents the location of beaches. Where no beaches occur, bedrock is exposed directly to wave action. Areas of critical and noncritical erosion are also presented in the figure. The influence of geological structures and processes on the shoreline is apparent. Critical erosion is defined as erosion which presents serious problems because the rate of erosion, considered in conjunction with economic, industrial, recreational, agricultural, navigational, demographic, ecological, and other relevant factors, indicates that action to halt such erosion may be justified. This definition is from the Army Corps of Engineers (1971) and acknowledges that existing data on many of the factors are insufficient to quantify this decision, and that structural measures taken to solve problems in one area may just transfer the problem elsewhere. Noncritical erosion is that erosion for which structural measures may not be justified and where management to prevent or minimize adverse effects may be more appropriate than action to halt erosion. The condition of no erosion is also indicated in Figure 2-4 and signifies stable or accreting conditions.

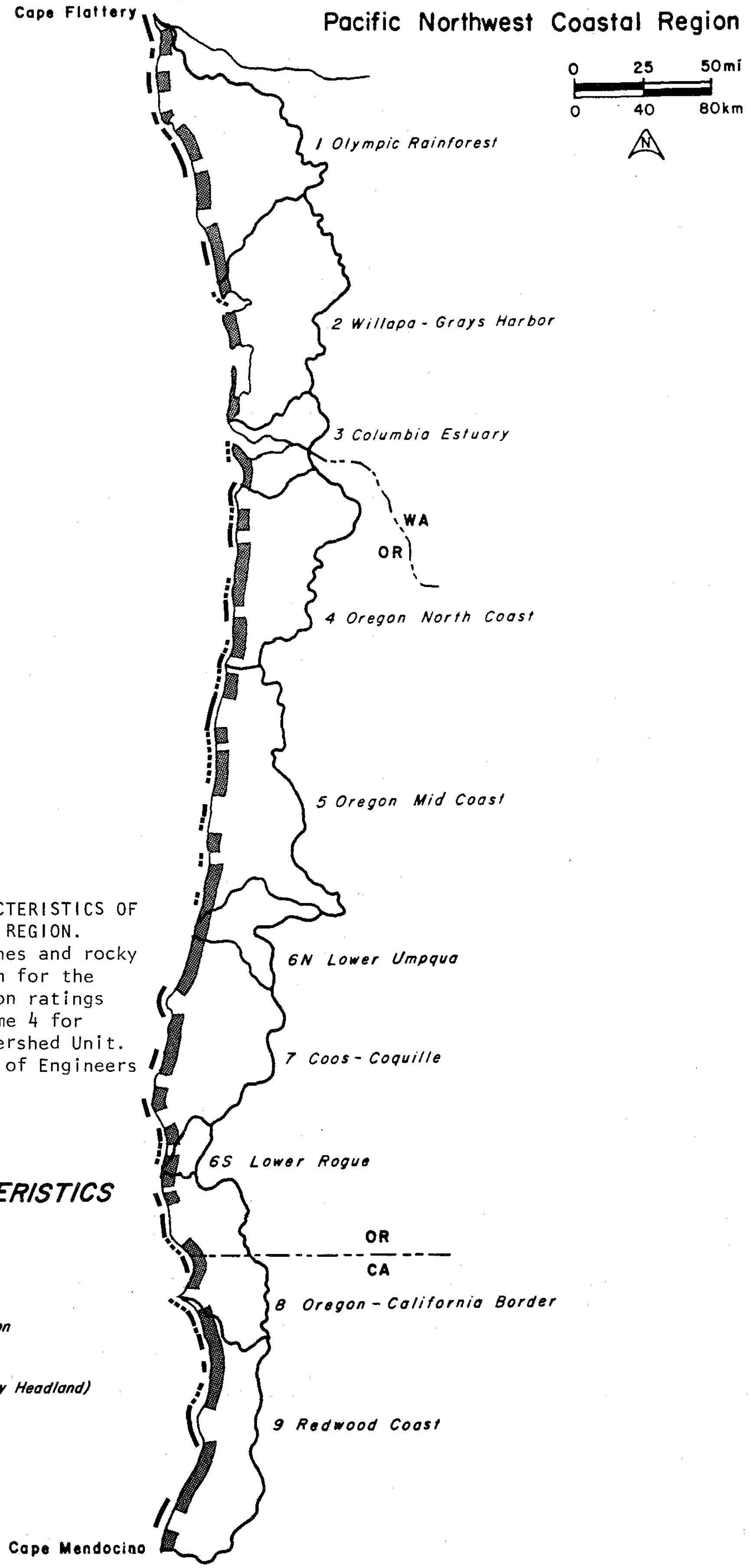
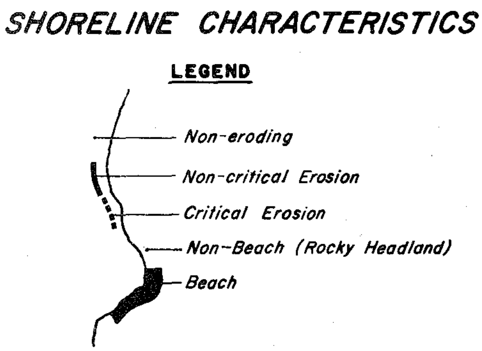


FIGURE 2-4. SHORELINE CHARACTERISTICS OF THE PACIFIC NORTHWEST COASTAL REGION. Generalized locations of beaches and rocky bluffs and headlands are shown for the study area coast. ACOE erosion ratings are also presented. See Volume 4 for more detailed coverage by Watershed Unit. (Adapted from U.S. Army Corps of Engineers 1971 and 1973C.)



2.2.3 Seismicity and Faults. As mentioned in Section 2.2, the Pacific Northwest Coastal Region is where the North American (Continental) Plate interacts with the Gorda and Juan de Fuca (Sea Floor) Plates. Subduction of oceanic crust beneath the continent occurred in the past along the continental border, which is effectively the entire study area. Subduction zones are characterized by a heavy density of earthquake epicenters (Toksoz, 1973-74). However, earthquake activity in this region, along these subduction boundaries, has been slight in recent times. This fact, plus the absence of a bordering oceanic trench, indicates that subduction is either not presently active, or active at a considerably reduced rate.

Most of the moderate quake activity affecting the region has been associated with the Blanco Fracture Zone and the Mendocino Escarpment (see Figure 2-1). Both these features, which are to the west beyond the shelf edge boundary of the study area, are transform faults associated with the movement of plates past each other. California's San Andreas Fault may extend seaward as the Blanco Fracture Zone and/or the Mendocino Escarpment (Iacopi, 1964; Tobin and Sykes, 1968; and Bolt et al., 1968).

Couch et al. (1974) have summarized data from coastal and offshore earthquakes of the Pacific Northwest. Figure 2-5 presents epicenters of these earthquakes from 1853 to 1973. Magnitude ranges using the Modified Mercalli Scale of earthquake shock intensities are indicated in Figure 2.5. Brief descriptions of intensities V, VI, and VII of this scale, as presented by Iacopi (1964), are as follows:

V. Felt indoors by practically everyone, outdoors by most people. Direction can often be estimated by those outdoors. Awakens many, or most, sleepers. Frightens a few people, with slight excitement; some persons run outdoors.

VI. Felt by everyone, indoors and outdoors. Awakens all sleepers. Frightens many people; general excitement, and some persons run outdoors.

VII. Frightens everyone. General alarm, and everyone runs outdoors.

The Mercalli scale ranges from I to XII, and panic is general for intensities IX through XII. The descriptions of intensity include effects, for example, on buildings, cars, furniture, water pipes, roads, railroad tracks, wave production on water bodies, earth changes, and animals' reactions.

Identified faults on land, both active and otherwise, are described in Volume 4. Most earthquake activity is produced by the offshore features of fracture zones and spreading ridges.

Tsunamis, or seismic sea waves, are produced by forces that vertically displace the surface of the ocean. Most tsunamis are generated by offshore earthquakes that vertically displace the bottom. The tsunamis that have affected the study region in recent years were generated by distant earthquakes in Alaska, Japan, and Chile. Earthquake activity offshore of Washington, Oregon, and Northern California has not generated any significant tsunamis. Tsunamis affecting the Pacific Northwest Coastal Region are discussed in Section 2.7.2.2.

2.2.4 Sediments. The distribution of sediments within estuaries is a function of many different parameters, which are discussed in Section 2.6.3. Estuary-specific data appear in Volume 4 for the individual Watershed Units. Sediments on land are dealt with in Section 2.2.5 (Soils) which follows. Sediments within rivers are not presented here as a lithospheric feature, but rather are covered in the Inland Sediment Transport discussion (Section 2.5.4).

Estauries have sediments that are both riverine and marine in origin, with a zone of gradation between the two. Most of the sand-sized sediment carried by rivers is deposited in estuaries. Additional coastal sand is carried by littoral drift and tidal currents into the mouths of estuaries. Finer sediments (mud, or silt and clay size) pass through the estuaries and may spend some time on the shelf, but are eventually deposited beyond the outer shelf edge.

Processes affecting sedimentation and sediment distribution of the continental shelf are comparable throughout the study area. Sediment data are presented differently for Oregon and Washington and are sparse for Northern California. Because the processes are similar, some general findings for Oregon may be applicable throughout the region.

There is a seasonality of physical processes, affecting sediment distribution over the shelf in this region. These processes include precipitation and runoff, wind and waves, and currents. During the summer months of low wave activity, the midshelf region is covered with a layer of mud. This mud is resuspended by winter storm waves leaving clean sand covered with active

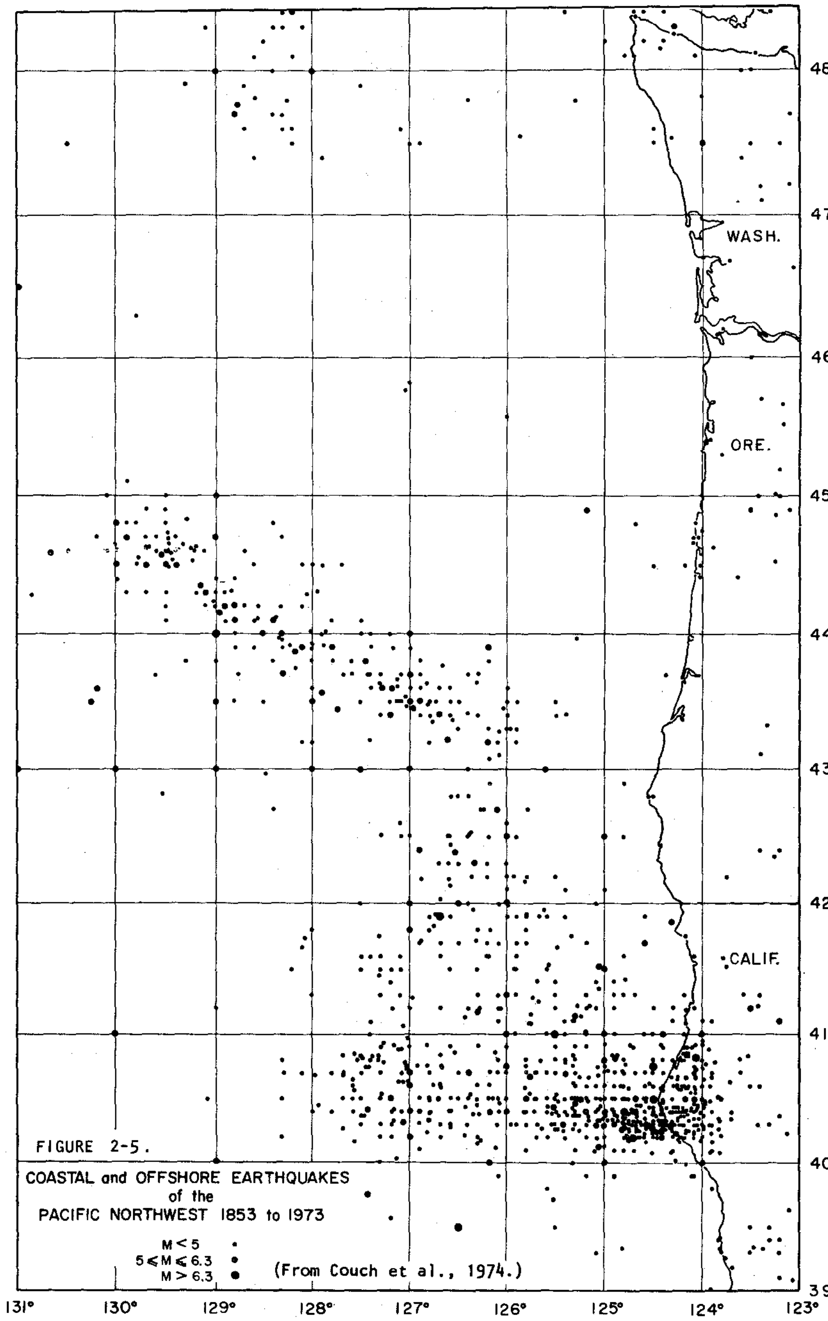


FIGURE 2-5.

COASTAL and OFFSHORE EARTHQUAKES of the PACIFIC NORTHWEST 1853 to 1973

(From Couch et al., 1974.)

ripple marks. In some places, mud is intermixed with the underlying sand by benthic organisms, forming a mixture of sand and mud. Kulm et al. (1975), using a box cores of sediments on the Southern Oregon Shelf, modeled the pattern of sediment facies distribution on the shelf (Fig. 2-6). Note that the vertical scale of the sediment in cross-section is only 16 inches (40 cm) thick. It is apparent that the mud and mixed-sand-and-mud deposits are thin, with sand the dominant sediment.

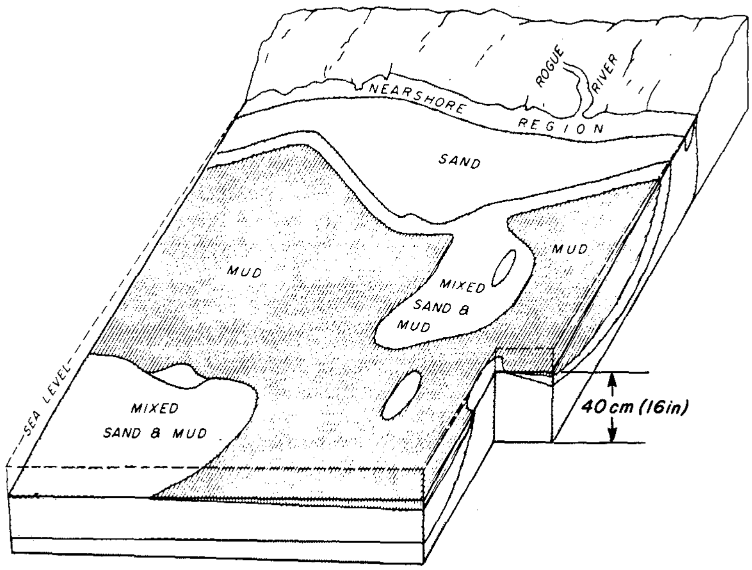


FIGURE 2-6. MODEL OF SEDIMENT FACIES ON THE CONTINENTAL SHELF DETERMINED FROM BOX CORES TAKEN ON THE SOUTHERN OREGON SHELF. The figure is not drawn to scale. Horizontally it portrays the shelf out to its edge (200 m). The vertical scale (of the sediment) is approximately 40 cm (16 in). The mud and mixed-sand-and-mud facies are quite thin over the shelf, overlying the predominant sand. (From Kulm et al., 1975.)

Roberts (1974) presents sediment data for the Washington Shelf, extending into Northern Oregon as well. The percent of gravel, sand, silt, and clay is given for each sediment sample obtained by the University of Washington from 1954 to 1972, and includes studies in Grays Harbor, Willapa Bay, and the Columbia River. Significantly, winter sampling carried out in this time frame was limited to only 1 out of 27 offshore cruises, and that one cruise sampled but five stations on the outer shelf. The sediment data are therefore biased to the summer condition and are not representative of the winter.

Reports of sediment off Oregon categorize the sediments as sand, mud, and muddy sand. Reports for Washington categorize the sediments as gravel, sand, coarse silt, and fine silt. The fine silt approximates mud, while the coarse silt is similar to the muddy sand. Sand is defined as consisting of particles which have diameters larger than 0.0625 mm (about 1/400th of an inch). Sediments consisting of more than 75% particles of this size are termed sand. Where less than 50% of the sediment by weight consists of sand-sized partilces, the sediment is termed mud. For those sediments that are 50% to 75% sand, the term muddy-sand is used (Byrne and Panshin, 1968). Figure 2-7 describes the surface sediment distribution on the continental shelf off Washington. The coarse silt of the outer shelf is probably similar to the mixed-sand-and-mud description on the Oregon Shelf. The gravel areas are indicative of scouring of finer materials, and may be correlated with more intense wave action. (See Section 2.6.2.1 of Watershed Unit 2 in Volume 4.) Figure 2-8 presents the surface sediment distribution on the continental shelf off Oregon.

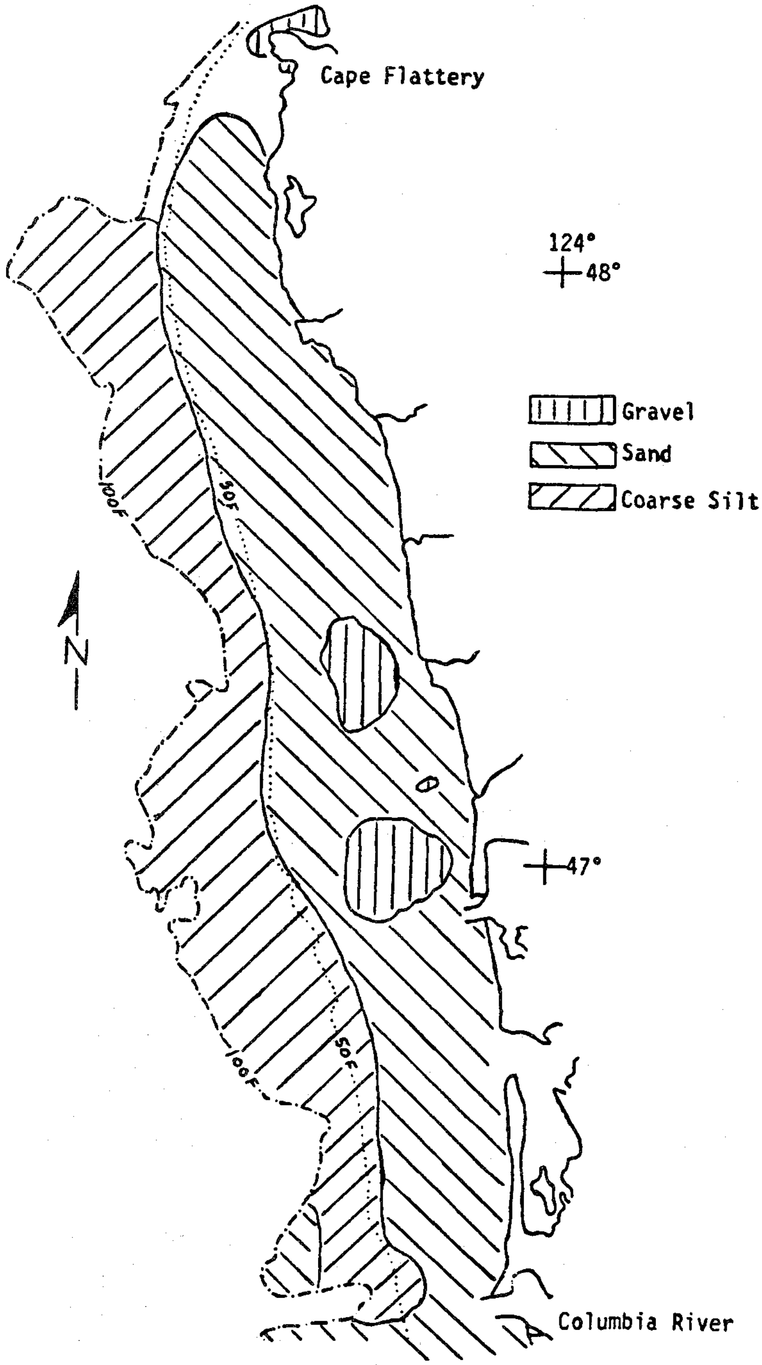


FIGURE 2-7. DISTRIBUTION OF SEDIMENT TYPES ON THE CONTINENTAL SHELF OFF WASHINGTON. (From Barss et al., 1977.)

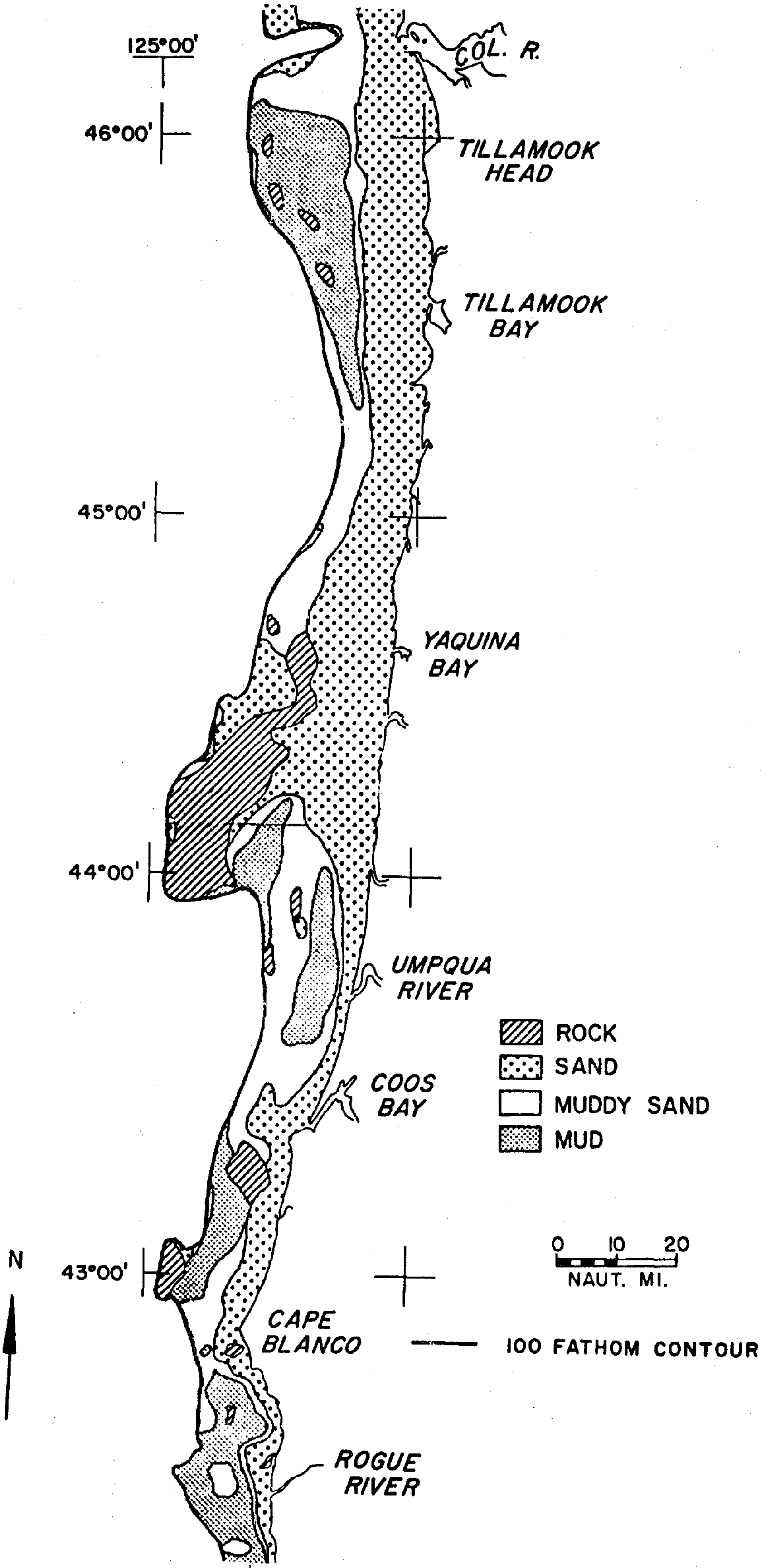


FIGURE 2-8. SHELF AND UPPER SLOPE SEDIMENT DISTRIBUTION FOR THE OREGON COAST. (From Byrne and Panshin, 1968.)

Sediment compositions reflect different benthic habitat conditions, and the organisms that inhabit them are uniquely adapted to their particular conditions. Sediment characteristics for Northern California's Shelf are indicated by Strand (1969, 1973), and are similar to the rest of the region. The following discussion concerning the distribution of sand off Oregon is from Byrne and Panshin (1968) and is generally applicable to the entire region.

> Sand occurs in two major areas on the continental shelf, close to shore and at the shelf edge. The nearshore sand is usually gray. It extends from the shoreline out to a depth of about 50 fathoms (90 meters) off the northern and central Oregon coast. In the vicinity of the Umpqua River, sand is limited to shallower water, generally 30 fathoms (60 meters) or less, and forms a narrow belt along the coast at least as far south as the Rogue River. Sand which occurs as patches near the edge of the shelf is more variable in its characteristics than the nearshore sand. Shelf-edge sand may be somewhat coarser than the nearshore sand, and may vary in color from yellow or brown to dark green. In many areas, it contains appreciable amounts of broken shells. p. 2.

From Figure 2-7 it is apparent that the 50 fathoms (90 meters) depth limitation for the nearshore sand holds true as the dividing line between sand and coarse silt. The patches of sand at the shelf edge off Washington and Oregon - and presumably California - are relict deposits, laid down at times of lower sea level associated with periods of glaciation. The lack of depositions of finer sediments at the shelf edge has kept these sands exposed.

Sediment sources may be determined by analysis of their heavy mineral content. Major physiographic provinces, such as the entire Columbia River basin, the Oregon Coast Range, and the Klamath Mountains, contribute sediments that have characteristic heavy mineral assemblages. Analysis of the shelf sands has permitted an inference of a northward net littoral drift pattern, both during the late Pleistocene and during more modern times.

Kulm et al. (1968) gives evidence for possible commercially valuable placer deposits on the Southern Oregon Continental Shelf. These deposits are sands that are high in heavy mineral concentrations. These deposits have been associated with large magnetic anomalies. Similar areas exist on the shelf off Southern Oregon which may have large heavy mineral sediment concentrations buried below the surface.

2.2.5 Soils. As described in Volume 1, soils are a complex, dynamic body of materials resulting from the integrated effects of climate and living organisms acting on earthy parent materials conditioned by relief over time (USDA, 1975B). Soils are expressions of a number of environmental parameters in a given location, including rock type, organic input, topography, gradient, temperature, and precipitation, and as such are extremely variable.

Soils are described and classified using observable and measurable criteria such as color, texture (clay, silt, sand - see Figure 2-9), composition, zonation, moisture content, and organic influence. They are named for a local site with appropriate descriptors (e.g. Hoh fine sandy loam, Orford gravelly silty clay loam); these site- or area-specific soils can then be grouped by similarities to facilitate comparison, assessment of utility, management practices, etc.

With the complex and variable array of soil types found in the world, there is, needless to say, controversy over all-encompassing classification systems. Still, such systems are useful for comparisons of areas and regions of similar climate and vegetation.

Two widely accepted "great soil group" classification systems exist: the old 1938 classification (Baldwin et al., 1938) and the new 1960's National Cooperative Soil Survey Classification (USDA, 1960 and 1967 supplement). The former identified a number of great groups (e.g. podzol, chernozem, sols bruns acides) loosely organized into azonal, zonal, and intrazonal categories. The latter is based on a hierarchial system of six categories - order, suborder, great group, subgroup, family, and series - from broadest climatic grouping to site-specific series. The great groups of the two systems do not coincide in all cases; some overlapping and splintering occurs. The podzols of the old system, for example, are found in the cryorthods, fragiorthods, and haplorthods of the new. Table 2-1 presents approximate equivalents between the two systems. (See USDA, 1960, for details.)

Much of the soil information available for the study area does not deal with these major classification systems at all. Many reports refer to topographic groupings such as coastal, streamway, and upland soils, or to acidity or agricultural ratings, without reference to great groups or orders. Data in this study, therefore, reflect those classification systems which are available for the region.

TABLE 2-1. NEW (1967) SOIL ORDERS AND APPROXIMATE EQUIVALENTS IN BALDWIN ET AL., (1938) CLASSIFICATION. (From USDA, 1960.)

1967 Soil Order	Approximate Equivalents in 1938 Classification
1. Entisols	Azonal soils, and some Low Humic Gley soils.
2. Vertisols	Grumusols.
3. Inceptisols	Ando, Sol Brun Acide, some Brown Forest, Low-Humic Gley, and Humic Gley soils.
4. Aridisols	Desert, Reddish Desert, Sierozem, Solonchak, some Brown and Reddish Brown soils, and associated Solonetz.
5. Mollisols	Chestnut, Chernozem, Brunizem (Prairie), Rendzinas, some Brown, Brown Forest, and associated Solonetz and Humic Gley soils.
6. Spodosols	Podzols, Brown Polzolic soils, and Ground-Water Podzols.
7. Alfisols	Gray-Brown Podzolic, Gray Wooded soils, Noncalcic Brown soils, Degraded Chernozem, and associated Planosols and some Half-Bog soils.
8. Ultisols	Red-Yellow Podzolic soils, Reddish-Brown Lateritic soils of the U.S., and associated Planosols and Half-Bog soils.
9. Oxisols	Laterite soils, Latosols.
10. Histosols	Bog soils.

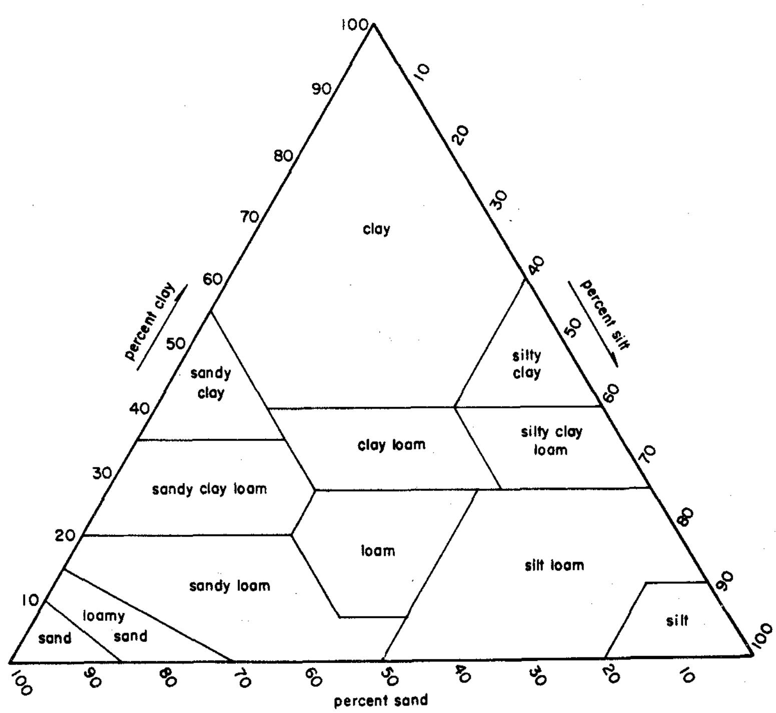


FIGURE 2-9. A GENERAL GUIDE FOR THE TEXTURAL CLASSIFICATION OF SOILS. (From Beaulieu and Hughes, 1975.)

Figure 2-10 shows the general distribution of soils in the region, using the 1938 classification system and grouping great groups into related soil associations for the purpose of generalized mapping.

Seven soil orders (of the USDA 1967 classification) are found in the study area, reflecting the varied and complex nature of the parent rock material in the region (as described in Section 2.2.2) as well as climatic variation. Table 2-2 lists these orders and the major great groups of both 1938 and the 1967 classification for Oregon and Washington coastal areas by physiographic province, as described by Franklin and Dyrness (1973). Major soil group designations for the Northern California coastal area soils are not available, but presumably include the same soils as listed in Table 2-2 for the Klamath Mountains province.

The soil orders listed in Table 2-2 are described briefly below (from Franklin and Dyrness, 1973). For further descriptions of these and the component suborders and great groups, see USDA (1960 and 1967 Suppl.).

Alfisols are soils that are medium to high in bases with gray to brown surface horizons and subsurface horizons of clay accumulation; they are usually moist but may be dry for a portion of the warm season.

Entisols are soils that have no pedogenic horizons, such as alluvial soils.

Inceptisols are soils which have weakly differentiated horizons; materials in the soil have been altered or removed but have not accumulated; they are usually moist but some are dry part of the time during the warm season.

Mollisols are soils with nearly black, friable, organic-rich surface horizons high in bases; they are formed mostly in subhumid and semiarid warm to cold climates.

Spodosols are soils with low base supply having in subsurface horizons an accumulation of amorphous materials consisting of organic matter plus compounds of aluminum and usually iron; they are acidic and coarse-textured, and are formed in humid and mostly cool or temperate climates.

Ultisols are soils which are low in bases and have subsurface horizons of clay accumulation; they are generally moist, but during the warm season may be dry part of the time.

Vertisols are clayey soils with wide, deep cracks when dry; most have distinctive wet and dry periods throughout the year.

Many of the soils in the high-relief mountainous areas are in a state of "profile immaturity" - regosolic or lithosolic, lacking genetic horizons except a thin A - due to soil creep, landslides, and other instabilities.

A general description of the coastal region's soils, taken from Franklin and Dyrness (1973), follows, beginning with the Olympic Peninsula province and continuing through the Coast Ranges and Klamath Mountains provinces.

> In the Olympic Mountains, a variety of soils have developed under both coniferous forest and subalpine meadow vegetation, derived from the sedimentary parent materials of the interior. Forested soils are reported to be Brown Podzolics (Spodosols) and Lithosols (Entisols). The Spodosols (probably Haplorthods) have a very dark grayish-brown silt loam surface horizon underlain by a dark yellowish-brown sandy clay loam B horizon. Soils developed under alpine meadow vegetation are classed within the Spodosol, Mollisol, and Inceptisol orders. The Spodosols have thin, gray sandy loam B2 horizons. The Inceptisols have very dark grayish-brown sandy loam subsurface horizons.
>
> The deeper, well-developed soils derived from basalt on the Olympic Peninsula are generally classified as Haplohumults (Reddish Brown Lateritic soils). Most often these soils are characterized by a reddish-brown silt loam or silty clay loam surface horizon underlain by a silty clay loam or silty clay subsoil showing the effects of clay accumulation. The sandstone parent materials situtated along the northern edge of the peninsula give rise to Haplumbrepts (Western Brown Forest soils). These are moderately deep soils with thick, dark-colored surface horizons. Surface textures are silt loam or silty clay loam, and the subsoil is either silty clay loam or silty clay textured.
>
> A large variety of soils in the Olympic Peninsula have formed in glacial till and outwash, depending on such factors as particle size and degree of compaction in parent materials. The majority of upland soils derived from glacial till have been classed as Xerochrepts (Regosols).

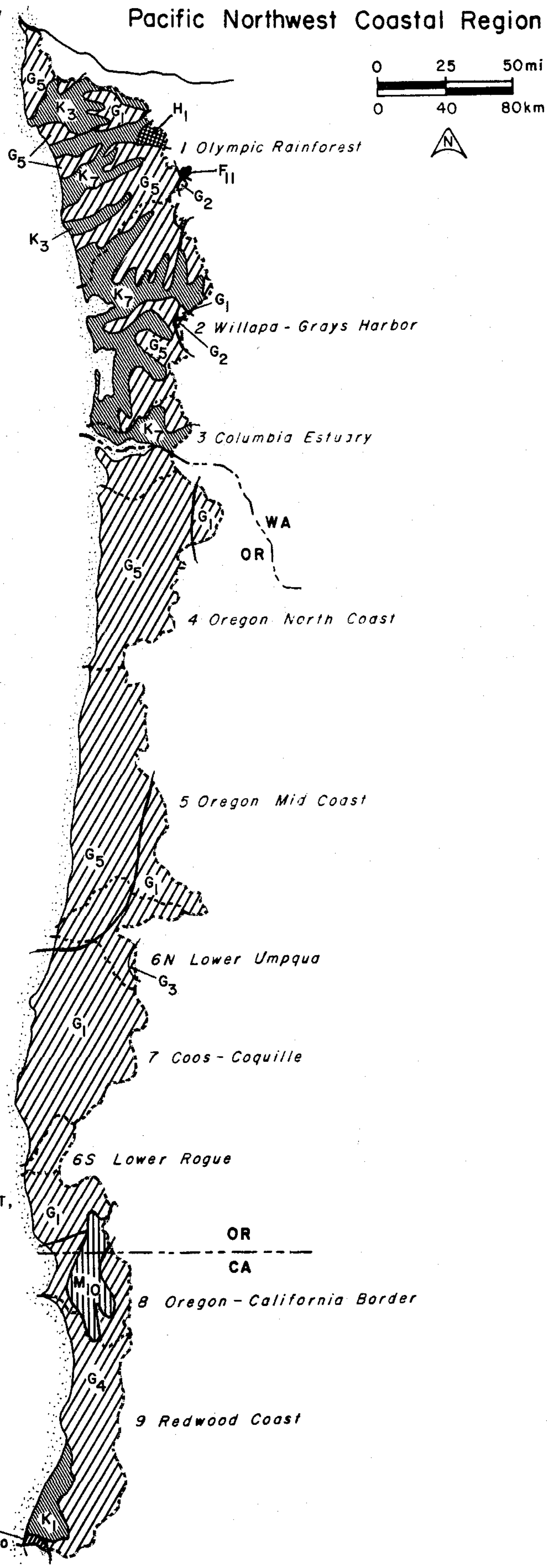


FIGURE 2-10. GENERAL SOIL GROUPS AND DISTRIBUTION IN THE REGION. This map, taken from Soils of the Western United States (Western Land Grant Universities et al., 1964), shows very general distributions of great soil groups (1938 classification) arranged in "associations." These groupings and their letter and number designations, as given in the above source, are presented in the key below.

SOILS

- DARK COLORED SOILS OF THE SUB-HUMID REGIONS
  - D_{11} - PRAIRIE, LITHOSOL
- SOILS OF THE COOL TO COLD, SUB-HUMID AND HUMID FORESTED REGIONS
  - F_{11} - PODZOL, BROWN PODZOLIC, LITHOSOL
- SOILS OF THE WARM, HUMID TO SUPER-HUMID FORESTED REGIONS
  - G_1 - REDDISH BROWN LATERITIC
  - G_2 - REDDISH BROWN LATERITIC, LITHOSOL
  - G_3 - REDDISH BROWN LATERITIC, NONCALCIC BROWN, ALLUVIAL, WESTERN BROWN FOREST
  - G_4 - REDDISH BROWN LATERITIC, WESTERN BROWN FOREST, REGOSOL, LITHOSOL
  - G_5 - SOLS BRUNS ACIDES, REDDISH BROWN LATERITIC, LITHOSOL
- SOILS OF THE COLD NON-FORESTED MOUNTAIN REGION
  - H_1 - ALPINE TURF, ROCKLAND, ALPINE MEADOW, ALPINE BOG
- RECENT ALLUVIAL SOILS
  - K_1 - ALLUVIAL
  - K_3 - ALLUVIAL, HUMIC GLEY
  - K_7 - HUMIC GLEY, ALLUVIAL
- IMMATURE SHALLOW SOILS ON CONSOLIDATED UPLAND MATERIALS AND MISCELLANEOUS LAND TYPES
  - M_{10} - LITHOSOL, ROCKLAND, PODZOL

TABLE 2-2 . PRINCIPAL GREAT SOIL GROUPS WITHIN THE THREE PHYSIOGRAPHIC PROVINCES OF COASTAL OREGON AND WASHINGTON. (From Franklin and Dyrness, 1973.)

Physiographic Province	1938 Classification System[1] Widespread Great Soil Groups	1938 Classification System[1] Less Abundant Great Soil Groups	1967 Classification System[2] Widespread Orders	1967 Classification System[2] Widespread Great Groups	1967 Classification System[2] Less Abundant Orders	1967 Classification System[2] Less Abundant Great Groups
Olympic Peninsula	Sols Bruns Acides Reddish Brown Lateritic Lithosol	Podzol Brown Podzolic Alpine Turf Alpine Meadow Humic Gley Alluvial Regosol (Rockland)[3]	Inceptisols	Xerochrepts Dystrochrepts Haplumbrepts	Spodosols	Haplorthods Cryorthods (Rockland)[3]
					Ultisols	Haplohumults
					Mollisols	Haploxerolls
					Inceptisols	Haplaquepts
					Entisols	Udifluvents
Coast Ranges	Reddish Brown Lateritic Sols Bruns Acides Regosol Lithosol	Noncalcic Brown Prairie Grumusol Humic Gley Alluvial	Inceptisols	Haplumbrepts	Inceptisols	Dystrochrepts Xerumbrepts Haplaquepts
			Ultisols	Haplohumults	Spodosols	Haplorthods
Klamath Mountains	Reddish Brown Lateritic	Sols Bruns Acides Noncalcic Brown Western Brown Forest Podzol Prairie Grumusol Humic Gley Alluvial Lithosol (Rockland)[3]	Ultisols	Haplohumults Haploxerults	Inceptisols	Haplumbrepts Xerochrepts Dystrochrepts
					Alfisols	Haploxeralfs Hapludalfs
					Mollisols	Haploxerolls
					Vertisols	Chromoxererts

[1]See Baldwin et al., 1938, or Western Land Grant Universities et al., 1964.

[2]See USDA, 1960 and 1967 supplement, or PNRBC, 1969.

[3]A miscellaneous land type in which rock outcrops or rock rubble dominate the landscape.

Such soils generally have a loam-textured surface horizon overlying a gravelly sandy loam substratum. Soils developed in till or glacial outwash on terraces are in most areas either Dystrochrepts (Sols Bruns Acides) or Haplorthods (Brown Podzolic soils). Textures range from gravelly silt loam to clay loam or silty clay loam. The Haplorthods often have a gravelly cemented layer at a depth of approximately one meter.

Alluvial soils occupying terraces along west-flowing rivers such as the Quinault, Queets, Hoh, and Soleduck are classed as Udifluvents. These are deep silt loam to very fine sandy loam soils which are moist throughout the year.

In the Coast Ranges, soils developing in the very extensive deposits of sandstone exhibit a wide range of characteristics despite the fact most are classified as Haplumbrepts (Western Brown Forest soils). On steep, smooth mountain slopes they tend to be shallow, stony loam textured, and brown or yellowish-brown in color. Deeper soils derived from sandstone colluvium occupy uneven, benchy slopes that generally exhibit some degree of continuing instability (e.g. Slickrock and Bohannon soils). On broad ridgetops, soils from sandstone parent materials tend to be deep, with a B horizon showing some clay accumulation and a thick surface horizon of high organic matter content (e.g. Astoria soil). Sandstone soils which show maximum profile development and are low in bases are classed as Haplohumults (Reddish Brown Lateritic soils). These soils have a much more reddish color, a silty clay loam-textured A horizon, and a silty clay B horizon.

Soils developed from siltstone or shale parent materials in the Coast Ranges resemble those derived from sandstone in some respects, but generally they are noticeably finer textured. Typically, they have a silt loam surface horizon and a silty clay or clay-textured B horizon. Those with thick, dark-colored A horizons are generally classed as Haplumbrepts, whereas soils with light-colored surface horizons have been classified as Dystrochrepts (Sols Bruns Acides).

Over most of the Coast Ranges Province, soils derived from basalt are Haplumbrepts. Deep, well-developed profiles are reddish-brown in color and are relatively stone free (e.g. the Henbre series). Surface textures are generally clay loam and the subsoil, a silty clay loam. Most often, however, basaltic soils tend to be fairly shallow and stony. Some Haplohumults on basalt parent materials are found in the southern portion of the province.

Sand dune areas are common along the Oregon coast. Soils on old, stabilized dunes are most often Haplorthods (Podzols and Brown Podzolic soils). These soils range from excessively drained to poorly drained and are characteristically loamy sand to fine sand textured (e.g. Netarts and Blacklock soils). Soils derived from alluvium along major streams are most commonly Haplaquepts (Low-Humic Gley soils) and Haplumbrepts (e.g. Knappa soil). The Haplaquepts are dominantly very poorly drained silt loams over silty clay loam soils formed in silty alluvium (e.g. Hebo soil). The most common flood plain soil series along the coast, from well drained to poorly drained, are Nehalem, Nestucca, and Brenner.

Upland soils in the western Klamath Mountains (which include the Siskiyous) are, for the most part, Haplohumults (Reddish Brown Lateritic soils). Parent materials for these soils include both sedimentary and basic igneous rocks. They are moderately deep (1 to 2 m to bedrock), reddish-brown soils possessing a silt loam or silty clay loam A horizon underlain by a silty clay B horizon (e.g. Orford soil). Scattered upland areas of peridotite or serpentine bedrock most often have reddish-colored soils which are classed as Hapludalfs (Gray-Brown Podzolic soils) or Xerochrepts (Regosols). Such soils (e.g. Sebastian) are invariably unproductive, having very shallow and stony profiles, as well as excessive amounts of magnesium relative to calcium.

The western Klamath Mountains contain a wide variety of bottom soils. The most important well drained soils derived from alluvium on terrace landforms are Dystrandepts and Haplumbrepts. The Dystrandepts (e.g. Ando soils) have a thick, very dark-colored silt loam surface horizon underlain by a silty clay loam subsoil. Haplumbrepts (Western Brown Forest soils) on terraces tend to be deep, well drained, and silt loam or loam textured. The most common poorly drained streamside soils are Haplaquepts (Low-Humic Gley soils). These wet soils tend to have silt loam surfaces and silty clay loam subsoils. The Soquel deep alluvial soils of Northern California support the pure stands of redwood characteristic of the coastal bottom lands in that area (Storie and Weir, 1953).

Roughly half of the land area of the Pacific Northwest Coastal Region has been or is being surveyed in great detail for information about soil types to determine recommended uses. Figure 2-11 shows those areas for which soil surveys have been published or are in progress. These reports are readily available from local or state offices of the Soil Conservation Service and are discussed further and cited in the bibliographies of each Watershed Unit in Volume 4.

Data on mineral and chemical composition of the region's soils are site-specific and cannot be generalized for the whole study area. Chemical analysis of soil is not a routine part of a

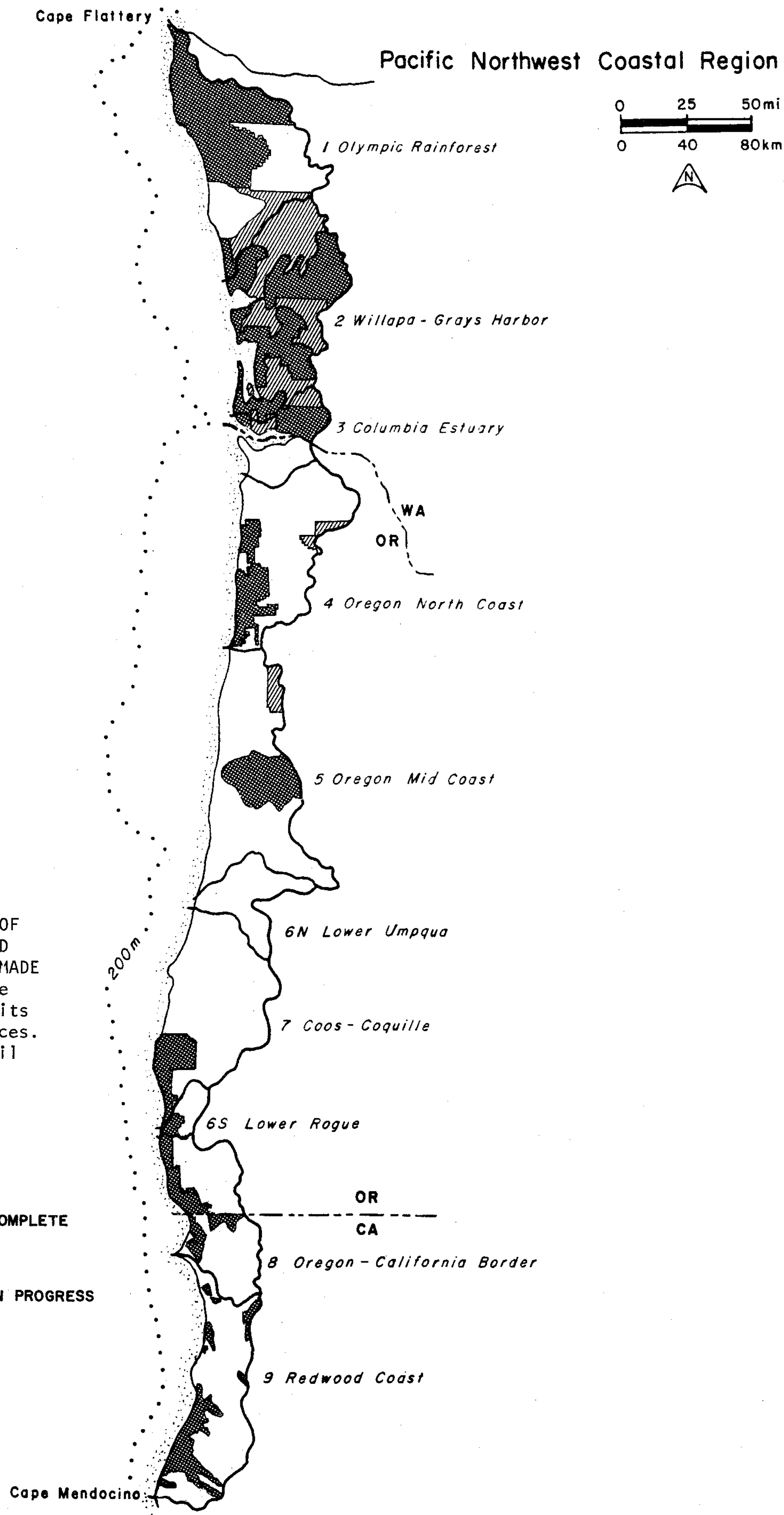


FIGURE 2-11. LOCATION OF AREAS FOR WHICH DETAILED SOIL SURVEYS HAVE BEEN MADE OR ARE IN PROGRESS. See individual Watershed Units in Volume 4 for references. (Compiled from state soil survey maps.)

SOIL SURVEYS

SOIL SURVEYS COMPLETE

SOIL SURVEYS IN PROGRESS

soil survey. It is undertaken only in the rare ecological studies in a region that require such data. Stoate et al. (1975), for example, include some chemical analyses of the soils in their study of the Mad River area in Northern California (Watershed Unit 9).

Forest Soils Committee of the Douglas-Fir Region (1957) includes a general discussion of the probable chemical nature of the soils of much of the study area, while acknowledging that few data exist. The soils of the whole region are well-leached, having been formed under high rainfall conditions. This leaching has resulted in soils from which all easily soluble materials have been washed out, producing acidic conditions. The pH range of the soils is from 4.3 to 5.4 in the region; these acidity levels are normal for forested regions of the world with high rainfall. Average nitrogen content ranges from 1900 to 6500 ppm (about 4,000 to 13,000 pounds per acre) and is intimately related to organic matter content. Available phosphorus (average) ranges from 2 to 20 pounds per acre (about 1 to 10 ppm), available potassium (average) from 210 to 340 pounds per acre (about 100 to 170 ppm). It must be stressed that these are very general values (with rough conversions) and that the soil composition is a function of local physical, environmental, and land use factors.

Information on the biological communities of the study region's soils is practically non-existent. The subject of the soil community is addressed in the notes on the Old Growth Western Hemlock ecosystem model in Chapter 3 of this volume (Section 3.2.1).

2.2.6 Chemical and Nutrient Cycling. General global cycles for oxygen, carbon, nitrogen, phosphorus, and sulfur are presented in Volume 1. No data exist to modify or quantify these models to characterize the region. Where data are available for portions of these cycles, they are presented in the notes accompanying the ecosystem models presented in Chapter 3 of this volume.

2.3 ATMOSPHERIC FEATURES

The climate of the Pacific Northwest Coastal Region is marine. The dominant winds at this latitude are from the west and the air, blowing over the Pacific, exchanges heat with the ocean and becomes nearly saturated with moisture from evaporation. As the air reaches the land mass, it rises, cools, and gives up considerable moisture. The climate of the region is thus dominated by the Pacific, having high rainfall and moderate temperature range. There is very little north-to-south variation in temperature and rainfall along the coast, but inland the coastal mountain ranges produce the temperature and precipitation extremes that do occur. In the Olympic Mountains, in Northern Washington, the coastal peaks are the highest of any in the study area, and average annual precipitation reaches nearly 250 inches (635 cm), the highest rainfall in the continental U.S. Extensive rainforests extend up valleys into the Olympic Mountain Range, where precipitation averages 100 to 200 inches a year (250 to 500 cm). Precipitation levels in the coastal mountains and valleys of Oregon and Northern California are also great, although not equaling the extremes of the Olympic peaks.

Most of the precipitation occurs in the winter months. Seasonal shifts in wind direction occur, which influence nearshore ocean currents, produce upwelling of cooler water, and further modify the coastal climate by producing fog, reducing insolation, and cooling the air.

High river runoff in the region, combined with direct precipitation at sea, makes the oceanic realm one of net dilution. That is, the surface salinity is less than that of the water below the surface. (In areas where evaporation exceeds precipitation and runoff, the surface salinity is greater than the water below the surface.)

The high precipitation and mild temperatures combine to create a unique habitat that promotes growth of large trees. The coolness of the coastal climate may discourage the settlement of people in the area..

Winter storms, though not equaling the East and Gulf Coasts' hurricanes, may still be severe, with winds often gusting in excess of 100 miles per hour. These storms also generate large waves which influence coastal processes of erosion, sediment transport, and deposition, causing hazardous conditions for shipping in the region.

Because of the low population densities and the constant "sweeping out" of the air by the clean westerlies off the Pacific, air quality in the study area is excellent. Occasional short-term pollution episodes occur near point-sources under unusual weather conditions, but these are minor and of little concern in regional air quality analyses.

General weather data and climatic description of the Washington and Oregon coastal regions have been prepared by the Oceanographic Institute of Washington (1977). Regionally descriptive information of atmospheric pressure, winds, storms, and resulting waves is available from National

Marine Consultants (1960, and 1961B). Oregon State University (1971) provides a regional climate discussion, and Lane (1965) discusses the heat budget off the coast of Oregon, including data on evaporation, back radiation and insolation. Annual averages of climatic data are graphically presented in the Climatic Atlas of the United States (U.S. Department of Commerce, 1968). Annual summaries with comparative data for specific locations within the region are prepared by the U.S. Department of Commerce (NOAA, Environmental Data Service) and are available through the National Climatic Center, Asheville, North Carolina. Phillips and Donaldson (1972) present a very useful description of the Washington coastal counties climate (available through the Cooperative Extension Service of Washington State University).

2.3.1 Meteorological Conditions. The following discussion of the region's general climatic features and its winter and summer characteristics is extracted largely from OIW (1977) and OSU (1971).

The climate of the study area is predominately mid-latitude, west-coast-marine type. The Washington, Oregon, and Northern California coasts are located approximately in the center of the zone of prevailing westerlies, with local winds varying from northwest to southwest throughout most of the year.

Most air masses that pass through the region have their sources over the Pacific Ocean. Hence, the ocean has a moderating influence on the weather in both winter and summer - a warming effect in winter and a cooling effect in summer. The Cascade Mountain Range forms a barrier protecting the area from the cold winter and warm summer continental air masses to the east.

2.3.1.1 Atmospheric Pressure. Two semi-permanent pressure patterns, the Aleutian Low and the North Pacific High, are the major large-scale features which control the climate of this region.

The North Pacific High is a large region of high pressure (an anti-cyclone) located off the west coast of the United States. The air flows around the North Pacific High in a clockwise fashion, and the weather in the High is generally fair.

The Aleutian Low, rather than being a single low pressure area, consists of a series of migratory low pressure centers which pass through the Aleutian Low region. The region lies over southwest Alaska and the Aleutian Islands and is characterized by prevailing pressures typically less than 1002.5 millibars (U.S. Department of Commerce, 1976). Winds blow in a generally counterclockwise direction around the Low, and the Low is an area where frontal storms form when warm, moist air from the south central Pacific meets the cold polar air mass.

The Aleutian Low dominates the winter weather in the Pacific Northwest. During the fall, the North Pacific High contracts to its winter position off the coast of California, and the Aleutian Low expands southward to extend over the Gulf of Alaska and the Bering Sea. Figure 2-12 shows the mean surface pressure pattern for the eastern Pacific during January. The counterclockwise flow of air around the Low brings prevailing winds from the west and southwest.

Frontal storms form in the Aleutian Low region and move eastward into British Columbia, Washington, Oregon, and Northern California. They bring the precipitation and cloudiness typical of a Pacific Northwest winter. Most precipitation during the rainy season (October to March) is associated with these winter storms.

Along the coast in winter, winds are generally from the west or southwest and temperatures are mild. Occasionally, winds from the north and northeast bring cold, dry polar air into the area. Unusually cold temperatures prevail in such a situation, but the cold spells usually last only a few days.

As summer approaches, the North Pacific High expands northward to its summer position while the Aleutian Low contracts northward. Figure 2-13 presents the mean pressure pattern for July. During summer, the High prevails over most of the eastern Pacific Ocean north of 20°N latitude almost to Alaska and from the western United States coastal area to 160°E longitude. The highest pressure is located at the latitude of San Francisco near 150°W longitude (U.S. Department of Commerce, 1976). Clockwise circulation around the High brings a prevailing air flow from the northwest to Washington and becomes northerly (from the north) as it flows over Oregon and Northern California.

Any storms in the northern Pacific Ocean are usually steered north of Washington, and summer is a time of little precipitation and generally fair weather.

Along the coast in summer, winds are mostly from the northwest and north, and speeds are usually lower than in winter. However, the heating of the land during the summer day and the resulting land-sea breeze effect modify the prevailing flow. Summer temperatures are generally mild. The

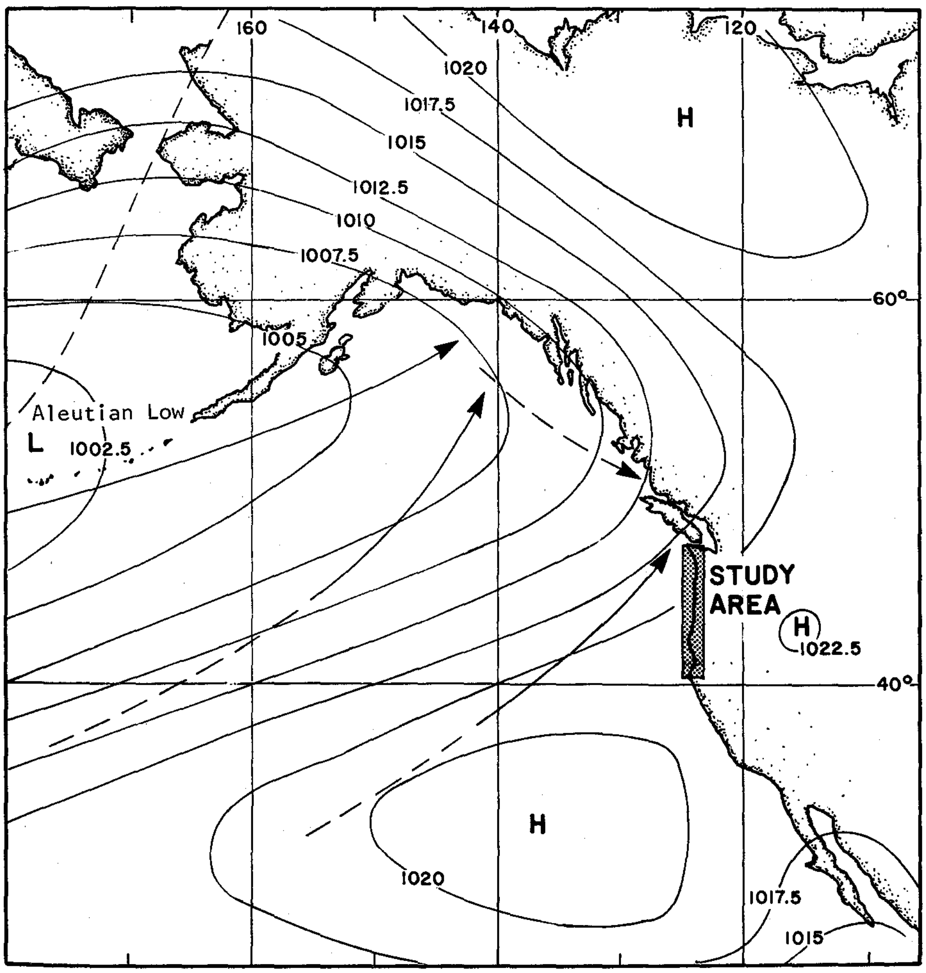


FIGURE 2-12. MEAN SURFACE PRESSURE PATTERN AND SURFACE LOW PRESSURE TRACKS FOR JANUARY. Pressure isobars are in millibars (1000 mb = 750 mm-Hg = 29.54 in-Hg). The low pressure tracks (arrows) show general winter storm paths in the region. (From U.S. Department of the Navy, 1958.)

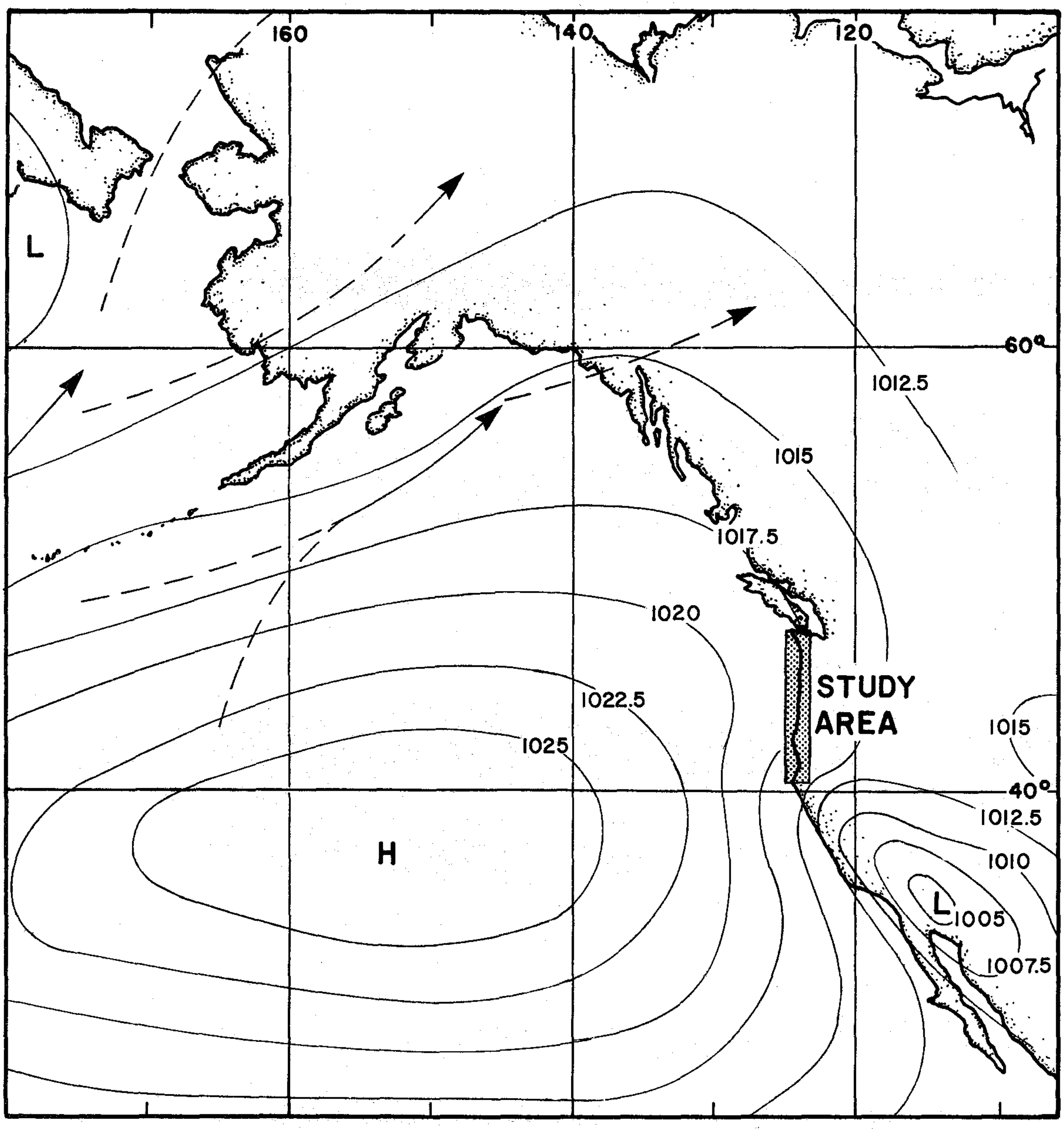


FIGURE 2-13. MEAN SURFACE PRESSURE PATTERN AND SURFACE LOW PRESSURE TRACKS FOR JULY. Pressure isobars are in millibars (1000 mb = 750 mm-Hg = 29.54 in-Hg). Th low pressure tracks (arrows) show general summer storm paths in the region. (From the U.S. Department of the Navy.)

highest temperatures are recorded when winds from the northeast and east bring warm air from the interior of the continent.

2.3.1.2 Winds. Figure 2-14 shows average direction and velocity of monthly winds for three offshore areas as computed from atmospheric pressure charts by Duxbury et al. (1966) for 1961-1963. A significant latitudinal variation is the direction and velocity of the summer winds, which increase in strength and become more northerly (to the south) with decrease in latitude. This increases the amount of upwelling nearshore in the southern part of the study area (see Section 2.7.2). Resultant wind speeds during the autumn and spring transition periods are relatively low due to the wide variability in wind direction during these seasons. Duxbury et al. (1966) prepared wind roses for each month showing frequency of occurrence of different wind speeds and directions.

Quayle and Fulbright (1975) have estimated return periods of extreme winds using existing climatological data for coastal areas of the United States. They define a mean return period as "the average number of years between successive occurrences of values greater than or equal to some threshold value." They define a maximum sustained windspeed as "having a duration (at or above the given speed) of approximately one minute, though the averaging time for most marine observations is more than one minute." Return periods for extreme sustained windspeeds are presented in Table 2-3.

Quayle and Fulbright note that peak gusts (duration usually less than 20 seconds) frequently occur and average about 1.4 times the sustained windspeed. Rogers (1966) reported winds gusting up to 240 km/hr (150 mph) from an oil rig off the Oregon coast. Applying the 1.4 multiplier for gust conditions to the sustained windspeed estimates of Table 2-3 for the Oregon coastal areas, it is likely that the wind gusts measured by Rogers represent the 100 year return period extreme.

TABLE 2-3. EXTREME SUSTAINED WINDSPEED ESTIMATES FOR SPECIFIED RETURN PERIODS ALONG THE PACIFIC NORTHWEST COAST.[1] (Adapted from Quayle and Fulbright, 1975.)

	5 YR		10 YR		25 YR		50 YR		100 YR	
AREA	Km/hr	(MPH)	Km/hr	(MPH)	Km/hr	(MPH)	Km/hr	(MPH)	Km/hr	(MPH)
Washington	124	(77)	135	(84)	150	(93)	163	(101)	176	(109)
Northern Oregon	124	(77)	135	(84)	152	(94)	163	(101)	178	(110)
Southern Oregon	126	(78)	135	(84)	152	(94)	165	(102)	178	(110)
Northern California	122	(76)	131	(83)	148	(92)	161	(100)	174	(108)

[1]Values are converted from original units (knots) and rounded to whole numbers.

2.3.1.3 Temperature. Temperatures in the coastal area are relatively mild and are usually similar to the ocean surface temperature. The change of ocean temperature is small during a day or a season, therefore the daily and seasonal variation in air temperature is smaller than it would be if the ocean were not an influence. Figure 2-15 presents average, maximum, and minimum air temperatures for selected open coast stations. Tatoosh Island is located off Cape Flattery, at the northern end of the study area. Eureka is located in Northern California, 30 miles (50 km) north of the southern end of the study area. Astoria is located approximately ten miles (16 km) inland from the mouth of the Columbia River and North Bend is located by Coos Bay. It is apparent that temperatures are similar along the entire coast of the study area. Inland temperatures vary with elevation and distance from the coast. Specific temperature data are presented in Volume 4 for individual Watershed Units.

2.3.1.4 Humidity. The relative humidity in the area is fairly high due to the influx of moist marine air with small fluctuations throughout the day. The highest humidity generally occurs in the hours after midnight, corresponding to the lowest temperatures of the day. The lowest humidity is usually observed in the afternoon when highest temperatures occur. Table 2-4 shows mean values of relative humidity at four times of day for Astoria and Tatoosh Island. The similarity is evident and extends down the coast to include the Eureka-Arcata area (U.S. Department of Commerce, 1977C).

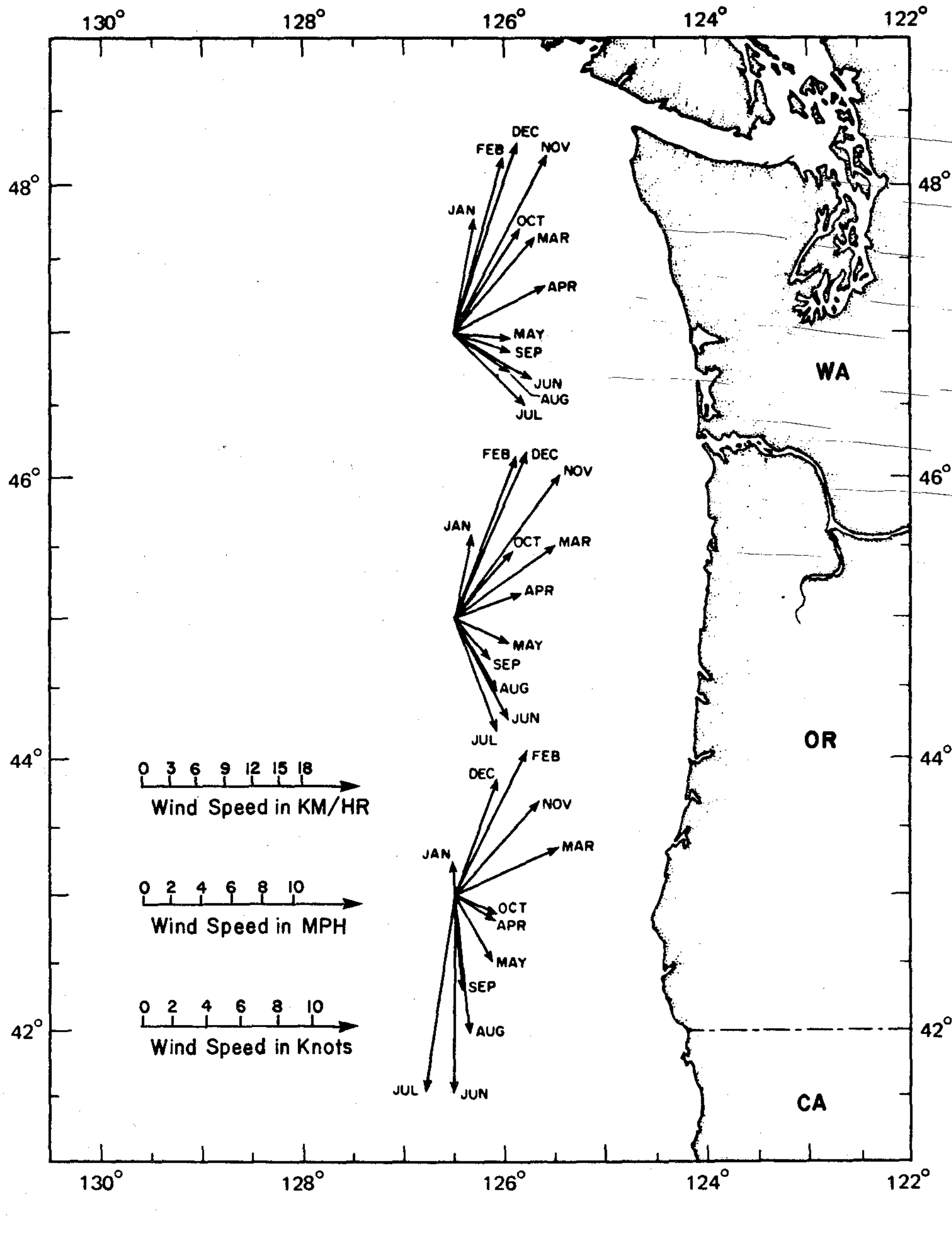


FIGURE 2-14. AVERAGE DIRECTION AND VELOCITY OF MONTHLY WINDS FOR 1961-1963. (From Duxbury et al., 1966.)

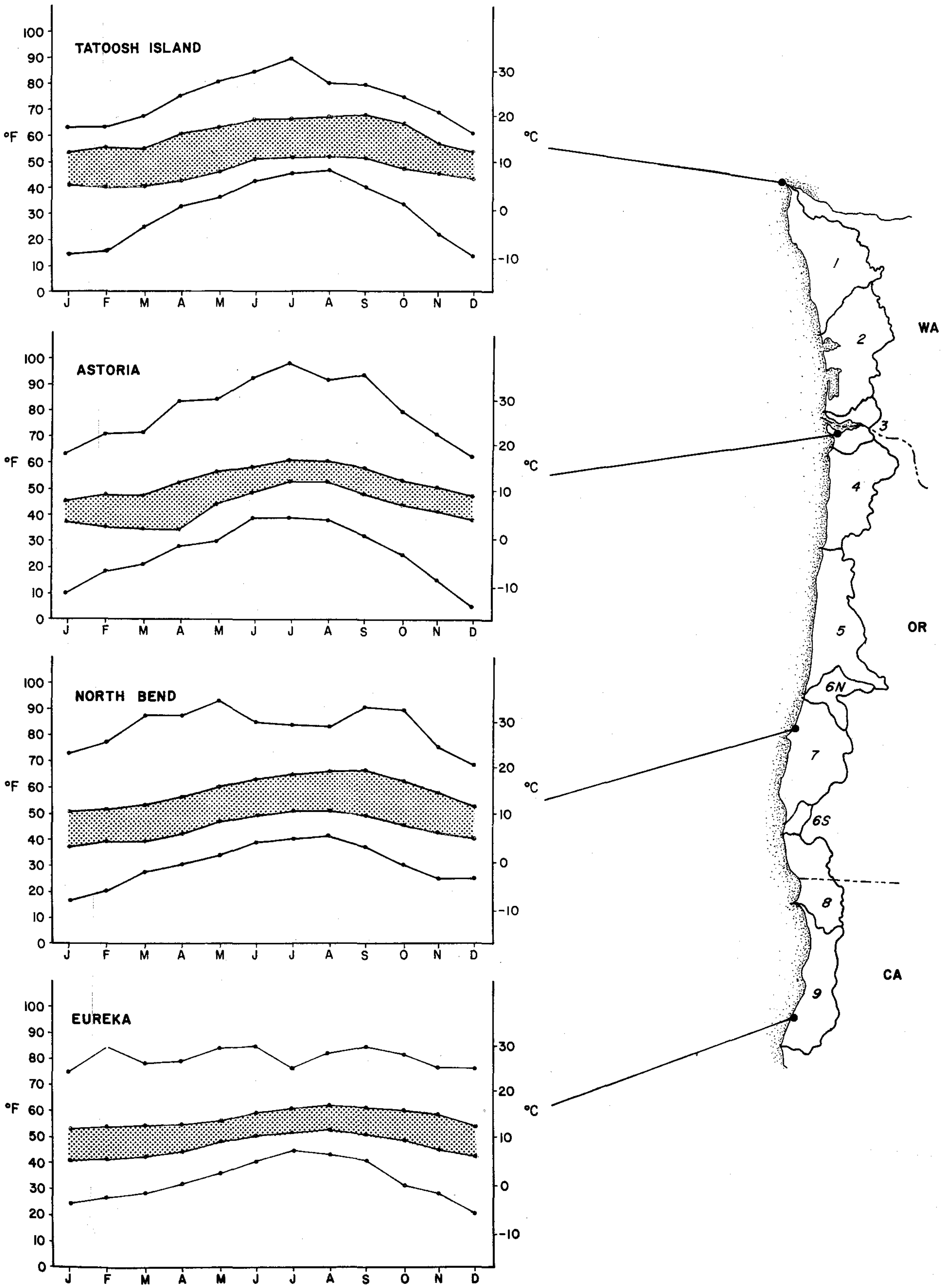


FIGURE 2-15. TEMPERATURE DATA FOR COASTAL STATIONS IN THE STUDY AREA. Darkened band shows average temperature range. Top and bottom lines show extreme high and low temperatures that have been measured. (Adapted from: Phillips and Donaldson, 1972; U.S. Department of Commerce, 1968, and 1977C; and Oceanographic Institute of Washington, 1977.)

TABLE 2-4. RELATIVE HUMIDITY DATA FOR THE PACIFIC NORTHWEST COAST. Relative humidity monthly means (in percent) are given for six-hour daily intervals (4 and 10 AM and PM Pacific Standard Time) at Astoria (Columbia River estuary) and Tatoosh Island (Northern Washington). (From Phillips and Donaldson, 1972.)

Time of Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
OPEN COAST													
Astoria (1953 - 1965)													
4 AM	87	88	88	89	90	90	91	93	93	91	90	89	90
10 AM	84	83	77	74	73	76	75	77	76	82	83	86	79
4 PM	78	76	69	70	69	71	69	71	70	74	78	81	73
10 PM	87	87	86	85	85	86	87	90	90	90	88	88	87
Tatoosh Island (1917 - 1965)													
4 AM	84	85	86	87	89	92	94	96	92	90	86	86	89
10 AM	82	81	80	80	82	86	89	90	87	85	83	83	84
4 PM	82	80	79	79	81	84	87	90	86	85	84	83	83
10 PM	82	82	82	83	86	89	92	94	90	87	83	83	86

2.3.1.5 Precipitation. Precipitation in the study area is generally produced by frontal storms moving inland from the Pacific Ocean and is enhanced considerably by orographic lifting along the slopes of the coastal mountains. This enhancement is effective even at the coast, and may have a back-pressure effect over part of the shelf. Elliott et al. (1971) measured precipitation from a stable platform (the "TOTEM" buoy of Oregon State University) moored over Heceta Bank, on the outer continental shelf off Central Oregon. They concluded that the presence of the coast increased the rainfall by a factor of 3.5. While acknowledging that their figure is only valid for coastal Oregon, and that the enhancement there may be much greater than at some other location around the Pacific, they feel that the magnitude of the change warrants further worldwide studies and revision of estimates of rainfall over the sea. Since storms affecting the Oregon coast are not significantly different from those affecting Northern California and Washington, this enhancement effect is probably representative of the entire study area.

The southward shift of the semi-permanent Aleutian Low during the winter months results in an increased frequency of frontal storms reaching the Pacific Northwest and a corresponding winter maximum of precipitation over the study area. About 80% of the annual precipitation along the coast occurs from October to March while 5% or less of the annual total occurs in July and August. Figure 2-16 presents mean monthly precipitation for coastal stations; the seasonal trends are apparent. Snowfall is generally rare and of brief duration along the coast due to the usually mild coastal temperatures, but becomes more common with increased elevation in the coastal mountains. Most winter precipitation falls as snow in the higher mountains; in the Olympics some moisture is retained year-round in the form of glacial ice and arctic-alpine snowfields. Most runoff of coastal streams and rivers is related to the winter storms, with the Columbia River and the small rivers draining the Olympics (Watershed Unit 1) exhibiting late spring peak flows associated with snowmelt (see Section 2.5.2).

Annual precipitation along the open coast averages 70 to 80 inches (180 to 200 cm) per year, generally decreasing to the south. The lowest coastal precipitation in the study area is at Eureka with only 39.8 inches (101 cm) per year (U.S. Department of Commerce, 1977C). Figure 2-17 presents annual precipitation totals for the entire study area; similar information in more detail is presented in the individual Watershed Units (Volume 4).

Orographic lifting produces increased totals inland to nearly 250 inches (635 cm) at the crest of the Olympic Mountains. The extensive rain forest region along the western slopes of the Olympic Mountains averages 100 to 200 inches (250 to 500 cm) per year. Inland precipitation totals in Oregon average 80 to 120 inches (200 to 300 cm), increasing upslope to 200 inches (500 cm) in the mountainous area just inland from Lincoln City in Watershed Unit 5. A similar pattern, to peaks of 100 to 120 inches (250 to 300 cm), occurs in the Klamath Mountains in Southern Oregon and Northern California.

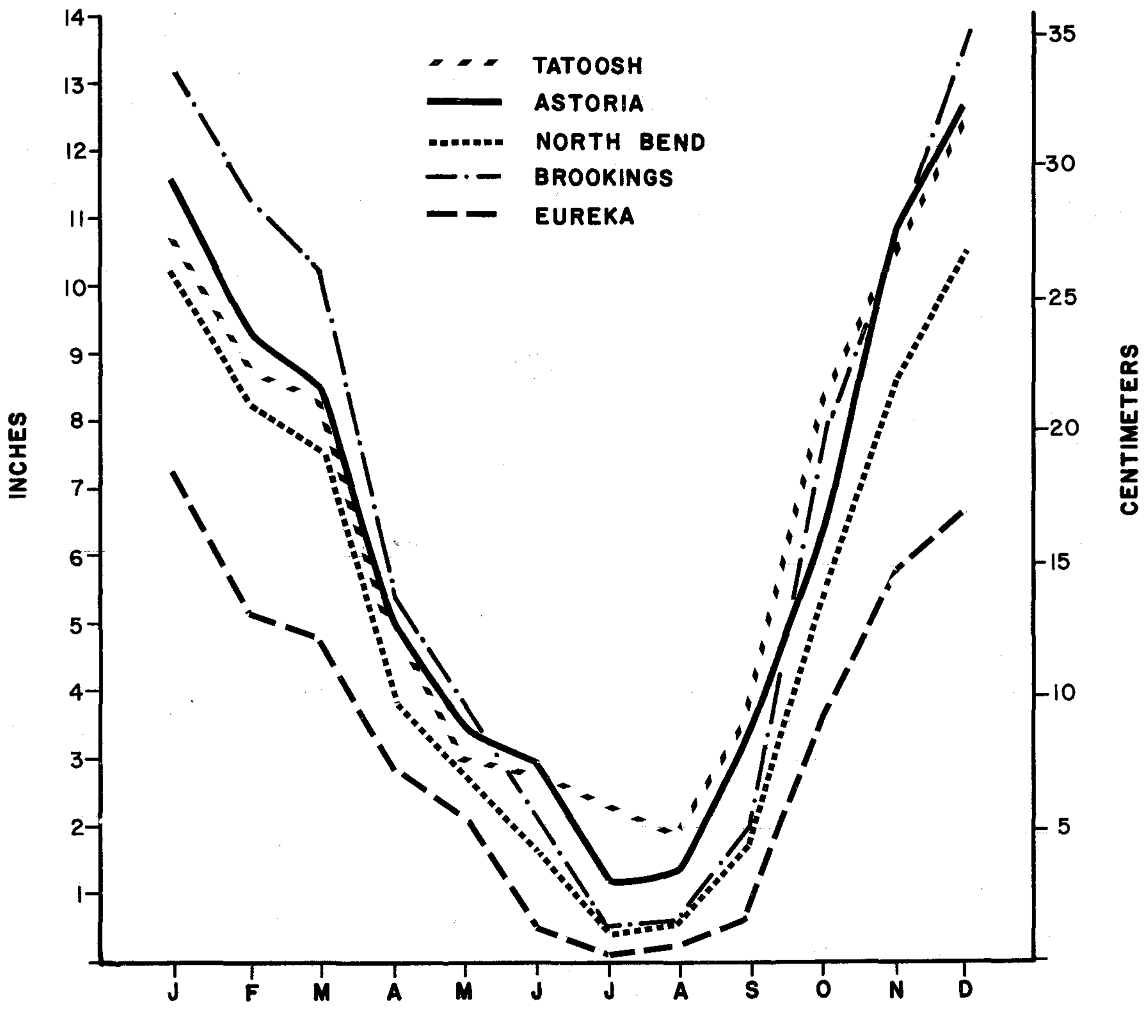


FIGURE 2-16. MEAN MONTHLY PRECIPITATION FOR COASTAL STATIONS. Seasonal trends are evident and uniform throughout the region. North to south variation trends should not be assumed from this figure, as additional data (not shown) for other sites along the coast produce a mixture of patterns related more to local topographical features than latitude. (From Phillips and Donaldson, 1972; Sternes, 1960; PNRBC, 1970; OIW, 1977; and U.S. Department of Commerce, 1977C.)

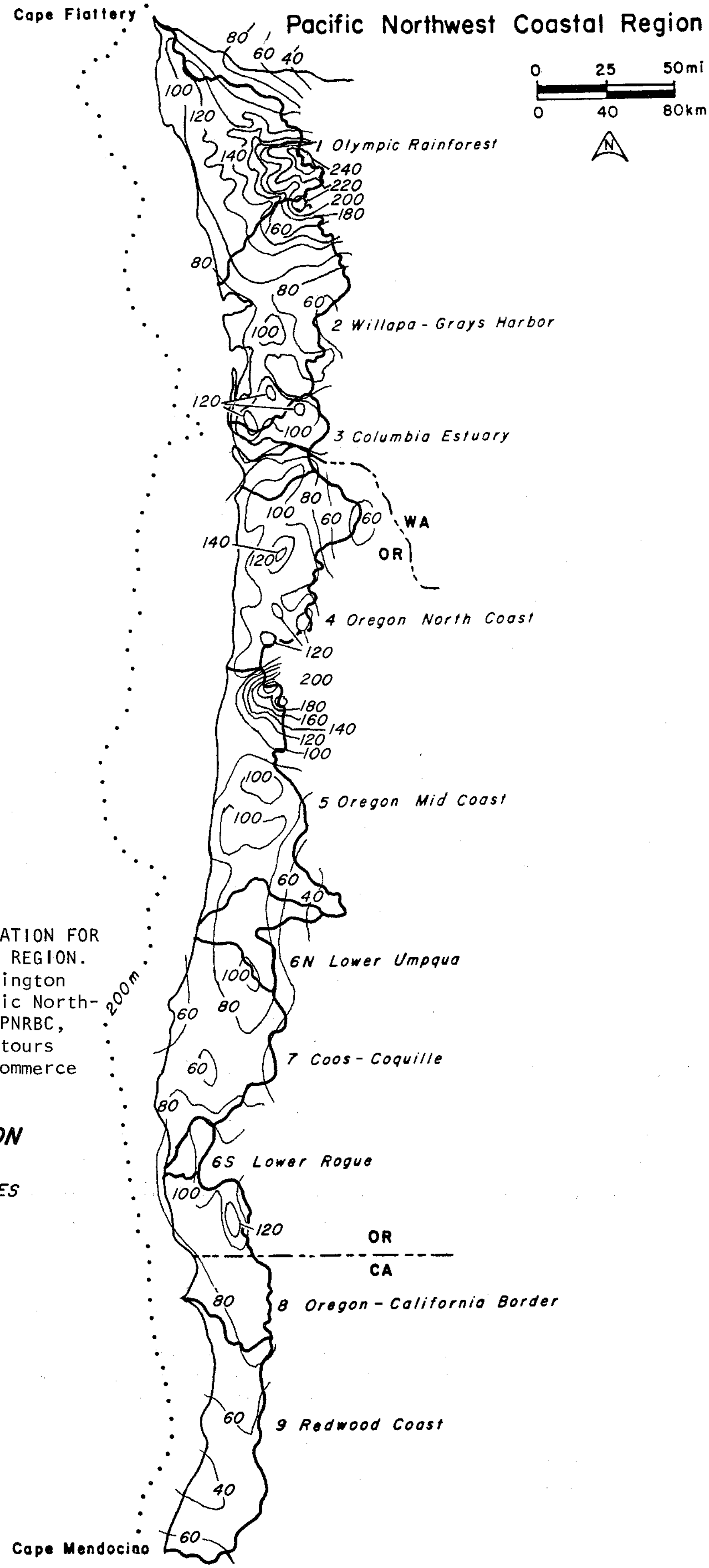
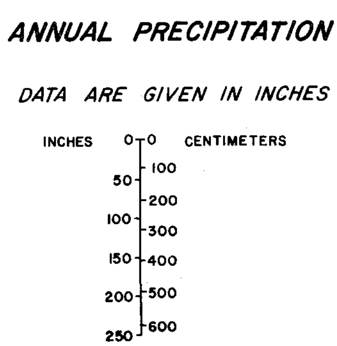


FIGURE 2-17. ANNUAL PRECIPITATION FOR THE PACIFIC NORTHWEST COASTAL REGION. Mean annual contours for Washington and Oregon are from the Pacific Northwest River Basin Commission (PNRBC, 1970) and "normal" annual contours are from U.S. Department of Commerce (1977C) for California.



Snowfall along the coast averages one to eight inches (2 to 20 cm) annually and is largely confined to the months of December through February. Snow ground cover along the coast rarely lasts more than two to three days at a time. Snowfall increases significantly inland with altitude to average 500 inches (1300 cm) near the crest of the Olympic Mountains. (This snowfall figure is reduced to equivalent water height and included in the annual precipitation discussion and figures.)

The range in annual precipitation totals from minimum to maximum extremes for many locations along the open coast is about 50 inches (130 cm). Figure 2-18 presents the departure of annual precipitation from the average for the period 1891-1969 for Aberdeen, Washington, located adjacent to Grays Harbor in Watershed Unit 2. The five year period from 1929 through 1933 shows a 60 inch (150 cm) range. During the three year period from 1933 to 1935, Tillamook, Oregon (Watershed Unit 4) recorded annual precipitation totals of 130 inches (331 cm) and 65 inches (164 cm), giving a range of 66 inches (167 cm). Record annual low and high precipitation totals for other locations include: Tatoosh Island, 50 to 114 inches (126 to 290 cm), and North Head (near Cape Disappointment at north tip of Columbia estuary mouth), 31 to 80 inches (78 to 203 cm).

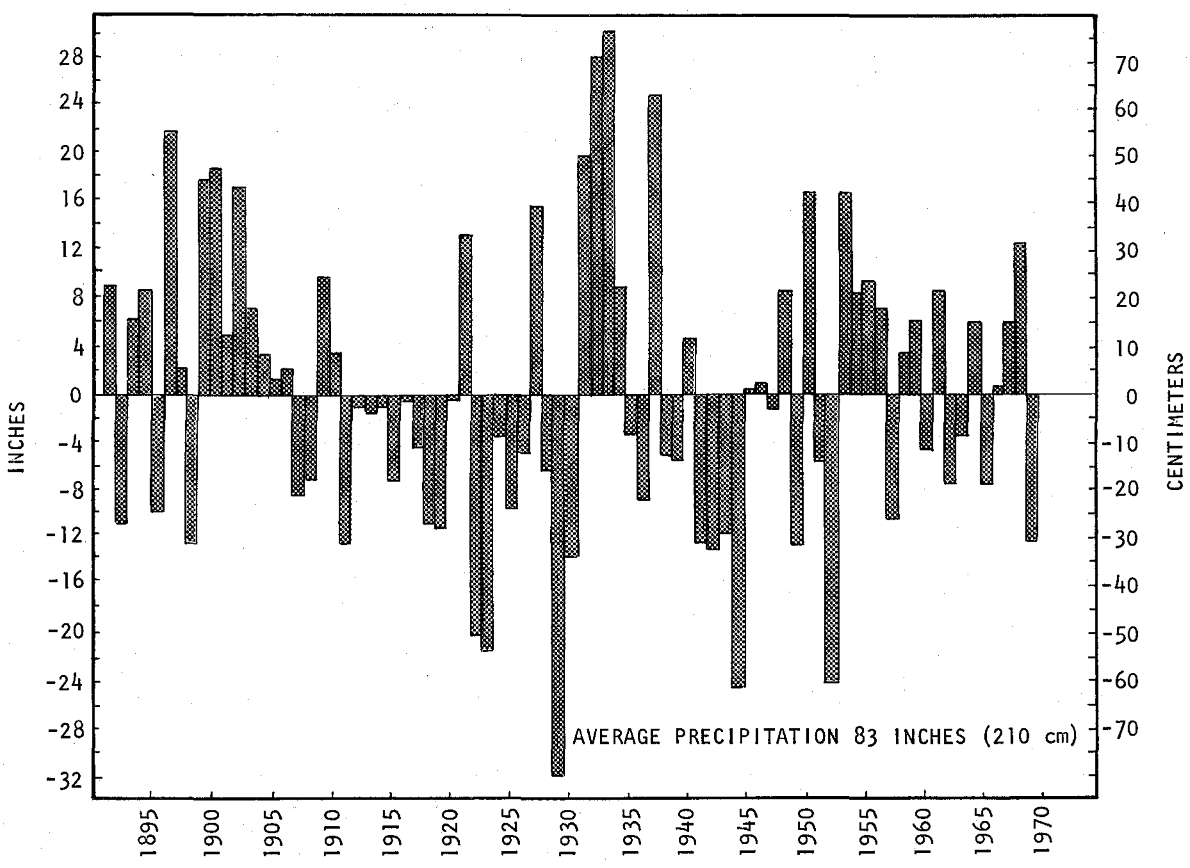


FIGURE 2-18. DEPARTURE OF ANNUAL PRECIPITATION FROM AVERAGE FOR PERIOD 1891-1969 AT ABERDEEN, WASHINGTON. (From Phillips and Donaldson, 1972.)

Snowfall along the open coast is extremely variable, many years having no snowfall at all. Greatest winter totals of snowfall approach 50 inches (130 cm) at many coastal locations. This decreases to the south, with the greatest annual snowfall at Eureka being only 3 in (7.5 cm). Greatest snowfall figures include 36 in (93 cm) at Tatoosh Island, 90 in (230 cm) at Aberdeen, and 31 in (81 cm) at Astoria.

The frontal nature of most precipitation along the open coast produces prolonged episodes of light to moderate rain, increasing in intensity as one moves inland (upslope), rather than brief episodes of intense rainfall indicative of thunderstorms. Most coastal locations can expect to receive a rainfall amount of one inch (2.5 cm) falling in one hour only once in every fifty years.

Since the precipitation intensity is light, the frequency must be great to account for annual rainfall totals. The number of days with measurable precipitation along the coast ranges from 199 at Tatoosh Island, to 187 at Astoria, 122 at Brookings, and 117 at Eureka.

2.3.1.6 Storms. When a low pressure center moves directly through the study area the weather may change rapidly. The low center is preceded by strong southeasterly to southwesterly winds that may reach gale force and generate sea waves of 20 ft (6 m) or more. Clouds and rain accompany the low center. After the passage of the low, winds veer to westerly or northwesterly and remain strong for a short period. The clouds soon break and a high pressure ridge may follow bringing periods of clear, cool, stable weather. These storms are significant in oceanic sediment transport, mixing, beach sediment transport, shoreline erosion, innundation of low-lying coastal areas, and blow downs of trees onshore. They are hazardous to vessels at sea and to manmade structures built in vulnerable locations.

Low pressure centers appear to follow "preferred" pathways as they move across the eastern Pacific. During the winter, when the North Pacific High has receded to its most southerly location, the path of storm centers also shifts to the south. The solid lines with arrowheads shown in Figure 2-12 depict the predictable paths of surface low pressure centers moving across the eastern Pacific. The dashed lines represent secondary paths of lows. These storm tracks are based on all available data for sea level systems from 1866 to 1954. The arrowheads end in areas of maximum storm frequency where tracks may cross, branch, or merge. Primary tracks are most frequent and well-defined. It must be kept in mind that frontal zones often extend for hundreds of miles to the south and west of the surface low pressure centers. Lows following these tracks can therefore affect the weather of the entire study area.

Figure 2-13 shows storm tracks along with the mean pressure pattern for July. The northward expansion of the North Pacific High and the resultant northward shift of these storm tracks is evident. In addition, summertime storms are usually less intense than those of the winter and their frontal zones rarely reach the study area.

2.3.1.7 Cloud Cover. Due to the predominant onshore flow of moist marine air during all seasons, and the relatively high frequency of frontal storm passage during winter months, cloud cover is a regular feature of the study area. Along the coast, cloudy skies (80 to 100% cloud cover) are reported for about one-half the days of the year. There is little difference in the number of cloudy days per year recorded from one station to another along the open coast. The differences observed are generally the result of local topography which influences the formation of radiation fog and sea fogs. There is a slight tendency for marine stratus to be somewhat less extensive in the southern portion of the coast due to the slightly reduced frequency of frontal storm passage in this area.

Marine stratus is the predominant type of cloud cover in the study area. It forms when extensive layers of relatively warm, moist marine air are cooled. Both orographic lifting, which results from air flowing over a significant topographic feature, and frontal lifting, which occurs when relatively warm air is forced to rise over a colder air mass, are responsible for the adiabatic cooling necessary for the formation of marine stratus. In addition, the flow of marine air over colder coastal waters of the California current and coastal upwelling regions can produce a marine stratus layer.

When the North Pacific High dominates the study area during the summer months, large scale atmospheric subsidence inhibits lifting and results in the most cloud-free season of the year. However, marine stratus can and does form during the summer by the cooling marine air flowing over cold coastal waters and by orographic lifting during those periods when the North Pacific High weakens. The high frequency of frontal passage during the winter months makes winter the cloudiest season.

Clear or partly cloudy days (0 to 70% cloud cover) average 12 to 18 days per month during the summer and decrease to an average of only four to seven days per month during the winter. Spring and fall average from eight to seventeen clear or partly cloudy days per month (Phillips and Donaldson, 1972; U.S. Department of Commerce, 1977C).

There is also a diurnal variation of cloud cover along the open coast. Marine stratus, particularly when formed by air passage over cold coastal surfaces, often forms at night when surface cooling creates an inversion which prevents the vertical mixing of air near the surface. Such stratus gradually dissipates during the day as solar heating warms the surface layer and allows more extensive vertical mixing. Marine stratus formed by frontal lifting is not usually subject to this diurnal variation.

Summer and fall are fog seasons along the open coast when the dominance of the North Pacific High creates frequent subsidence inversions. Subsidence inversions are created by the compression warming of air sinking to lower levels. The sinking air can become warmer than air at the surface which is then trapped beneath the temperature inversion. Strong northerlies cause episodes of intense upwelling of cold water near the coast. The cooling of marine air flowing over these waters then forms advection fog and stratus, which penetrate inland as far as the local topography, height of the inversion base, and land heating allow.

2.3.2 Air Quality. Subsidence inversions occur in the coastal area in the summer and fall. They limit the mixing depth and can allow locally generated air pollutants to concentrate in the shallow marine layer for some length of time. This may be further complicated by conditions that favor formation of advection fog.

A characteristic of the coast in the Pacific Northwest region is that it is not densely settled. Since the dominant winds are from the west, air pollution in the area is limited to that which is generated locally, the westerly winds being essentially pollutant-free when they arrive at the coast. The air quality is, therefore, quite good.

Local air quality problems are related to wood-processing industries, and include sulfur dioxide emissions from pulp mills and suspended particulates from various sources. Low-level, but measurable, air pollution from industrial sources has been measured on the Grays Harbor estuary (U.S. Army Corps of Engineers, 1976C). Coos Bay has monitored its air quality since 1969; air quality standards for gases were never exceeded between 1969 and 1975 (U.S. Army Corps of Engineers, 1975B). Suspended particulate matter did exceed 150 $\mu g/m^3$ once in a three year period in the Coos Bay area, with wood-processing facilities being the major source of this pollutant. In Yaquina Bay, wood processing again is the only significant source of air pollution, but as of 1975 was not considered significant enough for Oregon's Department of Environmental Quality to establish any air quality monitoring stations in the area (U.S. Army Corps of Engineers, 1975G).

An Environmental Impact Statement prepared for the Willapa Bay area noted that the major source of particulates in the air is the ocean, with typical values for suspended particulates (salts, etc.) in seashore air being about 35 $\mu g/m^3$. This level of salt spray "pollution" is typical for the entire coast and is a significant natural environmental factor in the coastal ecosystems.

Slash burning and wildfires, when occurring, contribute significant amounts of pollutants to the atmosphere. GEOMET (1978) reported the following annual ranges of pollutants from forest burning and wildfires combined for Oregon and Washington: total suspended particulates of 69,650 tons to 274,502 tons, nitrogen oxides of 8,194 tons to 24,583 tons, hydrocarbons of 40,971 tons to 163,792 tons, and carbon monoxide of 84,941 tons to 2,048,522 tons. These values are derived from low and high estimates and are for the total area of the two states, not just the coastal region.

For most of the study area, there is an absence of air quality data. This is largely due to the fact that the air is nearly pollution-free, excepting near the major settlements. The pollution that does occur is mostly related to wood-processing industries, which are concentrated adjacent to those estuaries with sufficient deep water to allow for shipping activities.

2.4 HYDROSPHERIC FEATURES - GENERAL HYDROLOGY

The precipitation pattern in the Pacific Northwest Coastal Region is one of wet winters and dry summers (see Section 2.3.1.5). Runoff patterns of coastal rivers exhibit peak flows in the winter associated with the increased precipitation. The model of the hydrologic cycle (Figure 2-17 in Volume 1) shows climate as a secondary regulating factor of precipitation. The precipitation pattern just described for the region is characteristic of west coast, mid-latitude climate. Another characteristic of the region's "maritime" climate is its mild winter temperatures, preventing large amounts of precipitation from being stored as snow or ice in the study area, except in the higher peaks of the region. Significant snow and ice storage of water does occur in Watershed Unit 1 in the Olympic Mountains, the only place where glaciers are found in the study area. The rivers draining the Olympics exhibit peak flows in the late spring associated with snow melt, as well as in the winter associated with heavy rainfall.

The Columbia River drainage basin extends inland beyond the crest of the Cascade Mountains (Figure 2-19) where the climate is more continental and large amounts of moisture are tied up in snowpacks. These snowpacks are not in the study area, but do influence Watershed Unit 3 and all the oceanic region through the discharge of the Columbia River. The Columbia River's seasonal discharge is characterized by a major sustained peak rate of flow frequently reaching 21,000 m^3/sec principally in May or June from interior snowmelt, a minor peak or peaks of short duration during winter that may equal or exceed this flow rate, and a yearly minimum flow of under 3,000 m^3/sec (100,000 ft^3/sec) usually found in September (Barnes et al., 1972). Figure 2-20 shows the Columbia River discharge curves for 1961, 1962, and a 15 year mean. The Columbia River flow is highly regulated by dams, well inland of the study area. The presence of the dams breaks up the seaward flow into many stream-then-lake-then-stream-then-lake sequences. The dams also regulate the peak flows.

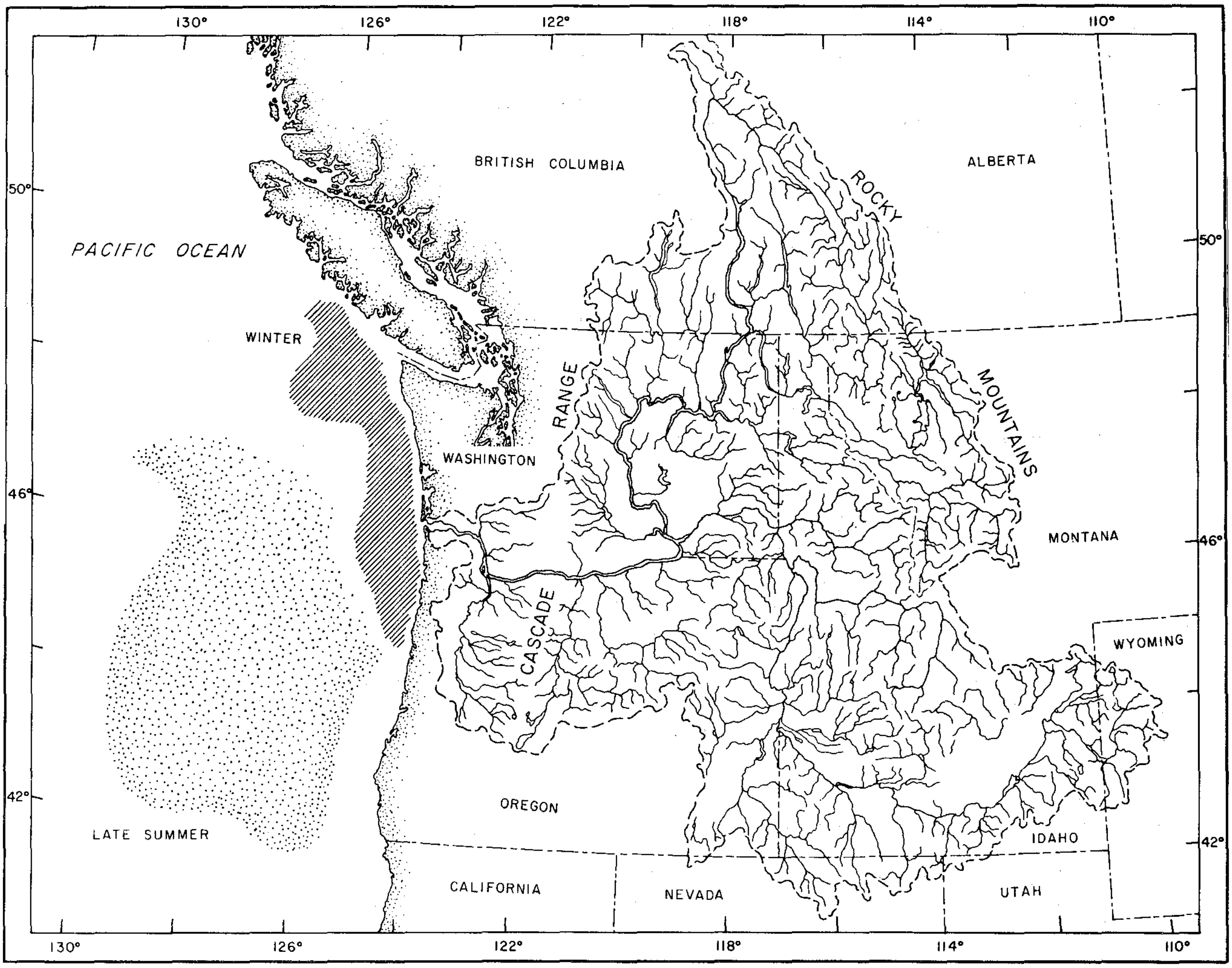


FIGURE 2-19. COLUMBIA RIVER DRAINAGE BASIN AND AVERAGE SEASONAL EXTENT OF THE COLUMBIA RIVER PLUME OFFSHORE. (From McGary, 1971.)

A great deal of water is tied up in soil moisture and ground water in the region. Much of this groundwater eventually makes its way to the ocean either directly or via streams and estuaries. Evapotranspiration is high, as the broadleaves and needles of the vast forest covering the region offer a maximum amount of plant surface area from which water may evaporate. Evaporation from the land and evapotranspiration, however, account for only about 20% of the water passing through the hydrologic cycle in the region; most water follows the path through percolation to ground water and through outflow to streams and on to the ocean through channelized runoff. Lakes do not represent a significant component of the region's overall hydrologic cycle.

Actual data on evaporation and evapotranspiration are scarce. Rogers and Swanson predicted 45.3 cm/year (17.8 inches/year) evapotranspiration for an old growth forest with a precipitation of 158 cm (62 inches) in the Pacific Northwest (reported by Edmonds, 1975). PNRBC (1970) reports approximately 60 cm (25 inches) of annual evapotranspiration for inland environments of the region. Evaporation from surface water near Coos Bay was 60 to 75 cm (25 to 30 inches) per year as calculated by Kohler et al. (1959). An upper limit to the combined losses of evaporation and evapotranspiration may be estimated by subtracting the annual runoff from the annual precipitation for a given location. Contours of annual precipitation for the study area were presented in Section 2.3.1 and annual runoff contours are presented in Section 2.5.3. This approach ignores changes in freshwater storage in lakes and ground water, as well as the direct flow of ground water into the ocean. Consequently, estimates of combined evaporation and evapotranspiration by this method are likely to be high, or represent an upper limit.

Most of the freshwater entering the Pacific in the study region comes from the Columbia River, the plume of which moves southwest in the summer and north in the winter (Figure 2-19). The net dilution of the surface waters of the Pacific, both within coastal estuaries and over the shelf, characterizes the regional hydrology.

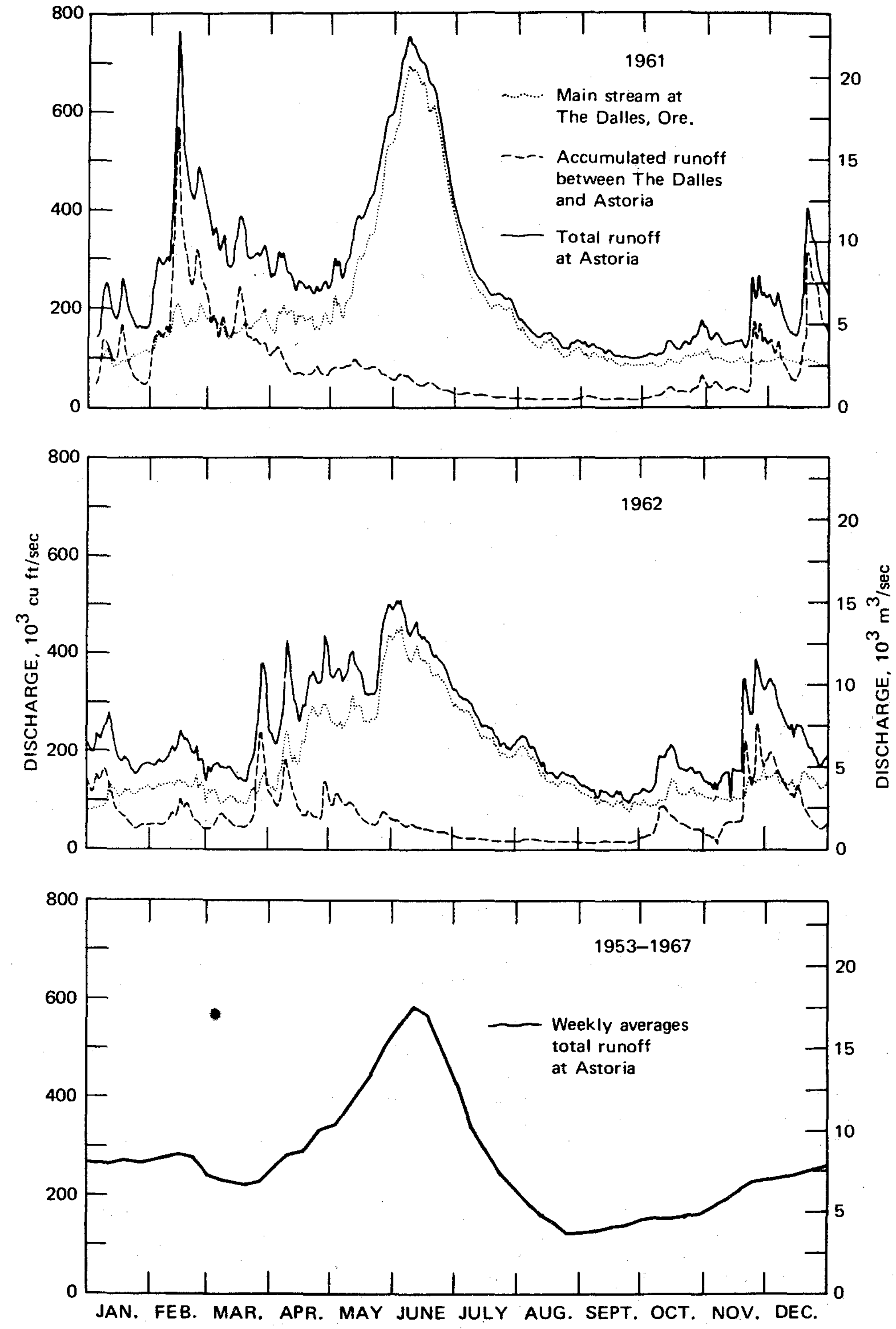


FIGURE 2-20. COLUMBIA RIVER DISCHARGE CURVES FOR 1961, 1962, AND A 15-YEAR MEAN. (From Barnes et al., 1972.)

The hydrologic cycle for the region begins with the atmosphere picking up moisture over the Pacific, then giving up the moisture as the winds move the moist air over the land. The routes this moisture follows in returning to the sea are modeled in Section 2.4 of Volume 1. The following Sections (2.5, 2.6, and 2.7) describe the hydrospheric features of the inland, estuarine, and oceanic environments, respectively, which the downward flowing runoff passes through in sequence, completing the cycle.

2.5 HYDROSPHERIC FEATURES - INLAND CONDITIONS

Precipitation in the region is high and greatly exceeds evaporation and evapotranspiration. The excess water is carried seaward in runoff by the coastal streams and rivers, and to a lesser extent by direct discharge of ground water to the ocean.

The study area has been divided into Watershed Units which were determined from the river drainage patterns. Figure 2-21 presents the drainage patterns of the major rivers in the study area. The drainage patterns are presented in greater accuracy and detail in Volume 4 for the individual Watershed Units. Rivers which extend inland of the eastern boundary are evident for Watershed Units 2, 3, 6N, 6S, and 9 in Figure 2-21. The drainage for the Columbia River was described in Section 2.4 and shown in Figure 2-19.

2.5.1 Precipitation and Condensation.

Precipitation values and seasonal patterns were given in Section 2.3 for the study region. Summer is the dry season, and along the coast it is also the fog season. Condensation from coastal fog may increase up to 26% the annual precipitation in the coastal area (Ruth, 1954). This is important in delineating the extent of the Sitka Spruce Zone along the coast, and is crucial to most of the flora in the Beach and Dune Zone.

2.5.2 Infiltration, Percolation, and Ground Water.

Infiltration rates have not been determined for soils within the region, but probably range from three to six inches per hour for sandy soils, one to four inches per hour for loams, and 1/8 to 1/2 inch per hour for clays (Forest Soils Committee of the Douglas-fir Region, 1957). Infiltration rates may vary according to types and density of vegetative cover.

Aquifer units for Washington and Oregon and their hydrologic characteristics are presented on regional charts and described in tabular form by PNRBC (1970). The aquifer units themselves are geological features; their descriptions and characteristics may be applied to similar geological units in Northern California as well. The following discussion of the various regional aquifer units is largely adapted from PNRBC (1970).

Alluvial deposits are the most important source of ground water supply for municipal, industrial, and irrigation use. However, these deposits are of limited extent and thousands of domestic and many small industrial and public supplies are obtained from other aquifers, most of which yield only small to moderate supplies.

Generally, the chemical quality of ground water from alluvium is good to excellent for most uses. Dissolved solids are mostly less than 500 mg/l (500 ppm) and the water is soft to moderately hard. Water at depths of several hundred feet may be saline, and saline water has been encountered in marine sedimentary rocks at depths of less than 100 feet (30 meters). Excessive iron is found locally in ground water in the dune areas.

The alluvial deposits are of three types: stream alluvium, glacial deposits, and beach deposits. Stream alluvium forms terrace and flood-plain deposits in the lower valleys. Most of the valleys are narrow and the deposits are generally less than 100 feet (30 meters) thick. Fine sand and gravel occur at many places and are good aquifers. Wells have moderate to large yields (200-1000 gallons per minute or gpm) and a few wells at favorable locations have large yields (over 1000 gpm).

Glacial outwash may underly, or be interbedded with, alluvium in valleys on the west slope of the Olympic Mountains. Well-sorted outwash deposits yield moderately large to large quantities of water (500-1000 gpm). The dune and beach deposits underlie narrow coastal plains in several reaches along the Washington, Oregon, and Northern California coasts. They consist predominantly of very well-sorted, fine to medium-grained sand. Their thickness usually ranges from about 50 to 200 feet (15 to 60 meters). Such deposits are very porous and moderately permeable, and yield moderate to large supplies (200-1000 gpm) to properly constructed and developed wells.

Terrace deposits of Quaternary age occur largely in Washington, where they underlie a low, broad terrace along the west and south flanks of the Olympic Mountains and the west side of the Coast Range. The deposits are predominantly fine-grained sand, silt, and clay and are believed to be largely of marine origin. However, lenses of medium to coarse sand and gravel are good aquifers and yield moderate to moderately large quantities of water (200-1000 gpm) at some places. Some

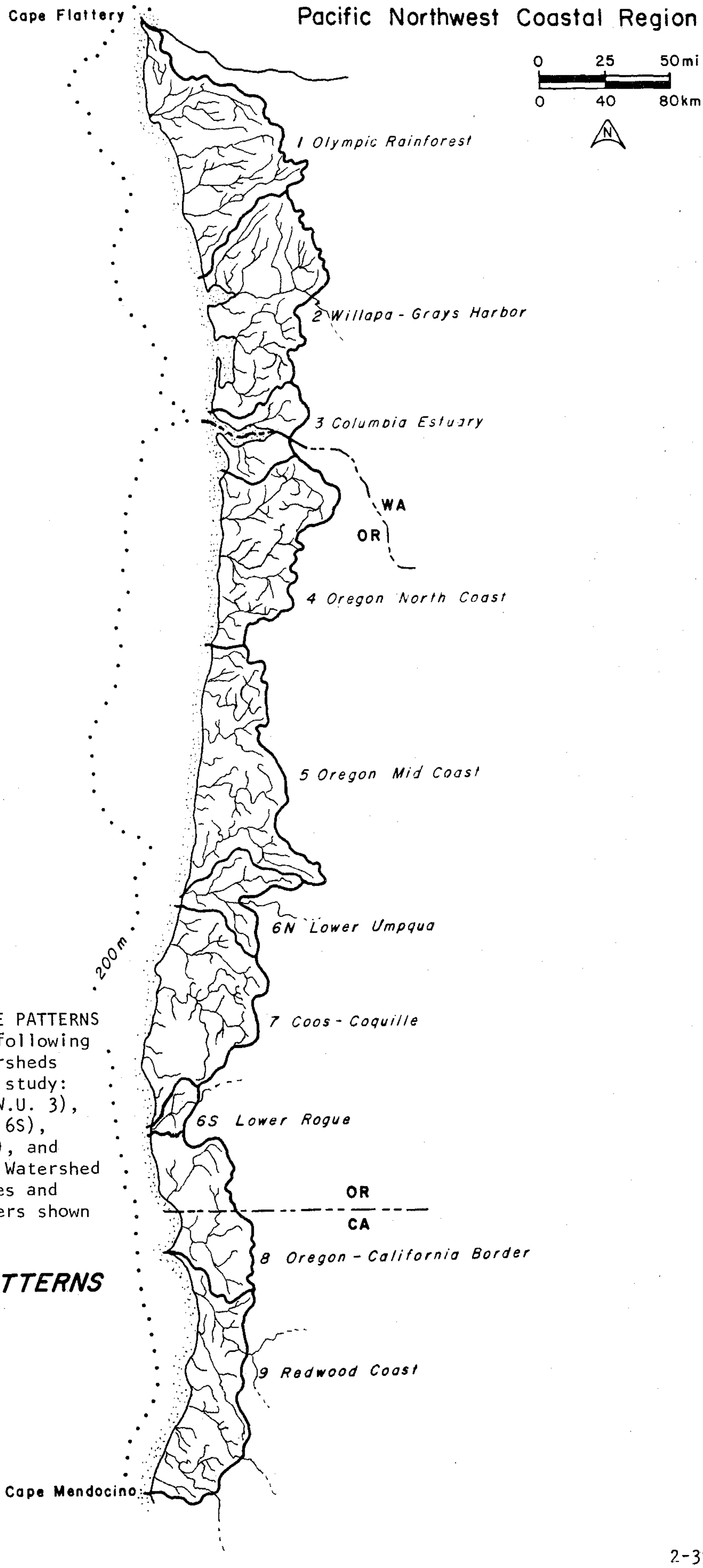


FIGURE 2-21. GENERAL DRAINAGE PATTERNS IN THE STUDY AREA. Note the following rivers that drain larger watersheds than are incorporated in this study: Chehalis (W.U. 2), Columbia (W.U. 3), Umpqua (W.U. 6N), Rogue (W.U. 6S), Klamath (W.U. 9), Mad (W.U. 9), and Eel (W.U. 9). See individual Watershed Unit maps in Volume 4 for names and detailed locations of the rivers shown here.

REGIONAL DRAINAGE PATTERNS

of these aquifers may be alluvial deposits in former stream channels. These deposits are commonly deeply weathered. Similar marine terrace deposits in Oregon extend southward in a narrow band from North Bend to Port Orford, and in Northern California occur at Crescent City and also just north of Humboldt Bay.

Sedimentary rocks of Tertiary age, chiefly of marine origin, crop out over extensive areas in the Coast Range of Oregon and Washington, and to a lesser extent, just inland of Humboldt Bay in Northern California. The rocks are chiefly sandstone, shale, and mudstone, with lesser amounts of limestone and conglomerate. Lava flows and pyroclastic rocks are interbedded in the sedimentary strata at some places. Most of the rocks are of Eocene age, but formations of Oligocene to Pliocene age also occur. For the most part, this aquifer unit has low to very low porosity and permeability and will yield only small supplies of water (1-20 gpm). Where the rock is greatly fractured, or the clastic rocks are coarser grained, moderate supplies (up to 200 gpm) are sometimes obtained from drilled wells. Water at depths of a few hundred feet is apt to be saline, especially where wells are drilled in synclines. At a few places saline water has been encountered at depths of less than 100 feet (30 meters).

Volcanic rocks occur on the north and south borders of the Olympic Mountains, in the inland portion of Watershed Unit 2, extensively in northern coastal Oregon, and between the Alsea and Siuslaw estuaries. They are absent in the Southern Oregon and Northern California portions of the study area. For the most part these volcanics consist of basaltic to andesitic flows, flow-breccia, pyroclastic rocks, and some interbedded sedimentary strata. The sedimentary interbeds commonly are tuffaceous. All of these rocks have been altered, mineralized, and cemented so that little of their original porosity remains. A thick, deeply weathered zone is considerably more porous but has moderately low permeability. The unweathered rock generally yields only very small supplies (1-10 gpm). Somewhat larger yields (5-20 gpm) are obtained in the weathered material and in the broken rock at the base of the weathered zone.

The rocks of pre-Tertiary and early Tertiary age in the Olympic Mountains are mostly massive marine sedimentary rocks. The unweathered rock has very low porosity and permeability and yields little water. A fairly thick weathered zone supplies a moderate base flow to streams.

The pre-Tertiary rocks in Southwestern Oregon and Northwestern California crop out chiefly in the Klamath and Siskiyou Mountains. They include a variety of sedimentary, metamorphic, and intrusive igneous rocks. The unweathered phase of all of these rocks has low to very low porosity and permeability. A weathered zone of varying characteristics has developed on them. On the fine-grained sedimentary and some of the metamorphic rocks, the weathered zone is shallow and clayey so that specific yield and permeability are very low. The igneous rocks, particularly the granite, have a thicker weathered zone that has somewhat higher specific yield and permeability; moderate yields (up to 200 gpm) are obtained from dug or shallow drilled wells at favorable locations.

During the winter, the water table rises rapidly and comes quickly to a level where ground water discharges into even the most minor of drainage channels in the rugged terrain. Almost everywhere ground water is effluent to streams throughout the year. Some reaches of streams in younger volcanic rocks may lose water where they cross particularly porous materials but they gain large quantities of ground water discharge in reaches upstream from the volcanic rocks. Short reaches of some lowland streams may temporarily lose water to bank storage.

2.5.3 Runoff. Table 2-5 presents mean annual river discharge into the Pacific Ocean from gauged river basins having a mean annual discharge of at least 10 m^3/sec (350 ft^3/sec). The rivers are arranged by Watershed Units with totals for each unit also listed. The term "gauged drainage area" refers to one for which the surface runoff has been directly measured; this differs from the actual drainage area by not including any ungauged areas between the last dowmstream station and the river mouth. Hence, the gauged drainage area is always less than the actual one. The listed discharge rates in Table 2-5 are therefore minimum values of the actual fresh water transport into the ocean.

As stated earlier, runoff patterns are closely correlated with precipitation patterns for most of the coastal region; the Columbia River with its late spring peak due to snowmelt is the only significant exception. The seasonal change of river discharge is summarized in Table 2-6 for the major rivers in the study area.

Roden (1967) evaluated river discharge into the Northeastern Pacific and the Bering Sea. In considering the rivers where activities by man have not markedly affected natural runoff, he noted that "there is very little evidence that natural streamflow has changed over the past half century."

TABLE 2-5. MEAN ANNUAL RIVER DISCHARGE INTO THE PACIFIC OCEAN FROM NORTHERN CALIFORNIA, OREGON, AND WASHINGTON OCEAN DRAINAGE BASINS. Only gauged river basins having a mean annual discharge of at least 10 m^3/sec are considered. Because of this, the values indicate a lower limit of the actual discharge into the ocean. Refer to Figure 2-21 for location of Watershed Units. Note that the drainage basins for the Chehalis, Columbia, Rogue, Umpqua, Klamath, Eel, and Mad Rivers extend well inland of the crest of the coastal range and that the Watershed Unit boundaries in Figure 2-21 do not portray this. (From Roden, 1967.)

WATERSHED UNIT	RIVER BASIN	GAUGED DRAINAGE AREA km^2	GAUGED DRAINAGE AREA (mi^2)	MEASURED MEAN ANNUAL DISCHARGE m^3/sec	MEASURED MEAN ANNUAL DISCHARGE (10^6 acre ft/yr)
1	Queets River basin	1150	443.8	117	2.99
1	Quinault River basin	684	264.0	79	2.02
1	Hoh River basin	655	252.8	71	1.82
1	Quillayute River basin	990	382.0	62	1.59
1	Dickey River basin	223	86.1	14	0.36
	TOTAL	3702	1428.7	343	8.78
2	Chehalis River basin	4700	1813.8	220	5.63
2	Humptulips River basin	337	130.0	37	0.95
2	North River basin	567	218.8	27	0.69
2	Willapa River basin	409	157.8	24	0.61
2	Naselle River basin	231	89.1	15	0.38
	TOTAL	6244	2409.5	323	8.26
3	Columbia River basin	661838	255406.2	7222	184.69
	TOTAL	661838	255406.2	7222	184.69
4	Nehalem River basin	1730	667.6	77	1.97
4	Wilson River basin	417	160.9	34	0.87
4	Nestucca River basin	236	91.1	28	0.72
4	Trask River basin	376	145.1	27	0.69
	TOTAL	2759	1064.7	166	4.25
5	Alsea River basin	924	356.6	51	1.30
5	Siletz River basin	524	202.2	45	1.15
5	Siuslaw River basin	882	340.4	25	0.64
	TOTAL	2330	899.2	121	3.09
6	Rogue River basin	12800	4939.6	302	7.72
6	Umpqua River basin	10100	3897.6	228	5.83
	TOTAL	22900	8837.2	530	13.55
7	Coquille River basin	1960	756.4	70	1.79
	TOTAL	1960	756.4	70	1.79
8	Smith River basin	1670	644.5	106	2.71
	TOTAL	1670	644.5	106	2.71
9	Klamath River basin	31400	12117.4	564	14.37
9	Eel River basin	8950	3453.8	234	5.98
9	Mad River basin	1260	486.2	44	1.13
9	Redwood Creek basin	720	277.9	31	0.79
	TOTAL	42330	16335.3	873	22.27

TABLE 2-6. MEAN MONTHLY RIVER DISCHARGE (m^3/sec) INTO THE PACIFIC OCEAN FOR SELECTED RIVERS. (From Roden, 1967.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	ANNUAL
					California, Ocean Drainage								
Klamath River near Klamath	1000	1217	831	851	685	388	164	103	101	194	377	861	564
Eel River at Scotia	465	581	354	261	101	34	9	4	3	24	123	389	195
					Oregon, Ocean Drainage								
Rogue River near Agness	312	352	260	229	181	94	47	37	36	64	154	427	182
Umpqua River near Elkton	443	450	350	278	191	113	51	34	33	56	196	364	213
Illinois River near Agness (enters Rogue)	210	256	195	158	105	25	11	7	5	37	139	284	119
Nehalem River near Foss	170	182	120	78	39	16	7	4	6	26	111	168	77
					Columbia River, Ocean Drainage[1]								
Columbia River at The Dalles, Oregon	2748	3025	3592	5703	10260	13990	9646	5268	3468	2812	2794	2821	5510
Willamette River at Wilsonville, Oregon	1628	1630	1186	942	742	455	234	173	199	377	915	1566	837
Cowlitz River at Castle Rock, Washington	370	352	299	324	344	289	150	76	64	123	300	415	259
Lewis River at Ariel, Washington	200	198	169	165	159	114	56	35	48	85	170	214	134
					Washington, Ocean Drainage								
Chehalis River at Porter	279	250	186	134	66	32	16	11	13	39	176	239	120
Queets River near Clearwater	214	171	144	112	91	68	45	25	39	98	170	224	116

[1] Columbia River discharge is presented graphically in Figure 2-20.

Annual runoff from the land is presented in Figure 2-22. Areas with higher runoff are topographic highs, which receive greater amounts of precipitation and have steeper gradients.

Monthly extreme value statistics for several rivers in the study area are presented in Table 2-7 along with the years of record the data are based upon. The statistics are based on daily values.

The Pacific Northwest River Basin Commission (1970) presents considerable information on observed monthly discharges of coastal rivers; maximum, mean, and minimum discharge curves; recurrence intervals for high, and low flow conditions; duration curves; and exceedence curves for rivers that drain the Washington and Oregon parts of the study area. Additionally, long-term variation of precipitation and streamflow is presented for numerous rivers (PNRBC, 1970).

Overbank flows occur on most of the coastal streams almost every year. Most of the developments on these adjacent lands are compatible with this occasional short-term flooding. More severe floods occur coincident with major regional flood conditions. Severe flooding sometimes occurs in single basins while adjacent areas experience minor flooding. Most flooding is of short duration, rarely exceeding 12 to 36 hours. Along the tidal reaches flooding occurs when river floodflows coincide with storm and higher than average tides. Combined tidal and storm influences are greatest in December and January, when peak river flows may also occur. Damaging floods may occur between November and April.

Larger streams, such as the Rogue, Umpqua, Coquille, Mad, Eel, and Klamath Rivers do not conform strictly to the above pattern. Because they drain much larger basins than the other coastal streams, they flood only after periods of more sustained rainfall.

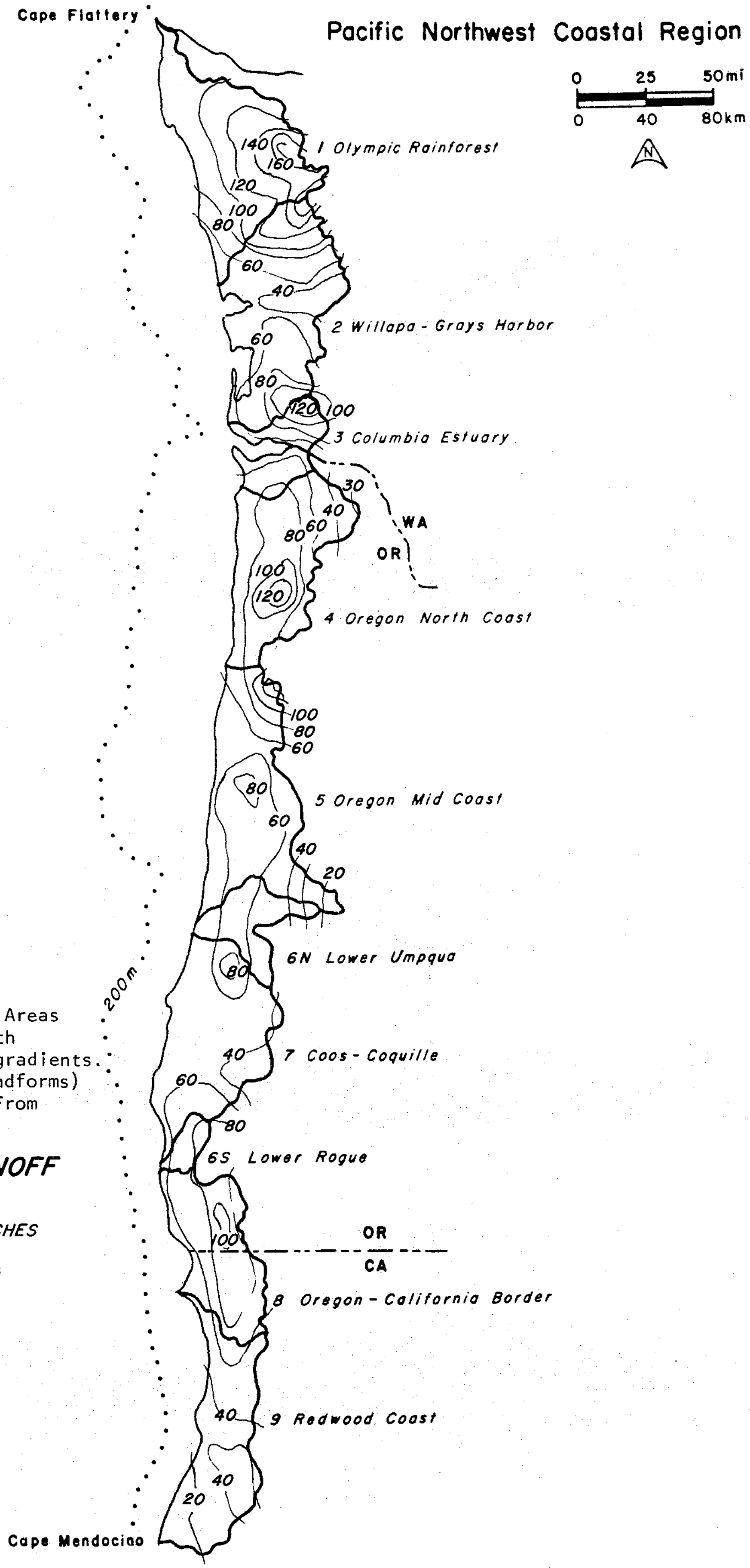


FIGURE 2-22. RIVER RUNOFF. Areas of high runoff correspond with topographic highs and steep gradients. Compare with Figures 2-2 (Landforms) and 2-17 (Precipitation). (From PNRBC, 1970.)

TABLE 2-7. MONTHLY EXTREME VALUE STATISTICS FOR SELECTED GAUGING STATIONS. The monthly extremes are obtained from sets of daily values. All units are in m^3/sec. (Multiply by 35.29 to convert to ft^3/sec.) (From Roden, 1967.)

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Dates of Highest and Lowest Extremes
Eel River near Scotia, California 1917-1965													
Highest maximum	6031.0	7391.0	4701.0	2917.0	1371.0	259.0	44.0	14.0	79.0	2832.0	4616.0	19369.0	Dec. 23, 1964
Mean maximum	1947.0	2429.0	1245.0	835.0	233.0	75.0	16.0	6.0	6.0	190.0	711.0	2137.0	
Lowest maximum	37.0	23.0	38.0	29.0	11.0	3.7	1.1	1.3	0.7	1.6	1.9	51.0	
Highest minimum	524.0	1031.0	311.0	303.0	129.0	47.0	12.0	6.8	5.7	19.0	64.0	351.0	
Mean minimum	108.0	155.0	126.0	107.0	51.0	16.0	5.4	2.9	2.4	3.1	10.0	50.0	
Lowest minimum	8.4	7.7	18.0	11.0	4.0	1.1	0.5	0.3	0.4	0.6	1.5	2.4	Aug. 13, 1924
Umpqua River near Elkton, Oregon, 1903-1965													
Highest maximum	4276.0	4446.0	2605.0	2393.0	2282.0	657.0	323.0	108.0	348.0	4531.0	4899.0	7362.0	Dec. 23, 1964
Mean maximum	1406.0	1332.0	830.0	536.0	362.0	200.0	81.0	39.0	49.0	229.0	876.0	1392.0	
Lowest maximum	121.0	163.0	197.0	142.0	76.0	36.0	25.0	21.0	24.0	27.0	25.0	90.0	
Highest minimum	487.0	351.0	411.0	322.0	244.0	193.0	68.0	46.0	40.0	102.0	170.0	379.0	
Mean minimum	156.0	179.0	174.0	160.0	115.0	67.0	36.0	29.0	27.0	30.0	45.0	108.0	
Lowest minimum	31.0	48.0	61.0	50.0	36.0	29.0	19.0	19.0	19.0	20.0	23.0	24.0	July 18, 1926
Columbia River at The Dalles, Oregon, 1879-1965[1]													
Highest maximum	8892.0	10222.0	11100.0	15688.0	28866.0	32828.0	25881.0	17188.0	7193.0	6003.0	7872.0	10421.0	June 6, 1894
Mean maximum	3699.0	4084.0	4946.0	7786.0	14120.0	16360.0	12535.0	6910.0	4168.0	3210.0	3337.0	3665.0	
Lowest maximum	1452.0	1699.0	2413.0	3313.0	6513.0	6116.0	5125.0	3568.0	2888.0	2189.0	1900.0	1721.0	
Highest minimum	4899.0	4899.0	4814.0	8863.0	12658.0	20926.0	17811.0	7306.0	4757.0	4248.0	4389.0	3738.0	
Mean minimum	2221.0	2333.0	2773.0	4129.0	7031.0	11179.0	6972.0	4093.0	2888.0	2503.0	2417.0	2294.0	
Lowest minimum	1019.0	1167.0	1606.0	1957.0	3822.0	5380.0	3958.0	2746.0	2158.0	1736.0	1495.0	1176.0	Jan. 12, 1937
Quinault River at Quinault Lake, Washington, 1934-1965													
Highest maximum	1008.0	1226.0	850.0	742.0	427.0	323.0	396.0	103.0	177.0	444.0	1167.0	935.0	Nov. 4, 1955
Mean maximum	376.0	340.0	187.0	171.0	155.0	116.0	88.0	40.0	61.0	220.0	391.0	405.0	
Lowest maximum	56.0	68.0	60.0	65.0	66.0	46.0	30.0	14.0	14.0	19.0	14.0	162.0	
Highest minimum	129.0	123.0	80.0	74.0	82.0	93.0	66.0	34.0	28.0	50.0	104.0	97.0	
Mean minimum	52.0	46.0	43.0	48.0	57.0	54.0	33.0	19.0	15.0	21.0	44.0	54.0	
Lowest minimum	21.0	20.0	24.0	29.0	36.0	23.0	14.0	10.0	8.0	10.0	9.0	10.0	Sept. 12, 1944

[1] These data do not represent total runoff of Columbia, as The Dalles is upstream of the Willamette and other lower Columbia tributaries. (See Figure 2-20 and Table 2-6.)

The Columbia River floods during the periods of high freshets, which result from the melting of snow throughout the headwaters in the spring. The upstream boundary of Watershed Unit 3 for this report is the approximate limit of the estuarine zone of the Columbia River. In this area, flooding may be compounded greatly by high tides, especially in December (associated with peak winter storm discharges) and in June (associated with peak snow melt). Islands within the estuary, as well as the land between Clatsop Spit and Astoria and to the east of Grays Bay on the Washington side, are subject to flooding. The Columbia River has numerous upstream hydroelectric dams which can be used to regulate the discharge and reduce the flood hazard downstream.

Floods of historic significance for rivers of Washington and Oregon are summarized by PNRBC (1971). In Northern California, very severe flooding occurred in December, 1964, with damages totaling $184 million. The Eel River reached a peak discharge of 23,800 m^3/sec (840,000 cfs) (CRFSC, 1971) which was comparable to a very high peak flow of the Columbia River (see Figure 2-20 for comparison). Record flooding occurred at the same time in the Rogue River (4,300 m^3/sec), the Coquille River (3,100 m^3/sec), the Umpqua River (7,500 m^3/sec), and the Alsea River (1,200 m^3/sec) with damages in Oregon totaling over $47 million (PNRBC, 1971). The freshwater and sediment input to the ocean, continental shelf and beaches was probably considerable.

2.5.4 Transport of Sediment. Water is a principal agent of erosion in this region. The effects of freezing and thawing on weathering is significant only in the higher mountains, with glacial erosion occurring only in the Olympics. The sediment transported by glacier-fed streams is a fine rock flour consisting of pulverized bedrock of the high Olympics. It is different than the fine silts and clays found in the water of the non-glacial streams and rivers of the rest of the study area (Gilluly et al., 1959).

Wind erosion is a significant process in some of the coastal areas where dune formations exist. The wind transport of sediment away from stabilized dunes results in deflation. Wind blown sediment on the barrier beaches may be transported into the estuaries behind them.

Although various erosive forces combine to weather the rocks and surficial deposits of the region, running water is the primary transporting mechanism. For the most part, measurements of riverine sediment transport have been limited to measurements of suspended-sediment concentration. Developments by man that alter the natural vegetation have increased the sediment yield locally (see Section 2.5.3 of Volume 1). Figure 2-23 presents the generalized sediment yield for the study area. The sources of data for this figure used different ranges in their subdivisions, although identical units. Hence, the figure separates the data and lists the separate ranges used. For the Oregon and Washington portions, highest observed suspended sediment concentrations in mg/l are also indicated.

Major flooding events can upset sediment yield stability of a region for as long as nine years afterwards (H.W. Anderson, 1972.)

2.6 HYDROSPHERIC FEATURES - ESTUARINE CONDITIONS

The shoreline of the Pacific Northwest Coastal Region is made up of beaches, rocky headlands and bluffs. Where the numerous coastal streams and rivers encounter the ocean, estuaries occur. Just as the region is characterized by its high amount of rainfall, and its correspondingly high runoff, its coastal area is characterized by its numerous estuaries. The characteristics of these estuaries are largely determined by the gradient at the river mouths. The lower the gradient, the greater the area subject to tidal action and the mixing of salt and fresh water, and therefore the greater the size of the estuary. The locations of the estuaries along the coast of the Pacific Northwest are presented in Figure 2-24. Area information for those estuaries greater than 2.0 km^2 (0.7 mi^2) is presented in Table 2-8. The percentage of total area that is intertidal is inversely proportional to the amount of runoff entering the estuary. (See Table 2-5 for runoff data).

The three major industries of the region - forestry, fisheries, and agriculture - all rely on and impinge on coastal estuaries. The problems associated with this multiplicity of use are exemplified by Coos Bay, where there is considerable shipping, log storage, an airport built on fill, and a portion (South Slough) set aside to remain in its natural condition as the first "Estuarine Sanctuary" in the United States, established under the Federal Coastal Zone Management Act of 1972. The purpose of an estuarine sanctuary, as defined in the Act, is to create natural field laboratories in which to gather data and make studies of the natural and human processes occurring within the coastal zone. Scientists and students are therefore provided the opportunity to examine ecological relationships within the area over a period of time. Research and education purposes which will provide information essential to coastal zone management decision-making is of major importance (U.S. Department of Commerce, 1974B). Coos Bay offers a valuable natural laboratory for comparing the impacts of human activities in the other parts of the Bay with a relatively undisturbed area in South Slough.

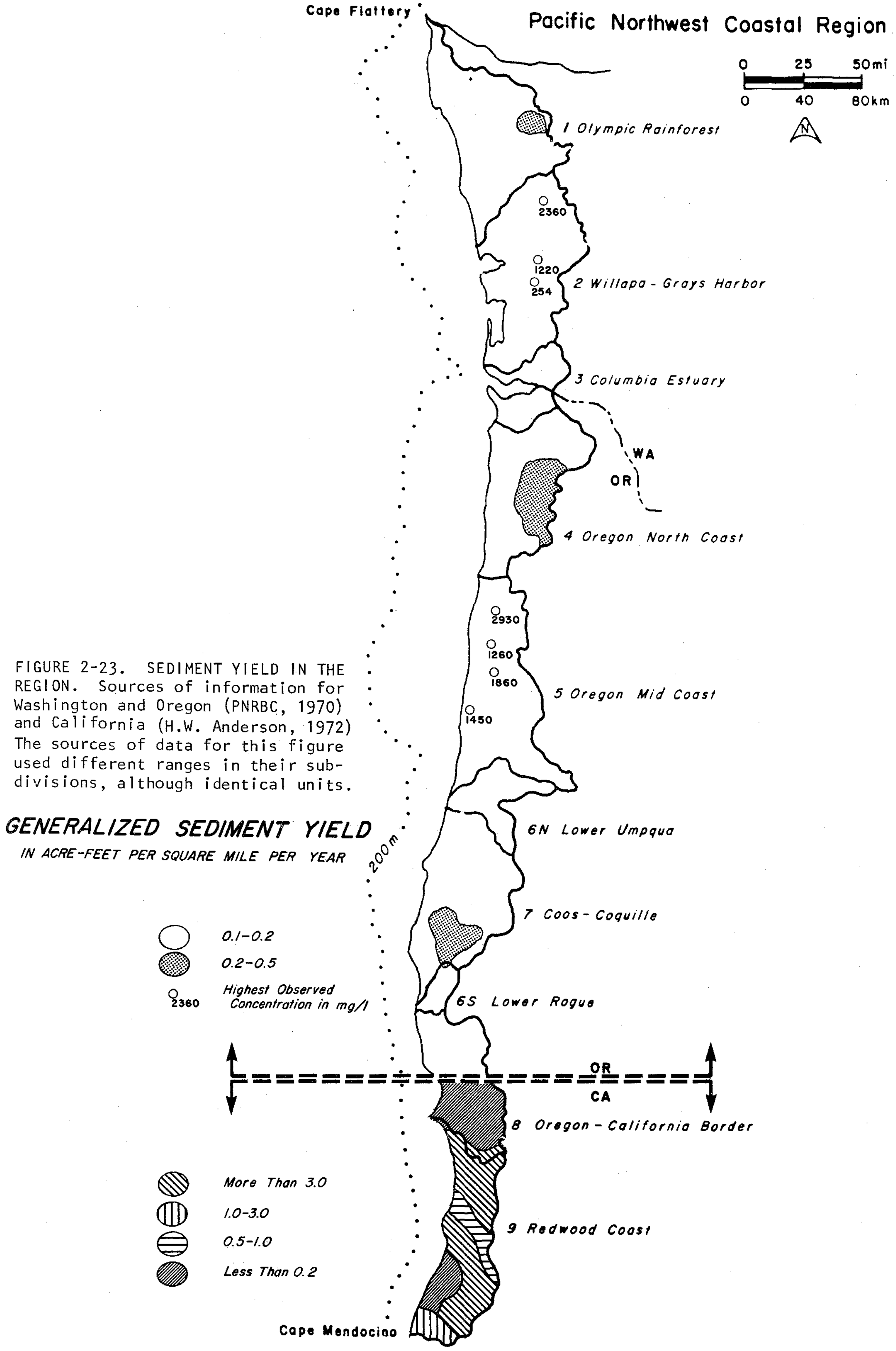


FIGURE 2-23. SEDIMENT YIELD IN THE REGION. Sources of information for Washington and Oregon (PNRBC, 1970) and California (H.W. Anderson, 1972) The sources of data for this figure used different ranges in their subdivisions, although identical units.

There is both an abundance and a dearth of information concerning the estuaries of the study area. Much is known about the Columbia River Estuary and has been summarized in works edited by Pruter and Alverson (1972) and Seaman (1977). Yaquina Bay has an extensive data base because of the activities of Oregon State University and its Marine Science Center. Coos Bay also has been studied by Oregon State University and others, as exemplified by inter-disciplinary research on dredging impacts (OSU, 1977A). Percy et al. (1974) summarizes much of what is known of the Oregon estuaries and provides an extensive bibliography. Morgan and Holton (1977A) provide a complete and recent bibliography of estuarine research in Oregon which also includes references concerning the inland drainage basins and the adjacent coastal beaches, dunes, and headlands. Wilsey and Ham (1974) developed a classification system that encompasses physical and biological parameters and applied it to the Oregon estuaries in a report that constitutes an inventory of estuarine resources. Discussions of the estuaries are included in reports by the Oceanographic Institute of Washington (1977) and Winzler and Kelly (1977) for the Washington Oregon area and the Northern California area, respectively. Additional estuarine data are available in reports (including Environmental Impact Statements) prepared by the Army Corps of Engineers that pertain to any navigational improvements in the estuaries (such as dredging or jetty construction).

There is a dearth of information because of the nature of estuarine processes. Spot measurements are of little value. In a large estuary, physical observations made at one location over a short period of time are not interpretable unless they can be firmly tied to a network of observations encompassing the entire estuary. Within an estuary, considerable differences may occur both in space and in time. Estuarine studies have lacked a unified approach. Neal (1977) states, "It cannot be said that the most studied of the estuaries, the Columbia River, is well understood with regard to its overall physical circulation, let alone the detailed circulation in any small area. Yet a large number of observations have been made. All lack a sufficiently generalized framework to account for some or all of the following factors: seasonal variability, yearly variability, wind-driven circulation, variation in runoff, effects of density structure, storm surges, and effects of tidal components (diurnal to 28 days)." Smaller estuaries have not been studied to any great extent. Oregon State University (1977A) concluded a four year, multi-disciplinary, coordinated study of Coos Bay, which sought not only to evaluate environmental impacts of dredging, but to develop a methodology that may be applied to other estuarine studies in the future.

Neal (1977) listed seven study objectives for the estuaries of Washington and Oregon, which may also be applied to Northern California. These objectives were determined in a meeting sponsored by the Bureau of Land Management in Portland in 1976 to evaluate data gaps and research needs that should be fulfilled prior to offshore development of oil and gas resources. These objectives are: 1) Predict upstream penetration of marine source water which might bear contaminants, 2) Understand downward mixing, as it may transport surface contaminants throughout the estuarine water column, 3) Estimate vertical motions which could transport contaminants from the bottom waters (marine source water) into the near-surface zone (i.e., photosynthetic zone), 4) Estimate flushing rates, as these determine residence times of a contaminant introduced into an estuarine system, 5) Estimate probable effects of local winds on surface contaminant distribution in an estuary, 6) Estimate lateral and longitudinal flow in broad, shallow estuaries, and 7) Adequately assess seasonal and year-to-year variability of parameters.

Given the present level of knowledge concerning estuarine processes, we cannot predict the environmental effects of some changes with certainty, and we do not even know the physical processes involved in others. This was the conclusion reached by Officer (1976) after reviewing two recent professional symposia on Geophysics, Estuaries and the Environment, and Transport Processes in Estuarine Environments. Although his comments concerned estuaries worldwide, there is nothing unique to this region that exempts it from his conclusion.

2.6.1 Estuarine Classification. Estuarine classifications under varying systems are related to runoff and gradient. These parameters may also be correlated to geologic provinces of the region as described in Section 2.2.2 of Volume 2, and are discussed in Section 2.6.1 of Volume 1, The Conceptual Model.

The gradient is greatest in Northern Washington (Watershed Unit 1), and Southern Oregon and Northern California (Watershed Units 8 and 9). These Watershed Units contain the Olympic and Klamath Mountain provinces. Estuaries within watersheds are generally small, bar-built estuaries. They are dual-sector estuaries in the Bauer system, lacking significant marineway (intertidal) sectors. Some of these estuaries may become "blind" estuaries in the summer when freshwater flow is not sufficient to prevent sealing off from the sea by deposition of beach sediments (Wilsey and Ham, 1974). Blind estuaries, such as Big Lagoon and Stone Lagoon in Watershed Unit 9, are open to the sea so seldom that they are not included in Table 2-8, but are discussed in Volume 4. Because the gradient of the river mouth is relatively steep in the estuaries of Watershed Units 1, 8, and 9, the intertidal area is small and the tidal prism is likewise small.

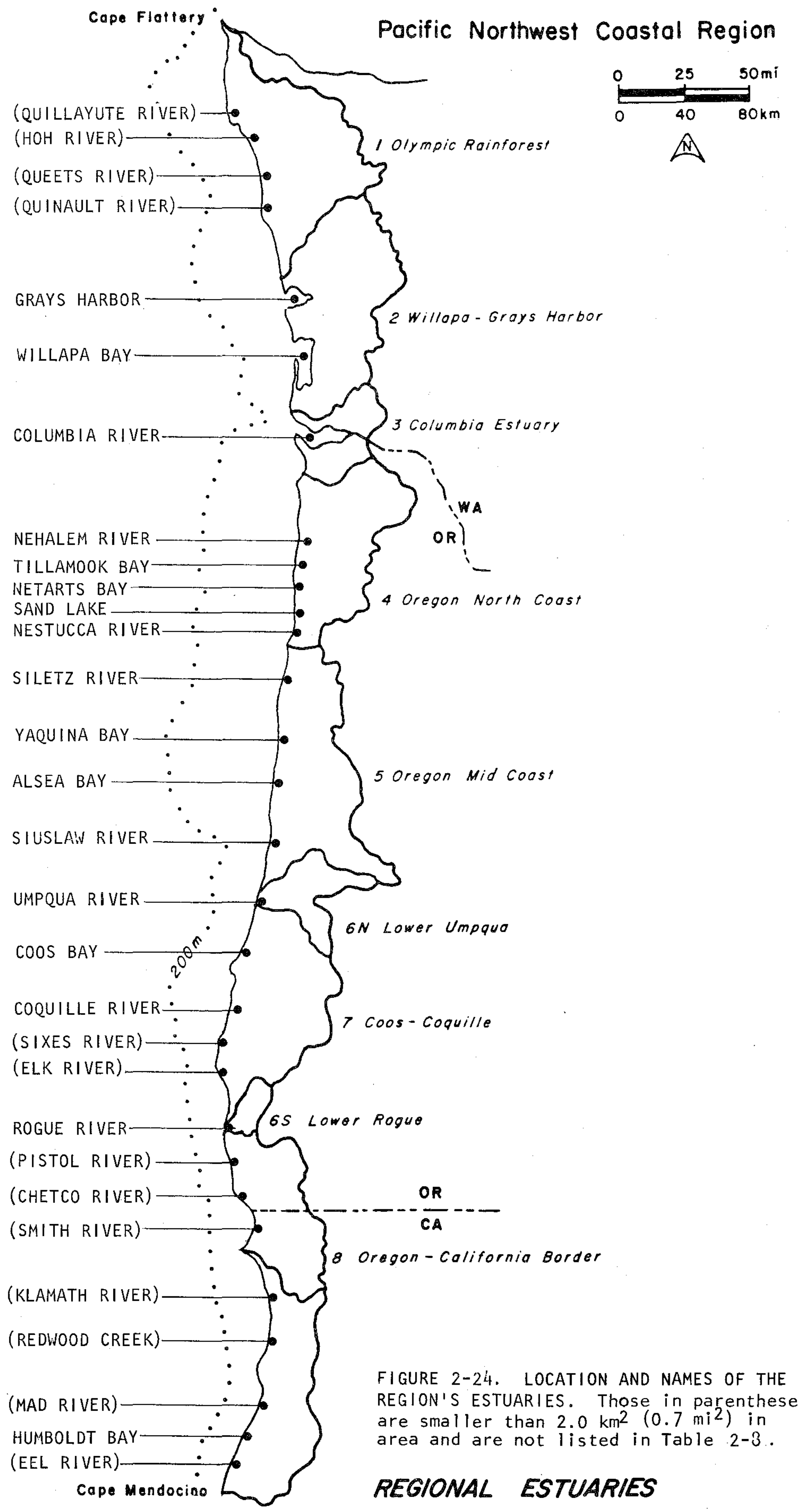


FIGURE 2-24. LOCATION AND NAMES OF THE REGION'S ESTUARIES. Those in parentheses are smaller than 2.0 km² (0.7 mi²) in area and are not listed in Table 2-8.

REGIONAL ESTUARIES

TABLE 2-8. SURFACE AREA[1] OF ESTUARIES IN WASHINGTON, OREGON, AND NORTHERN CALIFORNIA WHICH ARE LARGER THAN 2.0 km^2 (0.8 mi^2). (Compiled from Stein et al., 1966; Andrews, 1965; Hamilton, 1973; and Skeesick, 1963.)

ESTUARY	RELATIVE SIZE	TOTAL AREA		SUBMERGED AREA		INTERTIDAL AREA		
		km^2	(mi^2)	km^2	(mi^2)	km^2	(mi^2)	% OF TOTAL
GRAYS HARBOR	3	223.2	(86.2)	118.0	(45.5)	105.2	(40.7)	47%
WILLAPA BAY	2	347.4	(134.1)	157.9	(60.9)	189.5	(73.1)	55%
COLUMBIA RIVER	1	379.5	(146.5)	280.3	(108.2)	99.2	(38.3)	26%
NEHALEM RIVER	10	9.3	(3.6)	5.0	(1.9)	4.4	(1.7)	47%
TILLAMOOK BAY	6	33.5	(12.9)	16.7	(6.4)	16.8	(6.5)	50%
NETARTS BAY	9	9.4	(3.6)	3.3	(1.3)	6.1	(2.4)	65%
SAND LAKE	17	2.1	(0.8)	0.5	(0.2)	1.6	(0.6)	76%
NESTUCCA BAY	14	4.0	(1.5)	1.7	(0.7)	2.3	(0.9)	58%
SILETZ BAY	13	4.8	(1.9)	1.7	(0.7)	3.1	(1.2)	65%
YAQUINA BAY	8	15.8	(6.1)	10.3	(4.0)	5.5	(2.1)	35%
ALSEA BAY	12	8.7	(3.4)	4.7	(1.8)	4.0	(1.5)	46%
SIUSLAW RIVER	11	9.1	(3.5)	6.0	(2.3)	3.1	(1.2)	34%
UMPQUA RIVER	7	27.6	(10.7)	21.4	(8.3)	6.2	(2.4)	22%
COOS BAY	5	50.1	(19.3)	25.0	(9.6)	25.1	(9.7)	50%
COQUILLE RIVER	15	3.1	(1.2)	1.9	(0.7)	1.2	(0.5)	39%
ROGUE RIVER	16	2.5	(1.0)	1.9	(0.7)	0.6	(0.2)	24%
HUMBOLDT BAY	4	62.4	(24.1)	28.0	(10.8)	34.4	(13.3)	55%

[1] Areas measured extended from a line across the entrance of the estuary to the upper extent of tideland. The tideland area given is that land between mean high water and mean low water for all but Willapa Bay. Tideland area for Willapa Bay was measured from mean higher high water to mean lower low water. The difference in measurement does not significantly alter the total area of Willapa Bay, nor its assignment of relative size. The intertidal area of Willapa Bay is proportionately greater by 10 to 20% due to the greater tide range used for computation.

Tidal flows by themselves are not always sufficient to maintain the opening of the estuary to the sea. Humboldt Bay in Watershed Unit 9 is somewhat anomolous with its large intertidal area, but occurs in a low gradient plain of recent alluvial deposits.

The gradient of the coastal mountains in Watershed Units 2 and 3 is the least in the entire study area, and the three estuaries that occur there are the largest, ranging from four to six times larger than the fourth largest, Humboldt Bay, in Northern California. These estuaries are of the "drowned river valley" type, and have large intertidal areas. In the Bauer system they are "compound estuaries." The freshwater flow of the Columbia River distinguishes it from Willapa Bay and Grays Harbor. Although the Columbia River estaury is the largest in the study area, its intertidal area is only about one-half that of Willapa Bay or Grays Harbor.

The estuaries of Oregon that occur in the Coastal Range Province (Watershed Units 4, 5, 6, and 7) are larger than those in Watershed Units 1 and 8, and smaller than those in Watershed Units 2 and 3. Their size is also gradient controlled, related to their geologic province. They are of the "drowned river valley" type, or "compound estuaries" in the Bauer System. In this province, only the Umpqua and Rogue Rivers drain inland drainage basins, and because of their greater freshwater flow, their intertidal area percentages are small. Although these Watershed Units comprise about half of the total region, they contain 13 of the 17 estuaries which are greater than 2.0 km^2 (0.8 mi^2) in size.

It is important to recognize that within any estuary, there may be components (channels, basins, sloughs, etc.) that function in a manner unlike the rest of the estuary. Coos Bay is a good example of this, with the South Slough designated a National Estuarine Sanctuary, while the North Slough is heavily impacted by industry.

Classification of estuaries by salinity intrusion and mixing is simply not documented well enough yet, and within any estuary may change drastically in time and space. No classification system is adequate by itself for management purposes, without a detailed inventory of the resources of each individual estuary. Inferences from one region to the next are of limited value.

2.6.2 Tides and Currents. Tidal information for the coast and the estuaries in the study region is available in Tide Tables High and Low Water Predictions, West Coast of North America Including the Hawaiian Islands, published annually by the U.S. Department of Commerce (see USDC, 1977B). The tables are predictive, and cannot account for effects of wind, atmospheric pressure, or storm surges.

The influence of the tides in the estuaries and rivers is manifested in three different ways: 1) the maximum distance upstream at which tidally induced water-level fluctuations are observed, 2) the maximum distance upstream at which tidal inflow causes the river flow to reverse, and 3) the maximum distance upstream at which measurable amounts of seawater are found (Neal, 1972). Neal (1972) reports that tidal fluctuations in water level on the Columbia have been observed at Bonneville Dam (140 miles or 225 km upstream from the mouth), that tidal reversal of river flow at the surface and the bottom was observed about 53 miles (85 km) from the mouth, and that the maximum intrusion of ocean water is generally less than 23 miles (37 km) from the mouth.

Within estuaries, tidal ranges will vary with channel configuration and runoff, as well as wind and atmospheric pressure. Channel configuration and runoff will generally produce greater tide heights and ranges within the estuaries than on the open coast. This is illustrated for Yaquina Bay, Oregon in Fig. 2-24. There is a time delay in the tide as it moves up the estuary.

The Tide Table predictions present the mean and the mean diurnal (difference between higher high and lower low water levels) ranges for various stations along the coast, at the mouths of estuaries, and at stations within the estuaries. Table 2-9, extracted from the Tide Tables, summarizes the mean and mean diurnal predictions for the major estuaries in the study area.

Currents within the estuaries can be estimated using numerical or physical models that account for the estuarine configuation, runoff, and tidal forces. Engineering studies use these approaches to determine possible effects of projects that will alter the channel configuration, such as dredging, filling, or jetty construction.

Studies using a physical tidal model of the Columbia River have been carried out on the currents in Youngs Bay and are reviewed in the Columbia River Estuary Inventory document (Seaman, 1977). The studies were for a particular river discharge stage and are not applicable for other conditions.

Tidal current information for the estuaries in the study region is available in Tidal Current Tables Pacific Coast of North America and Asia, which is also published annually by the U.S. Department of Commerce (see USDC, 1977A). This information must be used with caution in those rivers with large freshwater discharge, as the less predictable runoff values are not included in these tables.

Currents are of particular interest to shipping and boating activities. The following discussion is quoted from portions of United States Coast Pilot 7, which is a guide to navigating the waters of the West Coast of the United States (U.S. Department of Commerce, 1976).

> The tidal currents (in Humboldt Bay) follow the general direction of the channels. In the main channel, the velocity is less than 2 knots (1 m/sec) and does not exceed 3 knots (1.5 m/sec). Between the jetties, the velocity is about 2 knots (1 m/sec), with a maximum of about 5 knots (2 m/sec) (p. 204).
>
> (For Coos Bay) a short series of current observations in the entrance taken during September indicated a velocity of about 2 knots (1 m/sec). The greatest observed ebb velocity was a little over 3 knots (1.5 m/sec). During long runouts an ebb current of 5 knots (2.6 m/sec) has been reported at Guano Rock (p. 216).
>
> The current velocity is about 2.4 knots (1.2 m/sec) on the flood, and 2.3 knots (1.2 m/sec) on the ebb in the Yaquina Bay entrance. Near Newport docks the velocity is 0.5 knots (0.3 m/sec). Off Yaquina, and 1 mile south of Toledo, the velocities are about 1 to 1.4 knots (0.5 to 0.7 m/sec) (p. 221).

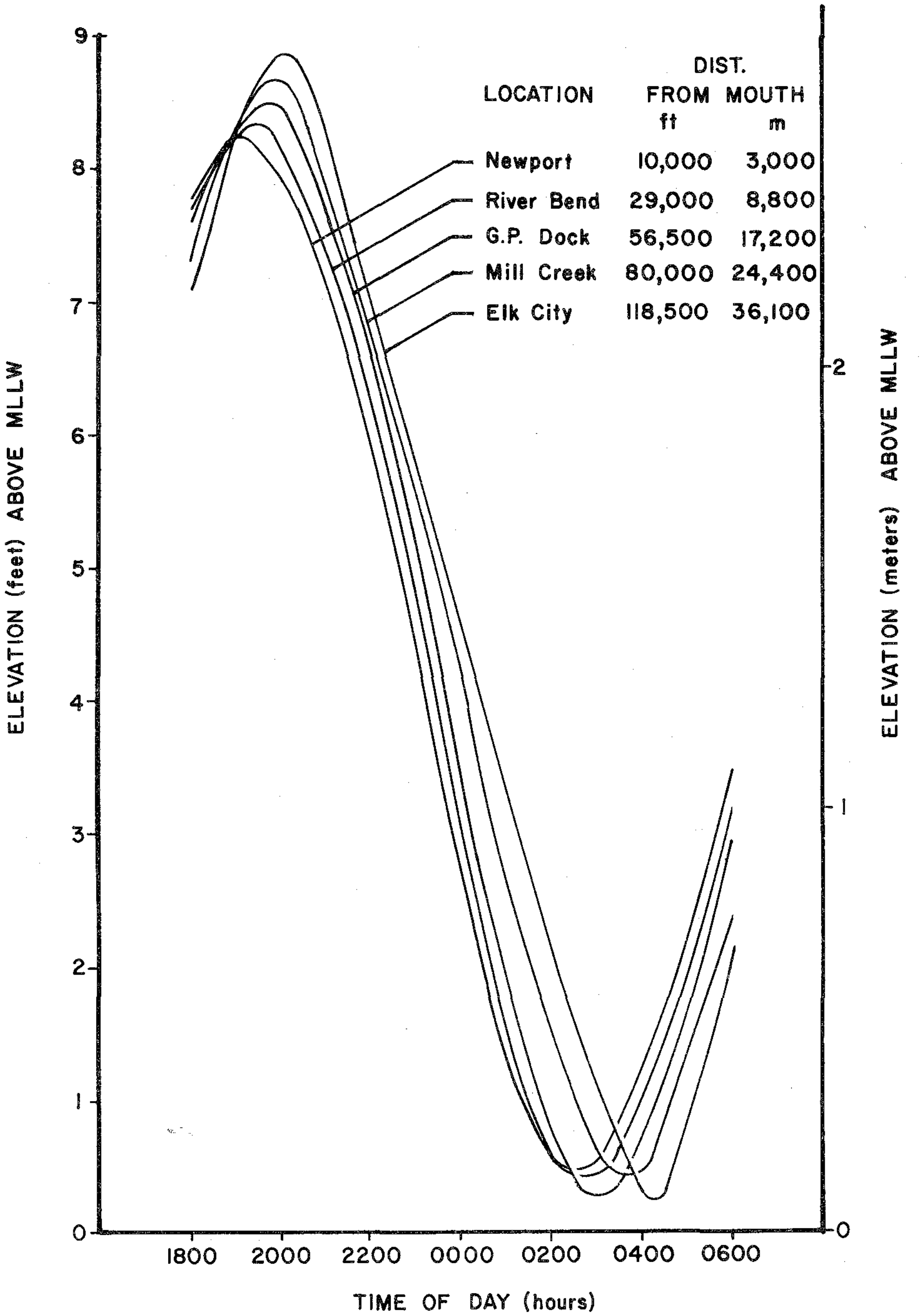


FIGURE 2-25. TIDAL ELEVATIONS IN YAQUINA RIVER ESTUARY MEASURED ON 23-24 JULY 1969. Tide height and range increase upstream. A time lag upstream is also apparent. (From Goodwin et al., 1970.)

TABLE 2-9. TIDE DATA FOR PACIFIC NORTHWEST COASTAL ESTUARIES. Mean range is from mean high water to mean low water. The mean diurnal range is the range between mean higher high water and mean lower low water. (From Tide Tables High and Low Water Predictions West Coast of North America Including the Hawaiian Islands, published annually by the U.S. Department of Commerce; see USDC, 1977B.)

WATERSHED UNIT	LOCATION	RANGES: MEAN FEET	RANGES: MEAN METERS	RANGES: DIURNAL FEET	RANGES: DIURNAL METERS	MEAN TIDE LEVEL FEET	MEAN TIDE LEVEL METERS
1	LaPush, Quillayute River	6.5	2.0	8.5	2.6	4.6	1.4
2	Grays Harbor, Point Chehalis	6.9	2.1	9.0	2.7	4.8	1.5
	Bay City	7.1	2.2	9.2	2.8	4.9	1.5
	Markham	7.2	2.2	9.2	2.8	4.9	1.5
	North Channel	7.6	2.3	9.7	3.0	5.2	1.6
	Aberdeen	7.9	2.4	10.1	3.1	5.4	1.6
	Montesano,Chehalis River	6.7	2.0	8.1	2.5	4.1	1.2
2	Willapa Bay, entrance	6.2	1.9	8.1	2.5	4.4	1.3
	Nahcotta	8.0	2.4	10.2	3.1	4.6	1.4
	Toke Point	6.5	2.0	8.5	2.6	4.5	1.4
	South Bend, Willapa River	7.8	2.4	9.8	3.0	5.2	1.6
	Raymond, Willapa River	7.8	2.4	9.9	3.0	5.3	1.6
3	Columbia River, entrance	5.6	1.7	7.5	2.3	4.0	1.2
	Ilwaco, Baker Bay, WA	6.0	1.8	7.6	2.3	4.0	1.2
	Chinook, Baker Bay, WA	6.2	1.9	7.9	2.4	4.2	1.3
	Point Adams, OR	6.4	2.0	8.3	2.5	4.4	1.3
	Astoria (Youngs Bay),OR	6.7	2.0	8.6	2.6	4.5	1.4
	Settlers Points, OR	6.3	1.9	8.0	2.4	4.1	1.2
	Harrington Point, WA	6.1	1.9	7.7	2.3	3.9	1.2
4	Nehalem River, Brighton	5.9	1.8	7.8	2.4	4.1	1.2
	Nehalem	5.6	1.7	7.2	2.2	3.7	1.1
4	Tillamook Bay, Barview	5.7	1.7	7.5	2.3	3.9	1.2
	Miami Cove	5.6	1.7	7.4	2.3	3.9	1.2
	Bay City	5.4	1.6	7.1	2.2	3.7	1.1
	Tillamook, Hoquarten Slough	5.2	1.6	6.6	2.0	3.3	1.0
4	Nestucca Bay, entrance	5.8	1.8	7.6	2.3	4.0	1.2
5	Taft, Siletz Bay	5.0	1.5	6.6	2.0	3.4	1.0
	Kernville, Siletz River	4.6	1.4	6.1	1.9	3.1	0.9
5	Yaquina Bay, entrance	5.9	1.8	7.9	2.4	4.2	1.3
	Newport	6.0	1.8	8.0	2.4	4.3	1.3
	Southbeach	6.2	1.9	8.2	2.5	4.4	1.3
	Yaquina	6.2	1.9	8.2	2.5	4.4	1.3
	Winant	6.3	1.9	8.2	2.5	4.3	1.3
	Toledo	6.3	1.9	8.1	2.5	4.2	1.3
5	Waldport, Alsea Bay	5.8	1.8	7.7	2.3	4.1	1.2
5	Siuslaw River, entrance	5.2	1.6	6.9	2.1	3.7	1.1
	Florence	5.0	1.5	6.6	2.0	3.5	1.1
6N	Umpqua River, entrance	5.1	1.6	6.9	2.1	3.7	1.1
	Gardiner	5.1	1.6	6.7	2.0	3.5	1.1
	Reedsport	5.1	1.6	6.7	2.0	3.6	1.1
7	Coos Bay, entrance	5.2	1.6	7.0	2.1	3.8	1.6
	Empire	4.9	1.5	6.7	2.0	3.5	1.1
	Coos Bay	5.6	1.7	7.3	2.2	3.9	1.2
7	Bandon, Coquille River	5.2	1.6	7.0	2.1	3.7	1.1
6S	Wedderburn, Rogue River	4.9	1.5	6.7	2.0	3.6	1.1

TABLE 2-9. ESTUARINE TIDE DATA, CONTINUED.

WATERSHED UNIT	LOCATION	RANGES MEAN FEET	METERS	DIURNAL FEET	METERS	MEAN TIDE LEVEL FEET	METERS
8	Brookings, Chetco Cove	5.1	1.6	6.9	2.1	3.7	1.1
9	Humboldt Bay, entrance	4.3	1.3	6.2	1.9	3.3	1.0
	South Jetty	4.5	1.4	6.4	2.0	3.4	1.0
	Hookton Slough	4.8	1.5	6.6	2.0	3.6	1.1
	Eureka	4.8	1.5	6.7	2.0	3.6	1.1
	Arcata Wharf	5.0	1.5	7.0	2.1	3.8	1.6
9	Eel River, entrance	4.4	1.3	6.3	1.9	3.4	1.1

[1]The current velocity is 3 knots (1.5 m/sec) in the entrance to Tillamook Bay (p. 224).

(For Willapa Bay) in the entrance the current velocity is about 2.5 knots (1.3 m/sec). Currents of 4 to 6 knots (2 to 3 m/sec) occur at times; the velocity is greatest on the ebb, particularly with a southerly wind. In the channel at South Bend, the velocity is about 1.2 knots (0.6 m/sec) on the flood and 1.4 knots (0.7 m/sec) on the ebb (p. 249).

(For Grays Harbor) in the entrance the current velocity is about 2.5 knots (1.3 m/sec), but velocities may reach 5 knots (2.6 m/sec). In the channels through the bay the velocities seldom exceed 3 knots (1.5 m/sec) (p. 251).

A detailed presentation of tides and tidal currents is available in the Columbia River Estuary Inventory of Physical, Biological and Cultural Characteristics, edited by Seaman (1977). Tidal current speeds and directions at numerous locations in the estuary are presented at three different times in 1959. The times correlated to a low river discharge of 155,000 cubic feet per second, a high river discharge of 380,000 cubic feet per second, and a peak river discharge of 565,000 cubic feet per second. Peak ebb currents of 10 to 11 ft/sec (about 3 m/sec) occurred at times of peak river discharge. The report summarizes other sources of current data, and concludes that the currents in the Columbia River estuary are still not well understood.

Analysis of currents within estuaries is essential for understanding the flushing rates of estuaries. Flushing refers to the time it takes for the water in a basin to replace itself. The combination of tidal forces and runoff will greatly affect the nature of mixing of salt and fresh water within the estuary, and hence its classification under any methodology that considers fresh and salt water distribution (see Volume 1, Section 2.6.1).

Simmons (1955) developed some very general criteria for relating flow to estuary type. He defined a "flow ratio" as the ratio of river flow per tidal cycle to tidal prism. He noted that when the flow ratio is greater than 1, the estuary is highly stratified (large salinity gradient), whereas a flow ratio of about 0.25 may indicate a partially mixed system, and flow ratios less than 0.1 tend to describe a well-mixed condition. Very high runoff rates may overpower the tidal forces and force out all salt water in some rivers at times of peak flow. However, the inward salt water flow near the bed of the estuary maximizes before it is reduced to zero by the overwhelming force of flooding water (Simmons, 1955; Silvester, 1974B). This pattern is highly significant in the nature of sedimentation within estuaries. Marine sediments may be deposited furthest upstream under highly stratified conditions, and may be totally removed when river flow is great enough to prevent sea water intrusion. Peak runoff of the Columbia River will reduce the inland excursion of sea water (Seaman, 1977). Peak runoff of the Sixes will totally purge sea water and marine sediments from its estuary (Boggs and Jones, 1976). Peak runoff into Yaquina Bay stratifies the water, allowing the maximum landward sea water excursion at the bottom (Kulm and Byrne, 1966).

2.6.3 Estuarine Sediment Transport. Sediment transport and deposition is seasonal in response to climatic and hydrographic variations. Maximum deposition occurs in winter for most of the estuaries in the region when river runoff is highest, littoral drift is from south to north, and the highest velocity winds are from the southwest. At this time, for example, beach sediments in Yaquina Bay may move from the tidal entrance (i.e. mouth) six miles (10 km) up the estuary (Kulm and Byrne, 1966). Sand dunes on the barrier bars by the entrance to many estuaries are eroded by winter winds, and the sand is blown into the estuaries. The contribution of suspended sediments from river flow is greatest in winter, with the exception of the Columbia, where spring runoff contributes the most suspended sediment. When a stratified system exists, the landward bottom currents are strongest, and intrusion of marine sediments into the estuaries is greatest. This occurs at times of high river discharge (i.e. winter) in all but the high gradient estuaries. In the high gradient estuaries, the river flow may completely overpower the tidal exchange, and prohibit any significant sea water and marine sediment intrusion. This was documented by Boggs and Jones (1976) in the Sixes River. When a well mixed condition exists there is a net non-tidal seaward drift at all depths, and sedimentation from marine sources is reduced.

Estuarine sediments reflect hydrographic conditions within upland riverine, local estuarine, and adjacent oceanic zones. Near the mouth of an estuary the sediments are mainly marine in origin; near the head of an estuary the sediments are mainly riverine. A transition zone exists in which the riverine and marine sediments are mixed. Figure 2-26 presents, as an example, the three types of sediment zones for Grays Harbor. It is evident that estuaries are depositional environments, with sediment supplies from both their headwaters and their mouths.

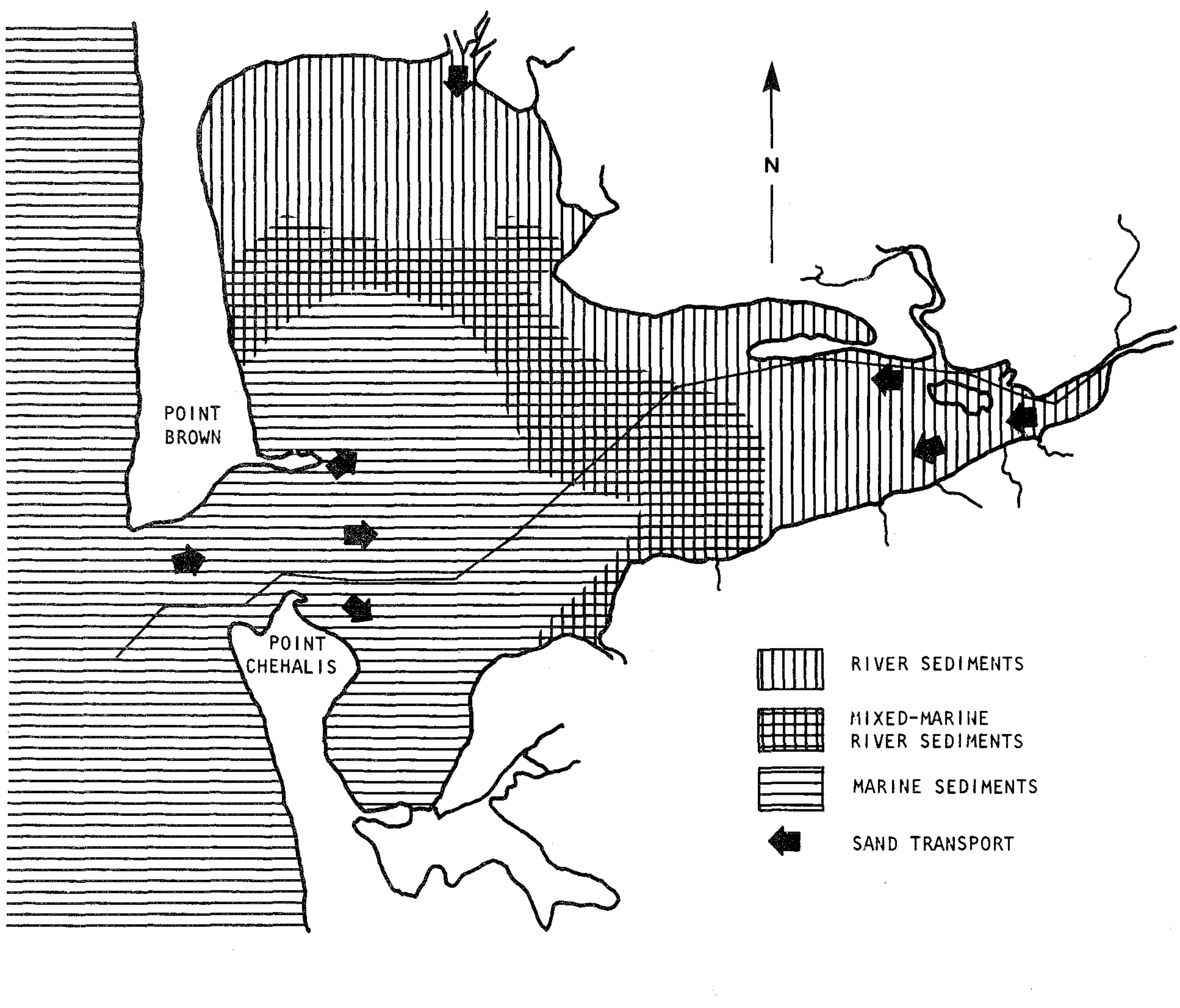


FIGURE 2-26. SEDIMENT DISTRIBUTION IN GRAYS HARBOR, WASHINGTON. Sediment from both riverine and marine sources is deposited in the estuary, with a moving, variable transition zone where the two source types mix. (From Phipps and Scheidegger, 1976.)

The distribution of marine and riverine sediments within an estuary varies with seasonal variations in runoff. High gradient estuaries with small tidal prisms may be dominated by marine sediment transport during periods of low river flow, only to completely flush these sediments out during periods of peak flow in the winter, depositing in their place coarser gravels carried in the streams as bedload. A detailed study of this seasonal reversal of flood/tide dominant sediment transport in the Sixes River estuary is given by Boggs and Jones (1976).

Byrne and Kulm (1967) used natural indicators such as sediment texture and composition to roughly model the winter and summer patterns of sediment transport within Yaquina Bay. Marine sands, identified by presence of yellow grains and certain key heavy minerals, are transported from the tidal entrance up the channel as far as Oneatta Point (six miles up the estuary) during the winter. A partly-mixed estuarine condition exists in the winter, permitting the upstream penetration of salt water and marine sands. During the summer, when river flow is reduced, the estuary is mixed from surface to bottom (dominated by tidal forces) and there is a net seaward movement at all depths. Consequently, very little marine sediment enters the estuary at this time. Maximum deposition of riverine and marine sediments takes place during winter and spring. Wind blown sand also is carried from the coastal dunes into the estuary, and then further transported by tidal currents.

Most of the riverine sediment transported to, and through, the estuaries is suspended. Tidal flow within the estuary transports suspended sediments alternately upriver and downriver. During slack water some of the particles settle through the water column. In a stratified or partially mixed system, the net current is landward near the bottom, and seaward near the surface. Consequently, settling particles enter the net-landward flowing layer. The settling process is accelerated by flocculation, caused by tiny suspended clay particles becoming attracted to themselves in the presence of salt water, forming larger, heavier, more rapidly settling particles. Over many tidal cycles, flocculation and settling cause suspended sediments to accumulate in the zone where the average flow near the bottom is zero. This zone is termed the "turbidity maximum" or null zone and has physical and biological significance, harboring some of the densest populations of microscopic food animals in the estuaries (Seaman, 1977). In the Columbia Estuary, during high river flow conditions, the suspended sediment peak concentration in the null zone oscillates with the tide, from about River Mile 3 to River Mile 8. During periods of low river flow, the peak sediment concentrations generally occur between River Miles 14 and 23 (Seaman, 1977). Dissolved materials in the riverine and in the marine waters may adsorb onto the flocculated suspended particles and precipitate out.

Bedload transport within estuaries is not well understood. Quantitative data are non-existent. The study of changes in sand dunes within the estuary channels of the Columbia at low river flow conditions led to the following qualitative description of bottom sediment transport:

> "Between Harrington Point and Tongue Point (River Miles 18 to 23), sediment movement along the bottom was seaward and generally confined to the navigation channel. Below Tongue Point, transport in the channel was upstream, while along the slopes adjacent to the channel, transport was seaward, at least as far downstream as River Mile 5. On the north side of the estuary sediment transport along the bottom was generally upstream in the deep channel, but it occurred in both directions on slopes. In the old ferry channel between Astoria and Ellice Point transport was in a northern direction at the south end of the channel, and it was in a southerly direction at the north end (Seaman, 1977)."

Computations based on radionuclide data suggest that about 30 percent of the fine sediment transported into the Columbia River estuary by the river may be retained in the estuary, the remainder making its way to the open ocean for eventual deposition along the beaches, the shelf, and the continental slope (Hubbell et al., 1971).

Local erosion can also contribute sediments to the estuaries. Figure 2-4 identified areas of critical and sub-critical erosion in the Pacific Northwest Coastal Region. One area hit very severely by erosion is Cape Shoalwater on the north side of the entrance to Willapa Bay. Andrews (1965) determined that sediment eroded from Cape Shoalwater is carried offshore, forming a tidal delta, and inshore, forming shoals and spits in Willapa Bay.

Biological effects on sediment content and sedimentation are great in estuaries. Organic content of estuarine sediments is greater than for inland riverine sediments or oceanic sediments on the shelf. Attached vegetation within the estuarine systems (eelgrass and salt marsh vegetation) breaks up water flow, promotes settling of particulate matter, and protects the sediment from scouring by currents.

Estuarine sediments contain an organic fraction, consisting of algal particles, small pieces of roots, remnants of planktonic animals, and so on (Guilcher, 1963). In the Pacific Northwest wood chips, sawdust, and bark are also significant, especially in estuaries where wood processing industries are located. These organic sediments are especially concentrated in areas where log rafting (for storage) has been common. The organic fraction sometimes constitutes a large volume of the estuarine sediment, and it leads to the formation of suspended flakes in which mineral particles are enclosed in fibrous networks. Nevertheless, the organic fraction is always considerably smaller in estuarine muds than the mineral fraction, which usually exceeds 90% by weight (Guilcher, 1963).

Kulm and Byrne (1966) found that one to seven percent of the sand fraction of sediment in Yaquina Bay was made up of calcium carbonate and that about five percent of the fine grained sediment in the lower reaches of the estuary were wood chips, sawdust, and plant material. Organic material in the Siletz estuary ranges from three to four percent (by weight) at the mouth to as much as twelve percent at the head of the bay, and up to eighteen percent in the first three miles of the river where log rafting was once common and wood debris is still present in the channel (Rauw, 1974).

Upstream developments that reduce the vegetative cover of the land will increase the sediment yield of the land, and therefore increase the rate of sedimentation within the estuaries. Significant developments of this type include clearcut logging, with associated road building, and agriculture.

Deposition of materials within estuaries is not only of geological interest, but is of concern to mariners because of shoaling in shipping channels. Dredging to establish shipping channels necessitates costly maintenance dredging programs as the channels continuously fill in. The Army Corps of Engineers is responsible for maintenance of the navigable waters of the country and prepares Environmental Impact Statements prior to major dredging projects.

Rates of sediment transport within the navigable channels of the region's estuaries are fairly well known from the amounts of material dredged and times of dredging for maintenance of the channels. For Yaquina Bay, an average of 245,400 cubic yards (188,000 m^3) of sediment was dredged annually from 1956 to 1961 from a navigable area of approximately 619,500 square yards (518,000 m^2). An average rate of accumulation of about 9 inches (23 cm) of sand per year occurred (Kulm and Byrne, 1966). In 1977, over $6 million was spent to dredge more than 9 million cubic yards (7 million m^3) of sediment from the channels of the Columbia River (Page, 1977).

Willapa Bay required maintenance dredging of 300,000 cubic yards (230,000 m^3) per year up to 1977 when the Army Corps of Engineers decided to discontinue it due to low benefit-to-costs ratio (ACOE, 1976H).

The Siletz estuary is considered one of the most heavily sedimented estuaries in Oregon, and siltation is considered a major water quality problem within the estuary as well (ACOE, 1976I; Percy et al., 1974). Sixty-five percent of its surface area is intertidal (see Table 2-8 for comparison with other estuaries).

Humboldt Bay also is heavily sedimented. Over half of its total area is intertidal. The Humboldt Bay Master Plan (Koebig and Koebig, Inc., 1975) classifies the Bay as about seventy percent intertidal. Table 2-8 presents a lower intertidal area percentage of 55% from Skeesick (1963), while a literature survey by the University of Washington (1955B) said 68% of the area was intertidal. These figures may be compatible, representing the differences in area between mean high and low, and mean higher high and lower low. Regardless of how computations are made, much of the Bay is shallow. The high tide area of Humboldt Bay was decreased from 108 km^2 to 67 km^2 (47 mi^2 to 26 mi^2) in the last 120 years. Much of this decrease may also be related to rapid infilling associated with alteration of the contiguous lowlands and watersheds by man's activities (Koebig and Koebig, Inc., 1975). Records of maintenance dredging in Eureka Channel show an average of 81,000 cubic yards (62,000 m^3) of material is dredged each year, which represents a siltation rate in the channel of 16 centimeters (6 in) a year.

Of key concern in any dredging project is the disposition of the dredge spoil material. Dredging and disposal of dredge spoil is a significant mechanism of selective sediment transport in estuaries. Dredge spoils may be taken out to sea and dumped in specially designated sites, or they may be deposited on diked marshland, also specially selected. The land disposal may destroy the productive marshland, although the filled sites may become useful for agriculture or industrial development. Dredging produces certain short-term effects, such as increased turbidity, decreased dissolved oxygen, direct removal of benthic organisms, and smothering of adjacent benthic habitats by settling fine sediments. Toxic substances (which include naturally-occurring and man-made pollutants) that were removed from the water column by sedimentation may be re-released to the water, with potentially harmful biological effects. Less obvious, but potentially very important, are the chronic effects of year-to-year maintenance dredging programs. Repeated dredging will alter equilibrium conditions of sedimentation and biological processes.

Short term and long term physical, biological, and human impacts of dredging in estuaries are discussed in two documents by Oregon State University (1977B and 1977C). Both documents are guides for review of Environmental Impact Statements that focus on dredging in estuaries. One (OSU, 1977B) is a basic guides manual for reviewers, and the other (OSU, 1977C) is a more detailed technical manual. The two manuals are cross-referenced.

2.6.4 Chemical Properties. The chemical properties of the estuarine waters reflect the chemical properties of their source waters - the rivers and the ocean - along with any additional inputs or changes within the estuaries themselves.

The fact that the Pacific Northwest Coastal Region is not densely populated is the main reason that most of the region's estuaries are essentially un-polluted. Exceptions occur in the more populated and industrialized estuaries with associated shipping activities (Grays Harbor, Yaquina Bay, Coos Bay, Humboldt Bay). Only the Columbia River receives significant quantities of discharge from human activities upstream from its estuary.

For most of the estuaries in the region, the tidal ranges and/or the river flows represent relatively high volumes compared to the volumes of the estuaries. Therefore, flushing times (the time it takes for the estuarine water to be replaced by inflow of salt and and fresh water) are short. For some of the high gradient rivers from small watersheds, such as in Units 7 and 8, the flushing times are much longer in the summer due to low river flow, and small tidal prisms exist. During periods of high runoff, these rivers (and other high gradient rivers in Watershed Units 1 and 9) completely dominate tidal forces and flush out all salt and brackish waters.

The processes of flushing, mixing, and runoff, as well as the wide ranges of salinity and temperature that occur, affect the chemical processes and the distribution of chemical components within estuaries. Most of these processes are seasonal and/or tidal. Biological processes, many of which are also seasonal, are significant in consumption and regeneration of nutrients and dissolved gases. Human activities around estuaries increase waste loading, resulting in concentrations of pollutants that are generally higher than inland or marine areas. Human activities may also contribute wastes upstream, or may actually alter or regulate the river flow through damming for various purposes. As noted earlier, the degree of salt water intrusion and marine sedimentation is related to the estuarine circulation pattern which is determined largely by the amount of freshwater discharge into and through the estuary.

Often, chemical studies of estuarine waters and sediments are carried out in seeking answers to particular pollution problems. The Columbia River was unique in the world during the operation of the Hanford plutonium producing reactors in Central Washington because of the high levels of radioactivity introduced into the river, its estuary, and the adjacent ocean. These areas were studied extensively in the 1960's by researchers from various disciplines and institutions, financed largely by the then Atomic Energy Commission. The released radioactive nuclides served as tags on the river water, the sediments, and the organisms that inhabited the water or the sediment of the river, its estuary, and its adjacent oceanic zone. Reports from much of this past research have been compiled in one volume by Pruter and Alverson (1972). This work has been drawn on heavily in this regional characterization of the Pacific Northwest Coast.

As stated in Section 2.6, there is considerable variability in the region's estuaries, and there is a lack of sufficient chemical and physical data to adequately describe most of them. It is risky to take chemical information for one estuary and make inferences concerning another.

Some general information concerning some of the region's estuaries follows. Additional information is presented in Section 2.8 (Water Quality), and in Volume 4.

Herrman (1975), during fish bioassay studies in Grays Harbor, measured a number of chemical parameters in the water and sediments in an industralized portions of the estuary. Table 2-10 presents averages of the water quality chemical data for the time periods of the bioassay studies. Table 2-11 presents a chemical analysis of the benthic substrate in an area sampled on one day in May, 1974.

In Willapa Bay, the dissolved oxygen level appears to be influenced most strongly by physical factors such as wind and waves, which move in from the ocean and add to the dissolved oxygen level by agitating the surface of the water, and temperature, which affects the water's ability to hold dissolved oxygen. The maximum dissolved oxygen concentration is 15 mg/l, which shows the influence that low winter temperatures and wind and wave action have on the dissolved oxygen. Representative winter levels are between 8 and 11 mg/l; these levels hold up through May or June, then drop off to summer levels of 6 to 9 mg/l. Coastal upwelling and high water temperature in the shallow bay are responsible for the lower summer values. The coming of autumn brings an upturn in the oxygen concentration until the winter values and winter conditions are reached. Occasionally, in the Willapa River near Raymond, oxygen concentrations of 5 mg/l have been measured (U.S. ACOE, 1976H).

TABLE 2-10. WATER QUALITY AVERAGES IN GRAYS HARBOR DURING PERIODIC TESTING IN 1974. (From Herrman, 1975.)

Parameter	May 21-25	June 24-28	July 2-6	July 29-August 2
Temperature °C				
Surface	12.7	15.7	16.1	18.3
Bottom	13.0	15.2	15.9	17.9
Dissolved Oxygen (mg/l)				
Surface	7.45	6.35	5.88	5.60
Bottom	6.90	6.05	5.78	5.43
Salinity (o/oo)				
Surface	3.2	10.1	11.3	12.7
Bottom	6.1	13.9	14.1	15.4
pH				
Surface	6.99	7.07	7.15	7.14
Bottom	6.94	7.15	7.25	7.22
BOD (mg/l)				
Surface	4.55	2.08	1.60	2.27
Bottom	5.13	2.58	1.45	1.97
Turbidity (JTU)				
Surface	13.5	4.95	5.30	4.06
Bottom	16.1	6.80	6.70	4.98
Total Suspended Solids (mg/l)				
Surface	30.9	17.0	14.9	12.2
Bottom	38.4	26.5	20.1	14.2
NO_3-N (μg/l)				
Surface	40.9	43.3	39.9	46.4
Bottom	17.8	34.1	39.4	55.3
Total PO_4-P (μg/l)				
Surface	54.8	45.6	35.8	25.8
Bottom	70.9	59.6	45.2	31.7
Chlorophyll "A" (μg/l)				
Surface	2.52	4.17	3.04	2.58
Bottom	3.74	6.45	3.92	3.20
Carotenes (μg/l)				
Surface	1.86	2.86	1.74	1.03
Bottom	3.03	4.43	1.91	1.24
Sulfides (mg/l)				
Surface	[a]	0[b]	0[b]	0[b]
Bottom	[a]	0[b]	0[b]	0[b]

[a] No data were obtained (test methodology failure).

[b] Below limit of detection.

Park et al. (1972) measured various chemical parameters in the Columbia River and its estuary and plotted the monthly values obtained against the salinity. Figure 2-27 presents plots of these temperature and chemical parameters obtained in 1967. Where a line slopes up to the right it indicates that the ocean is the main source of that parameter, and where a line slopes up to the left, the river is the main source. Coastal upwelling is evident in the increases in PO_4 and NO_3 and the decreases in O_2 with increases in salinity during the summer months. Based on the 1966 and 1967 data, Park et al. (1972) concluded that the average chemical composition of the Columbia River water (not the estuary) includes 0.5 μM phosphate, 12 μM nitrate, 160 μM silicate, 1.0 meq/liter alkalinity, 1.0 mM total carbon dioxide, and 7.4 ml/liter oxygen. The average pH of the river water is 7.7. Oceanic values for chemical properties are discussed in Section 2.7.5. Within the estuary values will vary with degree of mixing of the two source waters and biogeochemical processes.

Chemical data for Yaquina Bay are tabulated for five stations in Table 2-12. The pH decreases from 8.1 (slightly basic) at the station nearest the mouth, to 7.05 (almost neutral) at River Mile 15.3. The dissolved oxygen concentration values reflect the oceanic conditions near the mouth, the minimum value of 3.5 mg/l relates to coastal upwelling. Higher oxygen values such as 10.4 mg/l at River Mile 3.7 reflect productivity.

TABLE 2-11. CHEMICAL ANALYSIS OF GRAYS HARBOR BENTHIC SUBSTRATE SAMPLES. Analyses are expressed on wet weight and dry weight bases. Data were collected on May 25, 1974. TVS = Total Volatile Solids and is a measure of the organic content. COD means Chemical Oxygen Demand. Kjeldahl-N is a measure of the organic nitrogen found in plant cells and NH_3. (From Herrman, 1975.)

Location	Gross Features (Percent)							Metals - mg/kg (ppm)													
	Moisture	TVS		COD		Kjeldahl-N		Cadmium		Chromium		Copper		Lead		Mercury		Nickel		Zinc	
		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Pile Dolphin 50 ft West of Port Dock	67.7	3.9	10.1	3.8	11.6	0.09	0.29	0.4	1.3	21	66	19	60	0.16	0.51	0.01	0.03	13	40	30	93
Port Slip No. 1	53.7	3.5	7.5	3.0	6.4	0.07	0.16	0.4	1.0	25	54	25	54	0.15	0.32	0.02	0.04	19	40	38	82
Off East End of Test Barge 50 ft	59.9	3.8	9.4	4.0	9.9	0.11	0.27	0.7	1.7	23	58	26	64	0.21	0.53	0.02	0.05	13	32	37	92
Off West End of Test Barge 50 ft	52.3	3.5	8.3	3.5	8.3	0.08	0.19	0.4	1.1	25	60	22	53	0.32	0.75	0.02	0.05	17	39	34	81
Rennie Island at Station 2A	58.6	3.8	9.1	3.5	8.4	0.08	0.10	<0.4	<1.0	14	34	16	39	0.26	0.62	0.02	0.05	<3	<6	19	46
Averages	58.4	3.6	8.9	3.6	8.9	0.09	0.20	0.5	1.2	22	54	22	54	0.22	0.55	0.02	0.04	13	31	32	79

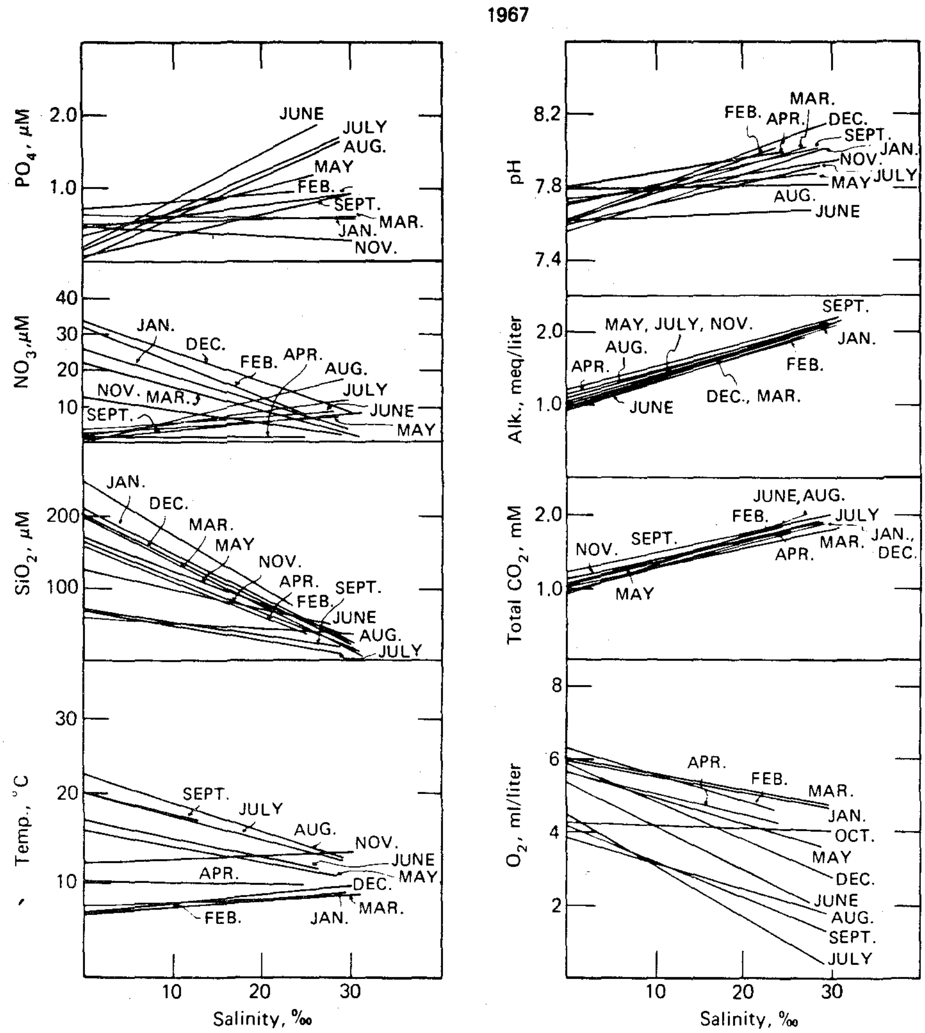


FIGURE 2-27. TEMPERATURE AND CHEMICAL PARAMETERS AS A FUNCTION OF SALINITY IN COLUMBIA RIVER ESTUARY NEAR ASTORIA. A salinity of 0 represents straight river water and a salinity of greater than 30 is nearly all oceanic water; salinities between these extremes represent proportionate amounts of river and oceanic water mixed. This is, where a line slopes to the right it indicates that the ocean is the main source of that parameter (e.g., PO_4), and where a line slopes to the left, the river is the main source (e.g., SiO_2). (From Park et al., 1972.)

TABLE 2-12. SELECTED WATER QUALITY DATA FOR YAQUINA BAY AND RIVER. (From ACOE, 1975G.)

Location, Sampling Duration, and Parameter	No. of Samples	Maximum	Minimum	Mean
(a) Yaquina Bay at Newport Bridge (Hwy-101), River Mile 1.0, Water Quality Analysis 1960-1973				
DO (mg/l)	31	9.8	3.5	8.4
BOD (mg/l, 5-day)	30	6.6	0.0	1.2
pH (Standard Units)	31	8.6	7.6	8.1
Salinity (ppt)	22	34.1	22.4	29.7
(b) Yaquina Bay at McLean Point, River Mile 2.2, Water Quality Analysis 1960-1973				
DO (mg/l)	32	9.8	4.5	8.4
BOD (mg/l, 5-day)	32	6.6	0.0	1.2
pH (Standard Units)	32	8.4	7.6	8.1
Salinity (ppt)	23	34.1	17.8	28.2
(c) Yaquina Bay at Coquille Point, River Mile 3.7, Water Quality Analysis 1960-1973				
DO (mg/l)	32	10.4	4.8	8.3
BOD (mg/l, 5-day)	29	4.3	0.0	1.2
pH (Standard Units)		8.3	7.6	8.1
Salinity (ppt)	24	33.5	9.4	27.3
(3) Yaquina River below Toledo, River Mile 11.8, Water Quality Analysis 1960-1967				
DO (mg/l)	4	7.40	4.00	5.05
DO (% Saturation)	4	71.00	43.00	52.75
BOD (mg/l, 5-day)	4	3.70	.20	1.58
pH (Standard Units)	4	7.40	6.90	7.20
Total Alkalinity (mg/l $CaCO_3$)	4	88.00	49.00	68.50
NH_3-N (mg/l Total)	1	.31	.31	.31
NO_3-N (mg/l Total)	4	.12	.01	.05
Ortho-PO_4 (mg/l PO_4)	4	.10	.01	.053
(3) Yaquina River above Toledo, River Mile 15.3, Water Quality Analysis 1966-1967				
DO (mg/l)	3	6.20	4.10	5.13
DO (% Saturation)	3	60.00	44.00	53.00
BOD (mg/l, 5-day)	3	3.40	.60	1.70
pH (Standard Units)	4	7.20	6.90	7.05
Total Alkalinity (mg/l $CaCO_3$)	4	70.00	22.00	48.50
NH_3-N (mg/l Total)	1	.31	.31	.31
NO_3-N (mg/l Total)	4	.08	.02	.06
Ortho-PO_4 (mg/l PO_4)	4	.11	.01	.04

Coos Bay is heavily impacted by industrialization, logging, and shipping. Coos Bay is unique in that the South Slough is not impacted but has remained in a natural condition. There is concern about the effects of activities in other parts of the estuary upon the South Slough. Oxygen values as low as 1 to 2 mg/l have been reported in the Bay during late summer and early fall (PNRBC, 1971), probably a result of low oxygen content of the oceanic source water, low river runoff, and higher biological oxygen demand from the addition of organic wastes.

A multidisciplinary study of the environmental impacts of dredging in estuaries was conducted in Coos Bay, where these impacted and natural areas exist (OSU, 1977A). The study was an assessment of long term or chronic effects of dredging, rather than short term, more visible effects. Short term effects include increased turbidity, decreased light, and increased chemical and biological oxygen demand, all of which are measureable in the water. Long term effects, however, are best measured in the estuarine sediments. Physical, chemical, and biological characteristics of the sediments at ten stations in Coos Bay are given in Table 2-13. The locations of these stations are presented in Figure 2-28. Stations 1 through 6 are in South Slough and document relatively natural conditions. Station 7 is in the outer main channel of the Coos Bay system, an area of maintenance dredging and additional scouring from prop-wash; it is an

TABLE 2-13. SUMMARY OF SOME PHYSICAL, CHEMICAL, AND BIOLOGICAL PARAMETERS SAMPLED AT TEN STATIONS IN COOS BAY, OREGON. The following symbols are used: A = tidal action, B = storms, C = ship traffic anchor drag, D = sedimentation, E = rare storms, F = bioturbation, G = coarse, G* = very coarse, H = high, I = fine, I* = very fine, L = low, M = moderate, P = present, V = variable, - = information not available. See Figure 2-27 for location of core sampling stations. Refer to OSU (1977A) for approximate ranges covered by these general terms, which were deliberately generalized to aid in characterizing the particular stations. (From OSU, 1977A.)

CHARACTERISTIC	STATION									
	1	2	3	4	5	6	7	8	9	10
Volatile Solids	M	M	M	M	H	LM	L	H	H	H
Primary Turnover Mechanism (Approximate Frequency)	B (yr.-mo.)	AB (mo.)	BE (yr.)	A-B (mo.)	D-E (Decades +)	F (wk.)	A (hrs.-	C (mo.)	C (mo.)	D-E (Decade - year)
Grain Size	G	G	G	G	I	G	G*	I	I	I*
Refractory Organics	-	-	-	-	-	-	-	-	-	-
Dissolved Oxygen Within Water[2]	H	H	H	H	H	H	H	L	L	V
Diel Dissolved Oxygen Variations	L	L	L	L	L	L	L	L	L	H[3]
Chronic Turbidity[4]	No	No	No	No	No	No	No	Yes	Yes	No
Shear Strength[4]	H	H	H	H	H	H	H	L	L	L
Susceptibility to Erosion[5]	M	M	M	M	L-M	M	L-M	-	H	-
Sand Waves	none	none	none	none	none	none	p	none	none	none
Relative Sediment Consolidation	M-H	M-H	M-H	M-H	M-H	M-H	M-H	L	L	M
Tidal Currents	M	M	M	M	VL	M	H	L	L	VL
Free Sulfides	none	none	none	none	none	none	none	none	none	P
Total Sulfides	M	L	M	M	M	L	VL	M	M	H
SO_4 Gradient	L	L	L	L	M	L	VL	M	M	H
Redox Potential	M	M	M	M	L	M	H	M	M	VL
Soluble Organic Carbon	-	L	M	M	L	L	L	M-H	M	H
Ammonia	L	L	L	L	L	L	L	M-H	M	H
Permanent Animal Burrows	P	none	P	none	P	P	none	none	none	P
Burrowing Characteristics	deep	rapid	deep	rapid	-	HBT[6]	rapid	highly motile	highly motile	I
Stress Indicator Species	-	-	-	-	HR[7]	-	-	HR	HR	HR
Carnivorous Predators	P	P	P	P	LA[8]	P	P	none	none	none
Eelgrass	P	none	P	none	none	none	none	none	none	none
Algal Mats	none	none	none	none	less dense brown	none	none	none	none	very dense green
Void Ratio	L	L	L	L	L	L	L	H	H	H
Penetration Resistance	H	H	H	H	L	L[9]	-	L	L	L

[1] Relative approximations; at depths less than 10 cm would be higher.

[2] Based on fall sampling, 1974 and 1975.

[3] (Bella et al., 1972) and fall sampling, 1975.

[4] Based primarily upon diver observations.

[5] Based on *in situ* scour tests.

[6] High biological turnover, ghost shrimp bed, many burrows.

[7] High reproductive capacity species.

[8] Infauna absent, motile species present.

[9] Influenced by the high biological turnover.

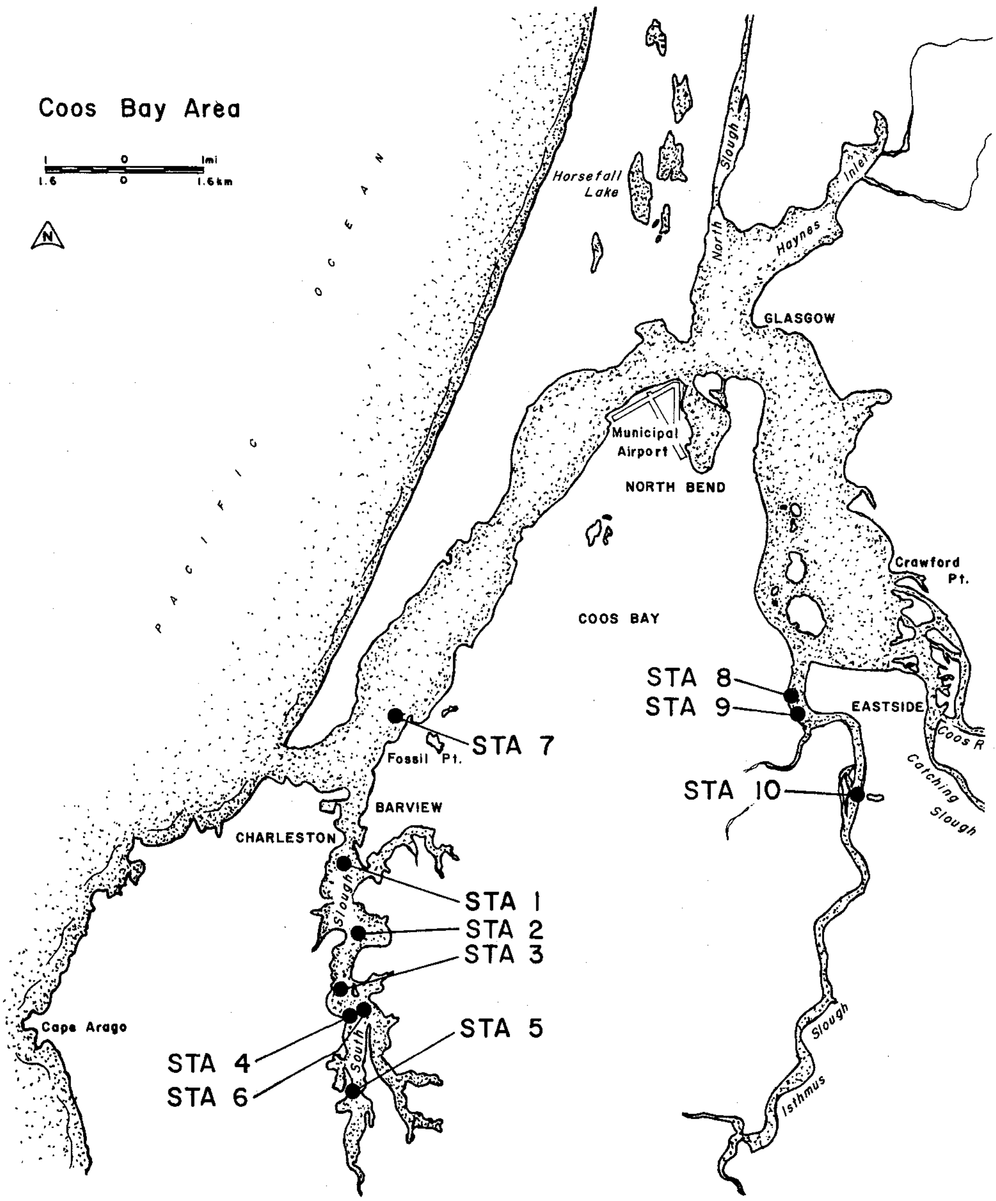


FIGURE 2-28. LOCATION OF DETAILED SEDIMENT CORE SITES IN SOUTH AND ISTHMUS SLOUGHS, COOS BAY, OREGON. See text and Table 2-13 for discussion. (From OSU, 1977A.)

modified, but well-flushed, location. Stations 8 and 9 are located within the upper main dredged channel of Coos Bay within Isthmus Slough. The shore in this area is impacted by logging and construction; the channel is dredged and experiences frequent turnover from vessels dropping, dragging, and raising anchors. Station 10 is in a heavily diked area in which log storage appears to have increased the input of organics.

A purpose of the 18-month Coos Bay study (OSU, 1977A) was to develop a simple yet useful method of assessing many parameters in general terms, in order to characterize and compare two segments of an estuarine system. No significant work has been done in other estuaries to assess the long-term chronic effects of dredging. Environmental Impact Statements on dredging proposals all dwell on the short-term effects.

Although it is difficult to take data from one estuary and make assumptions about another, such was the purpose of the Coos Bay dredging impact study. Assessment of other estuaries can benefit from the methodology of this study, and results can be cautiously compared. To date, this has not been done for other estuaries in the region. Additional discussion of the Coos Bay study is presented in Volume 4.

Additional chemical data for the region's estuaries are presented and discussed in Section 2.8 (Water Quality).

2.7 HYDROSPHERIC FEATURES - OCEANIC

Oceanographic features of the continental shelf for the study area are described in detail in The Columbia River Estuary and Adjacent Ocean Waters Bioenvironmental Studies (Pruter and Alverson, editors, 1972), Oceanography of the Nearshore Coastal Waters of the Pacific Northwest Relating to Possible Pollution (prepared for the Environmental Protection Agency by Oregon State University, 1971), A Summary of Knowledge of the Oregon and Washington Coastal Zone and Offshore Areas (prepared for the Bureau of Land Management of the Oceanographic Institute of Washington, 1977), and A Summary of Knowledge of the Central and Northern California Coastal Zone and Offshore Areas (prepared for the Bureau of Land Management by Winzler and Kelly, 1977).

The coastal area for this region is characterized by a series of sandy beaches interspersed with rocky headlands. The coastline is oriented in a north-south direction and, except for local headlands and bays, is nearly straight. Most of the coastline is subjected to the full impact of breaking waves which are severe in the winter. The winter wave environment produces turbulent mixing from surface to bottom over the shelf and affects productivity, the physical and chemical structure of the water column, and sediment transport processes along the shore and over the shelf.

The offshore surface current is to the south in summer and to the north in winter, responding to seasonal changes in the winds. The current also responds to short term wind changes (on the order of several days) so the seasonal current should be considered as a seasonal net-flow. In the summer months, northerly winds generate a southerly current which has an offshore component at and near the surface due to the effect of the earth's rotation. This wind-driven current (deflected to the right in the northern hemisphere) is called Ekman transport (Barnes et al., 1972). The replacement of this offshore flowing surface water by deeper water is called upwelling. Upwelling brings cooler water, high in nutrients, to the surface and influences both coastal weather and biological productivity.

Many coastal rivers empty into the ocean. Precipitation and runoff combined exceed evaporation, and the surface waters are lower in salinity than waters at depth. Two large rivers, the Columbia and the Fraser, drain vast inland basins, and contribute most of the fresh water to the shelf water, especially off Washington. These large rivers have peak flows in the late spring and early summer associated with snow melt, while most of the coastal rivers peak in the winter following storms. The dilution effect of the Columbia River extends to well offshore of Northern California during the summer, during the winter it heads north, hugging the Washington coastline up to the entrance to the Strait of Juan de Fuca. The Columbia River plume has been characterized by its temperature (Pak et al., 1970), salinity (Budinger et al., 1964; Pak et al., 1970; Barnes et al., 1972), turbidity (Pak et al., 1970), alkalinity (Park, 1966), radioactivity (Carey et al., 1966; Osterberg et al., 1966; Frederick, 1967), and productivity (G. C. Anderson, 1964, 1972). Sediments on the Northern Oregon and Washington Shelf are largely derived from the Columbia.

The salinity, temperature, and resultant density structure of the water column are caused by the interactions between land runoff and oceanic water passing through the area in the regional circulation. Mixing processes and upwelling affect the vertical structure along with the source inputs, and all vary seasonally.

The shelf in the region is narrow to the south (about 24 km or 15 mi), widens to 55 km (35 mi) off Central Oregon, and then varies from 30 to 70 km (20 to 45 mi) wide to the north. The shelf break (outer edge of the shelf) off Washington is scalloped by numerous submarine canyons, of which the Astoria and Juan de Fuca Canyons are considered to be still active in sediment transport.

Nearshore is relatively free of pollution. Upwelling in summer brings deep water to the surface with its lower oxygen and higher nutrient concentrations. The operation of plutonium-producing reactors at Hanford introduced a large amount of radionuclides into the Columbia River in earlier years, and analyses of its traces in the water column, the sediments, and the biota have been conducted (Pruter and Alverson, eds., 1972). Pollution problems do exist in some of the estuaries, and may have some local offshore effects.

The rich supply of nutrients brought to the surface by upwelling stimulates the growth of phytoplankton, resulting in population explosions that are commonly called "blooms." Following the blooms there is an increase in zooplankton which feed on the phytoplankton. The large zooplankton population in turn provides food for higher trophic levels. The success and timing of the fisheries in the Pacific Northwest is closely correlated with the timing and the location of the upwelling zones (OSU, 1971).

Littoral sand transport along the coast is responsive to the local wind-generated wave action and moves sand northward during the winter and southward during the summer. The more severe winter storms generate higher waves tending to make the annual net movement northward, but local variation does occur. Beach sediment is supplied by erosion of cliffs and bluffs by wave action and from the hinterland by high gradient streams and rivers.

The ocean acts as a moderator of the coastal climate. Coastal fog in the summertime is produced by the interaction of warm summer air and cooler upwelled oceanic water near the coast. Precipitation is high in the region as the moisture laden oceanic air encounters the coastal mountain ranges and is common in winter months.

For the most part, there is uniformity in the coastal region. Plant and animal composition of the entire region shows similarity from south to north. Common species reported in Northern Washington have also been reported in Northern California and vice versa. There are no major faunal or floral boundaries in the region, and the differences in biota seen between the boundaries of the region generally occur gradually (Ricketts and Calvin, 1968; p. 386).

The biologic community must adapt to the physical, chemical, and geologic system. Since the general ecological factors that are thought to control biological distributions (such as temperature, substrate, salinity) all show a relative uniformity throughout the region, the absence of biological boundaries is not surprising.

2.7.1 Structure of the Water Column. A discussion of the regional vertical temperature and salinity structure and of the Columbia River was given in Section 2.7.1 of the Conceptual Model (Volume 1), and was illustrated in Figure 2-30 in that volume.

Seasonally-averaged surface temperature and salinity distributions for this region are presented for summer and winter conditions in Figures 2-29 and 2-30. These distributions are based on three years of data (1961-1963). Although real temperature and salinity values were used in deriving these figures, it must be emphasized that they represent averaged values and are conceptual in nature (McGary, 1971). The effects of coastal upwelling in the summertime are apparent in the band of cooler, saltier water nearshore.

The data on which Figures 2-29 and 2-30 are based were collected from a series of 35 cruises in which over 3,300 hydrographic stations (water sampling locations) were taken, and represent the most comprehensive study of the total area undertaken to date. An atlas has been prepared (McGary, 1971) showing the distribution of salinity, temperature, density, and dissolved oxygen for the region, by season, for the surface, 10 m, 20 m, 30 m, 75 m, 100 m, 150 m, 200 m, 300 m, 500 m, 800 m, and 1000 m depth levels.

The nearshore region (within a few miles of the shore) was not intensively sampled in that study due to the difficulties of shipboard operations in and near the surf zone. A more rapid way to survey a large area for surface temperature is with an airborne infrared radiometer. Figure 2-31 presents more detailed surface temperature contours in the nearshore region of Oregon based on an infrared survey taken on a summer day. The straight lines in Figure 2-31 represent the flight track of the airplane. This technique makes it possible to determine in more detail the nearshore temperature structure. Off Central and Southern Oregon, a difference of 6°C is evident from the shore to the edge of the continental shelf, a result of active upwelling (OSU, 1971). The data presented in Figure 2-31 show a particular upwelling event. These events, common in the summer and fall, are sporadic, and the nearshore temperature conditions may vary considerably in short time spans (several days).

Runoff from the Columbia River and the Fraser River (which enters the Pacific via the Strait of Juan de Fuca) dilutes the nearshore surface waters off Washington and Northern Oregon. Upwelling, which strongly influences nearshore surface temperature and salinity off Northern California and Southern and Central Oregon, is less influential in this northern region due to the higher runoff.

Temperature and salinity data have been collected from three lightships on the shelf, and from numerous shore stations along the coast. The names and locations of the lightships and shore stations are presented in Figure 2-32. Mean monthly surface temperatures recorded by the lightships are presented in Figure 2-33. Blunts Reef, off Cape Mendocino, is strongly influenced by upwelling and the lowest mean temperatures actually occur in the summer time. The highest temperatures occur at the Columbia River mouth due to the warming of the river water as it flows seaward over the land, and the failure of upwelled water to penetrate the surface plume. Umatilla Reef, off Northern Washington, shows some summer cooling, but not greately affected by upwelling. The coastal stations also reflect the effects of coastal upwelling and the Columbia River plume. Temperature data for the lightships and for the shore stations are summarized by OSU (1971).

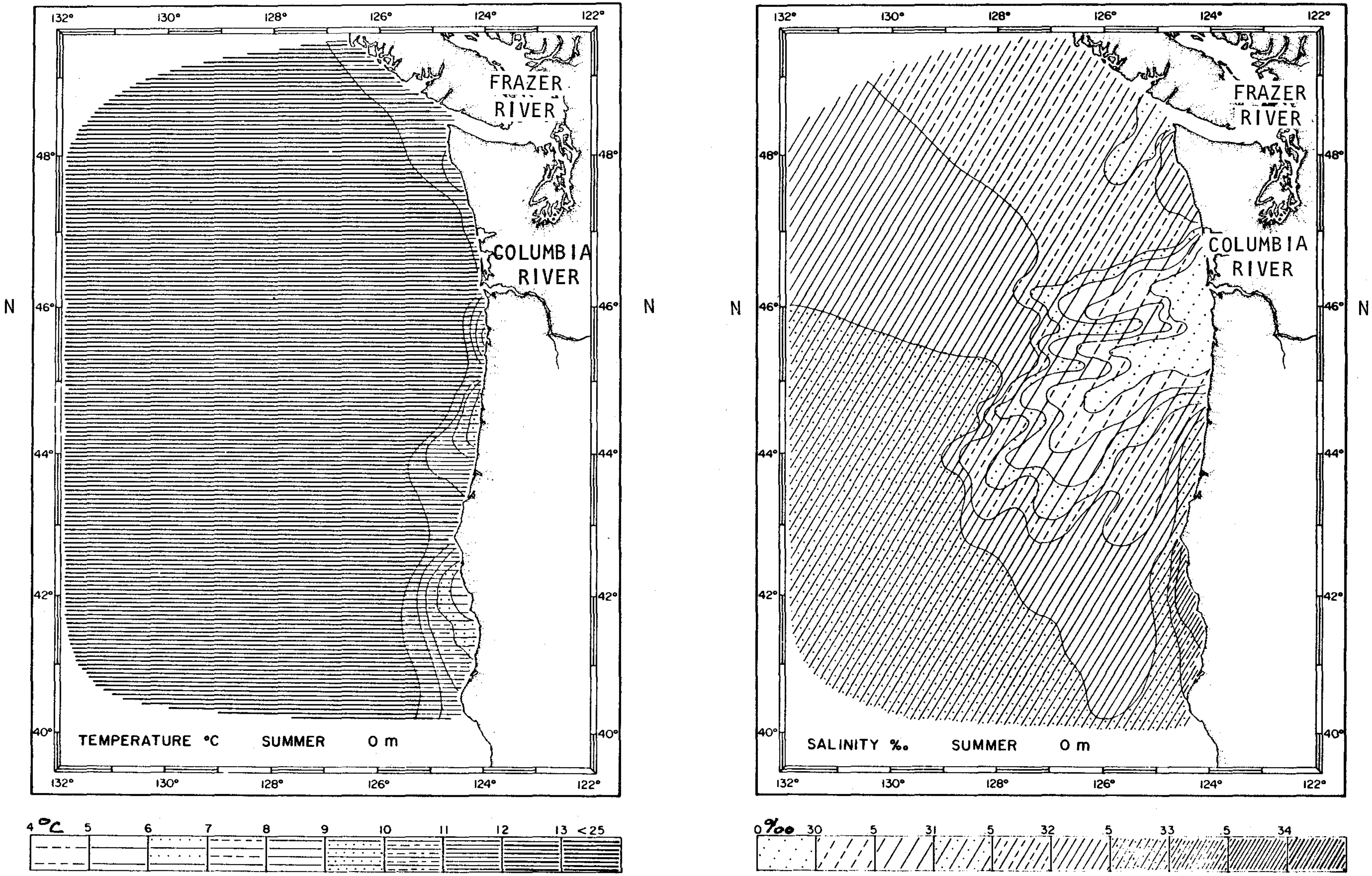


FIGURE 2-29. SUMMER TEMPERATURE AND SALINITY AT THE SURFACE, OFFSHORE NORTHERN CALIFORNIA, OREGON, AND WASHINGTON. Distribution shown is averaged from data obtained during summer months of 1961, 1962, and 1963. (From McGary, 1971.)

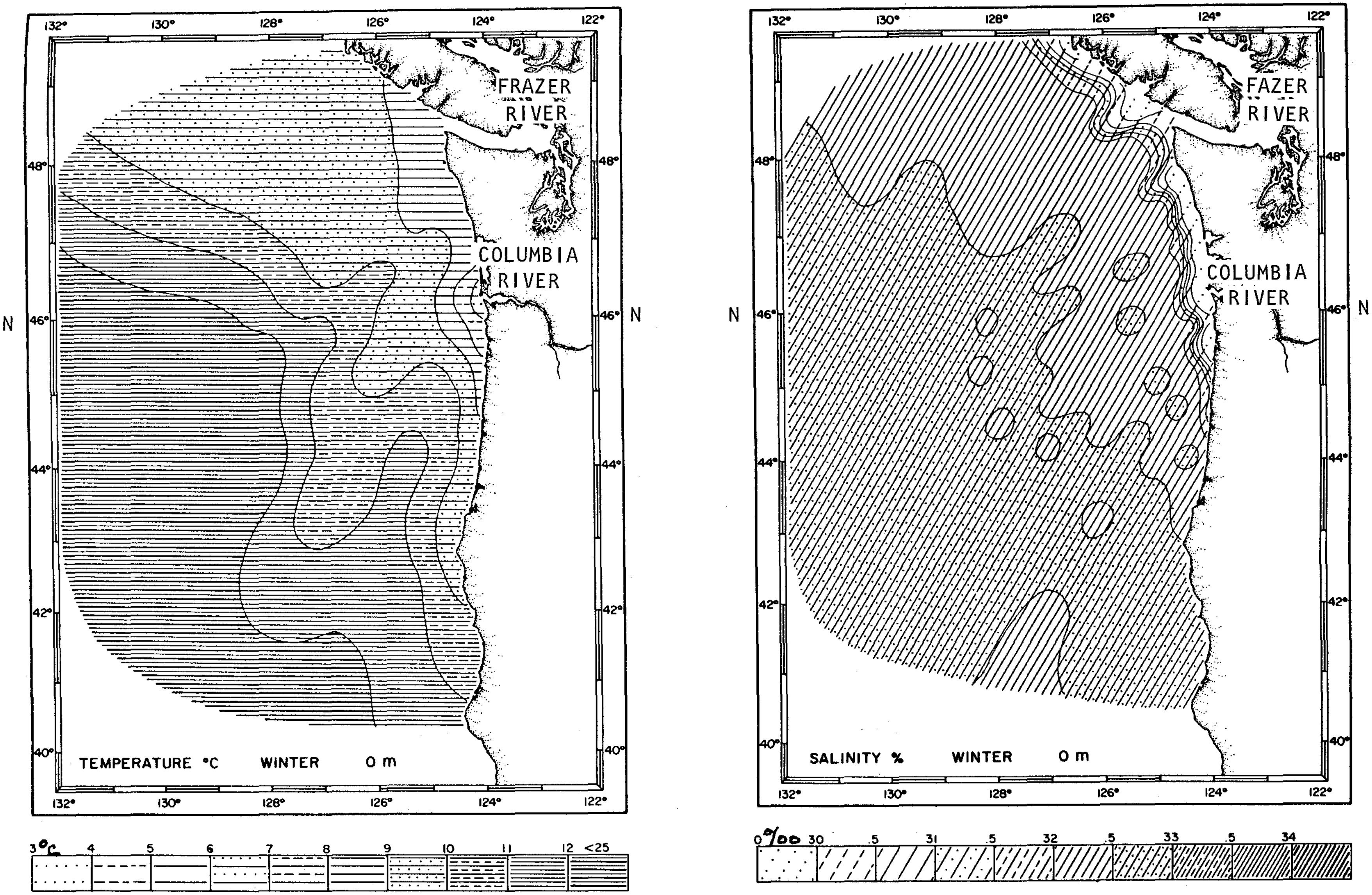


FIGURE 2-30. WINTER TEMPERATURE AND SALINITY AT THE SURFACE, OFFSHORE NORTHERN CALIFORNIA, OREGON, AND WASHINGTON. Distribution shown is averaged from data obtained during winter months of 1961, 1962, and 1963. (From McGary, 1971.)

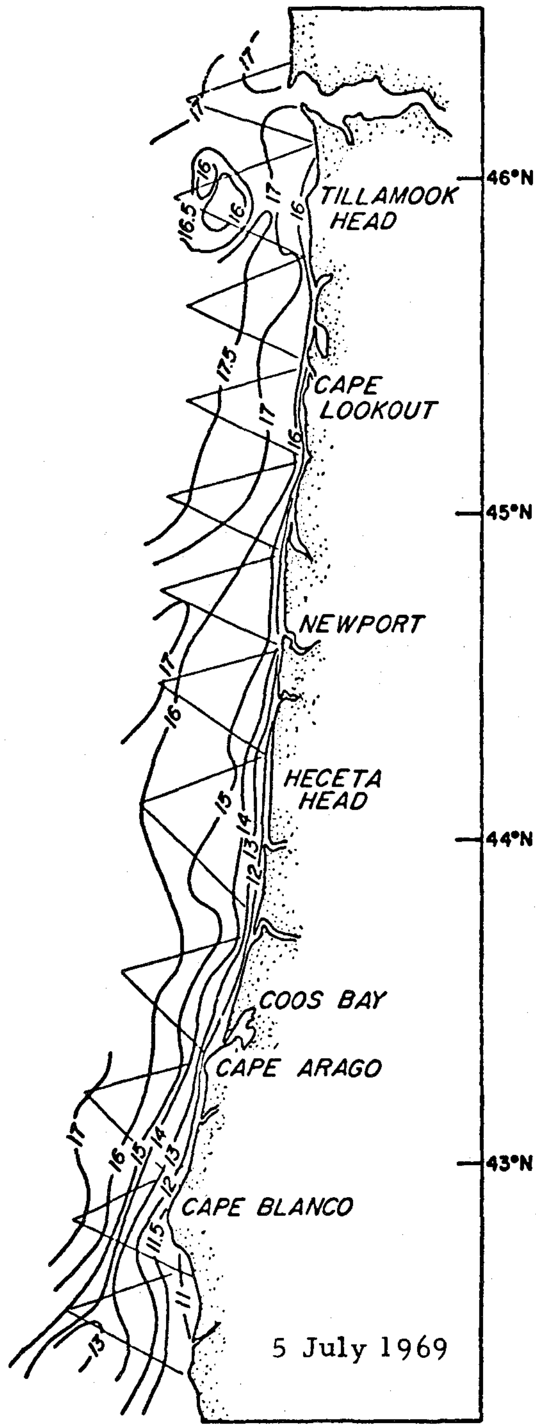


FIGURE 2-31. OREGON NEARSHORE SURFACE TEMPERATURE CONTOURS (°C) FOR 5 JULY 1969 AS DETERMINED FROM AN AERIAL INFRARED SURVEY. The zig-zag line shows the flight track. This technique shows greater detail nearshore and is a more synoptic perspective than the seasonally averaged offshore views in Figures 2-29 and 2-30. (From OSU, 1971.)

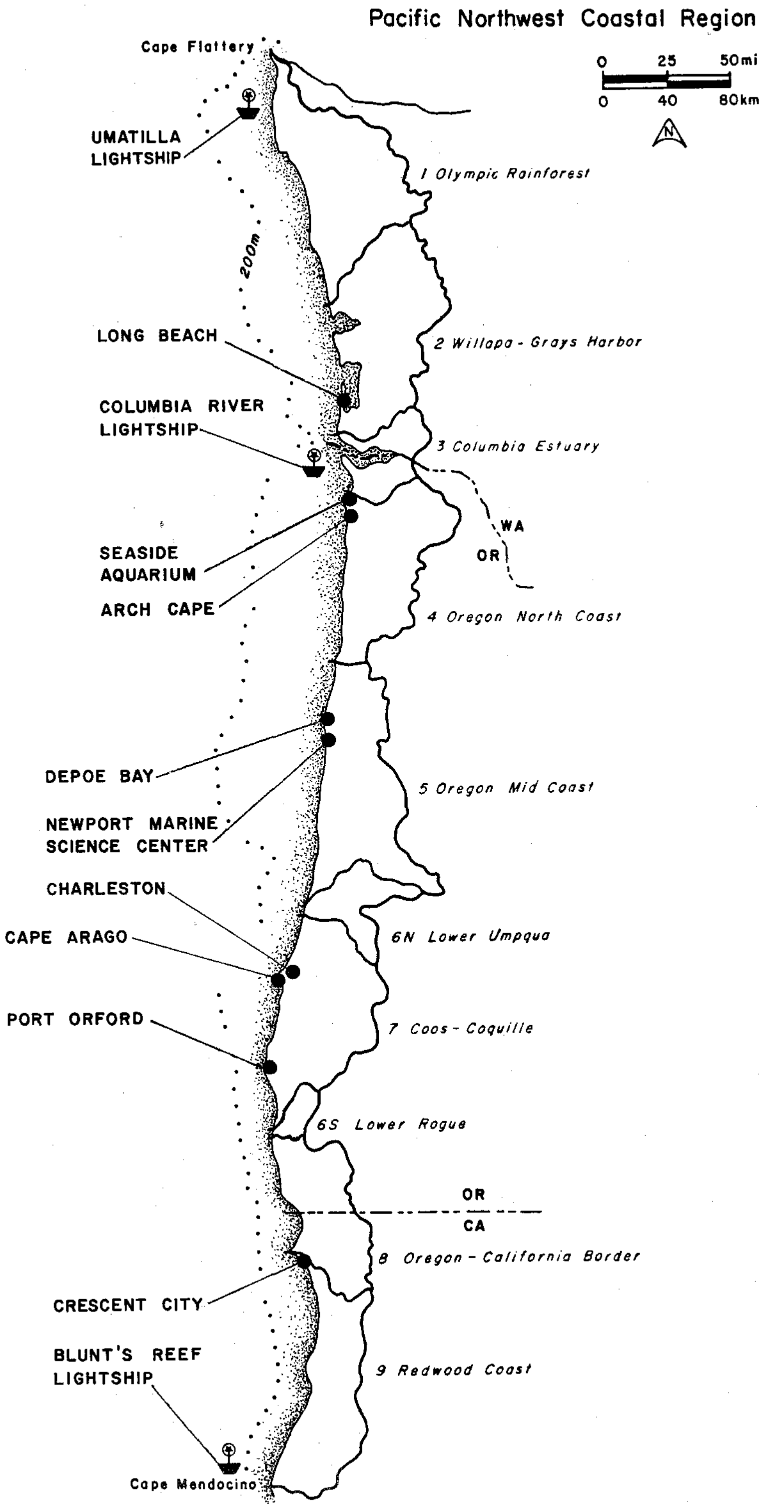


FIGURE 2-32. LOCATION OF SHORE STATIONS AND LIGHTSHIPS FOR WHICH THERE ARE TEMPERATURE AND SALINITY DATA. (After OSU, 1971.)

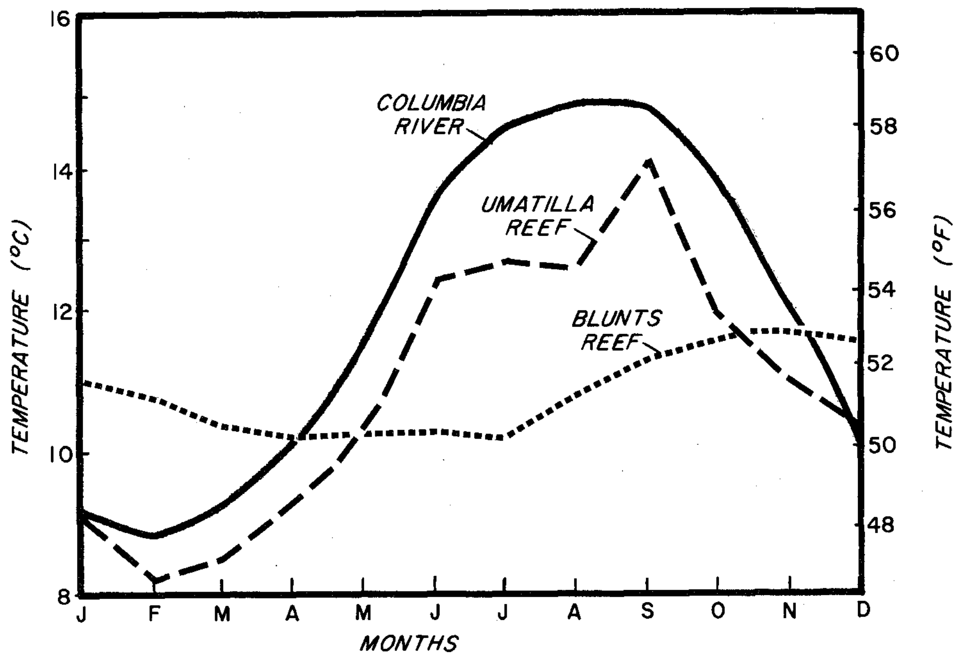


FIGURE 2-33. MEAN MONTHLY SURFACE TEMPERATURES RECORDED AT THREE LIGHTSHIPS ALONG THE PACIFIC NORTHWEST COAST. Blunts Reef (off Cape Mendocino) is greatly affected by summertime coastal upwelling. The Columbia River Station shows the warming and cooling effects of the river plume. The Umatilla Reef lightship is off Northern Washington and its surface temperature closely follows that of the Columbia River Station, except during July and August when upwelling manifests itself at the surface and greatly alters the shape of the curve. Data are from the following periods: Umatilla Reef (1966-1969), Columbia River (1965-1969), and Blunts Reef (1923-1964). (From OSU, 1971.)

2.7.2 Movements of Oceanic Waters.

2.7.2.1 Waves. The wave environment in the Pacific Northwest is not equalled anywhere else in the continental United States. Waves are the driving force in sediment transport processes both along the shore and over the shelf. The biological community along the open coast and on the shelf has had to adapt to a very high energy environment. Navigation of vessels is hazardous because of the waves, both in the open sea and at the entrances to bays and estuaries where wave-driven sediment produces shallow sand bars and fills in navigation channels. The nature of the wave environment of this region is documented in the following discussion.

National Marine Consultants (1960, 1961A, and 1961B) analyzed three years of weather data and have "hindcast" the resultant swell and sea waves that would have approached four deep water stations off the coast of Northern California, Oregon, and Washington. Wave data were presented in monthly and annual tables listing the frequency of occurrence of waves by direction, period (T_s), and deep water significant wave height (H_s). Significant wave height means the highest 1/3 of the waves averaged together, and approximates the "average heights" that would be reported by visual observation (i.e. significant wave height does not mean the highest waves).

The hindcast data of National Marine Consultants has been utilized in a number of ways. Johnson et al. (1971) computed wave power arriving at these stations utilizing the hindcast data. Ballard (1964) utilized the data to compute longshore components of wave energy for points south and north of the Columbia River to help in evaluating longshore sediment transport. The data have been applied to wave refraction studies for four areas on the Southern Oregon coast

(U.S. ACOE, 1975E) and on the Central Washington Continental Shelf (Loehr and Ellinger, 1974). Bourke et al. (1971) evaluated the hindcast statistics and concluded the following:

1. "the highest waves always occurred in winter, when waves approached from the southwest to south-southwest
2. the shortest period waves occurred in summer
3. in all seasons, the predominant direction of swell was from the northwest to west; long period swell also approached from this direction
4. the predominant direction of local sea was from the southwest to south-southwest in autumn and winter, from the north to northwest in spring and summer, and showed more variability in dominant direction than the swell
5. in all seasons, the longest period sea approached from the southwest to south-southwest
6. sea was generally higher than swell, but the periods of the swell exceeded the periods of the sea
7. the longest period swells occurred in August and were from southern hemisphere storms
8. the longest period sea waves occurred in winter
9. in all seasons, periods of calm occurred at the frequency of 25% to 30%, but the calmest season was autumn."

Figure 2-34 presents the locations of the four deep water stations of the National Marine Consultants' data. Other wave data stations that will be discussed are also presented.

Tables 2-14, 2-15, and 2-16 present wave data from the National Marine Consultants (1961B) for station 3, located at the shelf edge off the Columbia River. The tables are for the most severe month (December), the mildest month (August), and an annual summary, respectively. Generally the more southerly stations (1 and 2) are a little calmer and station 4 to the north is a little rougher (OIW, 1977).

Extreme wave conditions have been documented. Rogers (1966) obtained wave data from an oil rig off the Oregon coast and reported seas with waves of 15 m (50 ft) height occurring under winds gusting up to 240 km/hr (150 mph). Watts and Faulkner (1968) reported waves up to 18 m (60 ft) with one wave 29 m (95 ft) high generated by the constructive summation of large waves from two separate storms. Larsen and Fenton (1974) successfully obtained wave records from Cobb Seamount for the winter of 1972-73. Cobb Seamount lies about 500 km (300 miles) due west of Willapa Bay and the peak rises to within 35 m (115 ft) of the surface. A 21 m (69 ft) wave was measured. The waves crossing Cobb Seamount are representative of the waves approaching the coast of the Pacific Northwest. Figure 2-35 presents data from Cobb Seamount for January to April, 1973. The lower line is the significant wave height and the upper line is the maximum wave height observed. The instrument measured waves for 20 minutes every eight hours. Figure 2-36 compares Cobb Seamount data with data obtained on the continental shelf off Tofino, B. C. (see location in Figure 2-34) for February, 1973, when both instruments recorded data. It is apparent from this comparison that the Cobb Seamount data are representative of the waves that approach the West Coast, and that for the most part there is a decrease in wave heights on the shelf due to refraction. On occasion, refraction will produce increased heights, depending on wave period, direction of approach, and bathymetry.

Quayle and Fulbright (1975) used existing climatological data and a statistical approximation technique to estimate mean return periods for maximum sustained winds, and significant and extreme wave heights for coastal areas of the United States. Maximum sustained windspeed is defined as having a duration (at or above the given speed) of approximately one minute. Peak gusts (duration usually less than 20 seconds) frequently occur and average about 1.4 times the sustained windspeed. Table 2-17 presents the results of Quayle and Fulbright's analysis for Southern Oregon. Northern Oregon and Washington had similar extremes. See Section 2.3.1.2 (p. 2-27) of this volume for an explanation of "return periods."

Zopf et al. (1976) have developed a method for measuring nearshore ocean wave characteristics with a land-based, long-period vertical seismometer. Six seismometers are now installed on the Pacific Coast (locations shown in Figure 2-34). Direct readouts are available at the Portland office of the National Weather Service which provide a valuable tool in short-range nearshore ocean wave forecasting. Specific data for the Yaquina Bay area have been summarized by Creech (1973). Data from the seismometer stations have been utilized in studies of wave conditions and beach erosion on the Oregon Coast (Komar et al., 1976B).

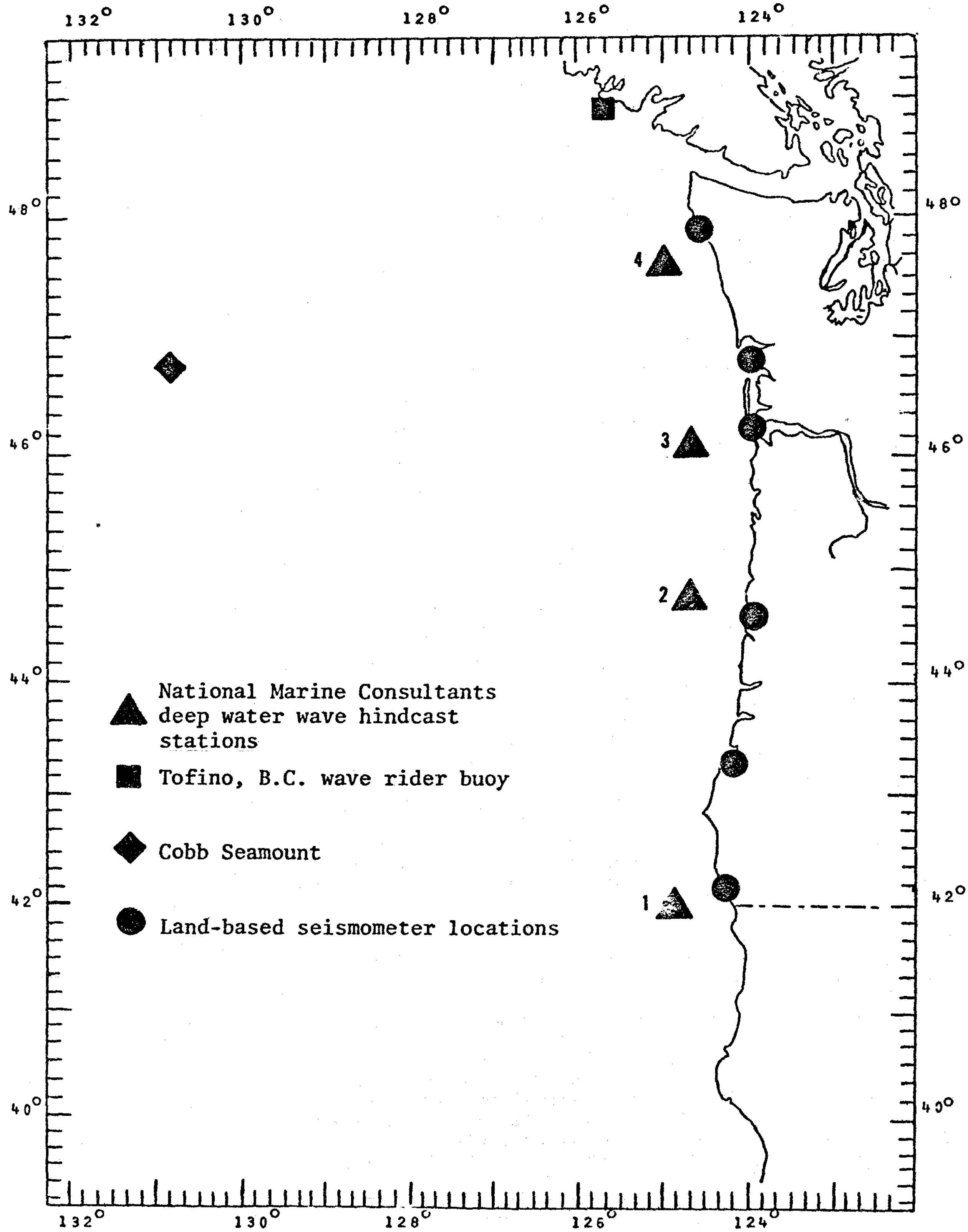


FIGURE 2-34. WAVE DATA SAMPLING LOCATIONS. (From OIW, 1977.)

SWELL AVERAGE TOTAL HOURS 1,152.5

DIR. / H_s \ T_s	NNW 6-8	NNW 8-10	NNW 10-12	NNW 12-14	NNW 14-16	NNW 16-18	NNW 18+	NW 8.6% 6-8	NW 8-10	NW 10-12	NW 12-14	NW 14-16	NW 16-18	NW 18+	WNW 41.2% 6-8	WNW 8-10	WNW 10-12	WNW 12-14	WNW 14-16	WNW 16-18	WNW 18+
1-2.9								.3	1.8	.8		.3			4.3	1.8	.3	.5	1.1		
3-4.9								1.3	.8	.3	.5	.3			1.8	7.3	1.6	.5	.5	.3	
5-6.9									1.6	.3	.3				.3	4.8	1.1	1.1	2.2		
7-8.9																1.6	3.2	1.1	.3	.3	
9-10.9																.3	1.6	.8	.5		
11-12.9																	1.1	.3	.3		
13-14.9																			.3		
15-16.9																					
17-18.9																					
19-20.9																					
21-22.9																					
23-24.9																					
25-26.9																					
27 +																					
Σ								1.6	4.2	1.4	.8	.6			6.4	15.8	8.9	4.3	5.2	.6	

DIR. / H_s \ T_s	W 59.6% 6-8	W 8-10	W 10-12	W 12-14	W 14-16	W 16-18	W 18+	WSW 20.2% 6-8	WSW 8-10	WSW 10-12	WSW 12-14	WSW 14-16	WSW 16-18	WSW 18+	SW 7.6% 6-8	SW 8-10	SW 10-12	SW 12-14	SW 14-16	SW 16-18	SW 18+
1-2.9	4.3	3.2	.5	.5	1.6	.5	.5	1.6	3.8	.8	1.6	.5	.8		.8	1.6					
3-4.9	2.4	8.1	3.5	4.0	2.2	.8		.8	1.1	1.8	.8	.3				.5	.5		.3		
5-6.9		5.6	1.8	1.1	1.1	1.1			1.6						.3	.3	.3		.3		
7-8.9		2.2	1.6	2.2	1.6				.5	.3						.5	.8				
9-10.9		.8	.5	1.6	.5	.3			.5	.5			.3			.3	.5				
11-12.9		.3	.3		.5	.3				.3	.3										
13-14.9		.3	.5	.5	.3					.5											
15-16.9			.3	.3						.3							.3				
17-18.9			.3	.5							.3	.3	.3				.3				
19-20.9												.3									
21-22.9				.3	.5																
23-24.9				.3																	
25-26.9																					
27 +																					
Σ	6.7	20.5	9.3	11.3	8.3	3.0	.5	2.4	7.5	4.5	3.0	1.4	1.4		1.1	3.2	2.7		1.6		

DIR. / H_s \ T_s	SSW 10.6% 6-8	SSW 8-10	SSW 10-12	SSW 12-14	SSW 14-16	SSW 16-18	SSW 18+	S 7.1% 6-8	S 8-10	S 10-12	S 12-14	S 14-16	S 16-18	S 18+	SSE 6-8	SSE 8-10	SSE 10-12	SSE 12-14	SSE 14-16	SSE 16-18	SSE 18+	Σ
1-2.9	.5	2.7	1.8					.3	1.8													40.9
3-4.9		1.6							1.3													45.2
5-6.9		1.8							.5	.8												28.3
7-8.9		.3	.5						.5	.5												18.0
9-10.9		.3	.8						.5													10.6
11-12.9										.3												4.0
13-14.9												.3										2.7
15-16.9			.3							.3												1.8
17-18.9																						2.0
19-20.9																						0.3
21-22.9																						0.8
23-24.9																						0.3
25-26.9																						
27 +																						
Σ	.5	6.7	3.4					.3	4.6	1.9		.3										154.9

SEA

DIR. / H_s \ T_s	N 1.3% 4-6	N 6-8	N 8-10	N 10-12	N 12+	NNW 4-6	NNW 6-8	NNW 8-10	NNW 10-12	NNW 12+	NW 2.1% 4-6	NW 6-8	NW 8-10	NW 10-12	NW 12+	WNW 5.9% 4-6	WNW 6-8	WNW 8-10	WNW 10-12	WNW 12+
1-2.9	.8										.5					.3				
3-4.9	.5											.5				.5	1.6			
5-6.9												.5					1.1			
7-8.9																	.3	.5		
9-10.9																		.8		
11-12.9														.3				.3	.5	
13-14.9																				
15-16.9														.3						
17-18.9																				
19 -22.9																				
23 - 27																				
Σ	1.3										.5	1.0		.6		.8	3.0	1.6	.5	

DIR. / H_s \ T_s	W 9.3% 4-6	W 6-8	W 8-10	W 10-12	W 12+	WSW 7.0% 4-6	WSW 6-8	WSW 8-10	WSW 10-12	WSW 12+	SW 9.9% 4-6	SW 6-8	SW 8-10	SW 10-12	SW 12+	SSW 16.0% 4-6	SSW 6-8	SSW 8-10	SSW 10-12	SSW 12+
1-2.9	1.1					.3					1.1					1.1				
3-4.9	.5	2.2				.5	.8					1.3				.3	2.2			
5-6.9		.8	.3				1.1					2.4					4.3	.3		
7-8.9		.8	2.7				1.1	1.6				.5	1.8					2.4		
9-10.9								.5	.3				.8	.3			.3	.8	.3	
11-12.9				.3					.5				.3	.3				.5	.5	
13-14.9				.3					.3				.3	.5					1.6	
15-16.9				.3															.3	
17-18.9														.3					.8	
19 -22.9																			.3	
23 - 27																				
Σ	1.6	3.8	3.0	.9		.8	3.0	2.1	1.1		1.1	4.2	3.2	1.4		1.4	6.8	4.0	3.8	

DIR. / H_s \ T_s	S 15.3% 4-6	S 6-8	S 8-10	S 10-12	S 12+	SSE 7.6% 4-6	SSE 6-8	SSE 8-10	SSE 10-12	SSE 12+	OFFSHORE 4.4	CALM 21.2	Σ 25.6
1-2.9	4.8					.5							10.5
3-4.9		1.6				1.3	.3						14.1
5-6.9		2.4					1.1						14.3
7-8.9		.3	1.1				.5	1.1					14.7
9-10.9			.5	.3			.3	1.1	.5				6.8
11-12.9			.3					.3					4.1
13-14.9				1.3					.3				4.6
15-16.9			.5	.3									1.7
17-18.9				.8	.3								2.2
19 -22.9				.3	.5			.3					1.4
23 - 27													
Σ	4.8	4.3	2.4	3.0	.8	1.8	2.2	2.8	.8		4.4	21.2	100.0

TABLE 2-14. AVERAGE HEIGHT-PERIOD-DIRECTION FREQUENCY DISTRIBUTION FOR SWELL AND SEA WAVES APPROACHING STATION 2 (SEE FIGURE 2-34) OFF THE CENTRAL OREGON COAST FOR DECEMBER, THE ROUGHEST MONTH. Data are based on analysis of three years of weather data for the Pacific Ocean. H_s is the significant wave height, defined as the average of the highest 1/3 waves, and T_s is the average wave period associated with H_s. (From National Marine Consultants, 1961B.)

SWELL AVERAGE TOTAL HOURS 720.9

DIR.	NNW 1.6%							NW 25.2%							WNW 41.5%						
H_s \ T_s	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+
1-2.9		1.6						5.4	8.3	5.6	.3	.5			6.7	5.4	3.5	2.7	.3	.3	
3-4.9								.8	1.3	1.6	.3				3.2	5.9	4.8	2.9	.8	.5	
5-6.9										.3	.8					1.1	2.9	.5			
7-8.9																					
9-10.9																					
11-12.9																					
13-14.9																					
15-16.9																					
17-18.9																					
19-20.9																					
21-22.9																					
23-24.9																					
25-26.9																					
27 +																					
Σ		1.6						6.2	9.6	7.5	1.4	.5			9.9	12.4	11.2	6.1	1.1	.8	

DIR.	W 23.7%							WSW 3.5%							SW 1.1%						
H_s \ T_s	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+
1-2.9	2.7	2.2	1.6	1.3	.3			.5	.3	.3					1.1						
3-4.9	2.4	3.8	2.2	1.3	.3			.5	.5	.5											
5-6.9		1.8	.8	.8	.3				.3												
7-8.9			1.1	.8						.3											
9-10.9																					
11-12.9									.3												
13-14.9																					
15-16.9																					
17-18.9																					
19-20.9																					
21-22.9																					
23-24.9																					
25-26.9																					
27 +																					
Σ	5.1	7.8	5.7	4.2	.9			1.0	1.4	1.1					1.1						

DIR.	SSW 0.3%							S							SSE							Σ
H_s \ T_s	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	
1-2.9	.3																					51.2
3-4.9																						33.6
5-6.9																						9.6
7-8.9																						2.2
9-10.9																						
11-12.9																						0.3
13-14.9																						
15-16.9																						
17-18.9																						
19-20.9																						
21-22.9																						
23-24.9																						
25-26.9																						
27 +																						
Σ	.3																					96.9

SEA

DIR.	N 2.4%					NNW 10.8%					NW 32.7%					WNW 2.6%					W 6.2%				
H_s \ T_s	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+
1-2.9	1.8					6.2					22.6					1.8					5.4				
3-4.9		.3				.8	2.7				.5	7.8				.3	.5					.5			
5-6.9		.3					1.1					1.3										.3			
7-8.9													.5												
9-10.9																									
11-12.9																									
13-14.9																									
15-16.9																									
17-18.9																									
19 - 22.9																									
23 - 27																									
Σ	1.8	.6				7.0	3.8				23.1	9.1	.5			2.1	.5				5.4	.8			

DIR.	WSW 1.6%					SW 4.0%					SSW 2.7%					S 1.4%					SSE 1.9%					OFFSHORE	CALM	Σ
H_s \ T_s	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	0.4	33.3	33.7
1-2.9	1.3					3.2					2.2					.3					.5							45.3
3-4.9	.3					.3	.5					.5					.3					.3						15.6
5-6.9																												3.0
7-8.9																		.3					.3					1.1
9-10.9																		.5										0.5
11-12.9																								.5				0.5
13-14.9																							.3					0.3
15-16.9																												
17-18.9																												
19 - 22.9																												
23 - 27																												
Σ	1.6					3.5	.5				2.2	.5				.3	.3	.8			.5	.3	.6	.5		0.4	33.3	100.0

TABLE 2-15. AVERAGE HEIGHT-PERIOD-DIRECTION FREQUENCY DISTRIBUTION FOR SWELL AND SEA WAVES APPROACHING STATION 2 (SEE FIGURE 2-34) OFF THE CENTRAL OREGON COAST FOR AUGUST, THE CALMEST MONTH. Data are based on analysis of three years of weather data for the Pacific Ocean. H_s is the significant wave height, defined as the average of the highest 1/3 waves, and T_s is the average wave period associated with H_s. (From National Marine Consultants, 1961B.)

SWELL AVERAGE TOTAL HOURS 10,508.45

DIR.	NNW .85%							NW 12.43%							WNW 35.97%						
T_s / H_s	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+
1-2.9	.04	.30	.34					1.45	4.34	2.12	.07	.22			2.47	4.54	3.25	1.28	.80	.27	.02
3-4.9		.02	.02					.59	.69	.55	.19	.12	.02		2.15	5.44	2.62	1.21	.61	.33	.02
5-6.9		.02	.02					.07	.50	.32	.18	.11			.25	2.11	2.10	.97	.64	.05	.02
7-8.9		.02	.02					.02	.02	.32	.09				.05	.64	1.09	.53	.17	.02	
9-10.9			.05						.05	.13	.02					.17	.41	.25	.22		
11-12.9									.02		.07					.02	.27	.32	.05		
13-14.9										.02							.07	.16	.05		
15-16.9										.02							.09	.02	.02		
17-18.9										.05	.02						.04			.02	
19-20.9											.02	.02					.02	.02			
21-22.9																			.02		
23-24.9																					
25-26.9																					
27 +																					
Σ	.04	.36	.45					2.13	5.62	3.55	.66	.47	.02		4.90	12.92	10.06	4.76	2.58	.69	.06

DIR.	W 38.80%							WSW 14.47%							SW 6.43%						
T_s / H_s	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+
1-2.9	2.56	4.71	2.89	1.92	1.20	.37	.04	1.16	2.13	1.66	.72	.81	.19		.51	.96	.47	.30	.05	.02	
3-4.9	1.65	5.74	3.07	1.55	1.08	.52		.57	1.87	1.31	.70	.17	.05		.51	.67	.32	.07	.21	.05	
5-6.9	.21	2.00	1.48	1.15	.48	.19		.09	.47	.42	.30	.07	.02		.05	.55	.17	.14	.05	.02	
7-8.9	.04	.94	.84	.52	.31	.02		.02	.20	.21	.09		.02			.23	.37	.12	.02		
9-10.9		.18	.53	.46	.19	.05	.02		.12	.23	.05		.07			.02	.17	.15	.02		
11-12.9		.07	.23	.17	.12	.02	.02		.02	.07	.14	.07					.07		.02		
13-14.9		.02	.25	.20	.12	.02				.07	.08	.05					.02	.02	.02		
15-16.9			.07	.05	.07	.02				.07	.02						.02		.02		
17-18.9			.05	.11		.02	.02				.02	.02	.02				.02				
19-20.9				.05	.02							.02									
21-22.9				.02	.07																
23-24.9			.02	.02							.07										
25-26.9																					
27 +				.04																	
Σ	4.46	13.66	9.43	6.26	3.66	1.23	.10	1.84	4.81	4.04	2.20	1.21	.37		1.07	2.45	1.65	.80	.41	.09	

DIR.	SSW 7.03%							S 3.78%							SSE 0.9%							Σ
T_s / H_s	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	
1-2.9	.40	1.47	.87	.09	.02			.35	1.25	.28	.02					.05						49.02
3-4.9	.58	.91	.32	.02	.05			.21	.42	.18												37.36
5-6.9	.11	.52	.35	.07	.02			.05	.22	.12						.02						16.70
7-8.9	.02	.21	.23	.09					.16	.07												7.72
9-10.9		.09	.21						.14	.02												4.08
11-12.9		.02	.09						.02	.09	.02					.02						2.03
13-14.9			.02	.10						.02		.02										1.34
15-16.9		.02	.05	.04	.02					.10												0.72
17-18.9				.02							.02											0.45
19-20.9																						0.17
21-22.9																						0.11
23-24.9																						0.11
25-26.9																						
27 +																						0.04
Σ	1.11	3.24	2.14	.43	.11			.61	2.21	.88	.06	.02				.09						119.85

SEA

DIR.	N 3.50%					NNW 5.04%					NW 16.47%					WNW 4.43%					W 6.10%				
T_s / H_s	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+
1-2.9	2.06					2.25					7.32					1.44					2.77				
3-4.9	.25	.59				.35	1.41				1.07	4.18				.35	1.10				.21	1.50			
5-6.9		.42					.62					1.69	.02				.54					.77	.02		
7-8.9			.16					.28				.02	1.20				.05	.48				.09	.51		
9-10.9			.02										.37					.19	.02				.14	.02	
11-12.9									.04				.02	.41				.02	.11				.07	.02	
13-14.9									.07					.05					.09					.09	
15-16.9														.05										.09	
17-18.9										.02				.07					.02						
19 – 22.9																				.02					
23 - 27																									
Σ	2.31	1.01	.18			2.60	2.03	.28	.11	.02	8.39	5.89	1.61	.58		1.79	1.69	.69	.24	.02	2.98	2.16	.74	.22	

DIR.	WSW 3.77%					SW 7.25%					SSW 7.43%					S 11.31%					SSE 3.13%					OFFSHORE	CALM	Σ
T_s / H_s	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	2.90	28.67	31.57
1-2.9	1.00					2.49					1.57					3.07					.49							24.46
3-4.9	.31	.90				.35	1.26				.30	1.10				.48	1.95				.30	.52						18.28
5-6.9		.73					1.11					1.42	.02				1.83	.02				.54						9.75
7-8.9		.19	.27				.37	.77				.16	.86	.02			.09	.97				.04	.39					6.92
9-10.9			.12	.02				.18	.05			.05	.51	.07			.04	.71	.05			.05	.21	.08				2.90
11-12.9			.02	.09				.22	.13				.21	.24				.40	.55				.17	.07				2.79
13-14.9				.10				.07	.16				.05	.40				.18	.27				.12	.05				1.70
15-16.9														.12				.05	.18	.02				.04				0.55
17-18.9			.02						.05					.19					.31	.04			.02	.02				0.76
19 – 22.9														.05	.07				.04	.02			.02					0.22
23 - 27										.04				.02						.04								0.10
Σ	1.31	1.82	.43	.21		2.84	2.74	1.24	.39	.04	1.87	2.73	1.65	1.11	.07	3.55	3.91	2.33	1.40	.12	.79	1.15	.93	.26		2.90	28.67	100.00

TABLE 2-16. AVERAGE ANNUAL HEIGHT-PERIOD-DIRECTION, FREQUENCY DISTRIBUTION FOR SWELL AND SEA WAVES APPROACHING STATION 2 (SEE FIGURE 2-34) OFF THE CENTRAL OREGON COAST. Data are based on analysis of three years of weather data for the Pacific Ocean. H_s is the significant wave height, defined as the average of the highest 1/3 waves, and T_s is the average wave period associated with H_s. (From National Marine Consultants, 1961B.)

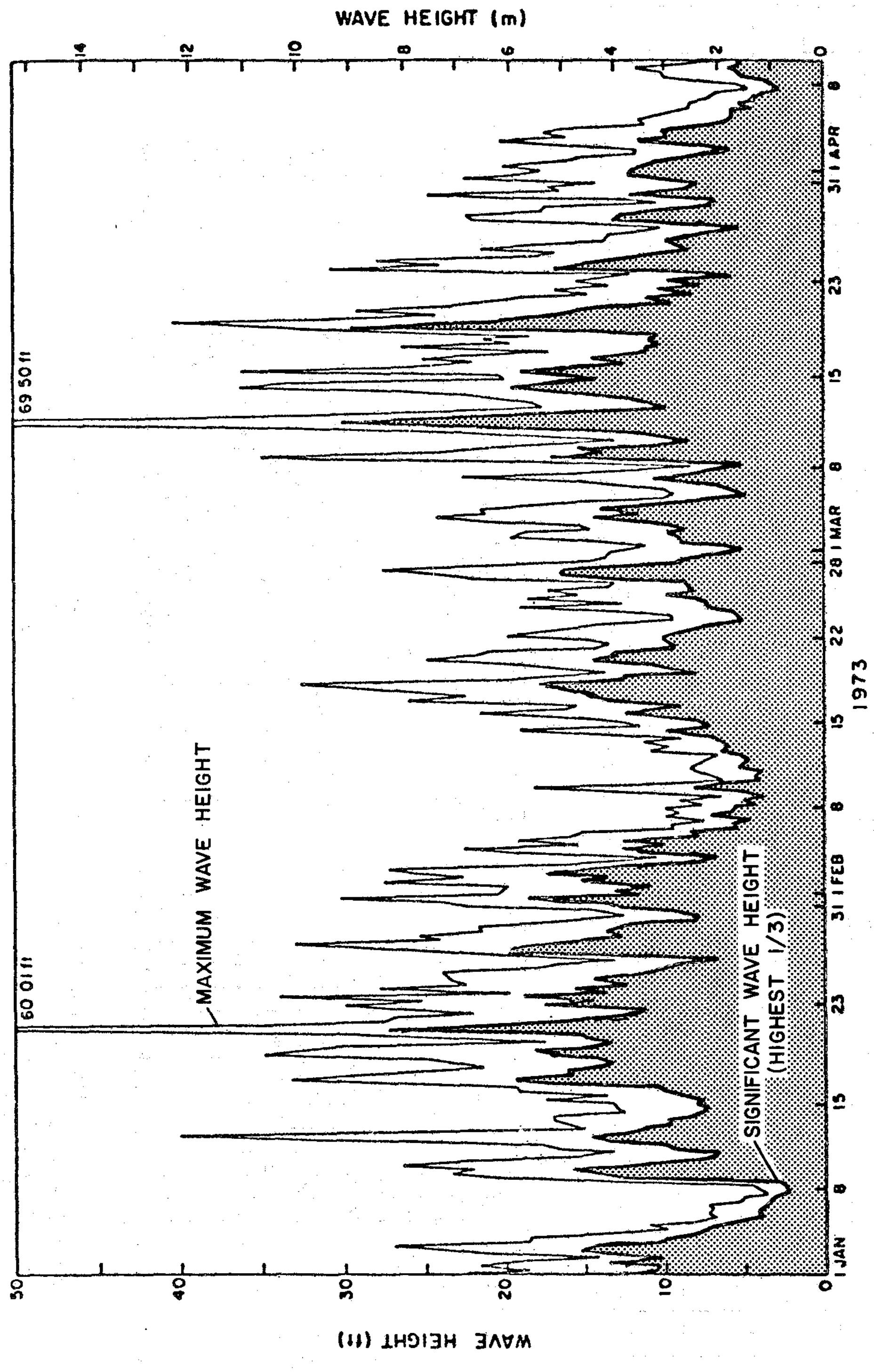
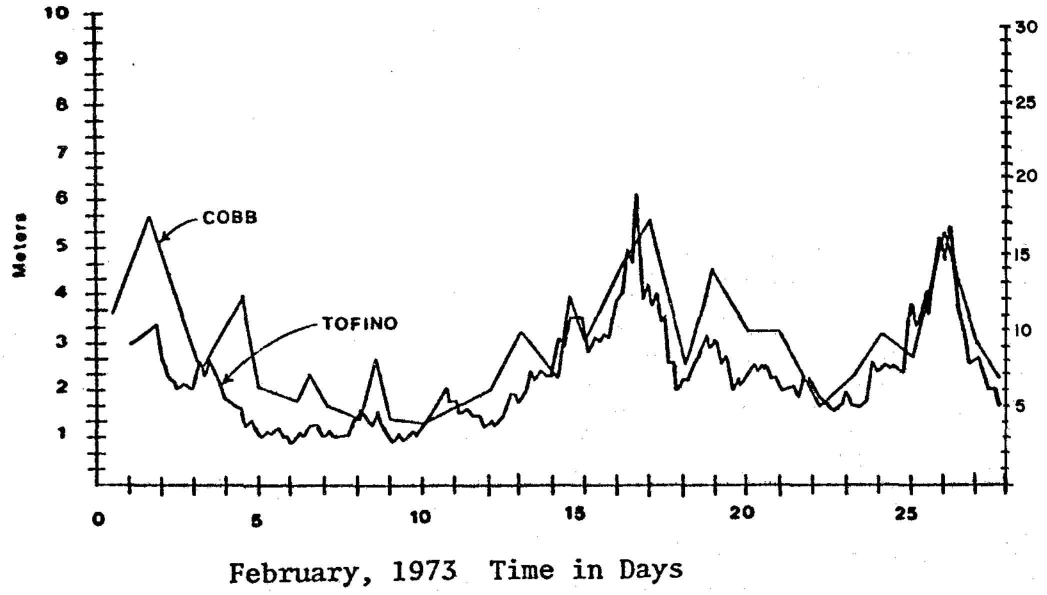


FIGURE 2-35. COBB SEAMOUNT WAVE DATA, JANUARY-APRIL, 1973. (From Loehr and Ellinger, 1974, as adapted from Larsen and Fenton, 1974.)



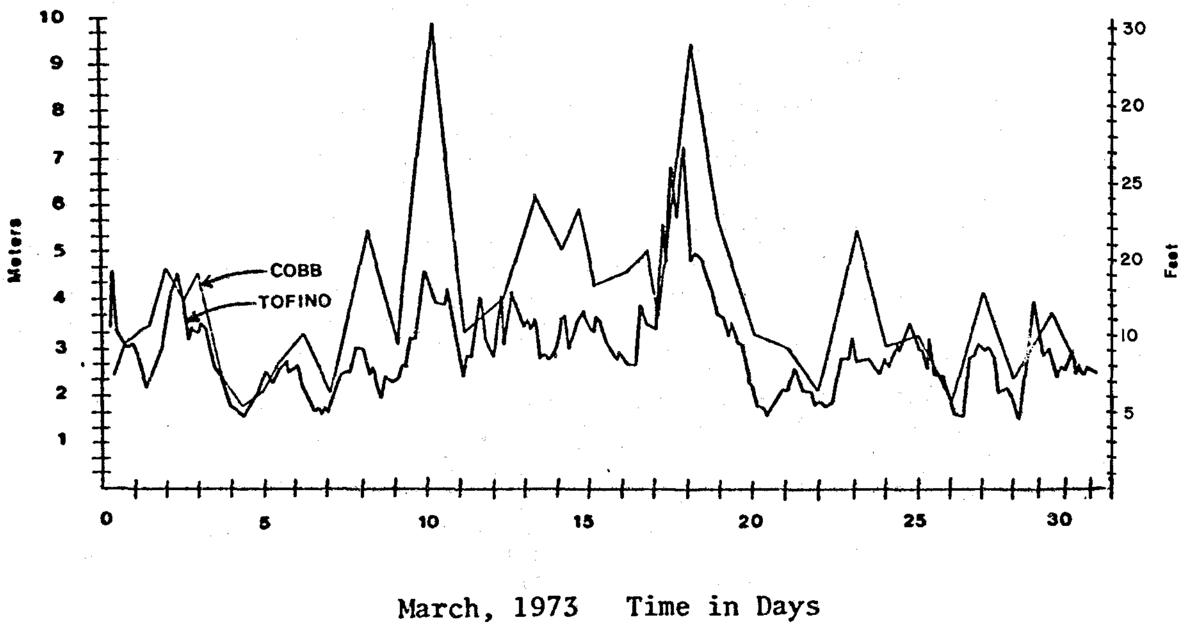


FIGURE 2-36. COMPARISON OF SIGNIFICANT WAVE HEIGHTS RECORDED AT TOFINO AND COBB SEAMOUNT (SEE FIGURE 2-34 FOR LOCATIONS) FOR FEBRUARY AND MARCH, 1973. (From OIW, 1977.)

TABLE 2-17. WIND AND WAVE EXTREMES FOR SPECIFIED RETURN PERIODS FOR SOUTHERN OREGON COAST. (From Quayle and Fulbright, 1975.)

Extreme Sustained Windspeed Estimates: km/hr (knots)					Significant Wave Height[1] Estimates: meters (feet)					Extreme Wave Height Estimates: meters (feet)				
5yr	10yr	25yr	50yr	100yr	5yr	10yr	25yr	50yr	100yr	5yr	10yr	25yr	50yr	100yr
126 (68)	135 (73)	152 (82)	165 (89)	178 (96)	12 (39)	13 (44)	16 (52)	18 (58)	20 (65)	21 (70)	24 (80)	28 (93)	32 (105)	36 (118)

[1]Significant wave height is the average of the highest 1/3 waves.

2.7.2.2 Tsunamis. Hazards associated with a seismic sea wave (tsunami) are primarily due to the rapid change in water level between the wave crest and sea level. A warning system exists for the Pacific, called the Tsunami Information Center, in Hawaii. Between 1946 and 1976, tsunami warnings and partial evacuation along the coast of this region occurred in 1952, 1963, 1964, and 1965. The 1964 event destroyed two bridges and temporarily stranded 100 residents and recreationalists in Washington (Marts, 1976); in Oregon, four people were swept to sea and drowned (Seattle Times, 28, 29, and 31 March, 1964). Within the study area, Crescent City was the hardest hit by the 1964 tsunami. Eleven people were killed and $30 million damage occurred to the town. Figure 2-27 presents the record of wave heights at coastal stations and estuaries in the study area for the 1964 Alaskan Earthquake tsunami. This tsunami struck at high tide, which compounded its impact.

2.7.2.3 Tides. The tide occurs progressively later in the day as it moves northward along the coast. As the tide wave crosses onto the shelf it slows. The tide wave is a shallow water wave even in the deepest part of the ocean (i.e. the water depth is less than one half the length of the tide wave, and its velocity is regulated by the depth). Tide predictions for the Pacific Northwest coast are available from the U.S. Department of Commerce Tide Tables High and Low Water Predictions, which is published annually for the proceeding year. Tide currents over the shelf and along the open coast are weak. When the tide enters a restricted body of water, such as an estuary, the tidal currents are significant. These are discussed in Section 2.6.2. Tidal heights will also be amplified in estuaries due to channel constrictions and shape. Figure 2-38 presents tide data as recorded on the shelf off Southern Washington. It is presented here to illustrate in a two month record the presence of the diurnal (once daily) and semi-diurnal (twice daily) components of the tide. The inequalities between successive lows is readily apparent. The tide is presented as a change in sea level observed as pressure changes by an instrument moored on the bottom at 75 m (245 ft).

2.7.2.4 General Oceanic Circulation. Currents have been studied in this region by use of surface drift bottles (Wyatt et al., 1972), drogues set to drift at different depths (Stevenson and Patullo, 1967), seabed drifters that moved with the bottom currents (Morse et al., 1968), geostrophic computations based on pressure gradient forces (Budinger et al., 1964), wind drift computations (Duxbury et al., 1966), near-surface to near bottom measurements with current meters (Mooers et al., 1968; Huyer et al., 1975; Smith, J.D., et al., 1976; Sternberg and McManus, 1972), and biological indicators (Cross and Small, 1967). This list of references excludes many works, but indicates the various ways in which currents are studied and provides some access to the literature. Local expertise exists at the Pacific Marine Environmental Lab, NOAA, Seattle, and the departments of oceanography at Oregon State University and the University of Washington. Data gaps and research needs are identified in a conference workshop proceedings funded by the Bureau of Land Management (Massoglia, 1977) and include a lack of current meter data 1) at the sea surface, 2) "nearshore" (seaward of the surf zone to the 50 m depth contour), and 3) over the entire Northern California and Southern Oregon Continental Shelf. Because of this lack of data, much of what is written about these three zones is by inference.

The principal element of oceanic mass circulation at the surface in the Northeast Pacific is the eastward-moving Subarctic Current driven by the dominant westerly winds. As the Subarctic Current approaches the Northwest Coast, it splits into northward and southward moving components as shown in Figure 2-39. The southward component becomes the California Current and is the dominant surface feature of mass circulation off the coast of Washington, Oregon, and Northern California.

In the summer, the flow rate of the California Current is boosted by the prevailing northerly winds near the coast, in a band about 150 km (100 miles) wide, at a speed of about 10 cm/sec (0.2 mph) (OSU, 1971). Because of the configuration of the coast and the effects of the earth's rotation, this movement has an offshore component so that surface waters move seaward and are replaced by cooler, saltier, deep waters upwelling close inshore.

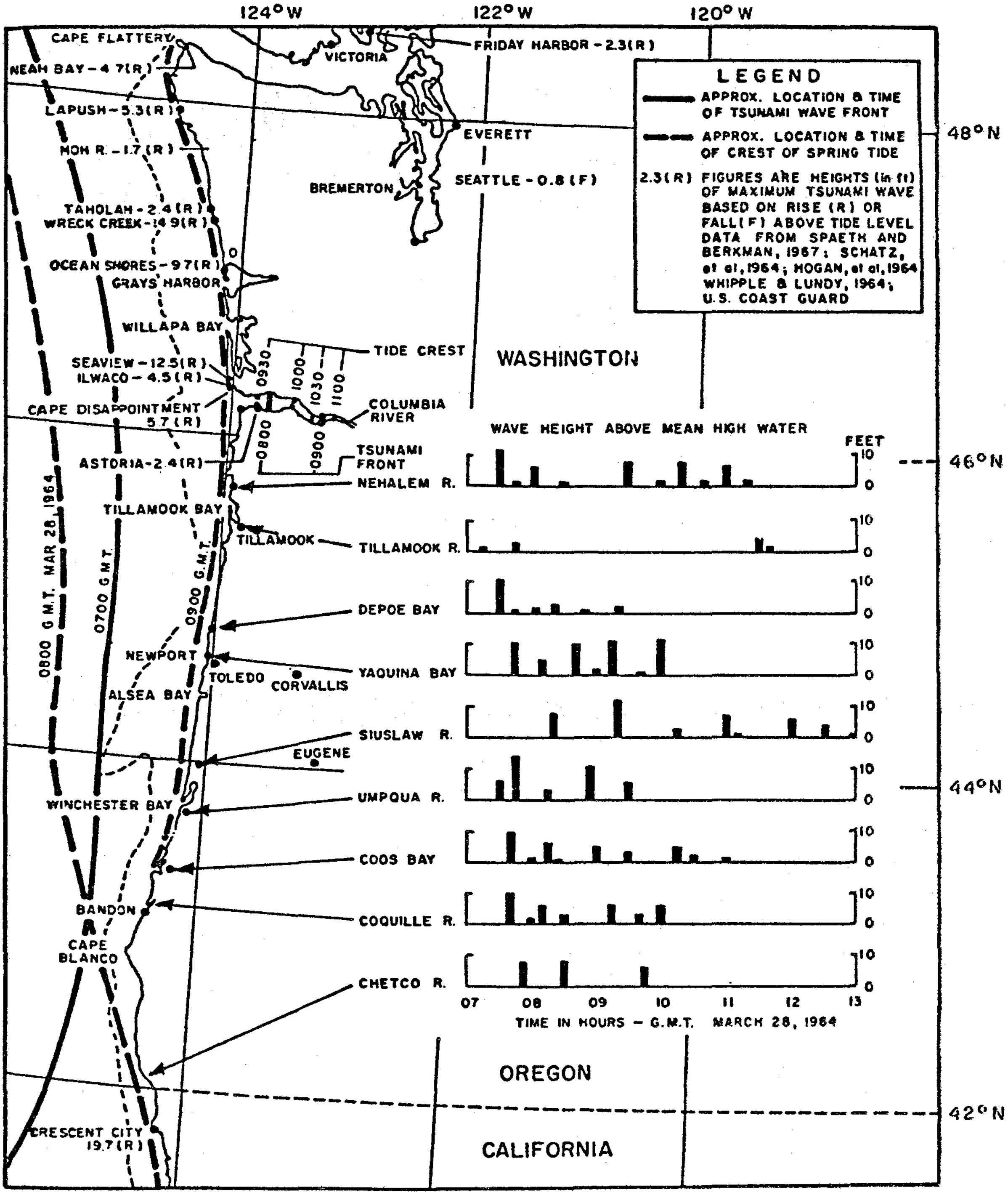


FIGURE 2-37. RECORD OF SEISMIC SEA WAVE (TSUNAMI) HEIGHTS AT PACIFIC NORTHWEST COASTAL STATIONS FROM THE 1964 ALASKAN EARTHQUAKE. (From Wilson and Torum, 1968.)

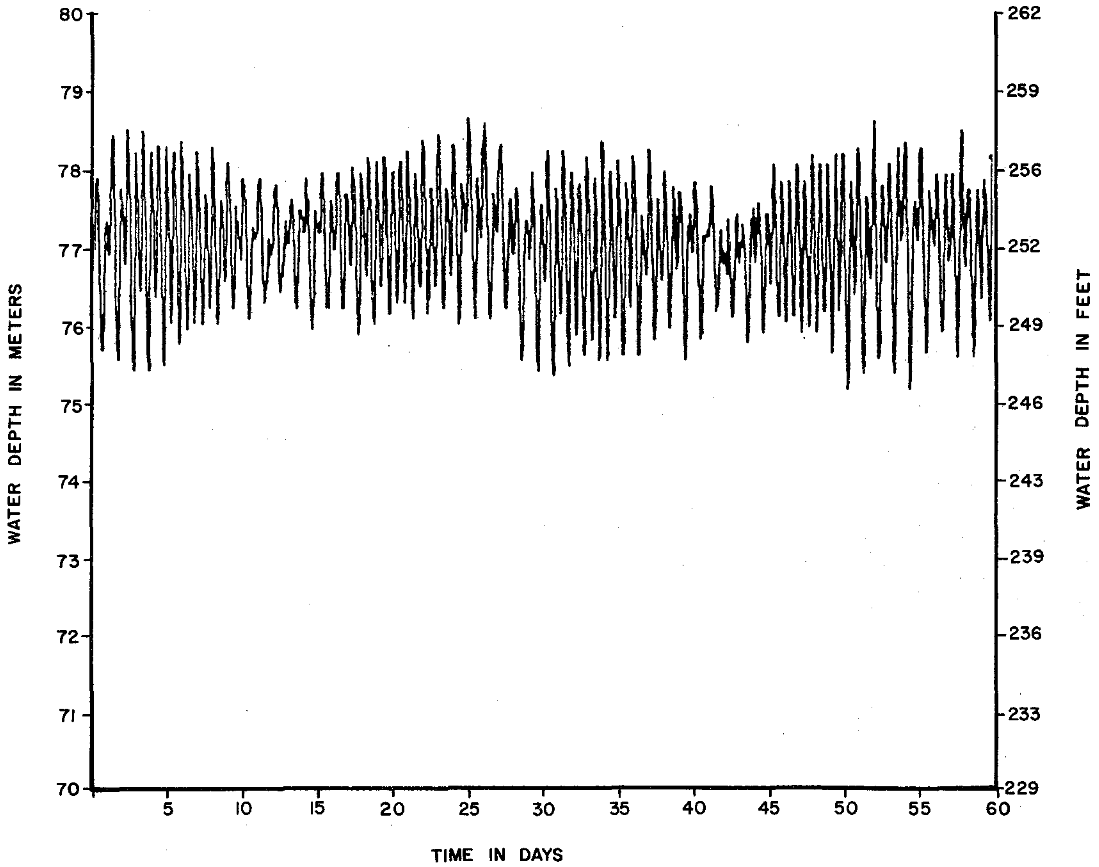


FIGURE 2-38. PRESSURE RECORD FROM 21 AUGUST TO 22 OCTOBER, 1969, FROM A LOCATION ON THE SHELF OF SOUTHERN WASHINGTON. Pressure measurements correspond to sea level, and the changes in pressure (after surface waves are filtered out) gives a record of the tide over the shelf. (From Hopkins, 1971.)

During the winter, when upwelling has subsided, the general southward flow of coastal water is interrupted by a narrower (90 km or 55 mi wide), more intense (25 to 45 cm/sec or ½ to 1 mph) northward flow at the surface (OSU, 1971). This current, sometimes referred to as the Davidson Current, had formerly been regarded primarily as a product of local wind stress (Ingraham, 1967). However, Favorite et al. (1974) considered it to be a surface expression of the California Undercurrent, a northward-moving deep flow that extends from the coast to 50 km (30 mi) offshore. The California Undercurrent is a year-round feature of the general oceanic circulation and brings warmer, more saline water into the region from below the Sub-arctic boundary. The warm temperatures in the winter, as recorded by the Blunts Reef Lightship (see Figure 2-32) at the surface, are due to this northerly winter flow at the surface. Cross and Small (1967) discovered that certain species of copepods were suitable as reciprocal indicators of seasonal surface current changes off Oregon as far north as the Columbia River. The distribution of the species studied was not dependent on upwelling, nor influenced by the Columbia River Plume. Their study did not include Washington waters.

Figure 2-40 shows progressive vector diagrams representing currents at 20 m (65 ft) and 60 m (195 ft) as recorded from arrays of current meters located 5, 10, and 15 mi (8, 16, and 24 km) off the coast from Depoe Bay, Oregon, during the summer. The poleward (north) motion of the deeper water is evident while the shallower water is flowing to the south. Figure 2-41 indicates northerly bottom currents on the Washington Shelf as inferred from seabed drifter paths. The northerly bottom current is the California Undercurrent, and although weak, is significant in sediment transport. By itself, it is not strong enough to pick up and move bottom sediment on the shelf. The oscillatory motion at the bottom associated with the passage of long period waves may be sufficient to pick up and suspend bottom sediments over the shelf to be transported by the regional currents.

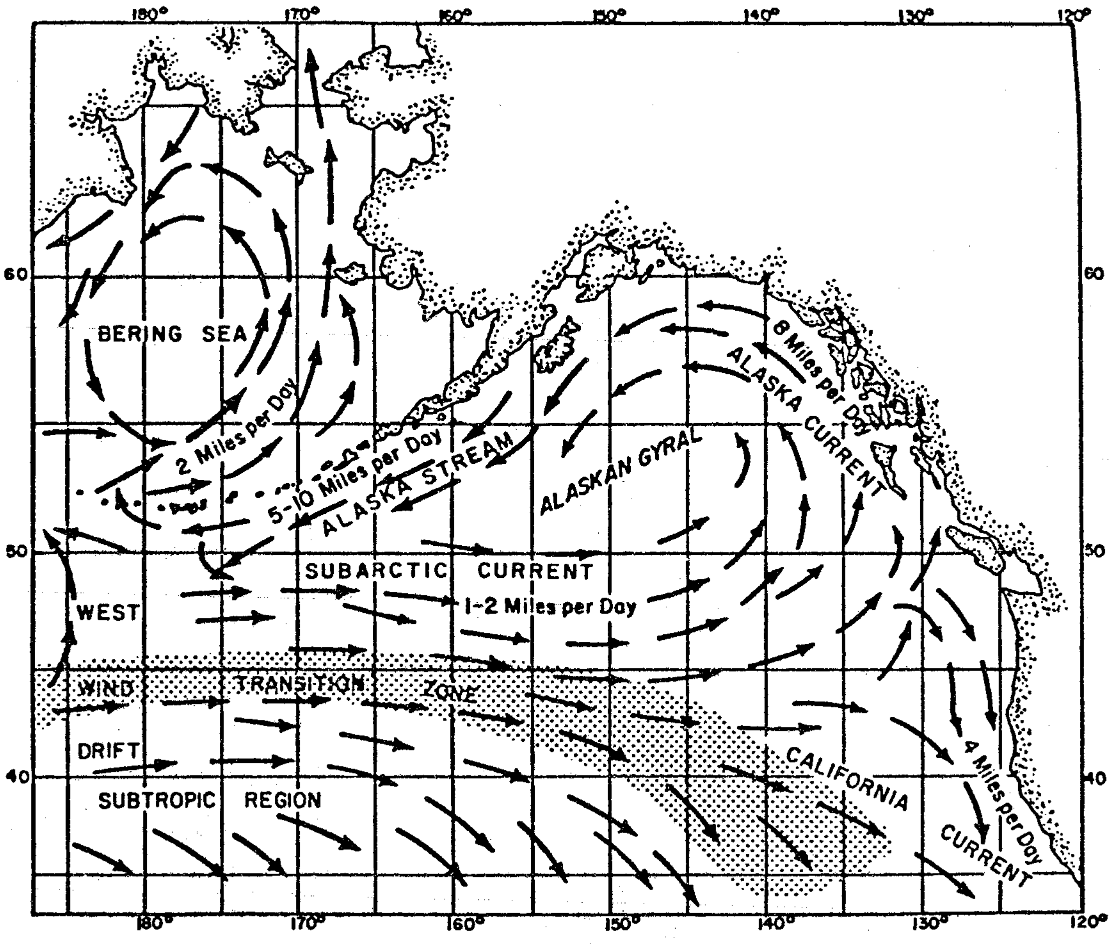


FIGURE 2-39. GENERAL OCEANIC CIRCULATION IN THE NORTHEAST PACIFIC. A current speed of five miles per day is approximately 0.2 miles per hour or ten centimeters per second. (From U.S. Bureau of Land Management, 1974.)

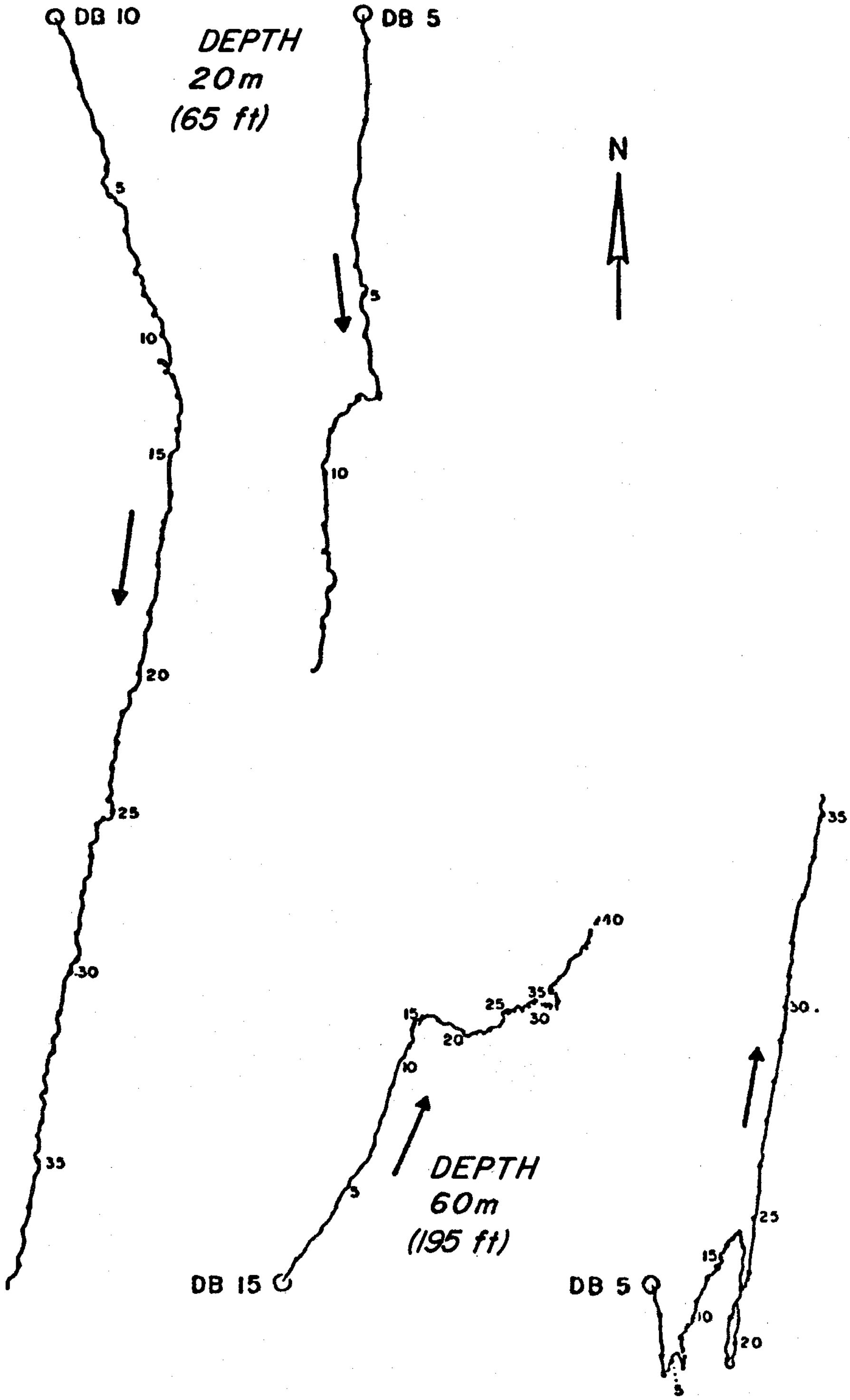


FIGURE 2-40. PROGRESSIVE VECTOR DIAGRAMS OF CURRENTS MEASURED 5, 10, AND 15 MI (8, 16, AND 24 KM) OFFSHORE OF DEPOE BAY, OREGON, FROM 15 AUGUST TO 24 SEPTEMBER 1966. Figures indicate the number of days since commencement of current meter recordings. (From Mooers et al., 1968.)

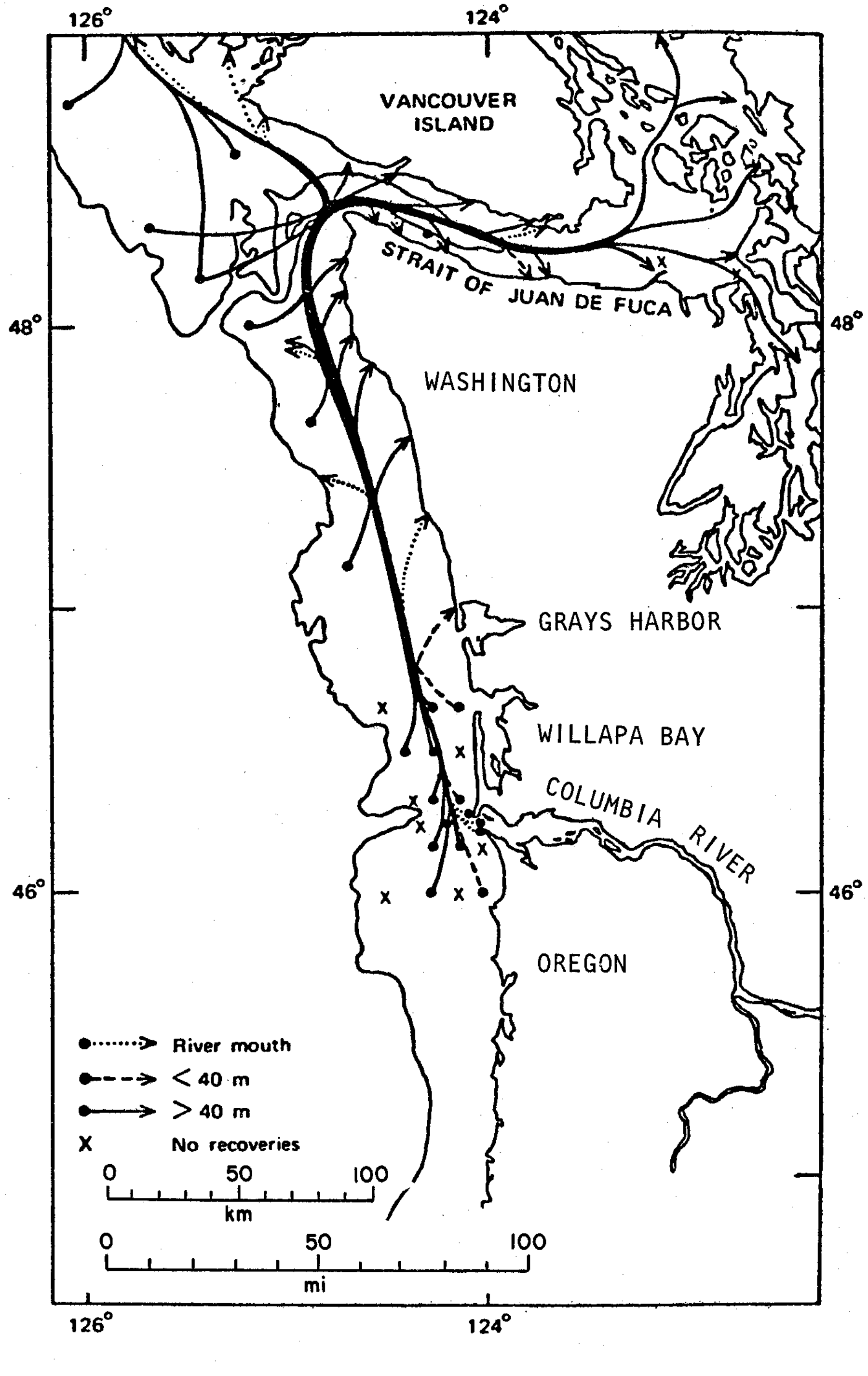


FIGURE 2-41. BOTTOM WATER MOVEMENT ON THE SHELF NORTH FROM THE COLUMBIA RIVER. Movement estimated by seabed drifters released at the points marked by a black dot (●) and recovered at the arrowhead location (→). The presumed drift path connects the two. (From Barnes et al., 1972.)

Huyer et al. (1975) compared current meter data from inshore and offshore locations off Central Oregon and Southern Washington and found there was good correlation. Sea level changes associated with wind drift and atmospheric pressure showed a strong correlation with changes in current velocity and may be important in developing a significant predictive capability for the regional ocean currents. Smith, J. D., et al. (1976) noted that steady state currents seldom exist over the Washington Shelf, because winds are continually fluctuating and the entire water column accelerates and decelerates, lagging the wind by several hours. Reversals of wind direction relative to seasonal means occur and produce "events" of southward flow during the winter or northward flow during the summer.

2.7.2.5 Longshore Currents. There is a lack of information concerning longshore currents in this region. Since longshore currents are a function of wave energy, approach, and shoreline orientation, they will vary considerably in speed and direction with changes in location or time. Longshore currents are important as mechanisms of sediment transport. Most of the sediment transport north of Cape Blanco is to the north (OIW, 1977). Seasonal shifts in direction occur, with southerly transport in the summer and northerly in the winter. Local variations in net transport occur and the rates of transport vary from place to place. Wave refraction and shoreline orientation produce some stretches of coast in which a net southerly transport occurs. Sediment transport is discussed in Section 2.7.4.

When longshore currents converge they form rip-currents which head seaward to just beyond the surf zone. Rip-currents will form at different locations along a beach, and may migrate. They are active in transporting sediment offshore, and in warmer climates are a threat to swimmers.

A current system consisting of a landward drift of water through the surf zone, longshore currents, and two bordering rip-currents defines a nearshore circulation cell (Komar, 1971). The entire circulation pattern along a length of beach consists of many individual cells. When the waves strike the shore at an angle, carry-over of sediment and water from one cell to the next will occur.

Specific values for longshore currents in the study area are lacking, but would be of limited use even if they were available. Such data would have to indicate where they were located within a circulation cell, wave data, location and time, and would represent only information specific to those conditions and would not be applicable elsewhere. Field measurements by Inman and Quinn (1952) indicate that maximum velocity of longshore currents appears not to exceed 100 to 150 cm/sec (2 to 3.5 mph). Longshore currents were measured by Fox and Davis (1974) in a study of beach erosion and sand bar migration conducted at three Central Oregon coast beaches. Littoral drift (the movement of sand on the beach face produced by wave run-up at an angle and subsequent backwash) will usually be in the same direction as the longshore current, which is in the surf zone.

2.7.2.6 Upwelling. Upwelling along the Pacific Northwest coast is most evident by its effects on the distribution of temperature at the surface, as was shown in Figures 2-29 and 2-30. Upwelling occurs mainly in the summer months when northerly winds coupled with the effect of the earth's rotation, set up an offshore surface drift (Ekman transport). Subsurface water, typically from 100 to 200 m, rises nearshore to replace that which is carried seaward in the surface layers (Gross, 1972).

Upwelling is strongest off Southern Oregon and Northern California (between Cape Blanco and Cape Mendocino). The seasonal pycnocline (region of strong density gradients) breaks to the surface forming a surface front approximately 10 to 20 km (6 to 12 mi) offshore. Shoreward of the surface front the waters will be low in dissolved oxygen content, high in salinity, high in nutrients, and high in alkalinity (Park et al., 1962). Seaward of the surface front the surface temperature may be 5 to 7°C (9 to 13°F) warmer than the surface waters in the upwelling region. Shoreline orientation is also significant, with greater upwelling occurring on the south side of major capes and points.

Low salinity surface water associated with the Columbia River plume and flow from the Strait of Juan de Fuca mask the surface expression of upwelling in those areas. Although upwelling is not evident at the surface off the Strait of Juan de Fuca, it is evident at depth and important in the replacement of bottom waters within the Strait of Georgia and Puget Sound.

Upwelling may also be induced by the seaward flow of the Columbia River plume, which mixes with marine waters as it flows seaward and also "drags" near-surface marine waters seaward by frictional stresses. This process is called "river-induced upwelling" (Budinger et al., 1964). River-induced upwelling is masked at the surface by the river plume, but is still important in bringing nutrients closer to the surface.

Upwelling is often studied from offshore water sample data in which the vertical density structure is constructed from temperature, salinity, and depth information. The distribution of lines of equal density (called isopycnals) when viewed in a transect over the continental slope and shelf normal to the coast may indicate the degree of upwelling.

In the winter, the isopycnals are more or less level, currents over the shelf are predominantly northward, and sea level at the coast is higher than average (in response to lower atmospheric pressure and pile-up of water along the coast from wind drift). This basically describes the non-upwelling condition. Downwelling may occur to remove the surface water added from wind drift, and the isopycnals may bend down towards the coast.

In spring and summer, during upwelling events, isopycnals are tilted upward toward the coast, the current is southward at the surface and sea level is lower than average (in response to higher atmospheric pressure and offshore Ekman transport).

Estimates of vertical velocity from displacement of isopycnals for specific short periods in this region range from 0.2 m/day to 17.3 m/day (0.7 ft/day to 57 ft/day) (Smith et al., 1966; Halpern, 1974; and Huyer, 1974). These estimates assume no mixing and result in underestimating the vertical velocity.

Numerical modeling of upwelling and coastal currents is helping to refine present theories. One model has been used as a time-dependent physical input into an ecosystem model to study the growth of phytoplankton in an upwelling region (Hamilton, 1977).

<u>2.7.3 Mixing Processes.</u> Mixing in the oceanic zone results from a combination of physical atmospheric processes and physical, biological, and geological oceanographic processes. Earth materials and fresh water enter the oceans through the flow processes described in the hydrologic cycle (Section 2.4 of Volume 1). The freshwater runoff of the Pacific Northwest Coastal Region was described in Section 2.5.2. Freshwater and the materials carried by it reach the ocean via estuarine zones (Section 2.6) where initial mixing with sea water occurs. The estuarine condition is defined as one of measurable dilution of sea water with fresh water derived from land drainage. The manner in which this dilution occurs is used in some estuarine classification systems (as described in Section 2.6.1 of Volume 1). Water and materials leaving the estuaries are subjected to oceanic mixing processes.

Estuarine mixing is largely a result of opposing tidal and river flows. Tidal action, river runoff, and wind create turbulent flow and velocity shear between denser inflowing salt water and less dense, outflowing fresh and brackish water. Tidal currents, altered by channel configuration (substantially increased at constriction points of width and/or depth) and runoff (affected by drainage basin size, precipitation, and snow melt) are the most important forces. Tidal currents vary significantly on semi-diurnal (twice daily), diurnal (daily), and approximate monthly cycles, while runoff for a given stream or river will vary with the frequency of storm occurrence and the season. Hence, the amount of freshwater entering the oceanic zone varies with location and time, and the degree to which it is already mixed with salt water also varies with location and time. In evaluating estuarine mixing, salinity is the single most important variable to measure.

As the water leaves the estuaries, tidal action and river currents become less important and wind mixing and other open-sea processes become dominant (Barnes et al., 1972). Considerable mixing occurs in the surf zone, and suspended sediments in the surface riverine-estuarine discharge are mixed with the marine waters and form a turbid layer which concentrates and moves seaward along density boundaries. Portions of the river plumes extending seaward of the surf zone form dilute, turbid layers at the surface, and move with the wind drift and regional circulation. In the winter time, the southerly winds hold the runoff nearshore, and enhance entrainment in the surf zone.

A conceptual model of suspended material transport across the continental shelf was presented in Section 2.7.4.1 of Volume 1. Qualitative measurements of turbidity throughout the water column at locations on the Northern Oregon Continental Shelf are presented and discussed by Harlett and Kulm (1973), and Kulm et al. (1975) and were used in formulating the conceptual model of suspended material transport across the shelf. Turbidity measurements and model show that surf zone mixing is significant in the distribution of sediments and water throughout the water column over the shelf.

Settling of suspended material redistributes particulate matter throughout the water column. Settling particulate matter also moves laterally with the currents. Over the continental shelf in summer, settling particles would experience a southerly transport with the California Current, and an offshore transport because of the Coriolis effect (Ekman transport). If settling particles are not carried off the shelf by these currents, they will settle through the poleward flowing California Undercurrent. The pathways of settling particles are complex and significant, because some contaminants (for example hydrocarbons or heavy metals) can adsorb onto particulate matter, and, as they settle, disperse throughout the water column and over the bottom.

Budinger et al. (1964), in characterizing the Oceanic Regime of the study area, identified three vertical zones in the water column (see Figure 2-30 in Volume 1). The surface zone extended down to 75 to 100 m (250 to 325 ft) which marks the lower limit of penetration of seasonal mixing effects (wind and waves). This zone is essentially uniform in salinity (except where over-ridden by the Columbia River plume) and the temperature decreases markedly with depth in summer, but is nearly uniform in winter.

Barnes et al. (1972) studied mixing of the Columbia River effluent at sea and noted that water properties and structure change more slowly with increased distance from shore, but, even at relatively great distances, mixing and dilution of ambient seawater seldom depresses the 32.5 $^{o}/oo$ salinity isopleth (which is used to define the edge of the Columbia River plume) below about 40 m (130 ft). The density difference (pycnocline) between the bottom of the plume and the ambient marine water decreases the vertical coefficient of eddy viscosity; motions generated at the surface promote turbulence in the upper layer, while having little effect below the pycnocline (Budinger et al., 1964, and Barnes et al., 1972).

As the Columbia River plume moves away from the river mouth, it gradually increases in both volume and salinity as it entrains and intermixes with ambient water both laterally and vertically (Barnes et al., 1972). Estimates of vertical diffusivity through the bottom of the Columbia River plume have been made by Budinger et al. (1964) and by Huang (1968, unpublished manuscript, discussed in Barnes et al., 1972) and are relatively low.

As mentioned in Section 2.7.2.1, severe winter waves have stirred sediments out to the edge of the continental shelf. The resuspension of bottom sediments is a mixing process affecting the bottom and the bottom water.

Upwelling (Section 2.7.2.6) is important when considering mixing processes, as it provides a means whereby water from 100 to 200 m is brought to the surface and can interact with surface water, atmosphere, and light-dependent biota. Regional currents (Section 2.7.2.4) determine the properties of the ambient marine water that will be interacting with and mixing with upwelled water and land runoff. Atmospheric processes are important, in that winds generate currents and waves, precipitation and heating reduce the density of surface water, creating stratification of the water column, while evaporation and cooling increase the density, encouraging overturning and mixing with deeper water.

The dynamics of mixing processes are currently being studied by Drs. Gregg and Halpern of the University of Washington, Dr. Niiler of Oregon State University, and Dr. Davis of Scripps Institution of Oceanography.

2.7.4 Oceanic and Coastal Sediment Transport. Unlike the inland region where sediment transport is by downhill gravity flow, varying in time and space with rates of runoff and the gradient, sediment transport in the oceanic and coastal regions is driven by wave action and regional currents. Physical processes in the Pacific Northwest oceanic and coastal zones are highly seasonal. Changes in runoff, winds, waves, and currents, and the resulting sediment transport and erosion or deposition patterns, are all seasonal.

From current studies off Central Oregon to Northern Washington, it is apparent that bottom currents in the region are nearly always to the north (see Section 2.7.2.4). Data for Northern California and Southern Oregon are lacking. Sediment transport on the shelf is to the north.

Waves move beach sediments to the south in summer and to the north in winter. The waves are most severe in winter, and there is considerable offshore movement of beach sediment, forming offshore sandbars in the surf zone, and narrower, steeper beaches. Summer waves carry the sediment onshore and rebuild the beaches to their summer profile (see Figure 2-35 in Section 2.7.4.1 of Volume 1). Winter waves, being more severe, stir the bottom and resuspend sediments over the shelf for transport in the regional bottom currents. Hence shelf sediment transport is tied closely to the wave environment.

Sediments in the region originate from erosion of headlands and bluffs, and from sediment discharged by streams and rivers. Most of the sediment transported through the estuaries to the oceanic zone is suspended. Except in high gradient streams, the bed load and coarser fractions of the riverine suspended loads are deposited in the estuaries. Coarser sediment fractions that do reach the ocean are transported seasonally through the estuaries at times of peak storm flows. The finer suspended sediments reaching the oceanic zone are deposited on the continental shelf and slope. These suspended sediments are generally too fine to deposit on beaches due to frequent wave action.

Marine sediments may also enter the estuaries and make up the coarser fraction of the sediments near the mouth. This transport may be by wind, blowing sand from the beach on the ocean side of a barrier sand spit into the estuary, or it may be by tidal current action at the mouth of the estuary. Sediment may also leave the estuaries by dredging operations, and be deposited on the continental shelf.

The U.S. ACOE (1971) conducted a national shoreline study and identified critical and non-critical erosion problem areas (see Figure 2-4). Some of these areas along the open coast represent the natural source of sediment for beaches within their drift sector, and measures taken to reduce this erosion will also reduce the supply of sediment "downstream", possibly resulting in more erosion. Severe erosion has occurred at Cape Shoalwater and Toke Point at the entrance to Willapa Bay, and at Point Chehalis (Grays Harbor). From 1887 to 1962 Cape Shoalwater eroded approximately 3,000 m (2 miles) to the north. Shoreline changes at Cape Shoalwater are documented in Andrews (1965) and U.S. ACOE (1971).

The onshore-offshore transport rate of sand is greatest during winter, when beaches may lose from 5 to 15 feet (1.5 to 4.5 m) of sediment thickness (OSU, 1971). Beaches are, in effect, buffer zones which absorb the impact of waves. The onshore-offshore transport of sand is of key importance in protecting the upland region (landward of the beach). Sandbars found under winter wave conditions cause waves to peak and break further offshore, and therefore dissipate much of their energy offshore. Beach profiles extending as far as 2000 ft (600 m) seaward of the mean lower low water shoreline have been obtained by Bascom and McAdam (1947) and have been related to more recent beach surveys by Komar (1977).

Komar and Rea (1976) have studied beach erosion on Siletz Spit, Oregon. During a particularly severe winter, houses built on the spit were threatened by the loss of beach due to offshore movement of sediment. The erosion may have been further complicated by the mining of beach sand deposits to the south.

Longshore transport of sediment occurs in the surf zone and on the beach face, and is driven by local wave effects. Mason (1953) stated that as much as 80 percent of sediment movement by wave action occurred inside the break-point. Waves vary in direction and energy continuously; refraction causes additional local variations along the coast as well, both in direction and energy.

Drift sectors for the region have not been identified, although numerous reports briefly discuss net sediment transport at specific locations. Not all reports for a given area are in agreement. Figure 2-4 presents the locations of beaches and headlands for the region.

The back and forth longshore transport and onshore-offshore transport of sediment results in relatively small net transports. Total transports may be great, however, and need to be considered when planning activities affecting shore processes (such as jetty construction at estuary mouths for navigation improvement).

Along the coast, headlands or manmade structures such as bulkheads, groins, jetties, and piers block or alter the waves and halt or reduce the natural longshore transport of sediment. Hence, some stretches of beaches may exhibit essentially one-way transport.

Interpretation of net sediment transport based on accumulation alongside of manmade structures is misleading, and should not be broadly applied. Any local evaluation of longshore sediment transport should consider seasonal transport directions and rates as well as well as net transport.

Scheidegger et al. (1971), using a heavy mineral analysis of the river basins of Northern California and Oregon, identified four major sources of sediments on the Oregon Continental Shelf. From dispersal patterns of sand-size sediments on the shelf, they determined that the dominant direction of littoral transport has been to the north at least during the last 18,000 years.

Sediment transport on the shelf is controlled by bottom currents. At times of significant wave activity large amounts of sediment will be suspended and transported. Sternberg and McManus (1972) used current data from the Southern Washington Continental Shelf and concluded the following:

1. The stronger bottom currents on the central continental shelf off the Washington coast are the result of meteorological conditions, most specifically wind stress associated with storms rather than wave surge.

2. Measured current speeds at 3 m (10 ft) off the sea floor frequently exceed 40 cm/sec (0.8 kt) during the winter months and may exceed 80 cm/sec (1.5 kt) during severe storms.

3. Current direction vectors show a high variability throughout the year; however, when averaged over monthly and annual periods, bottom velocities exceeding 40 cm/sec (0.8 kt) exhibit a net directional response, predominantly northward on the continental shelf of Washington.

4. The observed direction variability of the higher speed classes could account for significant sediment dispersal across the continental shelf; however, moving sediment would also experience a net northward migration as a result of the net transport of bottom water.

5. If approximately six major storms sweep the Washington Shelf per year, then a sedimentary particle might be displaced as much as 35 km (22 mi) northward and 12 km (7.5 mi) westward per storm, or the maximum annual displacement of a sedimentary particle eroded from the bottom would be approximately 220 km (140 mi or 120 nm) in a northwesterly direction (p. 181).

Komar et al. (1972) concluded that winter storm conditions off the coast generate waves that should commonly produce bottom orbital velocities capable of rippling the sediments to water depths of 150 to over 200 m (500 to over 650 ft) (which covers the entire shelf). Summer waves produce ripples at depths of up to 50 to 100 m (160 to 330 ft). Rippling of bottom sediments is indicative of sediment transport. In the absence of ripples, fine sediments may settle during summer months covering the midshelf with a layer of mud. This mud is resuspended by winter storm waves and the bottom becomes clean sand covered with active ripple marks.

Section 2.7.4 of Volume 1 presented a conceptual model of suspended sediment transport over the continental shelf of Oregon. Figure 2-42 presents the seasonal sedimentation patterns over the shelf for summer and winter conditions, including the deposition of a mud layer at midshelf in summer and the resuspension and seaward transport of the mud during the winter.

It is of interest to note that significant transport of sediment on the continental shelf occurs only under the influence of the most severe storms. Benthic species are adapted to withstand these events.

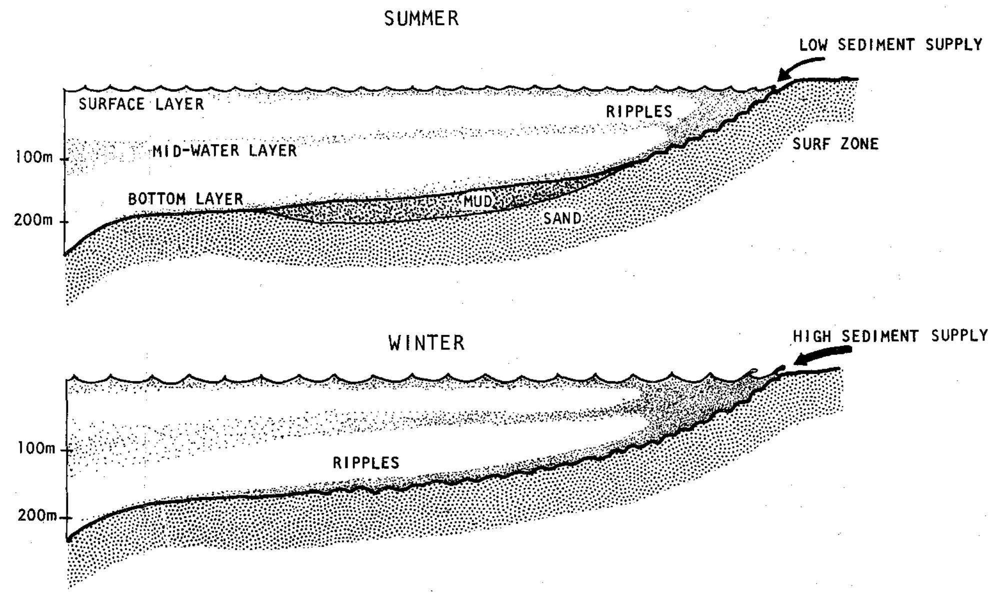


FIGURE 2-42. SEASONAL SEDIMENTATION REGIME FOR THE OREGON CONTINENTAL SHELF. Sediment rippling and turbid layer transport are enhanced during the winter due to high sediment input from coastal streams and long period waves that ripple the bottom sediments to water depths of at least 125 m (400 ft). Komar et al. (1972) determined long period waves may ripple the bottom sediments out to the shelf edge and that the shoreward extent of mud on the shelf is closely depth-controlled, suggesting it is governed by wave forces. Turbid layer transport, especially in the surface and mid-water layers, is greatest during late spring off the Columbia River. (Adapted from Kulm et al., 1975)

Dispersal of dredge spoils dumped on the continental shelf near the Columbia River is being studied by the University of Washington for the Army Corps of Engineers. A controlled dump of 600,000 cubic yards emplaced in July-August 1975 is being revisited and monitored.

2.7.5 Chemical Properties. Existing chemical data for Washington, Oregon, and Northern California's Continental Shelf and marine waters are scarce for parameters other than nutrient and oxygen determinations. Studies tracing the movement of artificial radionuclides generated and released into the Columbia River at the Hanford site in Eastern Washington were conducted in the 1960's. These releases provided tracers to indicate the behavior and transport of certain elements from the Columbia River through its estuary and into the oceanic region offshore. Analyses and conclusions from most of these studies are bound under one cover in The Columbia River Estuary and Adjacent Ocean Waters. Bioenvironmental Studies (Pruter and Alverson, eds., 1972). An estimated 95% of all low-level radioactive wastes released in the natural waters of the United States went into the Columbia River between 1944 and 1971, making this region truely unique from a radiochemical viewpoint, and offering unique opportunities for research.

Chemical studies are beginning to focus on pollutant chemicals, which may be toxic when present in very small quantities. The inability to measure these chemicals accurately with standardized techniques and without contaminating the sample has severely limited past efforts. Techniques are improving. It is recognized that the distribution of pollutants touches on all the disciplines of oceanography, and chemists are attempting to study critical pathways that a pollutant might take in the environment. Laboratory studies have more commonly "focused" on the effects (both lethal and sublethal responses of controlled concentrations of individual pollutants) upon different organisms. The Southern California Coastal Water Research Project (1975) has tabulated and cross-referenced data from many of these studies.

2.7.5.1 Dissolved Oxygen. The effects of winds and waves produce significant seasonal changes in surface and nearsurface oxygen concentrations. Wind-driven coastal upwelling brings colder, nutrient-rich, oxygen-depleted water close to the surface in the summer. In the uppermost layers (the photic zone) the combination of the nutrients supplied by upwelling and the relatively high light levels promotes rapid phytoplankton growth. This process adds considerable quantities of oxygen to these layers, obscuring the decreased oxygen effects of upwelling. During the winter, the stronger winds and resultant waves break up the surface layering and increase the effective surface area for air-water boundary processes.

Due to wind and wave mixing, the surface oxygen concentration in winter is near 100% saturation. Oxygen saturation values vary inversely with increases in temperature and salinity (Schlieper, 1972). The Columbia River effluent, cooler than the surrounding oceanic waters in winter, is pushed against the Washington coast by southerly winds. The cooler, less saline effluent contains a greater concentration of dissolved oxygen than the offshore marine waters, while both are near 100% saturation.

Figures 2-43 and 2-44 present summer and winter average dissolved oxygen concentrations for the surface and for water at 20 m (65 ft). The oxygen data are from studies made during 1961-63 by the University of Washington. Although real oxygen values were used in deriving these figures, it must be emphasized that averaged values are represented. The summer dissolved oxygen concentration at 20 m (Figure 2-43) shows the effects of coastal upwelling as a band of low oxygen concentration nearshore. The nearshore surface (0 m) concentrations for the summer are high because of oxygen production by phytoplankton and may exceed 100% saturation. The winter dissolved oxygen concentration at the surface (Figure 2-44) shows the extent of the Columbia River plume as a band of higher oxygen concentration hugging the Washington coast.

The nearshore dissolved oxygen distribution was evaluated by Oregon State University (1971) using data obtained from National Ocean Data Center, OSU data reports, and the California Water Quality Control Board. The OSU study analysed data from within 18.5 km (10 nm) of the coast. The data were divided geographically into five sections that covered most of the nearshore areas off Washington, Oregon, and Northern California. Nutrient (phosphate, nitrate, and silicate) and pH data were also reviewed. Monthly means for 0, 10, 20, 30 and 50 m were obtained and graphed along with extreme values. No apparently significant latitudinal variations within the area were noted. Figure 2-45 presents O_2, nutrient, and pH values for 0, 20, and 50 m (0, 65, and 160 ft), for the nearshore coastal area between Newport, Oregon, and the Columbia River. The following observations are taken from the OSU report (1971):

1. Average O_2 concentrations are higher at the surface than at 20 m (65 ft) throughout the year

2. The highest and lowest surface O_2 concentrations are found in summer months: June, July, and August; this is probably due to the competing influences of photosynthetic production and upwelling

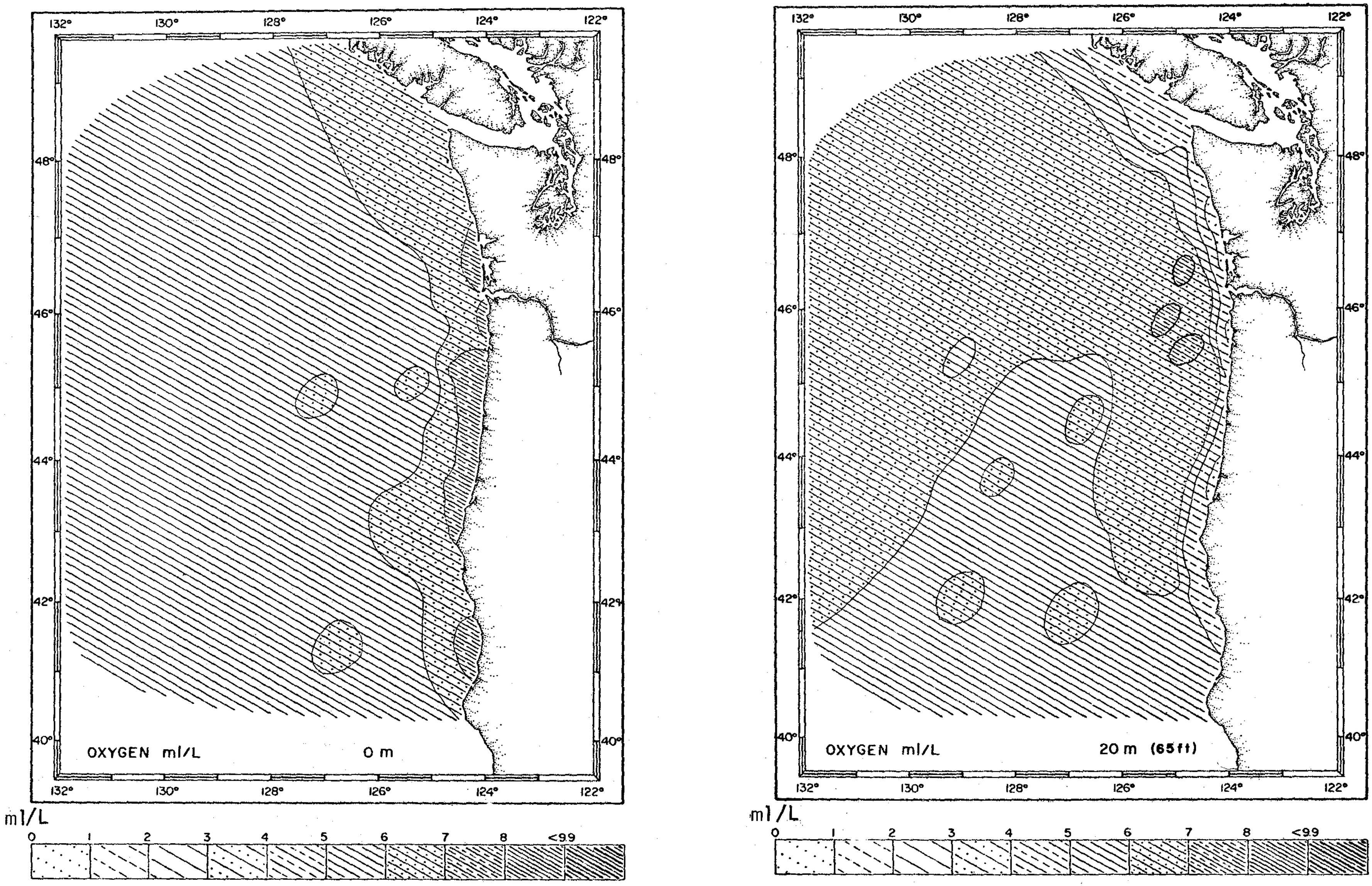


FIGURE 2-43. AVERAGE SUMMER DISSOLVED OXYGEN CONCENTRATIONS AT THE SURFACE AND AT 20 METERS. The effect of coastal upwelling is evident at the two depths. Upwelled water is rich in nutrients and low in dissolved oxygen. At 20 m there is a band of low oxygen water nearshore. At the surface, high phytoplankton productivity made possible by the supply of upwelled nutrients super-saturates the water with oxygen. (From McGary, 1971).

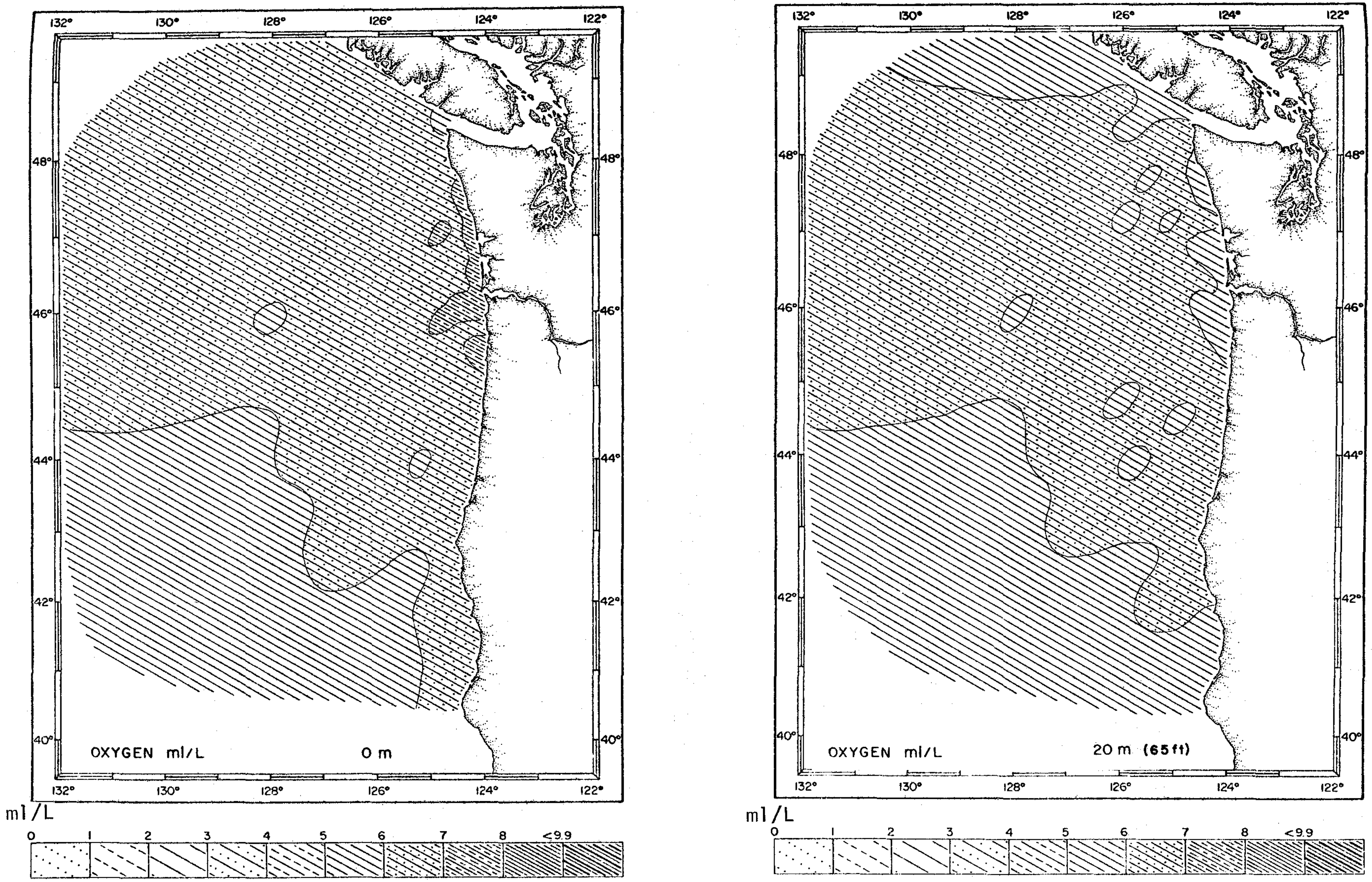


FIGURE 2-44. AVERAGE WINTER DISSOLVED OXYGEN CONCENTRATIONS AT THE SURFACE AND AT 20 METERS. The effect of the Columbia River in winter is to cool and dilute the surface nearshore water along the Washington coast. Saturation values increase with decreases in temperature and salinity. Surface oxygen saturation values are near 100% and therefore high dissolved oxygen concentration is evident in the cooler, diluted water of the Columbia River plume. (From McGary, 1971.)

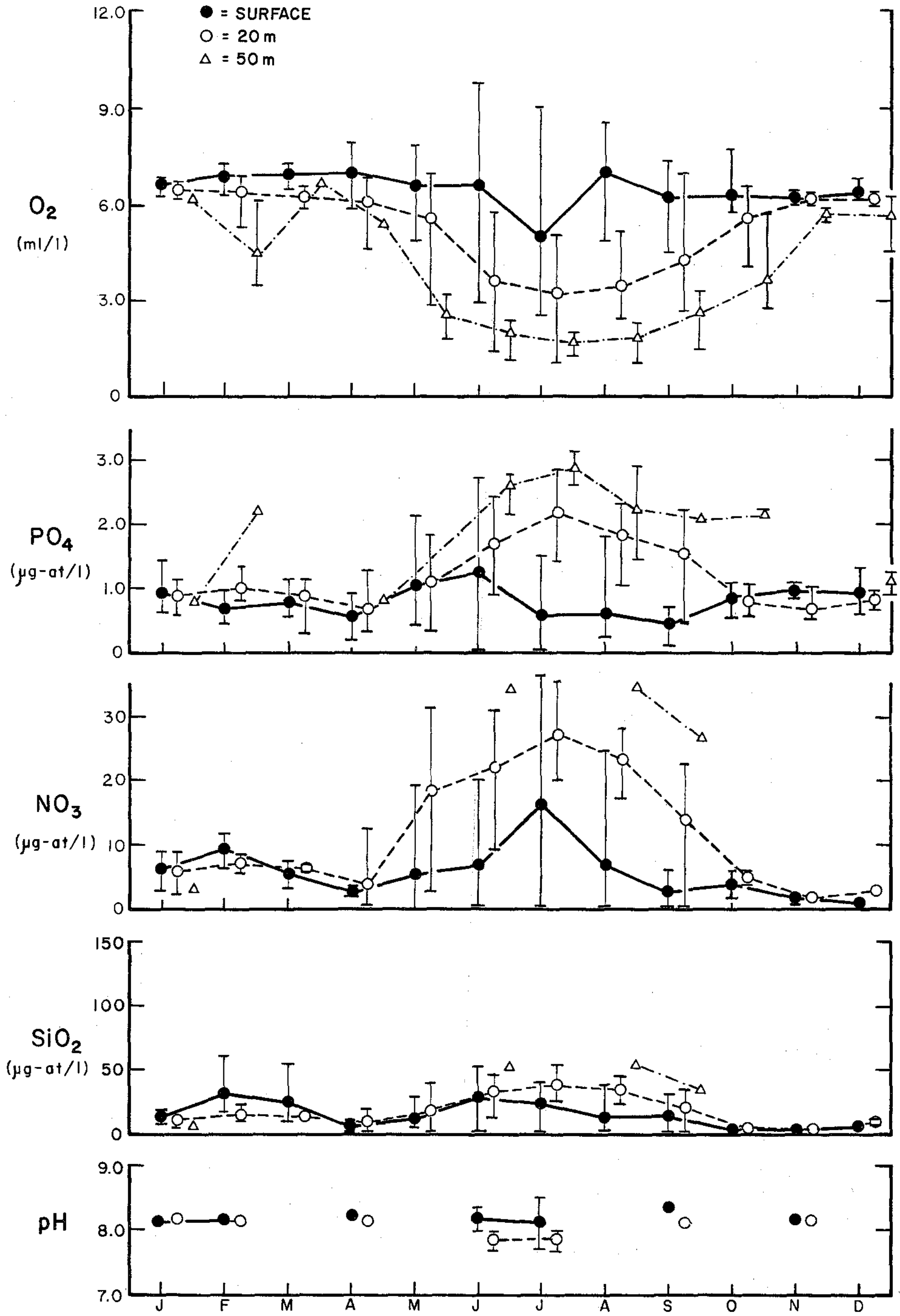


FIGURE 2-45. ANNUAL VARIABILITY OF CHEMICAL PROPERTIES IN NEARSHORE NORTHERN OREGON WATERS (WITHIN 18.5 KM OR 10 NM). Monthly means and range of values are plotted. Summertime decreases in oxygen and increases in phosphate and nitrate are the result of upwelling. (Data compiled by OSU, 1971, from various sources.)

3. The averaged gradient between the surface and 20 m (65 ft) is steeper in the summer months. Surface values are not lowered as much as 20 m (65 ft) values

4. Surface O_2 values are about 6.3 to 7.0 ml/l unless affected by strong upwelling.

As can be seen in Figure 2-45, an inverse relationship exists between the dissolved oxygen concentration and the nutrient concentrations. Pytkowicz (1964) described the relationship between oxygen and phosphate concentrations from the surface to 1,000 m (3,300 ft) for a region off the shelf of Northern Oregon. A subsurface oxygen maximum develops in the summer and Pytkowicz postulated that this is because more of the excess oxygen produced by phytoplankton is lost above this layer due to higher respiration and exchange with the atmosphere. The subsurface oxygen maximum appears over large parts of the North Pacific in summer at a depth corresponding to the deeper part of the winter-mixed layer. Stefansson and Richards (1964) postulate that processes taking place in spring and summer along the Washington and Oregon coasts have an effect on the concentrations in this subsurface maximum to positions at least 400 to 500 km (250 to 300 miles) offshore. Upwelled water close to the shore is denser than the offshore surface water. As the upwelled water moves offshore it is enriched rapidly with oxygen by photosynthesis and mixing with water richer in oxygen. Stefansson and Richards stated that this offshore movement and sinking along density gradients of the upwelled water contributes to the formation of the subsurface oxygen maxima. They further stated that whether or not the oxygen produced by photosynthesis escapes fairly quickly to the atmosphere depends on the balance of the rates of upwelling, photosynthesis, and the subsequent removal of these waters offshore and their sinking below the immediate surface layer.

2.7.5.2 Nutrients. Mean nitrate, phosphate, and silicate concentrations in microgram atoms/liter (µg-at/l) are given in Figure 2-45 for the nearshore area off Northern Oregon. General observations from the Oregon State University study (1971) concerning the nearshore nutrients for Oregon and Washington are:

1. The highest and lowest surface nutrient values are found in the summer months; dissolved silicon (silicate) values are strongly affected by runoff and may be higher at other times of the year; primary production and upwelling are probable causes of the wide variations in surface values.

2. The averaged gradient between the surface and 20 m (65 ft) is steeper in the summer months.

3. Exclusive of upwelling, representative surface nutrient values are:

   $PO_4^{\equiv}$: 0.7 µg-at/l
   NO_3^{-}: 5 µg-at/l
   $Si(OH)_4$: 10 µg-at/l.

Stefansson and Richards (1964) analyzed the distribution of nutrients, temperature, density, oxygen concentration, and apparent oxygen production (AOP) for the Washington and Oregon coasts. Figure 2-46 presents mean seasonal variations of these properties in the upper 30 m (100 ft) in the nearshore region off Central Washington, for the period January 1961 to June 1962. No subsurface oxygen maximum existed in this nearshore zone. Stefansson and Richards reviewed the same parameters for the upper 100 m offshore beyond the shelf and continental slope. In comparing the nearshore and offshore data the following observations can be made. In the spring, nutrients are used up rapidly in both areas. In the offshore area, near-surface phosphate concentrations decreased from about 0.90 µg-at/l in April to less than 0.5 µg-at/l in late May, and nitrates decreased from 5-6 µg-at/l to very low values. The low values persisted through September, but the concentrations of nitrates increased in the late fall and winter due to vertical mixing, returning to the levels observed in April. In the nearshore area, the maximum concentrations were more than 1 µg-at/l of phosphate and about 7 µg-at/l of nitrate, and persisted until March. These values then declined to about the same low levels observed offshore in May. After late May, the surface layers in the nearshore area are replenished with nutrients by upwelling, and nutrient concentrations approach their winter values in late summer. In 1961, the spring depletion in the nearshore area occurred only during a short period preceding the onset of the most active upwelling.

Figure 2-46 is representative of the nearshore region off Central Washington rather than the entire region. As noted earlier, upwelling is more intense off Central and Southern Oregon and Northern California so nutrient concentrations or biological processes may be higher in these regions by comparison.

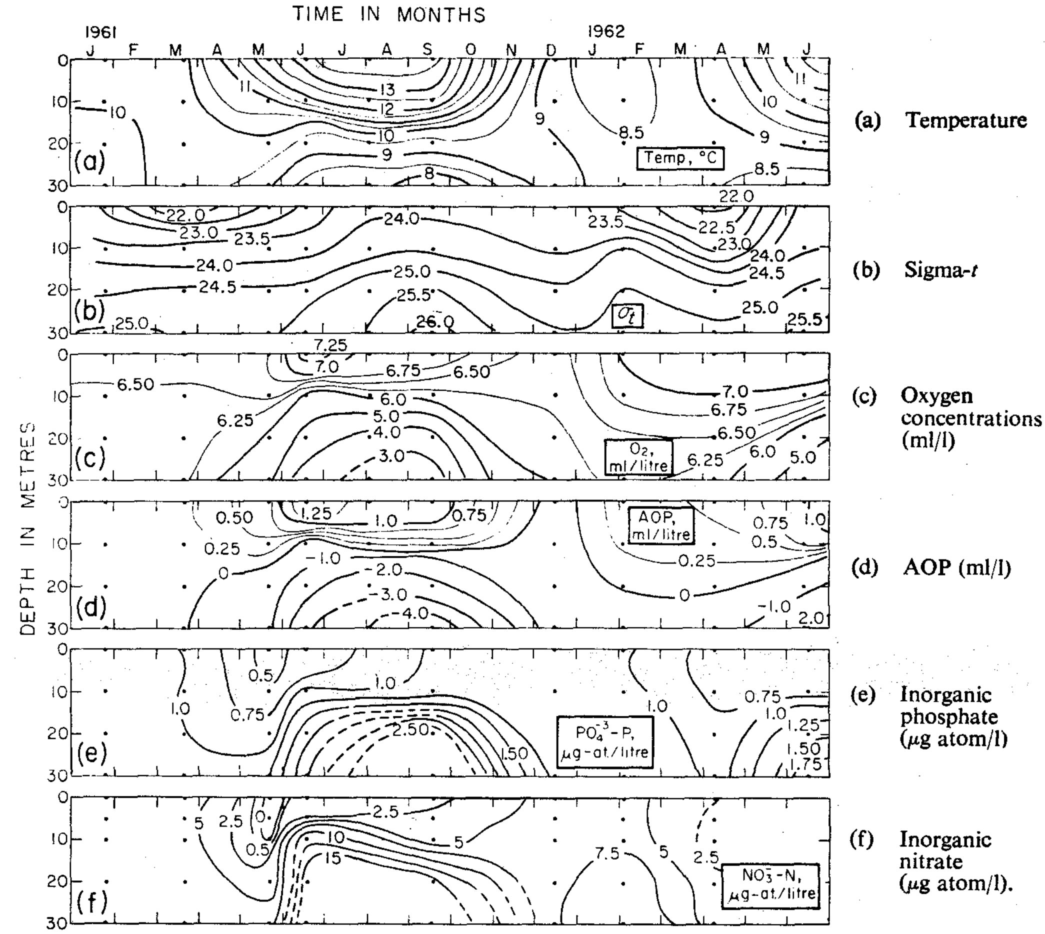


FIGURE 2-46. MEAN SEASONAL VARIATIONS OF OCEANIC PROPERTIES FOR THE NEARSHORE REGION OFF CENTRAL WASHINGTON. The term sigma-t refers to the density and is defined as sigma-t = (density - 1) x 1000. The term AOP stands for Apparent Oxygen Production, which is the excess concentration of oxygen greater than the equilibrium saturation concentration. Data are for the upper 30 m (100 ft) inside the 150 m isobath between 46°50' and 47°40'N Lat., January 1961-1962. (From Stefansson and Richards, 1964.)

2.8 WATER QUALITY

The water quality of the streams in the Pacific Northwest Coastal Region is determined by the nature of their drainage basins, including the geology of the watershed, the seasonal precipitation patterns, and the activities of various industries in the watershed, especially the forest products industry. The generally low human population density in these drainage basins has helped to preserve the pristine quality of the water.

Coastal estuaries are the sites of most of the cities, industry, and smaller communities in the study area. The activities of man and the discharge of effluents into the rivers and estuaries have an impact on the coastal area and the quality of the estuarine water. The estuarine water, in turn, enters the ocean where mixing and dilution is great.

Substances introduced into the waters of the Pacific Northwest by man include domestic sewage, organic wastes, pesticides, pulp mill effluents, and other industrial discharges. Waste heat enters Humboldt Bay from a nuclear power station. Suspended sediment loads of rivers are increased as a result of logging and other activities within the watershed, which also affect temperature and dissolved oxygen concentrations. Sea disposal of dredge spoils also occurs in the region.

The study area is characterized by high precipitation and high runoff. Its greater runoff, greater tidal range, greater number of estuaries, and lower population density make this region one of high water quality.

2.8.1 Point and Non-point Sources. Water pollution sources are described as either point sources or non-point sources. Significant point source pollutants in the Pacific Northwest coastal rivers and their estuaries include municipal discharges, industrial discharges, pulp mill effluents, thermal effluents, and organic wastes from food and fish processing. Non-point sources are considerably harder to identify and control and, in the case of many forms of pollutants, are more significant than point sources. For example, the total yearly suspended solids load of the Columbia River is 6 million tons, and the point source contribution to this is about 68,000 tons or 1.1% (Seaman, 1977).

Agricultural and forestry practices are non-point sources of suspended sediments, fertilizers, and pesticides. Forestry practice guidelines of the Environmental Protection Agency for application of chemicals and water monitoring are given by Newton and Norgren (1977). Additional information on the effects of forest management on stream water quality are described in Fredriksen (1972) and U.S. Environmental Protection Agency (1976A); this subject is discussed further in Section 2.5.3 of Volume 1 and in Section 4.2 of Volume 2. Coliform bacteria may enter the waters from such non-point sources as septic tank sewage and cattle feeding near streams.

The most significant thermal effluent in the study area is from the nuclear generating station in Humboldt Bay. Adams (1975) studied the effect of this discharge on macroflora and fauna of the Bay and concluded that species abundance and diversity increased in the area sampled. However, the California State Fish and Game Commission (1965C) reported a kill of ten tons of fish during a single "backflush" treatment of the intake pipe. Aluminum plants and nuclear plants upstream on the Columbia also discharge waste heat but are inland from the study area. Solar heating of storage ponds behind dams provides considerable heating of water and are a non-point source of heated water also.

Pulp and paper mills discharge solid organic wastes and dissolved chemical wastes. OSU (1971) and Gehm (1973) present reviews on pulp and paper mill wastes in the Pacific Northwest.

2.8.2 Criteria, Standards, and Regulations. Criteria for judging water quality affecting the Pacific Northwest have been established by the Environmental Protection Agency (1976B), and the States of Washington, Oregon, and California. Ott (1978) reviewed the use of water quality indices by states in this country. A "water quality index" was defined by Ott as any mathematical approach which aggregates data on two or more water quality variables to produce a single number. Indices may be classified into four general categories: (1) indices of general water quality, (2) indices for specific water uses, (3) indices for planning, and (4) statistical approaches. Ott compares various indices which are in use today. At present, only ten states utilize water quality indices. In the study area, Oregon is the only state to do so. Oregon, as of June, 1977, had developed its own criteria and applied them to monthly water quality reports from the Willamette River Basin; Ott expects that Oregon will apply this index to all river basins in the state. Currently 16 states are involved in evaluating or developing water quality indices for utilization, and another 14 states have completed consideration of indices. Washington and California have completed evaluation of water quality criteria, but have not adopted their usage. See Ott (1978) for further discussion.

Disposal of dredge spoils also affects water quality. Criteria for determining acceptability of dredge spoil disposal to the nation's waters have been established by the U.S. EPA as presented by O'Neal and Sceva (1971). A summary of these criteria is presented in Table 2-18.

Table 2-19 gives the Washington State water quality criteria for marine and frewhwater environments. Four parameters (dissolved oxygen, temperature, coliform bacteria, and turbidity) were selected because they relate to a water's ability to support aquatic life, the water's sanitary quality, and its clarity.

The State of Oregon established general water quality standards that apply to all waters of the state except when clearly superseded by special water quality standards applicable to specifically designated waters. Table 2-20 presents the Oregon standards. Because of the generally high quality of Oregon rivers, water regulations were designed to preserve the fisheries, rather than the usual practice of establishing standards to protect human health.

Marine and estuarine waters of Oregon, as well as the waters of the Rogue River, have special water quality standards, which are given in Tables 2-21 and 2-22, respectively.

The Columbia River and its estuary constitute the border between Washington and Oregon. Table 2-23 compares the water quality standards for Oregon and Washington portions of the Columbia River estuary and its tributaries. Although Washington does not have criteria for dissolved chemical substances, additional effluent limits for individual industries are published by the EPA.

Statewide water quality standards for marine waters of California are available from the U.S. Environmental Protection Agency (1978). Water quality control plans were established for the Klamath River Basin and the North Coastal Basin by the California State Water Resources Control Board in 1975 (Bureau of National Affairs, 1978). Water quality standards that specifically apply to the Klamath River Basin and the North Coastal Basin are presented in Table 2-24.

Table 2-25 presents coastal water quality criteria for toxic substances other than biocides as established by the EPA and the National Academy of Sciences. More detailed quality criteria for water are available in the EPA's Quality Criteria for Water (1976B). These last two documents cover a wider range of chemicals and substances than are presented in Table 2-25 and include the rationale behind the limits as established.

2.8.3 Regional Quality Measurements. Water quality for California is discussed by the California Region Framework Study Committee (1971). Detailed discussions of water quality for Oregon and Washington are given by PNRBC (1970) and OIW (1977). Seaman (1977) discusses water quality of the Columbia River and its estuary.

Water quality measurements and unprocessed data from Washington, Oregon, and California are available through the information retrieval program, STORET, which is operated by the EPA and discussed in Section 2.8 of the Model (Volume 1). Oregon and Washington rank second and third in the U.S. in the number of stations routinely sampled for water quality data in the STORET program, with 12,772 and 11,205 stations, respectively; California ranks 18th with 3,100 stations reported.

Regional STORET data and statistical analyses for specific sites or river basins from which measurements have been taken can be obtained from the Freedom of Information Officer, U.S. Environmental Protection Agency, Office of Public Affairs, 1200 Sixth Avenue, Seattle, WA 98101. Data files for the following general areas should be specified: Pacific Northwest, Oregon Coast Basin, Washington Coast Basin, Northern California Coast Basin. Table 2-26 provides an example of the type of data available from a single station in the study area.

The considerable water quality data available for the region are not summarized here, as they are Watershed Unit specific. The reader is directed to the references above and to Volume 4 for coverage of particular watersheds.

TABLE 2-18. CRITERIA FOR DETERMINING ACCEPTABILITY OF DREDGED SPOIL DISPOSAL TO THE NATION'S WATERS. (From O'Neal and Sceva, 1971.)

The decision whether to oppose plans for disposal of dredged spoil in U.S. waters must be made on a case-by-case basis after considering all appropriate factors, including the following:

(a) Volume of dredged material.
(b) Existing and potential quality and use of the water in the disposal area.
(c) Other conditions at the disposal site such as depth and currents.
(d) Time of year of disposal (in relation to fish migration and spawning, etc.)
(e) Method of disposal and alternatives.
(f) Physical, chemical, and biological characteristics of the dredged material.
(g) Likely recurrence and total number of disposal requests in a receiving water area.
(h) Predicted long- and short-term effects on receiving water quality.

When concentrations, in sediments, of one or more of the following pollution parameters exceed the limits expressed below, the sediment will be considered polluted in all cases and, therefore, unacceptable for open-water disposal.

Sediments in Fresh and Marine Waters	Conc. % (dry wt. basis)
**Volatile solids	6.0
Chemical Oxygen Demand (COD)	5.0
Total Kjeldahl Nitrogen	0.10
Oil-Grease	0.15
Mercury	0.001
Lead	0.005
Zinc	0.005

**When analyzing sediments dredged from marine waters, the following correlation between volatile solids and COD should be made:

$$T.V.S.\ \%\ (dry) = 1.32 + 0.98(COD\%)$$

If the results show a significant deviation from this equation, additional samples should be analyzed to insure reliable measurements.

The volatile solids and COD analyses should be made first. If the maximum limits are exceeded, the sample can be characterized as polluted, and the additional parameters would not have to be investigated.

Dredged sediment having concentrations of constituents less than the limits stated above will not be automatically considered acceptable for disposal. A judgment must be made on a case-by-case basis after considering the factors listed in (a) through (h) above.

In addition to the analyses required to determine compliance with the stated numerical criteria, the following additional tests are recommended where appropriate and pertinent:

Total Phosphorus
Total Organic Carbon (TOC)
Immediate Oxygen Demand (IOD)
Settleability
Sulfides
Trace Metals (iron, cadmium, copper, chromium, arsenic, and nickel)
Pesticides
Bioassay

The first four analyses would be considered desirable in almost all instances. They may be added to the mandatory list when sufficient experience with their interpretation is gained. For example, as experience is gained, the TOC test may prove to be a valid substitute for the volatile solids and COD analyses. Tests for trace metals and pesticides should be made where significant concentrations of these materials are expected from known waste discharges.

All analyses and techniques for sample collection, preservation, and preparation shall be in accord with a current FWQA analytical manual on sediments.

TABLE 2-19.* SUMMARY OF WATER QUALITY CRITERIA FOR WASHINGTON STATE. (From Washington State Department of Ecology, 1975.)

Class Designation	Typical Uses	(1) Dissolved Oxygen (mg/l)	(2) Temperature (°F)	(2) Total Dissolved Gas (% of Saturation)	pH	(3) Turbidity (JTU)	(2) Total Coliform (median values) (organisms/100 ml)
CLASS AA Exceeds requirements for substantially all uses	Potable water supply; fishing; swimming; fish and shellfish reproduction and rearing						
Fresh Water		9.5	60	110	6.5-8.5	5	50
Marine Water		7.0	55	110	7.0-8.5 (Var. 0.10)	5	70
CLASS A Meets or exceeds requirements for substantially all uses	Potable water supply; fishing; swimming; fish and shellfish reproduction and rearing						
Fresh Water		8.0	65	110	6.5-8.5	5	240
Marine Water		6.0	61	110	7.0-8.5 (Var. 0.25)	5	70
CLASS B Meets or exceeds requirements for most uses	Industrial and agricultural water supply; fishing; shellfish reproduction and rearing						
Fresh Water		6.5	70	110	6.5-8.5	10	1,000
Marine Water		5.0	66	110	7.0-8.5 (Var. 0.5)	10	1,000
CLASS C Meets or exceeds requirements of selected and essential uses	Cooling water; fish passage; commerce and navigation						
Fresh Water		5.0	75	110	6.5-9.0	10	1,000
Marine Water		4.0	72	110	7.0-9.0 (Var. 0.5)	10	1,000
LAKE CLASS Meets or exceeds requirements for all uses	Potable water supply; fishing; swimming; fish and shellfish reproduction and rearing	(4)	(4)	110	(4)	5	240

(1) Shall exceed the values shown.
(2) Shall not exceed the values shown.
(3) Shall not exceed the values shown beyond naturally occurring concentrations.
(4) No measureable change from natural conditions.
JTU = Jackson Turbidity Units

TABLE 2-20. OREGON STATE GENERAL WATER QUALITY STANDARDS. (From ACOE, 1975D.)

The following General Water Quality Standards shall apply to all waters of the State except where they are clearly superseded by Special Water Quality Standards applicable to specifically designated waters of the State.

No action or activity shall cause:

(1) The dissolved oxygen content of surface waters to be less than six (6) milligrams per liter.
(2) The hydrogen-ion concentration (pH) of the waters to be outside the range of 6.5 to 8.5.
(3) The liberation of dissolved gases, such as carbon dioxide, hydrogen sulfide or any other gases, in sufficient quantities to cause objectionable odors or to be deleterious to fish or other aquatic life, navigation, recreation, or other reasonable uses made of such waters.
(4) The development of fungi or other growths having a deleterious effect on stream bottoms, fish or other aquatic life, or which are injurious to health, recreation or industry.
(5) The creation of tastes or odors of toxic or other conditions that are deleterious to fish or other aquatic life or affect the potability of drinking water or the palatability of fish or shellfish.
(6) The formation of appreciable bottom or sludge deposits or the formation of any organic or inorganic deposits deleterious to fish or other aquatic life or injurious to public health, recreation or industry.
(7) Objectionable discoloration, turbidity, scum, oil slick or floating solids, or coat the aquatic life with oil films.
(8) Bacterial pollution or other conditions deleterious to waters used for domestic purposes, livestock watering, irrigation, bathing, or shellfish propagation, or be otherwise injurious to public health.
(9) Any measurable increase in temperature when the receiving water temperatures are 64°F or greater; or more than 0.5°F increase due to a single-source discharge when receiving water temperatures are 63.5°F or less; or more than 2°F increase due to all sources combined when receiving water temperatures are 62°F or less.
(10) Aesthetic conditions offensive to the human senses of sight, taste, smell or touch.
(11) Radioisotope concentrations to exceed Maximum Permissible Concentrations (MPC's) in drinking water, edible fishes or shellfishes, wildlife, irrigated crops, livestock and dairy products or pose an external radiation hazard.
(12) The concentration of total dissolved gas relative to atmospheric pressure at the point of sample collection to exceed one hundred and five percent (105%) of saturation, except when stream flow exceeds the 10-year 7-day average flood.

TABLE 2-21. WATER QUALITY STANDARDS FOR THE MARINE AND ESTUARINE WATERS OF OREGON (EXCLUDING ESTUARINE WATERS OF THE COLUMBIA RIVER). (From ACOE, 1975D; taken directly from App. E.)

The provisions of this section shall be in addition to and not in lieu of the General Water Quality Standards[1], except where this section imposes a conflicting requirement with the provisions of those standards, this section shall govern. No wastes shall be discharged and no activities shall be conducted which either alone or in combination with other wastes or activities will cause in marine or estuarine waters:

(1) Dissolved oxygen (DO). (Outside of zones or upwelled marine waters naturally deficient in DO). DO concentrations to be less than 6 milligrams per liter for estuarine waters, or less than saturation concentrations for marine waters.

(2) Organisms of the Coliform Group. (MPN or equivalent MF using a representative number of samples).
  (a) (For marine and shellfish growing waters). The median concentration of coliform bacteria of sewage origin to exceed 70 per 100 milliliters.
  (b) (For estuarine waters other than in shellfish growing areas). Average concentrations of coliform bacteria, where associated with fecal sources, to exceed 240 per 100 ml or to exceed this value in more than 20% of samples.

(3) Hydrogen Ion Concentration (pH). pH values to be outside the range of 7.0 and 8.5 over shellfish growing areas.

(4) Turbidity. (Jackson Turbidity Units, JTU). Turbidities to exceed 5 JTU above natural background values except for certain short-term activities which may be specifically authorized by the Sanitary Authority under such conditions as it may prescribe and which are necessary to accommodate essential dredging or construction where turbidities in excess of this standard are unavoidable.

(5) Temperature. Any significant increase above natural background temperatures, or water temperatures to be altered to a degree which creates or can reasonably be expected to create an adverse effect on fish or other aquatic life.

---

[1] See Table 2-20.

TABLE 2-22. SPECIAL WATER QUALITY AND WASTE TREATMENT STANDARDS FOR THE ROGUE RIVER BASIN IN OREGON. (From ACOE, 1975D; taken directly from App. E.)

(A) Special Water Quality Standards. The provisions of this sub-section shall be in addition to and not in lieu of the General Water Quality Standards[1], except where this sub-section imposes a conflicting requirement with the provisions of those standards, this sub-section shall govern. No wastes shall be discharged and no activities shall be conducted which either alone or in conjunction with other wastes or activities will cause in the waters of the Rogue River Basin:

(1) Organisms of the Coliform Group Where Associated with Fecal Sources (MPN or equivalent MF using a representative number of samples).
  (a) Mainstem Rogue River from the point of salt water intrusion, approximately R.M. 4, upstream to Dodge Park, river mile 138.4, and Bear Creek; average concentrations to exceed 1000 per 100 milliliters, except during periods of high surface runoff.
  (b) Rogue River above Dodge Park and all unspecified tributaries, average concentrations to exceed 240 per 100 milliliters, except during periods of high surface runoff.

(2) Dissolved Oxygen (DO) Dissolved oxygen concentrations to be less than 95 percent of saturation in spawning areas during spawning, incubation, hatching, and fry stages of salmonid fishes.

(3) pH (Hydrogen Ion Concentration). pH values to fall outside the range of 7.0 to 8.5.

(4) Turbidity (Jackson Turbidity Units, JTU). Any measurable increases in natural stream turbidities when natural turbidities are less than 30 JTU, or more than a 10 percent cumulative increase in natural stream turbidities when stream turbidities are more than 30 JTU, except for certain short-term activities which may be specifically authorized by the Department of Environmental Quality under such conditions as it may prescribe and which are necessary to accommodate essential dredging, construction, or other legitimate uses or activities where turbidities in excess of this standard are unavoidable.

(5) Temperature. Any measurable increases when stream temperatures are 58°F or greater; or more than 0.5°F increase due to a single-source discharge when receiving water temperatures are 57.5°F or less or more than 2°F increase due to all sources combined when stream temperatures are 56°F or less, except for short-term activities which may be specifically authorized by the Department of Environmental Quality under such conditions as it may prescribe and which are necessary to accommodate legitimate uses or activities where temperatures in excess of this standard are unavoidable.

(6) Dissolved Chemical Substances. Guide concentrations listed below to be exceeded except as may be specifically authorized by the Department of Environmental Quality upon such conditions as it may deem necessary to carry out the general intent of providing the highest and best practicable treatment and control and to protect beneficial uses.

	mg/l
Arsenic (As)	0.01
Barium (Ba)	1.0
Boron (Bo)	0.5
Cadmium (Cd)	0.003
Chloride (Cl)	25.
Chromium (Cr)	0.02
Copper (Cu)	0.05
Cyanide (Cn)	0.005
Fluoride (F)	1.0
Iron (Fe)	0.1
Lead (Pb)	0.05
Manganese (Mn)	0.05
Phenols (totals)	0.001
Total dissolved solids	100.
Zinc (Zn)	0.01

(B) Minimum Standards for Treatment and Control of Wastes. All wastes shall be treated, prior to discharge, in accordance with the following:

(1) Sewage Wastes.

(a) During the period of low stream flows (approximately June 1 - October 31 of each year), secondary treatment resulting in monthly average effluent concentrations not to exceed 20 mg/l of 5-day 20 degrees C Biochemical Oxygen Demand (BOD) and 20 mg/l of suspended solids or equivalent control.

(b) During the period of high stream flows (approximately November 1 - May 31 of each year) a minimum of secondary treatment or equivalent shall be provided and all waste treatment and control facilities shall be operated at maximum efficiency so as to minimize waste discharges to public waters.

(c) All sewage wastes shall be disinfected, after treatment, equivalent to thorough mixing with sufficient chloride to provide a residual of at least 1 part per million after 60 minutes of contact time.

(d) More stringent waste treatment requirements may be imposed, especially in headwater and tributary streams, where waste loads may be large relative to stream flows.

(2) Industrial Wastes.

(a) Industrial waste treatment requirements shall be determined on an individual basis in accordance with the provisions of Sections 41-010, 41-015, 41-020, 41-025, and 41-030 of the Oregon Water Quality Control Regulations.

(b) Where industrial effluents contain significant quantities of potentially toxic elements, treatment requirements shall be determined utilizing appropriate bioassays.

[1] See Table 2-20.

TABLE 2-23. WATER QUALITY STANDARDS FOR OREGON AND WASHINGTON PORTIONS OF THE COLUMBIA RIVER ESTUARY AND TRIBUTARIES. (From Oregon State Department of Environmental Quality, 1976, and Washington State Department of Ecology, 1975, as compiled by Seaman, 1977.)

Parameter	Oregon			Washington	
	Columbia River	Col.R.Estuary	Freshwater Trib.	Class A	Class AA
Dissolved oxygen	90% saturation	6 mg/l	90% saturation; 95% in spawning areas	8 mg/l fresh 6 mg/l marine	9.5 mg/l fresh 7.0 mg/l marine
Temperature	T>68°F: No increase; T<68.5°F: 0.5°F increase due to all discharges; T<66°F: 2.0°F increase.	No significant increase above natural.	Same as Col. Riv. except 58°, 57.5° and 56°, respectively.	Water temperature shall not exceed 65°F (fresh) or 61°F (marine) due to measurable (0.5°F) effects of discharge. Greater increases allowed at lower temperature.	Water shall not exceed 60°F (fresh) or 55°F (marine) due to measureable (0.5°F) effect of discharge. Greater increases allowed at lower temperature.
Turbidity (Jackson Turbidity Units, JTU)	10% increase over background conditions; exceptions may be granted.			5 JTU over natural background	
pH (log of hydrogen ion concentration)	6.5 to 8.5	7.0 to 8.5	6.5 to 8.5	6.5 to 8.5 (fresh)	7.0 to 8.5 (marine)
Fecal Coliform (MPN)	1000 per 100 ml (average), and no more than 20% of samples may exceed this value.		240 per 100 ml, and no more than 20% of samples shall exceed this value	240 (average), no more than 20% samples exceeding 1000 per 100 ml in freshwater.	50 (fresh) or 70 (salt) average, with no more than 20% exceeding 230 per 100 ml.
Total dissolved gases	Liberation of dissolved gases in sufficient quantities to cause objectionable odors or to be deleterious to fish life or other uses is prohibited; otherwise, 105% of saturation.			110% of saturation	
Radioactive material	Not to exceed maximum permissible concentrations for drinking water.			Less than those that might affect public health, the natural aquatic environment, or any water use (same for other toxic materials).	
Aesthetic values	Shall not be offensive to the human senses of sight, taste, smell or touch, be deleterious to fish or other aquatic life, affect the potability of drinking water or the palatability of fish or shellfish.			Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.	
Other prohibited conditions	Development of fungi or other growths having deleterious effects. Formation of deleterious bottom or sludge deposits. Discoloration, oily slick, floating solids, or coating of aquatic life.				

Dissolved chemical substances (Columbia River):

Substance	Concentration mg/l	Substance	Concentration mg/l
As	0.01	Fe	0.1
Ba	1.0	Pb	0.05
Bo	0.5	Mn	0.05
Cd	0.003	Phenols	0.001
Cr	0.02	Total Dissolved solids	500.
Cu	0.005		
CN	0.005	Zn	0.01
F	1.0	(applies only to freshwater)	

Dissolved chemical substances: Freshwater streams and tributaries: same except total dissolved solids 100 mg/l.

When the natural conditions exceed any of the above standards, the natural water quality is the standard.

TABLE 2-24. WATER QUALITY CRITERIA FOR KLAMATH RIVER BASIN AND NORTH COASTAL BASIN, CALIFORNIA. (From EPA, 1978.)

Color

Waters shall be free of coloration that causes nuisance or adversely affects beneficial uses.

Tastes and Odors

Waters shall not contain taste or odor-producing substances in concentrations that impart undesirable tastes or odors to fish flesh or other edible products of aquatic origin, that cause nuisance or adversely affect beneficial uses.

Floating Material

Waters shall not contain floating material, including solids, liquids, foams, and scum, in concentrations that cause nuisance or adversely affect beneficial uses.

Suspended Material

Waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses.

Settleable Material

Waters shall not contain substances in concentrations that result in deposition of material that causes nuisance or adversely affect beneficial uses.

Oil and Grease

Waters shall not contain oils, greases, waxes, or other materials in concentrations that result in a visible film or coating on the surface of the water or on objects in the water, that cause nuisance, or that otherwise adversely affect beneficial uses.

Biostimulatory Substances

Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.

Sediment

The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.

Turbidity

Turbidity shall not be increased more than 20 percent above naturally occurring background levels. Allowable zones of dilution within which higher percentages can be tolerated may be defined for specific discharges upon the issuance of discharge permits or waiver thereof.

pH

The pH shall not be depressed below 6.5 nor raised above 8.5.

Changes in normal ambient pH levels shall not exceed 0.2 units in waters with designated marine (MAR) or saline (SAL) beneficial uses nor 0.5 units within the range specified above in fresh waters with designated COLD or WARM beneficial uses.

Dissolved Oxygen

The dissolved oxygen concentrations shall not be reduced below the following minimum levels at any time.

Waters designated WARM, MAR, or SAL 5.0 mg/l
Waters designated COLD............. 6.0 mg/l
Waters designated SPWN............. 7.0 mg/l
Waters designated SPWN during critical spawning and egg incubation periods....... 9.0 mg/l

Bacteria

The bacteriological quality of waters of the North Coast Region shall not be degraded beyond natural background levels. In no case shall coliform concentrations in waters of the North Coast Region exceed the following:

In waters designated for contact recreation (Rec 1), the median fecal coliform concentration based on a minimum of not less than five samples for any 30-day period shall not exceed 50/100 ml, nor shall more than ten percent of total samples during any 30-day period exceed 400/100 ml.

At all areas where shellfish may be harvested for human consumption (SHELL), the median total coliform concentration throughout the water column for any 30-day period shall not exceed 70/100 ml nor shall more than ten percent of the samples collected during any 30-day period exceed 230/100 ml for a five-tube decimal dilution test or 330/100 ml when a three-tube decimal dilution test is used.

Temperature

Temperature objectives for COLD interstate waters, WARM interstate waters, and Enclosed Bays and Estuaries are as specified in the "Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays of California" including any revisions thereto. A copy of this plan is included verbatim in the "Plans and Policies Appendix" of the full Plan.

In addition, the following temperature objectives apply to surface waters:

The natural receiving water temperature of intra-state waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Board that such alteration in temperature does not adversely affect beneficial uses.

At no time or place shall the temperature of any COLD water be increased by more than 5°F above natural receiving water temperature.

Toxicity

All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal, or aquatic life. Compliance with this objective will be determined by use of indicator organisms, analyses of species diversity, population density, growth anomalies, bioassays of appropriate duration or other appropriate methods as specified by the Regional Board.

The survival of aquatic life in surface waters subjected to a waste discharge or other controllable water quality factors, shall not be less than that for the same water body in areas affected by the waste discharge, or when necessary for other control water that is consistent with the requirements for "experimental water" as described in Standard Methods for the Examination of Water and Wastewater, latest edition. As a minimum, compliance with this objective as stated in the previous sentence shall be evaluated with a 96-hour bioassay.

In addition, effluent limits based upon acute bioassays of effluents will be prescribed where appropriate, additional numerical receiving water objectives for specific toxicants will be established as sufficient data become available, and source control of toxic substances will be encouraged.

Pesticides

No individual pesticide or combination of pesticides shall be present in concentrations that adversely affect beneficial uses. There shall be no bioaccumulation in pesticide concentrations found in bottom sediments or aquatic life.

Chemical Constituents

Water designated for use as domestic or municipal supply (MUN) shall not contain concentrations of chemical constituents in excess of the limits specified in California Administrative Code, Title 17, Chapter 5, Subchapter 1, Group 1, Article 4, Section 7019, Tables 2, 3, and 4.

Waters designated for use as agricultural supply (AGR) shall not contain concentrations of chemical constituents in amounts which adversely affect such beneficial use.

Radioactivity

Radionuclides shall not be present in concentrations which are deleterious to human, plant, animal or aquatic life nor which result in the accumulation of radionucludes in the food web to an extent which presents a hazard to human, plant, animal or indigenous aquatic life.

Waters designated for use as domestic or municipal supply (MUN) shall not contain concentrations of radionuclides in excess of the limits specified in California Administrative Code.

TABLE 2-25. COASTAL WATER QUALITY CRITERIA FOR TOXIC SUBSTANCES OTHER THAN BIOCIDES, AS ESTABLISHED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY AND NATIONAL ACADEMY OF SCIENCES. (From OIW, 1977.)

Substance	Maximum Acceptable Concentrations (96 hr. LC_{50})[1,2]	Maximum Acceptable Concentrations (Milligrams or Micrograms/liter)[2]	Minimum Risk Threshold (Milligrams or Micrograms/liter)[3]
Antimony	1/50	0.2 mg/l	N.A.[4]
Arsenic	1/100	0.05 mg/l	0.01 mg/l
Barium	1/20	0.0 mg/l	0.5 mg/l
Beryllium	1/100	1.5 mg/l	0.1 mg/l
Boron	1/10	N.A.	5.0 mg/l
Cadmium	1/100	0.01 mg/l	0.2 µg/l
Chromium	1/100	0.1 mg/l	0.05 mg/l
Copper	1/100	0.05 mg/l	0.01 mg/l
Fluorides	1/10	1.5 mg/l	0.5 mg/l
Iron	N.A.	0.3 mg/l	0.05 mg/l
Lead	1/50	0.05 mg/l	0.01 mg/l
Manganese	1/50	0.1 mg/l	0.02 mg/l
Mercury	1/100	1.0 µg/l	N.A.
Nickel	1/50	0.1 mg/l	0.002 mg/l
Phosphorus	1/100	0.1 mg/l	N.A.
Zinc	1/100	0.1 mg/l	0.02 mg/l
Cyanides	1/10	0.01 mg/l	0.005 mg/l
Detergents	1/20	0.2 mg/l	N.A.
Phenolics	1/20	0.1 mg/l	N.A.
Phthalate Esters	N.A.	0.3 µg/l	N.A.
PCB's	N.A.	0.002 µg/l	N.A.
Sulfides	1/10	0.01 mg/l	0.005 mg/l

[1] The maximum acceptable concentration figures in this column are expressed as fractions of the 96 hr. LC_{50} for the most sensitive species in a given area. The 96 LC_{50} is that concentration of a substance which kills 50 percent of the test species within 96 hours under standard bioassay conditions.

[2] Data are Environmental Protection Agency official criteria where available; National Academy of Sciences data used where EPA data not available.

[3] National Academy of Sciences data, for concentrations "below which there is a minimal risk of deleterious effects."

[4] N.A. - Not Applicable.

STORET DATE 77/08/24

402204 146000000720

SIXES RIVER ABOVE US HWY 101
41 OREGON
PACIFIC NORTHWEST
OREGON COAST BASIN
21400000 04001002

/TYPA/AMBNT/LAKE

INDEX 1313158
MILES 0006.00

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM	BEG DATE	END DATE
00008 LAB	IDENT.	NUMBER	6	770394	-.209E+06	.000000		.000000	770693	770013	77/01/11	77/06/07
00010 WATER	TEMP	CENT	21	13.4047	17.1908	4.14618	.309306	.904770	22.0000	8.50000	65/09/28	77/06/07
00070 TURB	JKSN	JTU	16	10.0000	176.000	13.2665	1.32665	3.31662	46.0000	1.00000	65/09/28	76/11/17
00076 TURB	TRBIDMTR	HACH FTU	6	15.3333	745.467	27.3032	1.78065	11.1465	70.0000	1.00000	77/01/11	77/06/07
00080 COLOR	PT-CO	UNITS	22	9.27273	217.255	14.7396	1.58956	3.14249	50.0000	.000000	65/09/28	77/06/07
00094 CNDUCTVY	FIELD	MICROMHO	14	91.0000	258.615	16.0815	.176720	4.29796	110.000	67.0000	73/12/11	77/05/17
00095 CNDUCTVY	AT 25C	MICROMHO	22	93.5454	212.646	14.5824	.155885	3.10897	118.000	65.0000	65/09/28	77/06/07
00300 DO		MG/L	20	10.1150	.697201	.834986	.082549	.186708	11.2000	9.00000	65/09/28	77/06/07
00301 DO	SATUR	PERCENT	19	95.4737	16.9340	4.11510	.043102	.944068	104.000	89.0000	65/09/28	77/06/07
00310 BOD	5 DAY	MG/L	20	.514999	.081342	.285206	.553798	.063774	1.20000	.100000	65/09/28	77/06/07
00335 COD	LOWLEVEL	MG/L	9	7.00000	12.7500	3.57071	.510102	1.19024	16.0000	5.00000	76/10/20	77/06/07
00400 PH		SU	20	7.13499	.015034	.122613	.017185	.027417	7.40000	7.00000	65/09/28	77/06/07
00403 LAB	PH	SU	6	6.91666	.101758	.318995	.046120	.130229	7.30000	6.50000	77/01/11	77/06/07
00410 T ALK	CACO3	MG/L	22	25.3636	47.2905	6.87681	.271129	1.46614	35.0000	11.0000	65/09/28	77/06/07
00431 T ALK	FIELD	MG/L	5	25.0000	38.5000	6.20484	.248193	2.77489	32.0000	15.0000	77/02/15	77/06/07
00500 RESIDUE	TOTAL	MG/L	22	79.8182	922.824	30.3780	.380590	6.47662	185.000	55.0000	65/09/28	77/06/07
00530 RESIDUE	TOT NFLT	MG/L	22	17.6818	1084.13	32.9262	1.86215	7.01988	140.000	1.00000	65/09/28	77/06/07
00610 NH3-N	TOTAL	MG/L	22	.124545	.009778	.098886	.793977	.021083	.410000	.010000	65/09/28	77/06/07
00615 NO2-N	TOTAL	MG/L	9	.020000	.552E-09	.000024	.001176	.000008	.020000	.020000	76/10/20	77/06/07
00620 NO3-N	TOTAL	MG/L	14	.112143	.011326	.106423	.948996	.028443	.340000	.010000	65/09/28	75/12/10
00625 TOT KJEL	N	MG/L	6	.316666	.057667	.240139	.758335	.098036	.700000	.100000	77/01/11	77/06/07
00630 NO2&NO3	N-TOTAL	MG/L	9	1.15889	8.65505	2.94195	2.53859	.980649	9.00000	.090000	76/10/20	77/06/07
00650 T PO4	PO4	MG/L	10	.220000	.081777	.285968	1.29985	.090431	1.00000	.000000	73/12/11	76/12/14
00660 ORTHOPO4	PO4	MG/L	16	.032500	.000313	.017701	.544653	.004425	.060000	.010000	65/09/28	76/11/17
00665 PHOS-TOT		MG/L P	6	.047500	.000713	.026704	.562188	.010902	.085000	.020000	77/01/11	77/06/07
00680 T ORG C	C	MG/L	9	3.77778	4.19445	2.04804	.542127	.682679	8.00000	1.00000	76/10/20	77/06/07
00900 TOT HARD	CACO3	MG/L	22	30.3636	72.1477	8.49398	.279742	1.81092	46.0000	17.0000	65/09/28	77/06/07
00930 SODIUM	NA,DISS	MG/L	16	3.60000	.312023	.558590	.155164	.139647	4.90000	2.80000	73/12/11	77/06/07
00935 PTSSIUM	K,DISS	MG/L	16	.487500	.041167	.202896	.416197	.050724	.900000	.300000	73/12/11	77/06/07
00940 CHLORIDE	CL	MG/L	22	5.63181	2.03941	1.42808	.253574	.304468	10.0000	3.00000	65/09/28	77/06/07
00945 SULFATE	SO4-TOT	MG/L	22	5.35454	3.61399	1.90105	.355035	.405305	10.00000	2.00000	65/09/28	77/06/07
31505 TOT COLI	MPN CONF	/100ML	21	165.667	39615.4	199.036	1.20143	43.4333	620.000	45.0000	65/09/28	77/06/07
31615 FEC COLI	MPNECMED	/100ML	15	64.0667	2587.35	50.8660	.793955	13.1336	230.000	45.0000	73/12/11	77/06/07
70507 PHOS-T	ORTHO	MG/L P	6	.008667	.000031	.005610	.647251	.002290	.014000	.001000	77/01/11	77/06/07

TABLE 2-26. AN EXAMPLE OF STORET WATER QUALITY DATA. This printout shows one form of output from the EPA's STORET system and gives an indication of the range of parameters sampled. These data are from one station on the Sixes River in Watershed Unit #7.

Chapter Three — BIOLOGICAL ENVIRONMENT

Sections | Page

As described in the Model (Volume 1), and in the Introduction and Users' Guide, the biological components of the region are treated several times in this study, particularly by zones and habitats in Volume 3. The general habitat descriptions include characteristic flora and fauna. Community Composition lists, printed out from the Annotated Species List, include most of the significant organisms in each habitat community, arranged by trophic level. Food webs and ecosystem models, where available, further characterize the biology of each habitat.

The Annotated Species List (see Section 3.3 of Volume 1 and Part 2 of Volume 5) includes data on the organisms of the coastal region, their distribution, zone and habitat preferences, trophic levels, abundances, and status. This computerized data bank can be searched and manipulated in a number of ways, as described in the sections cited above, and forms an integral and indispensable part of the biological characterization of this study.

Chapter 3, as the outline in Volume 1 and above suggests, is not a comprehensive summary of the region's biology and thus is not similar to the treatment given the physical/chemical environment in Chapter 2. Rather, Chapter 3 outlines and gives examples of areas covered in other parts of this study, as well as providing summaries of some of these areas.

Biological zonation is discussed briefly in this chapter (descriptions of each zone may be found in Volume 3). Extent of the zones identified in the region are given, and some of the major factors which influence the differentiation and distribution of the zones are discussed.

The various models that have been developed for the zones and habitats of the study area are introduced in Chapter 3 of Volume 1. A general overview of the region's inland, coastal, and oceanic ecosystems is presented in the beginning of Section 3.2 (Biological Models). For the ecosystem model in particular, five key habitats (Old Growth Western Hemlock, Emergent Vegetation, Eelgrass, Unprotected Beach, and Euphotic Pelagic Ocean) have been selected and treated in greater detail, with regional data and references given for the significant processes and components of each ecosystem.

Similarly, terrestrial (Western Hemlock Zone) and estuarine succession models are treated here in some detail. Taken together, these models and their descriptions consitute a useful summary of the major environments of the region. This level of model treatment, although desirable to "flesh out" each habitat model, was not carried out for other zones and habitats, as such an effort was beyond the scope of the present study.

Organisms of particular interest in the region are discussed, with supporting data and references, in the Species of Concern section of this Chapter (3.4). This section serves as a useful summary of the significant plants and animals of the study area and the reasons for their importance. Detailed descriptions of selected species are found in Part 2 of this volume.

Finally, areas of ecological concern in the region are discussed briefly, with references to appropriate literature for further information. These areas are treated in greater detail in the Watershed Unit descriptions in Volume 4.

3.1 BIOLOGICAL ZONATION

Descriptions of the biological zones treated in this study, along with community types (habitats), are given in Volume 3. The tables in Part 2 of the Conceptual Model (Volume 1) compare the zonation system used in this study with zonation systems developed by other authors. A brief historical treatment of biological zonation is also given in Part 2 of the Model and expanded in Volume 3.

3.1.1 Distribution and Extent. Figure 3-1 indicates the distribution of biological zones within the region and demonstrates that the zones change with distance from the shore, with elevation, and latitude. The Western Hemlock Zone is the most widespread inland zone within the region. It is typically bounded by the Sitka Spruce Zone immediately along the coast and by the True Fir Zone at higher elevations. The Western Hemlock Zone is replaced by the Mixed Evergreen Zone and Redwood Zones in the southerly portions of the region, the Mixed Evergreen Zone being interior and more xeric (dry) than the Redwood Zone. Areas of the inland zones as well as the coastal and oceanic zones are given in Table 3-1.

Distribution, location, and size of estuaries in the region are discussed in Section 2.6.1 of Volume 2. Approximately 17 major estuaries (greater than 2 km^2) and an equal number of smaller estuaries occur within the region. The four largest estuaries are Columbia, Willapa Bay, Grays Harbor, and Humboldt Bay, which combined make up approximately three-fourths of the total estuarine area in the region. (See Figure 2-24 and Table 2-8.)

As indicated in Figures 2-2 and 2-4, beaches are well distributed all along the coast but are more intermittent in Northern Washington and Southern Oregon. Associated dunes are not as widespread, but occur intermittently from Grays Harbor, Washington, south to Coos Bay, Oregon, and again in the Humboldt Bay area, California.

The oceanic zones, which are defined in area by the continental shelf for purposes of this study, extend from the outer edge of the Surf Zone along the shoreline to the outer edge of the shelf over the whole length of the study area. The continental shelf in this region ranges from 15 to 65 kilometers (9 to 40 miles) in width, which is narrow compared to the shelf off the coasts of other parts of North America. The two hundred meter depth contour identifies the approximate break of the shelf. The width narrows in the southerly portions of the region, particularly at Cape Blanco and Cape Mendocino. The oceanic zones of the study occupy a part of the margin of the Northeast Pacific Ocean.

Human activity zones are defined here to exclude areas where such activities as agriculture, forestry, and fisheries take place. They include other areas where man has changed the environment, such as built-up areas, highways, and utility corridors. Most of the residential, commercial, and industrial areas of these zones of human activity occur in the Coastal Zones, along major estuaries and the shorelines. In the Inland Zones, they are usually along the rivers. Total population of human activity zones is only a few hundred thousand and these zones occupy a very small portion of the land of the study region.

3.1.2 Factors in Differentiation of Zones. As discussed in the Conceptual Model, biological zonation in the inland areas is principally determined by temperature and moisture. Figure 3-2 demonstrates the effect of these two factors in differentiating between the Western Hemlock Zone and the True Fir Zone. Other factors such as soil type, aspect, and slope alter the temperature and moisture regimes. The synergistic effects of slopes, moisture, elevation, aspect, soil type, and topography for the Siskiyou Mountains (Mixed Evergreen Zone) of Southwestern Oregon and Northwestern California are seen in Figure 3-3.

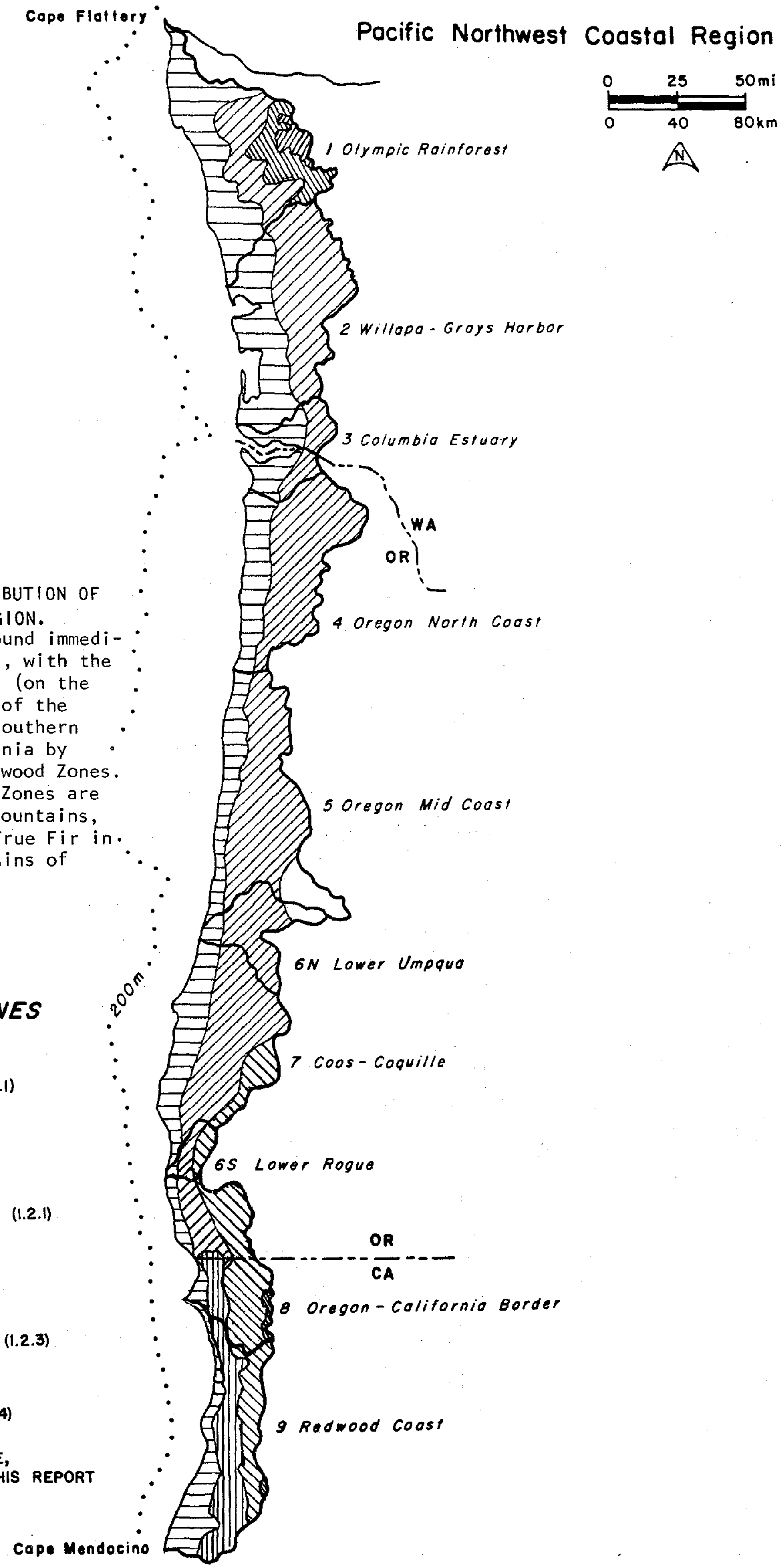


FIGURE 3-1. GENERAL DISTRIBUTION OF BIOLOGICAL ZONES IN THE REGION. The Sitka Spruce Zone is found immediately adjacent to the coast, with the Western Hemlock Zone inland (on the mountain slopes) over most of the region; it is replaced in Southern Oregon and Northern California by the Mixed Evergreen and Redwood Zones. True Fir and Arctic-Alpine Zones are restricted to the Olympic Mountains, except for small areas of True Fir in the Siskiyou/Klamath Mountains of Units #8 and #9.

INLAND BIOLOGICAL ZONES

- ARCTIC ALPINE (1.1.1)
- TRUE FIR (1.1.2)
- WESTERN HEMLOCK (1.2.1)
- REDWOOD (1.2.2)
- MIXED EVERGREEN (1.2.3)
- SITKA SPRUCE (1.2.4)
- INTERIOR ZONE TYPE, NOT COVERED IN THIS REPORT

TABLE 3-1. LENGTH OR AREA OF MAJOR INLAND AND COASTAL BIOLOGICAL ZONES OF THE PACIFIC NORTHWEST COASTAL REGIONS, BY WATERSHED UNITS.

	BEACH		ROCKY HEADLAND		ESTUARINE		DUNES		SITKA SPRUCE		REDWOOD		WESTERN HEMLOCK		MIXED EVERGREEN		TRUE FIR		ARCTIC ALPINE		INTERIOR VALLEY	
	LENGTH		LENGTH		AREA		AREA		AREA		AREA		AREA		AREA		AREA		AREA		AREA	
	mi	(km)	mi	(km)	mi^2	(km^2)	mi^2	(km^2)	mi^2	(km^2)	mi^2	(km^2)	mi^2	(km^2)	mi^2	(km^2)	mi^2	(km^2)	mi^2	(km^2)	mi^2	(km^2)
WATERSHED UNIT 1	55	(90)	25	(40)	<1	(<2)	8	(20)	1,350	(3,500)	---		540	(1,390)	---		520	(1,350)	90	(240)	---	
WATERSHED UNIT 2	45	(70)	---		220	(570)	55	(140)	920	(2,390)	---		1,400	(3,650)	---		30	(75)	---		---	
WATERSHED UNIT 3	20	(30)	5	(10)	145	(380)	21	(55)	250	(650)	---		375	(975)	---		---		---		---	
WATERSHED UNIT 4	55	(90)	15	(25)	22	(58)	12	(31)	400	(1,040)	---		1,600	(4,140)	---		---		---		---	
WATERSHED UNIT 5	70	(115)	20	(30)	21	(55)	30	(78)	400	(1,040)	---		1,725	(4,470)	---		---		---		250	(650)
WATERSHED UNIT 6	7	(10)	---		12	(30)	6	(15)	45	(115)	---		680	(1,760)	110	(280)	---		---		60	(155)
WATERSHED UNIT 7	70	(115)	25	(40)	21	(55)	178	(460)	375	(970)	---		1,480	(3,840)	280	(725)	---		---		---	
WATERSHED UNIT 8	30	(50)	20	(30)	1	(3)	15	(39)	100	(260)	105	(270)	215	(560)	965	(2,500)	40	(105)	---		---	
WATERSHED UNIT 9	85	(135)	15	(25)	25	(65)	10	(26)	340	(880)	965	(2,500)	---		570	(1,475)	15	(40)	---		---	
TOTAL	437	(700)	125	(200)	467	(1,210)	335	(870)	2,980	(7,720)	1,070	(2,770)	8,015	(20,760)	1,925	(4,980)	605	(1,565)	90	(240)	310	(805)

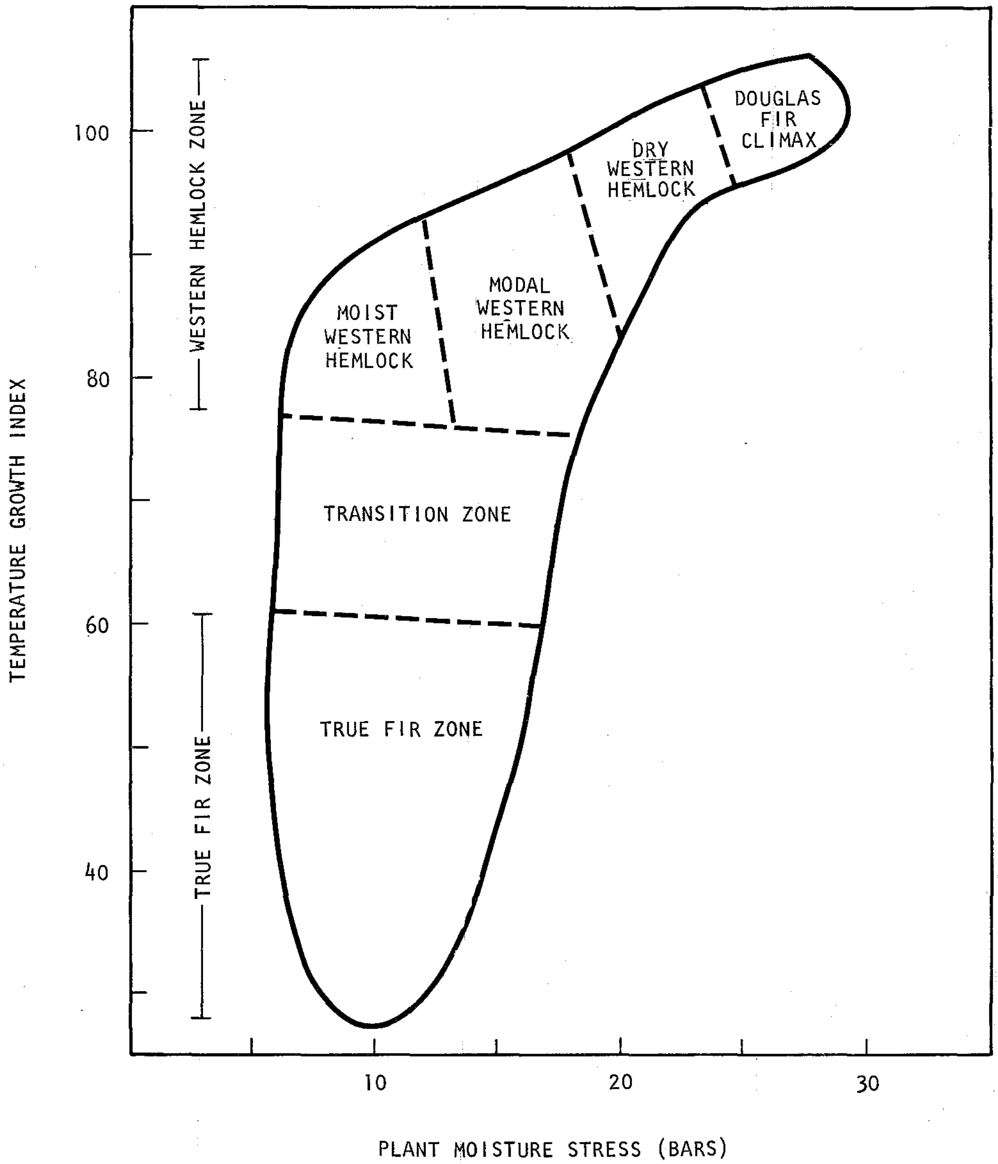


FIGURE 3-2. DISTRIBUTION OF TWO CLIMAX VEGETATION ZONES IN RELATION TO MOISTURE AND TEMPERATURE, DEFINED BY PLANT RESPONSE INDICES. Data are from the H.J. Andrews Experimental Forest on the western slopes of the Cascades in Central Oregon (outside, but in a similar environment to, the study area). (After Zobel et al., 1973.)

Within an inland biological zone, communities can be identified by vegetation which is dependent on temperature, moisture, soil suitability, etc. Community composition is also strongly affected by these factors, as are successional considerations (see Figure 3-3).

In the coastal areas, zones are differentiated by energy and morphology into different landforms (i.e. estuarine areas versus beaches and dunes versus headlands and rocky islands). The zones and community types (habitats) are primarily separated by differences in elevation (with regard to tide), substrate, and succession.

The oceanic shelf area is differentiated into pelagic and benthic communities which are further distinguished by differences in light and sediment or substrate type.

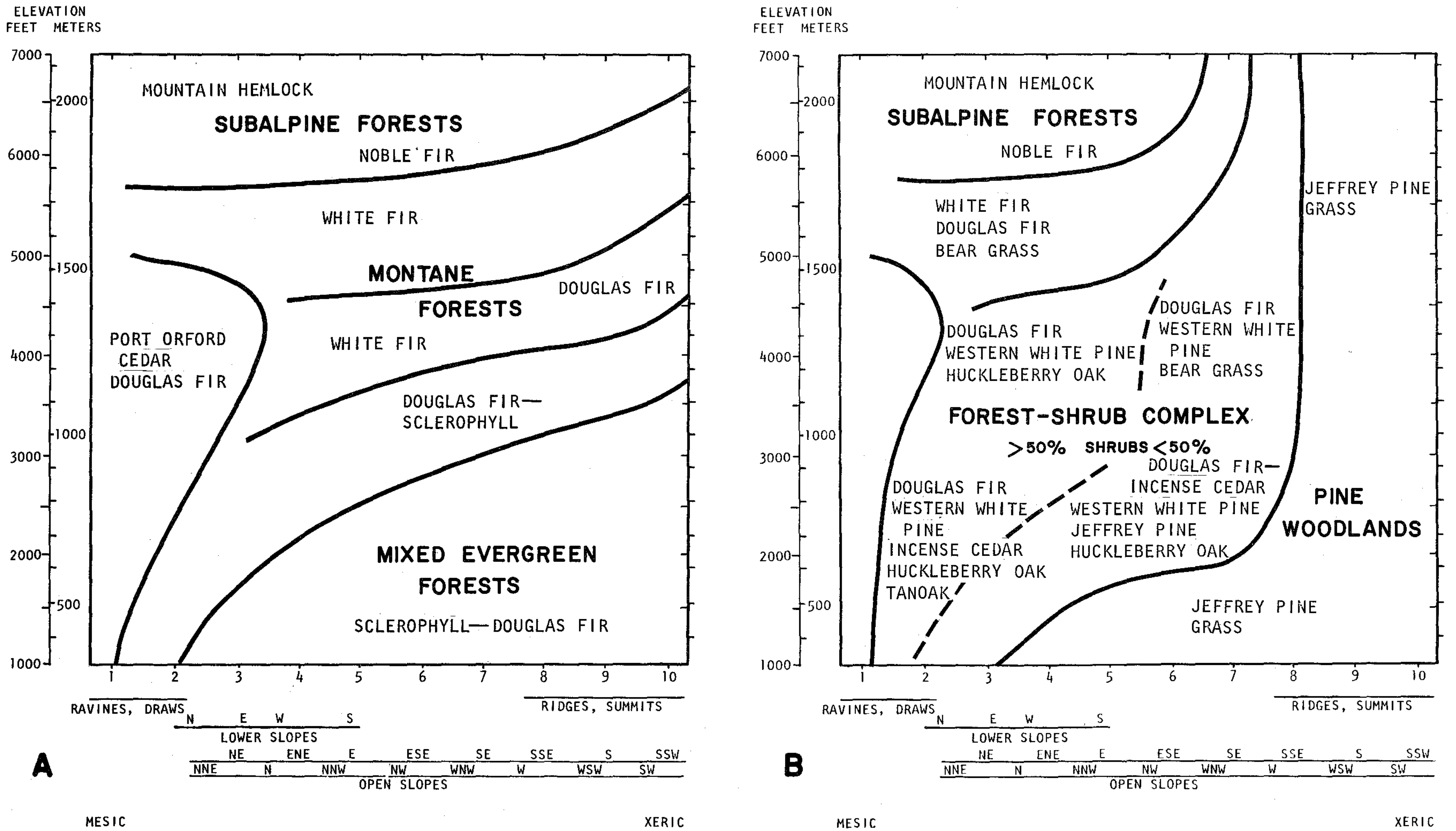


FIGURE 3-3. MOSAIC CHARTS OF THE CHARACTERISTIC VEGETATION FOUND ON (A) QUARTZ DIORITE AND (B) PERIDOTITE AND SERPENTINE IN THE CENTRAL SISKIYOU/KLAMATH MOUNTAINS SHOWING RESPONSE TO ENVIRONMENTAL CONDITIONS OF ELEVATION, MOISTURE, AND EXPOSURE. (Redrawn from Whittaker, 1960.)

Human activity zones are modified from the surrounding natural zones and are maintained in an artificial state by man. Habitats within these zones may include native, adventitious, ruderal, and planned vegetation, bare and paved areas, and structures of many kinds. These zones are differentiated by the continuing pressence of man and his activities and are distinguished by the kind and intensity of those activities.

To summarize, biological zones, communities (habitats), and community composition reflect a gradient of environmental conditions. Large differences in environmental conditions result in different biological zones, smaller changes result in different communities, and yet smaller changes in differences in community composition. The natural environment is a continuum, which for the sake of practicality and description, man has grouped into recognizable assemblages of flora and fauna, which he defines as biological zones, habitats, and physical conditions.

3.2 BIOLOGICAL MODELS

The complex components, processes, interactions, and interdependencies characteristic of the living world are perhaps best described by a series of conceptual models which, together, outline the general and significant biology of the zones and habitats of the region. Such modeling techniques are treated in Volume 1 (the Conceptual Model) and constitute the basic approach of this study to the biological and ecological characterization of the study region.

Ecosystem models, food webs, community composition models, and succession models have been developed for a number of the zones and habitats of the region, as described in Chapter 3 of Volume 1 and as discussed further in Part 1 of Volume 3. In the following sections (3.2.1 and 3.2.4), detailed discussions of selected models are presented as examples of key habitats in the region.

A general discussion of regional biology requires separation of the study area into the categories of Inland, Coastal, and Oceanic following the outline given in Volumes 1 and 3. The ecology and biology of these separate areas differ markedly and require separate, although interfacing, treatment. The following discussion summarizes the region's biology and gives an overview for the presentation of habitat-specific information.

Inland. The inlands of the study region have been divided into the following zones: Arctic Alpine, True Fir, Western Hemlock, Sitka Spruce, Redwood, and Mixed Evergreen. All of these zones, excluding the Arctic Alpine, are dominated by coniferous tree species which make up the vast majority of the biomass and are the principal producers. Different conifer species dominate in different zones, although some species (particularly Douglas fir) are a major component in several of the zones. Other important conifers are redwood, Sitka spruce, western hemlock, silver fir, and western red cedar. Significant broadleaf trees, primarily relegated to successional conditions or stressed environments, are red alder, big-leaf maple, tanoak, and madrone.

The causes of the conifer dominance in this region, uncharacteristic of most forests in this latitude, has been reviewed by Franklin and Dyrness (1973). They contend that the dominance is in part caused by the regional climate pattern in which much of the precipitation falls during cold months (late fall, winter, and spring) and the winter temperatures during these wet months are relatively mild. These conditions concomitantly provide a competitive advantage to conifers, as they are able to photosynthesize during the cooler periods when precipitation is plentiful and are better able to withstand late summer dehydration stress. Deciduous broadleaf trees are at a disadvantage in the region as they must carry on all their productivity during the warmer months when dehydration stress can be severe.

Kuckler (1946), on the other hand, concluded that the structure of the present regional forests is based on climatic conditions over geologic time (the evolution of the forests since the Miocene) and not on prevailing current climatic conditions.

The above hypotheses are not mutually exclusive as appropriate historical conditions for the evolution of the current coniferous forests were essential to their establishment, while their continuation must be based on current environmental conditions.

Productivity in the region's forests is high, with estimates of primary production ranging from fifteen to twenty-five metric tonnes per hectare per year (6-10 long tons/a/yr). Likewise, regional standing biomass estimates are large, with maximum values in old growth in the vicinity of 1,600 to 2,300 metric tonnes per hectare (640-920 long tons/a); volume of timber produced is among the highest in the world (up to 36 metric tonnes/ha/yr or 14 long tons/ha/yr) (Franklin and Dyrness, 1973). A substantial portion of the carbon fixation through photosynthesis occurs during the cooler fall and winter months as noted above.

The explanations of this high forest productivity and large standing biomasses of the region are speculative. High productivity is related to a combination of high precipitation, moderate temperatures, and well-developed soils; moderate decomposition rates and leaching along with nutrient-conserving soils and fairly closed nutrient cycling systems also play a role in the high forest productivity.

Large standing biomass, great size, and longevity of the trees of the region's forests is thought to be related to at least three factors. The first is the forest gene pool which, unlike that in many other temperate areas, was not depleted during the Pleistocene (Silen Doig, 1976). The second factor is the region's lack of strong winds which frequently disturb and blow down forests in similar latitudes (e.g. typhoons of Asia, hurricanes of Eastern United States) (Fujimori, 1971). Fire is a third factor, a natural catastrophic event infrequent in the northern portions of the study area but more prevalent in the southern portions of the region. Tree species in the southern portions, particularly the redwood, have developed thick, fire-resistant, fibrous bark (Fowells, 1965). Consequently, older trees are seldom killed by fires which would destroy other species.

Revegetation and reforestation occur rapidly in the favorable environment of the region. Sites are typically revegetated in less than one year following disturbance and young forests are typically reestablished within twenty years of disturbance. However, successional sequences are slow and in some cases (e.g. redwood) may take 1,000 years or longer to reestablish a climax community (see Section 3.2.4.1). Revegetation and reforestation can be considerably slowed in some areas by localized environmental conditions and historical events.

Regional community changes are more marked on an east-west transect than on a north-south transect through the study area. Changes in communities north to south are slow and gradual. The rapid east-west changes in elevation and concomitant climatic and soil conditions produce relatively rapid changes in communities (see Section 3.1).

Terrestrial forest food webs are largely detrital, with grazing in most years representing only a small fraction of annual production. As a result, the ratio of consumer to producer biomass is very small (around 0.001:1).

Significant producers include the dominant tree species (as mentioned above) and major understory plants such as evergreen huckleberry, red huckleberry, salal, red elderberry, and salmonberry. A large number of herbaceous species contributed to the lush plant growth of the region.

Primary consumers in the forests are insects and slugs. Insects provide the food base for most forest bird species. Other significant primary consumers are the recreationally important black-tailed deer, Roosevelt elk, and black bear, as well as the mountain beaver, and brush rabbit. Beaver and muskrats are major primary consumers in aquatic and riparian habitats. Predators are the bobcat, mountain lion, coyote, and the short-tailed and long-tailed weasels. The river otter, mink, and raccoon are important wetland predators. Inland game species include pheasant, grouse, and numerous species of waterfowl also.

Rare, endangered, or threatened species of the regions' inlands include the endangered Columbian white-tailed deer, the Aleutian Canada goose, and the Peregrine falcon. In addition, the spotted owl is becoming rare and potentially threatened in Oregon, and the bald eagle, common along rivers and coastal forests, is nationally classified as endangered in California and threatened in Oregon and Washington. The Karok Indian snail, found in some Northern California ravines, is proposed for endangered status on the national list.

The rare wolverine is thought to occur in the southerly portions of the region as well as the rare white-footed vole. The Olympic mudminnow, a small fish endemic to a few watersheds in the Olympic Peninsula and the Siskiyou Mountain salamander are potentially threatened. The grizzly bear and wolf, once common, have disappeared from the region.

Lakes are uncommon in the study area. Many small rivers and streams occur in the region, as well as the Columbia (see Section 2.5). Runs of anadromous fish, particularly chinook and coho (salmon) and steelhead (trout), are common in all of the coastal watersheds and are significant to the biology as well as the socioeconomics of the area.

Coastal. As in all coastal areas, the coastal zones of this region are transitional, ecotonal areas between inland terrestrial zones and oceanic marine zones, and, in the case of estuaries, they represent the interface of freshwater aquatic, terrestrial inland, and marine environments. In ecological theory, such "edge" environments typically have greater diversity and abundances of organisms as species characteristic of all the environments involved are present as well as those specific to the interface areas (E.P. Odum, 1971).

The coastal communities of this region follow, at least to some extent, the "edge" hypothesis. For the small relative areas they cover, they represent locations where fauna concentrate, with high diversity of species. These zones are, to various degrees, inhabited by oceanic, inland, and, in the case of estuaries, freshwater species.

As transitional areas, coastal zones are often difficult to define in precise terms. A case in point, the Estuarine Zone, has been defined in a variety of ways (see Section 2.6 of the Model, Volume 1). For example, some authors define an estuary in terms of salinity while others consider morphology. The upstream inland boundary and the marine boundary on rocky shores or sandy beaches are, by necessity, vague and inprecise. One can arbitrarily define the outer limit of the shore zones at the intertidal/subtidal boundary, or at the edge of the Surf Zone where the influence of high energy waves are felt. As previously mentioned in discussions of biological zonation in this study, the boundaries between zones and communities are typically gradients.

In this study, the coast has been categorized into three major habitat types: estuaries, beaches and dunes, and headlands and rocky islands, each divided into zones by tidal relationships. The differences among these general types are both physical and biological. They have differing mass transport phenomena, energy conditions, and consequently, different ecosystems, species, and food webs.

The majority of the coast in the region is bordered by beaches. Associated dunes comprise major portions of the coast in Southern Washington and Northern and Central Oregon. Headlands are common in Northern Washington and intermittent along the entire coast. The three largest estuaries occur in Watershed Units 2 and 3, with Watershed Units 7 and 9 also having large estuaries. The major estuaries have associated beach and dune areas comprised of spits and other adjacent landforms.

The coastal zones are so varied that no particular species or groups of species dominate them all. European beach grass is common on the foredune. The diatom Chaetoceros armatum is abundant in some surf zones. Shore pine and Sitka spruce are found on the stabilized dune. The progression in the dunes is from small-bodied, rapidly-reproducing, primative plants to large, long-lived, woody plants. Similar radical changes in dominant producers occur in rocky shores and estuaries. Faunal changes follow suit, with razor clams giving way to shorebirds, giving way to upland song birds and small mammals along an elevation gradient relative to the tides.

Likewise, the members of food webs differ along the inland/marine gradient. The major primary consumers in the inland areas are insects, while other invertebrates (e.g. crustaceans and molluscs) dominate the second trophic level in the more marine areas. The ratio of consumer to producer biomass typically increases as one moves seaward, reflecting the shift to grazing food webs and/or fairly rapid turnover detrital food webs.

Net/primary productivity in the region's salt marshes is nearly as great as that of the inland forests. Standing crop biomass, however, is considerably less than forest communities (although greater than most marine and other estuarine communities), which is an indication of the rapid nutrient cycling in the estuary and the large export of detritus to other estuarine and oceanic habitats. Similarly, eelgrass beds support a much higher consumer biomass than terrestrial forests (although their primary productivity is significantly less than that of the forests) because of the fast turnover and large quantities of wrack and detritus exported to other communities.

Predators vary considerably over the coastal zone. The roles played by the cougar, coyote, and bobcat are replaced in salt marshes and deflation plains by raptors, and by fish, marine mammals, and sea birds in the aquatic portions of these zones.

Headlands and islands are important to a number of species which are essentially terrestrial forms that have "reinvaded" the marine ecosystems. Sea birds and marine mammals utilize these areas as resting and breeding sites, still being dependent, at least through part of their life cycle, on terrestrial environments.

The estuary's role on the West Coast for the major marine fisheries is not well documented. In other regions, estuaries are important as an exporter of detritus and as a rearing area for juvenile crustaceans and fish of commercial value (E.P. Odum, 1971). Detrital production must be considered low in this region as the extent of the estuarine environment for the Northwest Coast is low compared to the Gulf Coast or East Coast of North America. There is evidence of the significance of estuaries to crustaceans of economic importance in the region. Seaman (1977) and Isakson (1976C) report concentrated use of estuarine areas by juvenile Dungeness crabs. However, the same juvenile crabs also use shelf waters and it is not known whether the estuarine concentrations are critical to the major populations. Estuaries are important to species of crangon shrimp (e.g. Crangon nigricauda and C. franciscorum) for reproduction and growth (Krygier and Horton, 1975), and also harbor significant populations of other shellfish.

Estuaries are of particular significance as throughways for the commercially and recreationally valuable anadromous fish of the region. Salmon juveniles (coho and chinook) are reported to remain in estuaries for an interval following their downstream migration (see the chinook and coho life cycle figures in Part 2 of this volume). Estuaries are of importance to the white and green sturgeon where major portions of their populations reside (Hart, 1973; Moyle, 1976). Estuaries are also important to other anadromous fish such as striped bass and sea-run cutthroat trout which remain feeding in and near estuaries as adults.

Other important game species in the coastal areas are the waterfowl. Black brant, American widgeon, mallard, pintail, canvasback, and Canada goose are the major hunted species. Razor clams are harvested in large numbers from the Beach Surf Zone in portions of the region, and big game such as black-tailed deer and black bear visit the shoreline and estuarine communities while foraging for food.

Rare, endangered, or threatened species of the coastal environments include the endangered Columbian white-tailed deer, the Aleutian Canada goose, the Peregrine falcon, and the brown pelican. Newcomb's littorine, an estuarine snail reported from three of the study area's estuaries, and the rocky coast snail are proposed for threatened status on the national list. The snowy plover, which is found in low numbers along the coastal beaches, is listed as threatened in Oregon, and the bald eagle, which frequents the immediate coast and estuaries, is nationally classified as endangered in California and threatened in Oregon and Washington. The sea otter, recently reintroduced in two populations along the coast, is listed as threatened in Oregon.

Oceanic. The neritic and littoral portions of the ocean are those areas overlying (pelagic) and on (benthic) the continental shelf, respectively. This is the extent of the oceanic "zone" included in this study, although it comprises a very small portion of the oceans as a whole. The biological zones of this shelf region for purposes of this study have been designated as Euphotic and Disphotic Pelagic Zones and Vegetated and Non-vegetated Benthic Zones.

The ocean over the shelf is the most fertile part of the marine system. In this region natural shelf fertility is augmented by the process of upwelling which brings nutrient-rich water to the Euphotic Zone. This extra nutrient supply sustains high phytoplankton productivity in the region.

Unlike most terrestrial systems, oceanic food webs are principally populated by grazers. A major characteristic of these oceanic grazing food webs is a high consumer to producer biomass ratio. Data have not been analyzed for the shelf waters of this region, but in other marine systems a 1:1 ratio or larger is not extraordinary (E.P. Odum, 1971). Terrestrial systems of this region, in contrast, have around a 0.001:1 consumer/producer biomass ratio (Edmonds, 1974). In the Non-vegetated Benthic Zone, the food web lacks any producers and is strictly detrital, although the demersal fish may migrate into the Euphotic Zone and join the phytoplankton-based food web.

Another interesting comparison of coastal with terrestrial systems is the size and longevity of the producers. In the Euphotic Pelagic ocean the producers are all microscopic plankton with very short life spans, and in the Vegetated Benthic ocean the producers (kelp, other algae, and surfgrass) are mostly macroscopic with annual life spans. In inland terrestrial ecosystems the dominant producers are all macroscopic - often very large in the study region - and generally long-lived (to 1200+ years in redwoods). Colinvaux (1973) reviews hypotheses of the phenomenon of phytoplankton dominance in the pelagic ocean, which include 1) smallness resists sinking, 2) smallness increases surface area and thus aids in uptake of nutrients, 3) smallness resists drifting in winds and currents, and 4) smallness promotes rapid turnover and thus efficient use of resources. In the shallow ocean, just seaward of and overlapping into the Surf Zone, light is not a problem and firm anchoring against currents is possible, with the result being dominance of macroscopic producers.

A third significant characteristic of oceanic food webs is their complexity and number of overlapping trophic levels. The simple producer-herbivore-carnivore food web paradigm is typically elaborated, with a number of intermediate predators and overlapping roles. Phytoplankton (e.g. diatoms) are eaten by zooplankton (e.g. copepods), which are eaten by yet larger crustaceans (e.g. shrimp), small fish (e.g. anchovy), or baleen whales, which may be eaten by larger fish, marine mammals, or sea birds, which, in turn, are eaten by other marine mammals (e.g. killer whale) and sharks (e.g. blue shark).

Many of the groups mentioned above prey on several trophic levels. For example, killer whales feed on marine mammals, such as seals, as well as salmon and other fish which seals prey on. Similar behavior is found throughout the food web. In many cases prey size is the principal factor in determining food habits (Sverdrup et al., 1942).

The phenomenon of diel vertical migration of large numbers of Disphotic Zone consumers and the general circulation and intermixing of the oceanic water help to explain the close interconnections among the various oceanic zones and habitats of the region. These biological communities are probably more closely related than those in the inland or coastal areas, and the boundaries (as discussed in the coastal section above) are even more vague and overlapping.

Oceanic communities vary in relation to depth and substrate type as well as other factors. These zones and habitats are distributed more or less evenly over the entire north-south length of the study area, although the higher energy of the northern portions of the oceanic shelf cause more sandy bottom to occur there and muddy bottom to be more common to the south.

Major commercial and recreational finfish species in the region's oceanic shelf waters include the following, in order by landing weight: albacore (tuna), sole (all species), coho (salmon), chinook (salmon), rockfish (all species), sablefish (black cod), ling cod, and smelt (all species, including eulachon). Major shellfish species harvested from the shelf include shrimp and Dungeness crab.

Rare, endangered, or threatened species in the oceanic environment include the following whales: blue whale, Pacific right whale, Sei whale, fin whale, humpback whale, gray whale, and sperm whale, all of which are nationally listed as endangered. The sea otter, which is found in at least two reintroduced populations along the coast in the kelp bed habitat, is listed as threatened in Oregon. The endangered brown pelican appears infrequently in the oceanic zones of the region.

3.2.1 Ecosystems. The ecosystem model, as described in section 3.2.1 of Volume 1, represents the major physical-chemical, biological, and socioeconomic components of each component habitat, their interactions, and the significant inputs and outputs of matter and energy that flow through the system.

Five representative habitats have been singled out for detailed treatment as examples of the major different environments of the region: terrestrial (Old Growth Western Hemlock), estuarine (Emergent Vegetation and Eelgrass), shoreline (Unprotected Beach), and oceanic (Euphotic Pelagic). These models and the notes on their components and processes follow in that order.

3.2.1.1 Old Growth Western Hemlock Ecosystem Model Notes. The old growth western hemlock community was, in pre-logging periods, the most extensive plant community in the coastal region. This ecosystem is a prime example of a pristine forested community and is representative of old growth climax communities displaying: large standing biomass, reduced net primary productivity (compared to earlier seral communities), fairly closed nutrient cycling, and microclimate homeostasis. Unlike many other types of forests, large amounts of carbon are fixed during cooler periods. Typical of most forests, the food web is principally detrital, i.e. consumer organisms account for only a small portion of the standing biomass and most of the energy flows directly from producers to decomposers through litterfall.

Productivity, respiration, and decomposition in this ecosystem are modulated daily and seasonally. Likewise, community composition, consumption, and other aspects and processes of the ecosystem show seasonal cycles. Events which occur sporadically or over long cycles, such as insect epidemics, windstorms, or droughts, also have profound effects on the function and structure of the community.

The old growth forest can be considered a "mined" resource, as few forest management programs provide for cutting rotation periods of an adequate duration for the maintenance of old growth communities. This habitat, as well as the other old growth communities of the study area, has been cut from most easily harvestable lands and has provided the bulk of economic returns to the forest industry.

The following discussion deals with specific components, processes, and relationships of the old growth forest ecosystem as notes to the habitat model, Figure 3-4. Biological processes are discussed first, beginning with (1) photosynthesis/primary productivity, and continuing with (2) shading, (3) uptake, (4) nutrient input from precipitation, (5) nitrogen fixation, (6) secondary productivity, (7) community composition, (8) litterfall, (9) mortality, and (10) decomposition. Physical processes follow: (11) weathering, (12) base exchange, (13) leaching, (14) runoff and evapotranspiration, (15) erosion and mass wasting, (16) nutrient losses, and (17) detritus losses. Disturbance to the ecosystem (18) from logging or natural perturbations is discussed next, followed by other human activities: (19) harvest and (20) recreational use of habitat. Finally, succession (21) as both gains and losses of habitat is treated briefly, with reference to further discussion in the Succession Model of Section 3.2.4.1. (Note: C.C. in Figure 3-4 indicates Carrying Capacity.)

#1. Photosynthesis/Primary Productivity. A summarized equation for photosynthesis, as reported by E. P. Odum (1971, p. 56), is as follows:

1,300,000 Cal. radiant energy + 106 CO_2 + 90 H_2O + 16 NO_3 + 1 PO_4 + mineral elements

equals

13,000 Cal. potential energy in 3,258 gms protoplasm (106 C, 180 H, 46 O, 16 N, 1 P, 815 gms of mineral ash) + 154 O_2 + 1,287,000 Cal. heat energy dispersed (99%).

As the equation indicates, the process of photosynthesis uses radiant energy to form organic molecules containing potential energy from carbon dioxide, water, nitrate, phosphate, and trace nutrients.

In the ecosystem modeling (Figure 3-4) the actual inputs of carbon and other nutrients are not shown although it is understood that they are required. Carbon dioxide is taken from the atmosphere and the remaining nutrients are typically taken from the soil.

Photosynthesis, which is often measured as primary gross production, is a function of several factors including light energy, nutrient availability, temperature, and moisture. Deficiencies in any of these factors independently or combined can reduce realized photosynthetic activities. A daily pattern of photosynthesis is imposed by light availability, while a seasonal pattern imposed by light, moisture, and temperature also occurs.

The effects of temperature, radiation, and vapor pressure deficit on net photosynthesis for selected tree species is given in Figure 3-5. Note the change of efficiency and requirements for Douglas fir during different times of the year. Saturation of photosynthesis for these species occurs at 1.25 Langly. Other limiting factors to photosynthesis are shown in Figures 3-6 and 3-7. Note the peaking of productivity at about 19^{o}C and the relationship between temperature and radiation.

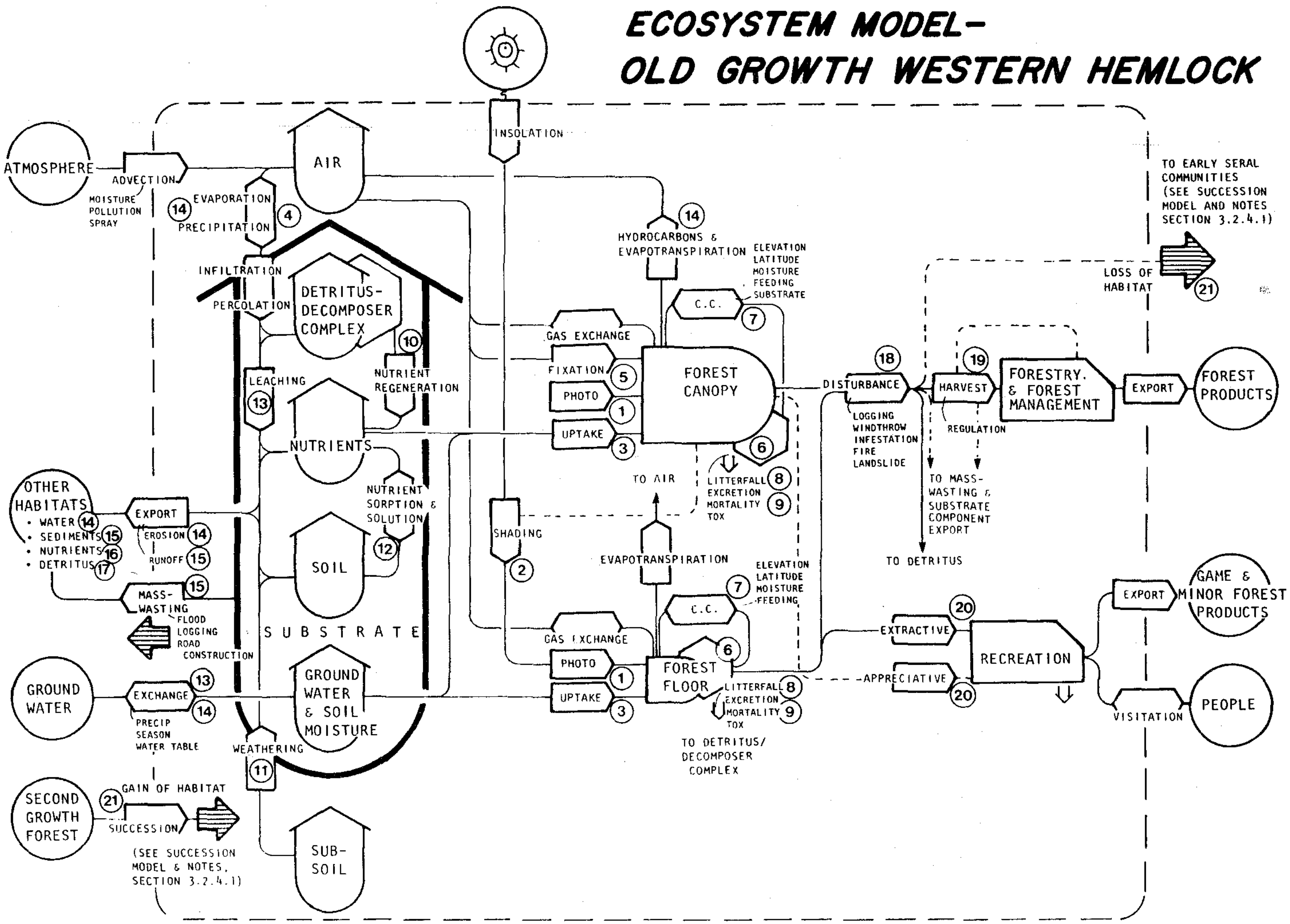


FIGURE 3-4. OLD GROWTH WESTERN HEMLOCK ECOSYSTEM MODEL.

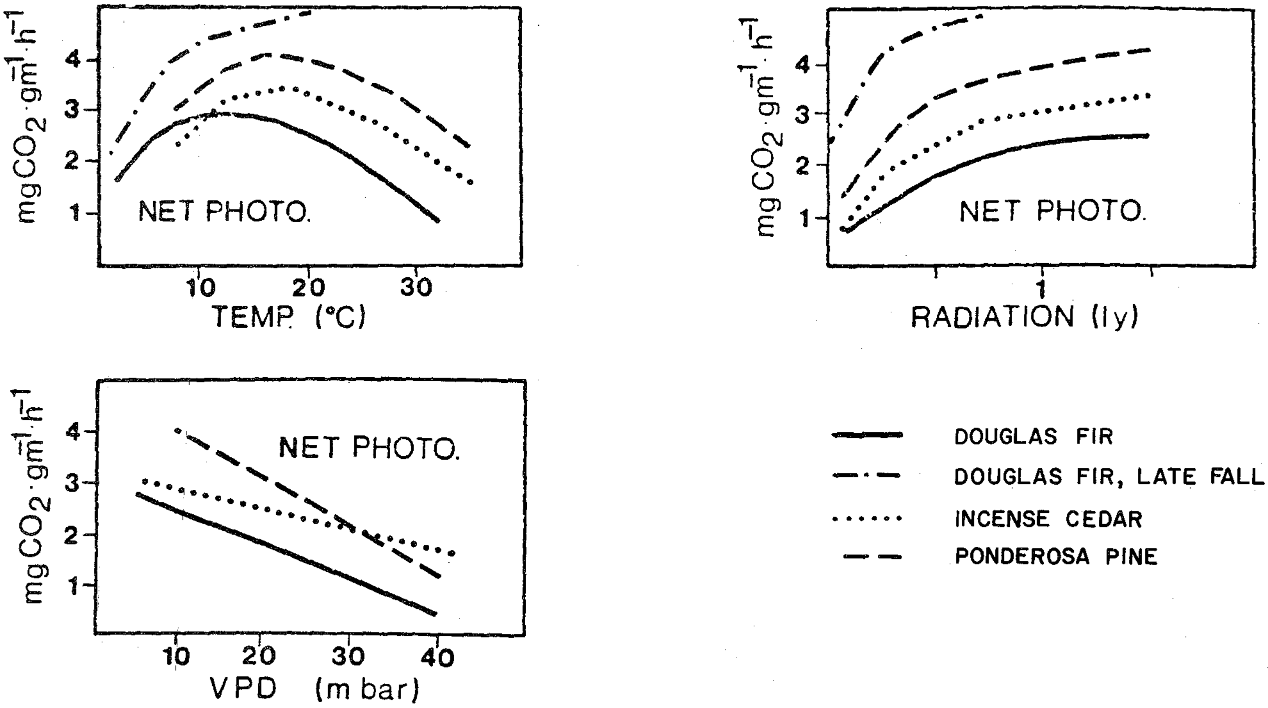


FIGURE 3-5. NET PHOTOSYNTHESIS AS A FUNCTION OF TEMPERATURE, RADIATION, AND VAPOR PRESSURE DEFICIT (V.P.D.) FOR THREE CONIFER SPECIES IN CALIFORNIA IN MILLIGRAMS CO_2 PER GRAM PER HOUR. Note that Ponderosa pine is not typical of the study area. Vapor pressure, the diffusion pressure of water, is measured in millibars (m bar) of mercury. A Langley (ly) is a unit of irradiance and equals 1 g cal/cm^2. (From Edmonds, 1975.)

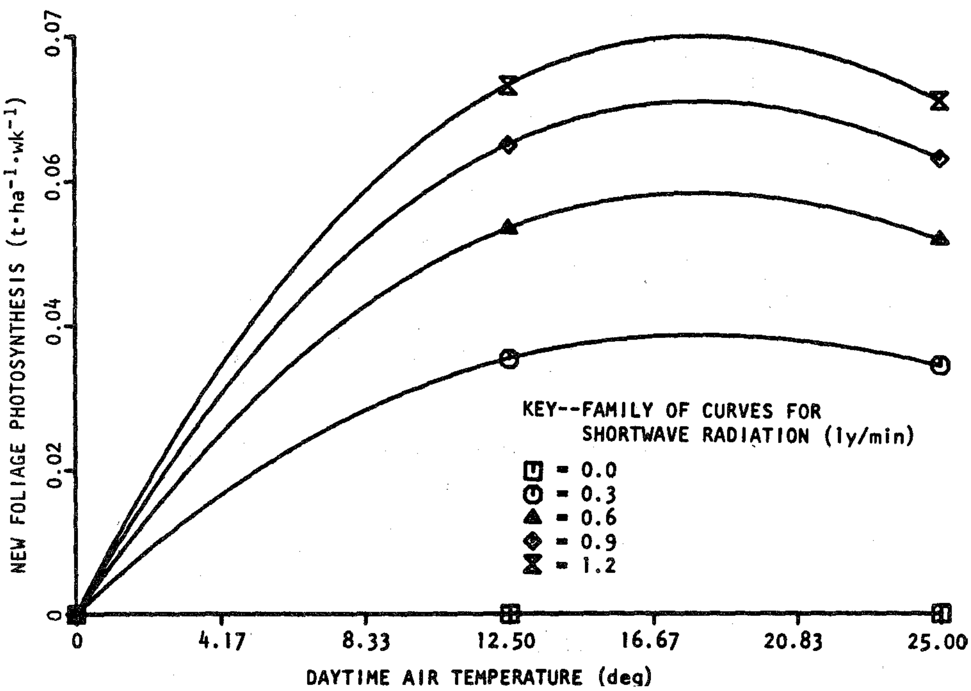


FIGURE 3-6. PHOTOSYNTHESIS BY NEW FOLIAGE OF DOUGLAS FIR AS A FUNCTION OF DAYTIME AIR TEMPERATURE AND MEAN SHORTWAVE RADIATION INPUT TO CANOPY. Held constant: foliage biomass = 5.0 t/ha, soil moisture = 3500 m^3/ha, day length = 0.5. (From Coniferous Forest Biome Modeling Group, 1977.)

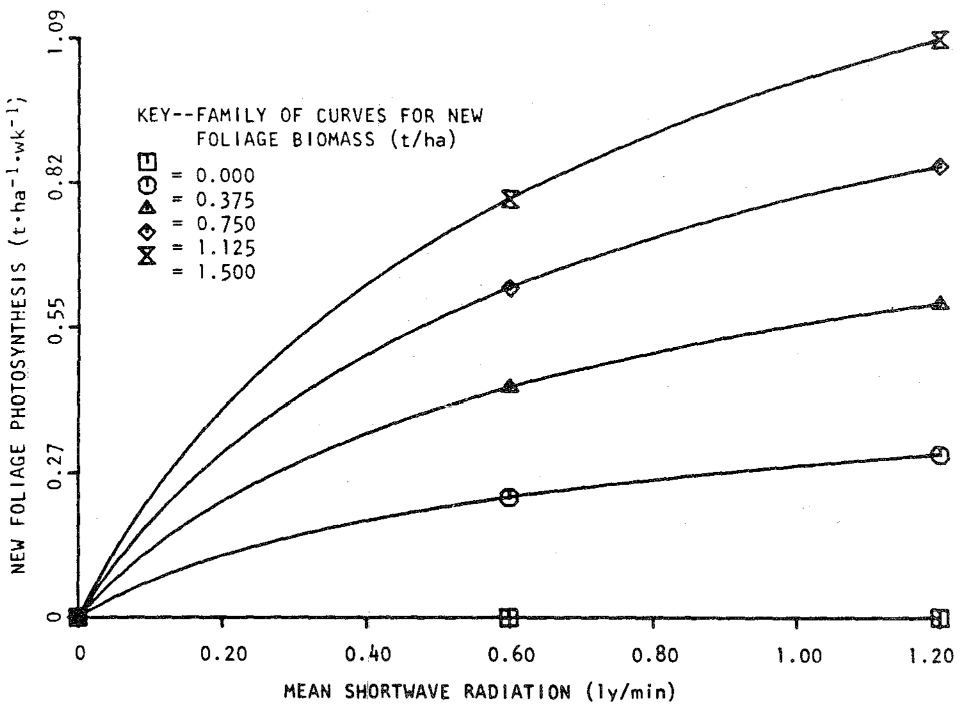


FIGURE 3-7. PHOTOSYNTHESIS BY NEW FOLIAGE OF DOUGLAS FIR AS A FUNCTION OF MEAN SHORTWAVE RADIATION INPUT TO CANOPY AND NEW FOLIAGE BIOMASS. Held constant: old foliage biomass = 4 t/ha, soil moisture = 3500 m^3/ha, air temperature = 15°C, day length = 0.5. (From Coniferous Forest Biome Modeling Group, 1977.)

3.2.1.1 Old Growth Ecosystem Model Notes (continued)

During different periods of the year photosynthesis is limited as indicated in Figure 3-8. Temperature and moisture affect photosynthesis by Douglas fir on a seasonal basis. Summer production is generally limited by moisture, while photosynthesis in fall, winter, and spring is more apt to be limited by temperature. Edmonds (1975)[1] reports that efficiency for a given level of light input is the greatest during fall and winter.

Nitrogen is generally the limiting nutrient for photosynthesis of coniferous forests in the study area (Gessel et al., 1969). Edmonds (1974)[1] reports that nitrogen fertilization of Douglas fir improves only the photosynthetic rate of new growth, and then only during periods of rapid growth. The photosynthetic response decreases considerably after the second year but growth continues to accelerate for a year to two with application of fertilizers. Edmonds (1975) provides some general relationships between nitrogen and foliage (Figure 3-9) and between nitrogen and wood growth (Figure 3-9) for coniferous forests of the study area.

Primary productivity is high in forested ecosystems within the region (Franklin and Dyrness, 1973). Selected sites produce as much as 36.2 metric tonnes per hectare of biomass per year (Fujimori, 1971), although 15-25 metric tonnes/hectare/year are more typical figures on better than average sites (Franklin and Dyrness, 1973), and values as low as 4.2 metric tonnes/hectare/year have been reported for old growth (Grier et al., 1974). Lieth and Box (1972) calculated a range of 15 to 21 metric tonnes/hectare/year based on evapotranspiration data for the region. Preliminary information on net productivity of Northwest coniferous forests compared to other ecosystems is indicated in Table 3-2.

---

[1] Edmonds (1975) and Edmonds (1974) are summaries and reports of ongoing International Coniferous Forest Biome Project research being conducted by numerous researchers. A list of publications identifying various research areas is provided by Edmonds (1977) and by annual directories published by the U. S. National Committee of the International Biological Program.

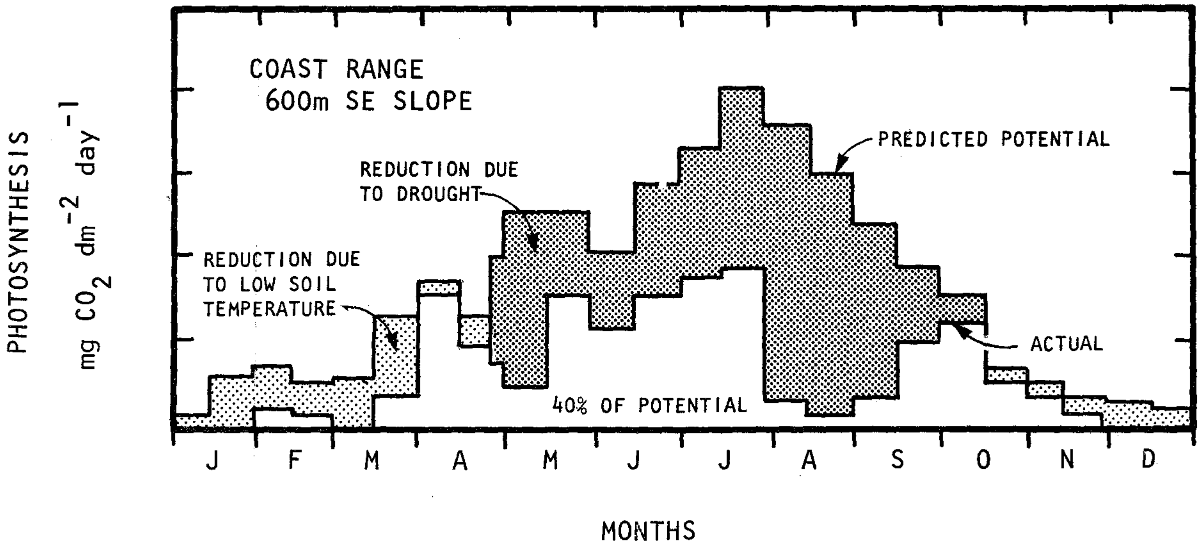


FIGURE 3-8. PREDICTED POTENTIAL AND ACTUAL PHOTOSYNTHESIS OF DOUGLAS FIR IN COASTAL OREGON. (From Edmonds, 1974.)

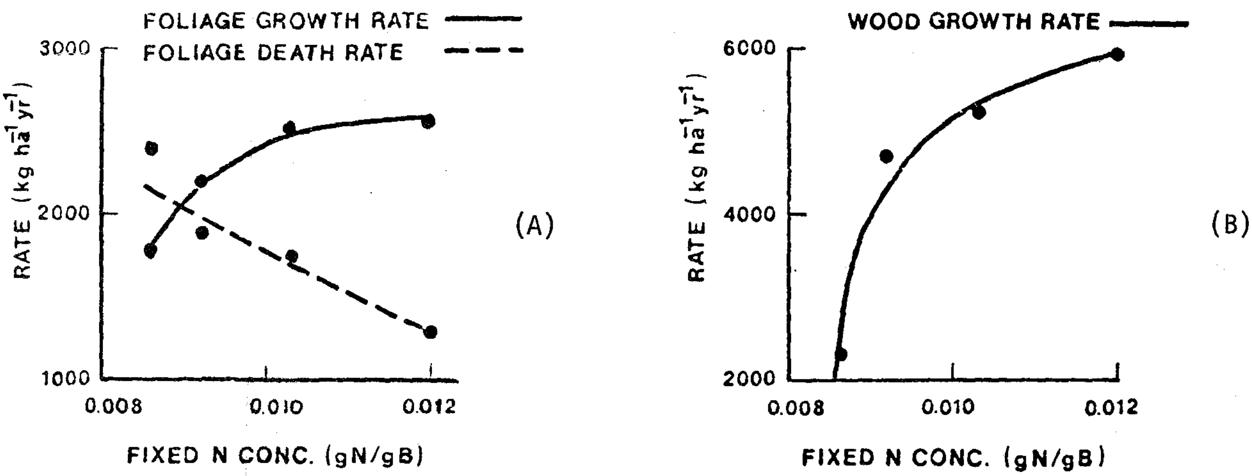


FIGURE 3-9. RELATIONSHIPS BETWEEN NITROGEN CONCENTRATION AND (A) FOLIATE AND (B) WOOD GROWTH FOR CONIFEROUS FOREST. N = total nitrogen, B = biomass. (From Edmonds, 1975.)

TABLE 3-2. NET PRIMARY PRODUCTION IN GRAMS OF CARBON PER SQUARE METER PER YEAR. (After U.S. National Committee for the International Biological Program, 1974.)

Coniferous Forest	Deciduous Forest	Grassland	Tundra
640	680	370	88

#2. Shading. As discussed in Note #1 (above), insolation is critical to primary productivity. Shading by overstory (canopy) species largely controls the relative degree of understory productivity on a given site. Concomitantly, annual species dependent on understory vegetation (and the food webs based on them) are similarly affected. In a young, vigorous forest the canopy is largely closed and little light reaches the understory. Hence, the understory vegetation plays an insignificant role in productivity or nutrient cycling (Cole et al., 1975). In old growth forests the canopy is opened to some extent by mortality of the dominant trees. The result is increased productivity and nutrient cycling in the understory (Grier et al., 1974).

An additional role of shading is its effect on regeneration. Only trees which are tolerant to low light intensities are able to reproduce under these conditions. Western hemlock and western red cedar are able to propagate in old growth forests while Douglas fir and red alder are unable to do so except in isolated openings (Fowells, 1965).

#3. Uptake. Photosynthesis and growth in plants require nutrients which are typically gained through ionic transport from the soil nutrient solution. At least thirteen mineral nutrients ranging in concentrations from parts per thousand for nitrogen and phosphorus to parts per million for copper are essential for forest growth in the region (Gessel et al., 1973), and become part of the biomass (Edmonds, 1974). The major carrier for nutrient ions is water and its presence is essential to the uptake and cycling process.

Symbiotic mycorrhizal fungi, which are poorly known for the study area are significant in the uptake process. J. Trappe and B. Zak have been collecting information on mycorrhizal relationships of species within the region. A bibliography is provided by Pacific Northwest Forest and Range Experiment Station (1977).

Leaf et al. (1973) summarized the following advantages of mycorrhizal associations:

1. Increased uptake of nutrients (particularly phosphorus) from the soil. The nutrient absorbing surface and the ability to extract difficultly-available nutrients from the soil are both increased over that of root hairs.
2. Increased water uptake from soil and thus greater resistance to drought.
3. Increased protection from pathogens through both mechanical and chemical means. Certain mycorrhizal fungi produce potent antibiotics *in vivo* (Marx, 1969).
4. Increased ability of the host to tolerate high soil temperatures. Certain mycorrhizal fungi can tolerate quite high temperatures themselves and it has been shown that the plants with which they are associated can also survive and grow under conditions which would not be tolerated by the same plants were they either non-mycorrhizal or mycorrhizal with other fungi (Marx et al., 1970). The practical application of this function will be tested soon in the reforestation of coal spoils on which trees have previously failed to survive.

In addition, several authors (Voigt, 1965; Weed et al., 1969) report that movement of ions from a mineral lattice to the absorbing surface of roots is promoted by mycorrhizal fungi and other rhizospheric and soil microorganisms. These microorganisms release metabolic by-products which increase the solubility of mineral lattice ions, thereby enhancing weathering of minerals and uptake of nutrients.

Trappe and Strand (1969) have documented that fumigation in nurseries has killed beneficial mycorrhizal fungi and resulted in stunted, sickly seedlings. Work is in progress (Zak, 1975) which has resulted in innoculating container seedlings with appropriate mycorrhizal fungi.

An interesting species interraction dealing with uptake and symbiotic relationships is described by Zak (1976). Foresters have noticed that two plant species, bearberry and Pacific madrone, are good "nurse" species for pine and Douglas fir reproduction. The beneficial relationship is based on compatible mycorrhizal fungi of the bearberry and madrone. The seedlings of pine and Douglas fir are able to utilize the established mycorrhizal system. Other species, e.g. vine maple, find the mycorrhizal fungi incompatible and their seedling must compete directly for nutrients.

Leaf et al. (1973) report that mites and collembolas (springtails) are important vectors in the spread of mycorrhizal fungi colonization. Maser (Anon., 1977) and Fogel and Trappe (1978) report a similar function by mycophagous (fungi-eating) small mammals within the study area.

Uptake rates are not available for old growth western hemlock forests. The following data for uptake and nutrient cycling (of selected nutrients) are from old growth Douglas fir in the Western Hemlock Zone in the Oregon Cascades.

Uptake rates vary seasonally and are less for old growth Douglas fir than for younger coniferous or deciduous forests (Edmonds, 1974). It is thought that climax western hemlock has even less of a nutrient demand than old growth Douglas fir. In general, nutrient requirements and uptake for old growth coniferous forests are low compared to second growth forests and other forests of the United States. Nutrient requirements seem to peak at forest stands of 75 years of age and decrease thereafter (Edmonds, 1974).

Since nutrient cycling is best treated as a complete process, a model is presented in Figure 3-10 for four nutrients and includes precipitation, litterfall, and leaching. Discussions of these processes and nitrogen fixation are in the following section. More detailed data on the four nutrients of Figure 3-10 in different parts of the coniferous forest ecosystem are presented in Table 3-3.

TABLE 3-3. NITROGEN, PHOSPHORUS, POTASSIUM, AND CALCIUM CONTENTS OF THE VEGETATION, LITTER, AND SOIL IN AN OLD GROWTH WESTERN HEMLOCK ZONE ECOSYSTEM. These data are from Watershed 10 in the H. J. Andrews Experimental Forest, which is located outside the study area on the western slope of the Cascades east of Eugene, Oregon. (From Edmonds, 1974.)

System Component	Dry wt. (kg/ha)	Nutrient Content (kg/ha)			
		N	P	K	Ca
Overstory					
Foliage	8,906	74.8	20.4	69.5	92.6
Branches	48,543	48.6	10.2	48.6	243.3
Bole	472,593	189.0	11.8	122.8	283.5
Roots	74,328	62.4	5.2	20.8	96.6
Understory					
Large shrubs					
Foliage	1,604	16.8	2.2	5.3	10.1
Stems	4,834	8.3	3.3	7.1	20.8
Small shrubs					
Foliage	1,991	17.0	2.1	8.6	11.0
Stems	270	0.7	0.2	0.6	0.8
Herb layer	65	0.9	0.3	1.4	0.7
Epiphytes	1,100	13.5			
Total vegetation	614,344	432.0	55.7	284.7	759.4
Litter layer					
Surface layers	43,350	433.5	61.1	49.8	363.3
Logs	55,200	132.5	8.6	20.1	80.1
Soil (0-100 cm)	79,250	4300.0	29.0[a]	1200.0[b]	5500.0[b]
TOTAL ECOSYSTEM	792,144	5298.0	154.4	1554.6	6702.8

[a]Exchangeable phosphorus.

[b]Ammonium acetate extracted.

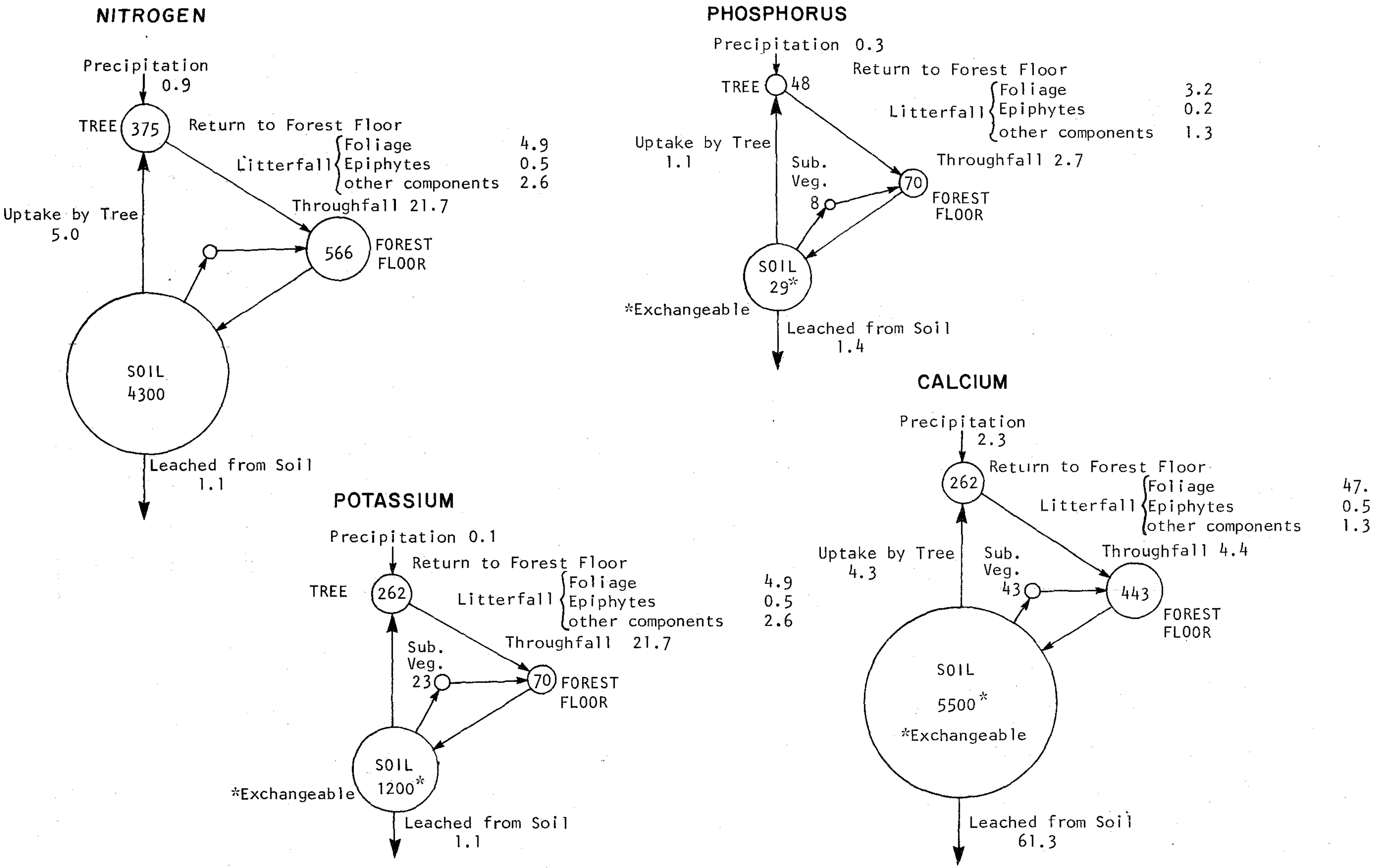


FIGURE 3-10. DISTRIBUTION AND CYCLING OF NITROGEN, PHOSPHORUS, POTASSIUM, AND CALCIUM IN AN OLD GROWTH DOUGLAS FIR ECOSYSTEM. Data are from the H. G. Andrews Experimental Forest, Oregon (on west slope of Cascades outside the study area). Nutrient capitals and flows are kg/ha and kg/ha/year, respectively. (From Edmonds, 1974.)

#4 and #5. Nutrients from Precipitation and Nitrogen Fixation. Nutrient inputs from precipitation are indicated in Figure 3-10 and are relatively low. Data specific to the Coastal Range are not readily available; however, due to salt spray and greater precipitation in the study area, volumes of these nutrients in rainfall should be greater. Edmonds (1974) reports that large quantities of nitrogen, phosphorus, and other nutrient cations as well as sodium and chloride ions are introduced by sea spray. The extent of this input is unknown.

A potentially significant input of nitrogen in old growth is through nitrogen-fixation by some epiphytic lichens. General epiphytic fall has been measured at 6.7 percent of the nitrogen of total litterfall (Edmonds, 1974) - an input of 5.6 to 12.8 kg/ha of nitrogen per year - but preliminary studies of Lobaria oregana, the most abundant macrolichen in old growth canopies (Pike et al., 1972), indicate a nitrogen-fixing potential, the only documented fixation in old growth (Denison et al., 1976). However, old growth is a relatively closed nutrient cycling system and this input of nitrogen is probably not critical.

Studies are currently under way to better document this phenomenon (Denison, personal communication). These inputs probably do not occur in second growth coniferous forests, as slow-growing lichens such as Lobaria species do not make up significant biomass. The sensitivity of epiphytic lichens to air pollution is well documented (Ferry et al., 1973; Denison and Carpenter, 1973).

#6. Heterotrophic (Secondary) Productivity. Forest ecosystems typically put much of their productive capacity into wood, and have detritus-based food webs with energy flow dominated by the plant to detritus chain (E. P. Odum, 1971). Preliminary data concerning heterotrophic (consumer) respiration for the study area's coniferous forests compared to other ecosystems are provided in Table 3-4.

TABLE 3-4. CONSUMER RESPIRATION IN GRAMS OF CARBON/m^2/YR. (From U.S. National Committee for the International Biological Program, 1974.)

Coniferous Forest	Deciduous Forest	Grassland	Tundra
370	520	199	88

For an old growth Douglas fir forest canopy, Strand (1974) reports an estimated 1.6% of net primary production (42.5 kg/ha/year) is consumed by grazing insects. A very small portion, 0.05% or 1.2 kg/ha/year, is taken by birds, principally as seeds. At high tree densities, circa 5 individuals/ha, Roosevelt Elk and black-tailed deer consume as much as 1.9 kg/ha/day and 0.6 kg/ha/day, respectively. In an old growth system density should be closer to 0.05 individuals/ha with consumption being reduced an order of magnitude, or a combined consumption of about 90 kg/ha/year. The reader is cautioned that these are very rough estimates that do not take into account seasonal changes in population densities or food requirements. The role of small mammals as consumers in forested ecosystems of the region has not been studied. Energetics of small mammals in grassland ecosystems have been reported (French et al., 1976; Koplin, personal communication, 1978) but generalization to Pacific Northwest forested systems is questionable. Densities and food habits of mammals have been documented (Whitaker and Maser, 1976; Fogel and Trappe, 1978; Hooven, 1977; Hooven and Black, 1976; and others) but translation into energetics has not been reported. Small mammal populations are often cyclic, and have been documented in grassland habitats within the study area (Koplin, 1978, personal communication, Department of Biology, Humboldt State University, Arcata, California). Hooven and Black (1976) provide some preliminary evidence of population fluctuation for the California red-backed vole in old growth forest. Likewise, the role of grazing invertebrates in the forest floor food web is not well known. Richter (1976) reports the consumption of approximately 31 kg/ha/year by a single species, the banana slug (Ariolimax columbianus), for a lowland second growth forest west of the Cascades dominated by an understory of braken fern, a preferred slug food species.

Percentage of primary productivity consumed in terrestrial ecosystems has been measured and modeled at 1.5% to 20%, the low figure for eastern deciduous forests (Bray, 1964) and the high figure for an old field ecosystem (Odum et al., 1962.). Forested ecosystems within the region typically have consumption rates which are at the lower end of the previously mentioned scale. Under normal conditions grazing webs represent only a small portion of production in forested ecosystems. A much greater proportion of net primary productivity is consumed with the occurrence of insect blights (e.g. black-headed budworm, hemlock looper, etc.). Under epidemic conditions a forest can be completely defoliated, representing greater than 300% of net primary productivity (Strand, 1974). Such epidemics, particularly if followed by a secondary invasion of boring insects, can result in extensive kills and initiation of early seral conditions and a succession pattern.

Weins and Nussbaum (1975) report that energy flow for the avifauna of Oregon West Cascades and Coastal forests varies from 10.5 to 20.8 Kcal/square meter/breeding season, with 30% of their intake as animal prey. Although bird standing biomass is typically two or three times greater in coniferous forests than grasslands, energy flow is nearly ten times as great (Weins, 1975). Lower body temperature, requiring greater metabolic activity, and the generally smaller size of the forest birds are thought to be the causal factors.

Biomass of consumers compared to producers in a forest ecosystem is very low. Canopy consumer biomass is estimated to be less than 1 kg/ha (Strand, 1974). Biomass of large mammals at high population levels is estimated at 5-11 kg/ha (Taber, 1973) and small mammals at 0.2 kg/ha (Edmonds, 1974). Slug biomass has been measured at 35 kg/ha (Richter, in press); however, they have a dual role as grazers and decomposers. Even with generous estimates, biomass of consumers is no greater than 50 kg/ha and comprises less than one-tenth of one percent of the standing biomass in an old growth forest. In early sere conditions, proportion of consumer biomass is significantly greater.

#7. Community Composition. Communities in forested environments of the study region are dominated by vascular plants (particularly trees) which make up 99.9% or more of the biomass. Consumers make up less than 0.01% of the total biomass (Edmonds, 1974). In contrast, the number of individual consumers, as well as the number of species, is greater than that of primary producers. In predominantly grazing systems the proportion of consumers increases and may be greater than 50% of the biomass (E. P. Odum, 1971).

Community composition for a generalized Old Growth Western Hemlock forest is provided in the Community Composition Model in Volume 3. Several factors influence community composition of old growth, the most apparent of which is moisture. Types of old growth stands related to moisture for the Western Hemlock Zone are provided in Table 3-5. (See Table 3-36 and related discussion in Section 3.2.4.1 for more details.)

TABLE 3-5. HYPOTHESIZED CLIMAX ASSOCIATIONS FOR THE WESTERN HEMLOCK (TSUGA HETEROPHYLLA) ZONE IN WESTERN OREGON ARRANGED ALONG A MOISTURE GRADIENT FROM DRY (TOP) TO WET (BOTTOM). (From Franklin and Dyrness, 1973.)

Pseudotsuga menziesii/Holodiscus discolor/Gaultheria shallon	DRY
Tsuga heterophylla/Acer circinatum/Gaultheria shallon	↓
Tsuga heterophylla/Rhododendron macrophyllum/Gaultheria shallon	↓
Tsuga heterophylla/Rhododendron macrophyllum/Berberis nervosa	↓
Tsuga heterophylla/Gaultheria shallon-Polystichum munitum	↓
Tsuga heterophylla/Polystichum munitum	↓
Tsuga heterophylla/Polystichum munitum-Oxalis oregana	WET

The change in vegetation cover will be reflected by a change in the dependent consumers. Some consumers are broad-niched and are able to exist in a wide variety of conditions (e.g. the common crow), while others (e.g. the spotted owl) are dependent on a specific habitat type such as old growth. Table 3-6 presents a list of such narrow-niched fauna from various sources.

The Annotated Species List provides an indication of the niche broadness of the species within the forested inland zones by indicating which habitat(s) specific species utilize.

The community of insects associated with dead or dying trees plays an important role in establishing forest composition as they destroy damaged or weakened trees, thereby reducing competition for resources among the remaining healthy trees (Deyrup, 1975). Typically these insects attack moribund trees; however, they also attack trees under temporary stress, thereby killing essentially healthy trees. Insects can reproduce to epidemic levels in areas of downed timber caused by windthrow or forest fire and go on to attack neighboring healthy trees (Furnis, 1941). Meslow and Wight (1975) and Wight (1974) document use of old growth by birds in Oregon west of the Cascades (see Succession Model, Figure 3-53, Section 3.2.4.1).

TABLE 3-6. WILDLIFE SPECIES IN THE REGION WHICH REQUIRE MATURE FOREST HABITATS FOR ALL OR A SIGNIFICANT PORTION OF THEIR LIFE CYCLE. (From USDA, 1976B; Silovsky and Pinto, 1974.)

Species	Species
BIRDS	Townsend's warbler[1,3] (migrant)
Great blue heron[3]	Hermit warbler[3]
Goshawk[1]	Western tanager[1]
Red-tailed hawk[1]	Black-headed grosbeak[1]
Osprey[1]	Evening grosbeak[1]
Great horned owl[1]	Pine siskin[1]
Spotted owl[1]	Red crossbill[1]
Saw-whet owl[1]	AMPHIBIANS
Vaux's swift[1]	Pacific giant salamander[1,3]
Pileated woodpecker[1]	Ensatinia salamanders[1]
Yellow-bellied sapsucker[1]	(Oregon ssp., painted ssp.)
Williamson's sapsucker[1,2]	California slender salamander[1]
Hairy woodpecker[1]	Clouded salamander[1]
White-headed woodpecker[1,2]	Foothill yellow-legged frog[1]
Black-backed 3-toed woodpecker[1,2]	Tailed frog[3]
Northern 3-toed woodpecker[1,2]	REPTILES
Hammond's flycatcher[1]	Northern alligator lizard[1]
Common raven[1]	Mountain kingsnake[1]
Clark's nutcracker[1,2]	MAMMALS
Gray jay[3]	Deer mouse[1]
Mountain chickadee[1]	Bushy-tailed woodrat[1]
Chestnut-backed chickadee[1]	Porcupine[1]
White-breasted nuthatch[1]	Pacific shrew[1,3]
Red-breasted nuthatch[1]	Coast mole[1]
Pygmy nuthatch[1,2]	Long-eared myotis[1]
Brown creeper[1]	Northern flying squirrel[1]
Winter wren[1]	White-footed vole[1]
Varied thrush[1,3] (migrant)	Red tree mouse[1]
Hermit thrush[1]	Western red-backed vole[1]
Golden-crowned kinglet[1]	Marten[1]
Ruby-crowned kinglet[1]	Fisher[1]

1 For USDA Siskiyou National Forest (USDA, 1976B).

2 Rare on the Siskiyou National Forest, if present.

3 Documented by Silovsky and Pinto (1974) for Siuslaw National Forest.

For the more conspicuous forest floor wildlife, community composition is controlled by the degree of canopy closure. A partially open canopy allows light to reach the understory thereby providing forage for ground dwelling foragers (e.g. black-tailed deer) and other organisms.

The occurrence of snags, snag-topped trees, and/or cavity trees plays an important role in the distribution of some canopy species, such as spotted owl and flying squirrel. Table 3-7 presents a list of some birds and mammals from this region that are either wholly or partially dependent on snags.

TABLE 3-7. WILDLIFE SPECIES IN THE REGION WHICH DEPEND ON DEAD AND DEFECTIVE TREES (SNAGS). (From USDA 1976A, Wight, 1974, and Silovsky and Pinto, 1974.)

Totally or heavily dependent

BIRDS	MAMMALS
Bufflehead[2]	Marten[1,2,3]
Barrow's goldeneye[2]	Fisher[1,2]
American goldeneye[2]	Raccoon[1]
Wood duck[1,2,3]	Chickaree[1]
Common merganser[2]	Western gray squirrel[1]
Hooded merganser[1,2,3]	Northern flying squirrel[1,2,3]
Rough-legged hawk[1]	
Ferruginous hawk[1]	
Red-tailed hawk[1,3]	
Swainson's hawk[1]	
Golden eagle[1]	
Bald eagle[1,3]	
American osprey[1]	
Peregrine falcon (duck hawk)[1]	
Merlin (pigeon hawk)[1]	
Kestrel (sparrow hawk)[1,2,3]	
Screech owl[1,2,3]	
Spotted owl[1,2,3]	
Saw-whet owl[1,2,3]	
Flammulated owl[1,2]	
Pygmy owl[1,2,3]	
Vaux's swift[1,3]	
Common flicker[1,3]	
Pileated woodpecker[1,2,3]	
Acorn woodpecker[1]	
Lewis' woodpecker[1,2,3]	
White-headed woodpecker[1,2]	
Red-shafted flicker[2]	
Yellow-bellied sapsucker[1,2,3]	
Williamson's sapsucker[1,2]	
Hairy woodpecker[1,2,3]	
Downy woodpecker[1,2,3]	
Black-backed 3-toed woodpecker[1,2]	
Northern 3-toed woodpecker[1,2]	
Ash-throated flycatcher[1]	
Tree swallow[1,2,3]	
Purple martin[1,3]	
Black-capped chickadee[1,2,3]	
Mountain chickadee[1,2,3]	
Chestnut-backed chickadee[1,2,3]	
Plain titmouse[1]	
White-breasted nuthatch[1,2]	
Red-breasted nuthatch[1,2,3]	
Pygmy nuthatch[1,2]	
Western bluebird[1,2,3]	
Mountain bluebird[1,2]	

Partially dependent

BIRDS	MAMMALS
Common merganser[1]	California bat[1,2]
Band-tailed pigeon[1]	Little brown bat[1,2]
Barn owl[1]	Big brown bat[1,2]
Violet-green swallow[1]	Ringtail[1]
Brown creeper[1,2]	Western harvest mouse[1]
House wren[1,2]	Deer mouse[1]
Winter wren[1,3]	Red tree mouse[1,2]
Bewick's wren[1,3]	Bushy-tailed woodrat[1]
Townsend's solitaire (in stumps)[1]	Porcupine[1]
Starling[1]	
House finch[1]	
English sparrow[1]	

[1]Listed by USDA (1976A) for Siskiyou National Forest.
[2]Listed by Wight (1974) for Western Oregon.
[3]Listed by Silovsky and Pinto (1974) for Siuslaw National Forest.

#8. Litterfall. Litterfall data for specific nutrients are provided in Figure 3-8 and in the discussion of Uptake (Note #3). Litterfall in old growth forests is greater than in second growth, with a greater amount coming from understory vegetation. Biomass of litterfall for an old growth Douglas fir forest is shown in Table 3-8.

TABLE 3-8. BIOMASS OF LITTERFALL FOR AN OLD GROWTH DOUGLAS FIR FOREST. (From Edmonds, 1974.)

Annual Litterfall	Dry wt. (kg/ha)
Foliage	
Overstory	1,480
Understory	1,800
Logs and branches	3,100
TOTAL LITTERFALL	6,380

Litterfall also nas a temporal component which is illustrated by Figure 3-11. Note the different peaks for different forms of litter.

Note that "litterfall" from consumers (feces and carcasses) is small compared to inputs from the producers, indicating the dominance of the producer over the detritus food web of old growth coniferous forests. Insect frass, spores, and carcasses provide an input of only about 3.8 kg/ha of nitrogen to the forest floor (Edmonds, 1975).

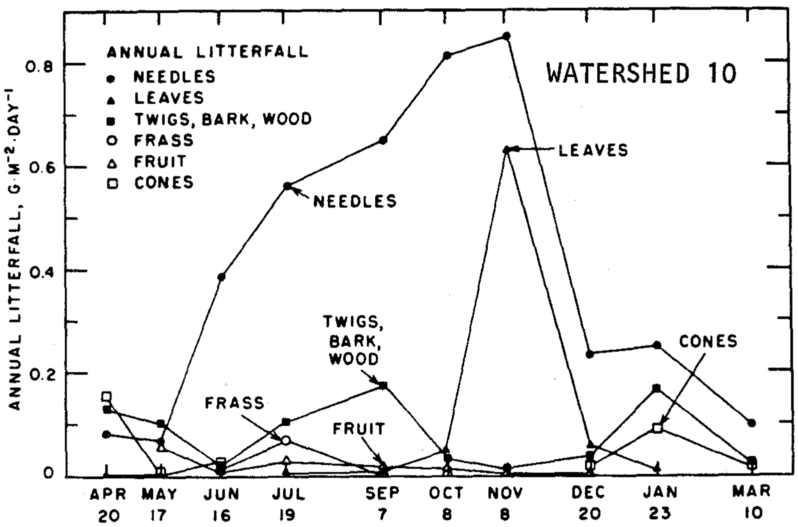


FIGURE 3-11. ANNUAL LITTERFALL IN AN OLD GROWTH CONIFEROUS FOREST BY GENERAL FORM. (From Edmonds, 1974.)

#9. Mortality. Factors, which cause mortality in vegetation for old growth western hemlock aside from harvesting, are windthrow, fires, landslides, insect attacks, fungi, and other diseases, as well as anomalous climatic conditions such as droughts or extended periods of temperatures atypical to the zone. These factors are significant in other types of forests in the region.

The most serious killing agents in old growth trees are heart rots and root rots. Of these, the fungi Poria werii and Fomes pini are the most serious in old growth western hemlock, Douglas fir, and western red cedar. Other Fomes, Poria, and Polyporus species also attack old growth. Dwarf mistletoe can cause mortality to old growth western hemlock trees. Western red cedar is the least susceptible to fungus-induced mortality (Fowells, 1965).

Insects are important agents of mortality for Douglas fir and western hemlock. The Douglas fir beetle and the flat-headed borer (in order of relative significance) have caused extensive kills in old growth Douglas fir. The hemlock looper is probably the most serious killing insect in western hemlock, although the western larch round-headed borer is a serious secondary invader of trees that have been defoliated by other insects. Insect epidemics can originate from insect invasions of fire-killed trees or blow-downs. Western red cedar old growth is not seriously affected by insect attack (Fowells, 1965).

Ground fires cause heavy mortality in western red cedar and, to a lesser extent, western hemlock. Old growth Douglas fir has thick bark which is fire resistant, making the species less susceptible to ground fires. Crown fires, on the other hand, may kill all of the above species. Forest fires are much more frequent in the southern portions of the zone in the study area and are documented by Loy et al. (1976) for Oregon. The majority of the Western Hemlock Zone in Oregon that occurs in the study area was severely burned in the 19th century (Loy et al., 1976).

Windthrow can be particularly serious if strong winds occur after a heavy rain which allows tree roots to be pulled from the soil. Of the old growth trees in this zone, Douglas fir is probably least susceptible and western hemlock most susceptible to this form of mortality.

Frequently, mortality in trees is a function of a combination of the above factors. Root and heart rot will weaken a tree and make it susceptible to windthrow or insect infestation. Likewise, trees damaged but not killed by fire are highly susceptible to insect infestation and rots. Trees with tops broken by wind or snow often become the host of heart rot. Consequently, mortality is usually a synergistic event.

In areas outside the study region, the introduction of gaseous air pollutants (particularly ozone) has caused serious mortality in trees, including 8% to 24% mortality in Ponderosa pine forests near Los Angeles (Westman, 1977). Toxic levels of oxidants are not expected to occur in the region due to low population levels, but sulfur dioxide from sulfite-process pulp and paper mills may become a localized concern within the study area. Davis and Wilhour (1976) list species-specific information on air pollution resistance of selected trees within the study area. Hay (1977) provides a useful bibliography on synergistic effects upon tree mortality of arthropods, plants, and air pollution.

Faunal mortality for the smaller organisms (e.g. deer mouse) is frequently high because of predation, as indicated in the Food Web Model. Severe winters can also cause high incidence of mortality among large species (see black-tailed deer species of concern model in Part 2). Some harvest of big game occurs, which removes individuals from the ecosystem. However, currently the most serious effect on mortality of old growth vertebrate species is indirect, through loss of habitat as a result of inadequate forest management practices. (See Notes #18, #19, #20, and #21.) As an example, Forsman (1976) reports that 52% of the spotted owl habitat found in the region (documented in a study from 1970 to 1974) has been cut or is scheduled for cutting.

#10. Detritus, Decomposers, and Decomposition. Decomposers play a significant role in nutrient cycling in old growth western hemlock as well as other forests of the study area. The majority of biomass and energy moves directly from producers to decomposers, with less than 2% of net primary production going through the grazing food webs (Edmonds, 1974, 1975; Strand, 1974.)

The role of decomposers in all ecosystems is one of releasing nutrients from organic material, thereby allowing uptake by plants and the subsequent recyling of nutrients through the food web. They act as soil conditioners and are important agents in community composition as they attack vegetation growing in suboptimal conditions or which has been otherwise stressed either by age or physical damage.

The following section, from Leaf et al. (1973), is applicable to the Western Hemlock Zone as well as other terrestrial zones in the area. The authors state that, "1) these (soil) organisms have an essential role in modifying soil organic matter; 2) soil organic matter in various stages of decomposition has a marked significance on the physical, chemcial, and biological soil properties; and 3) this significance, in turn, affects the productivity of the soil for higher plants and animals."

A successional pattern exists in the decomposition process. Some microorganisms, dependent on speed of response to growth, require freshly fallen leaves (Leaf et al., 1973). These organisms use soluble carbohydrates and amino acids, and are apt to be fungi and colonizing bacteria. These persist for only a short time and are typically followed by a series of successional species of fungi, bacteria, and actinomycetes, each stage using less soluble and more complex organic detritus. Finally the lignins, phenols, and other resistant materials are utilized by relatively few species of fungi and actinomycetes with fairly stable population numbers.

Bacteria, both aerobic and anaerobic, are the most numerous organisms in a forest decomposer community. Some of these have nitrogen-fixing capabilities. Aho et al. (1976) have documented nitrogen-fixation by gram-negative enterobacteria in high concentrations during early stages of white fir log decomposition in the Siskiyou Mountains of Oregon but data from the study area are nonexistent. Actinomycetes have a taxonomic position between bacteria and fungi, having characteristics of both. They are often associated with the breakdown of lignin and other resistant material, and are frequently affiliated with mites and collembola (springtails) which act as dispersal vectors. Fungi, although less numerous than bacteria, typically have the greatest biomass in forest soils. They are adapted to a wide range of acidic conditions and typically dominate acidic soil habitats because of reduced competition from bacteria and actinomycetes. Fungal species are common through the successional sequence. They are responsible for the majority of CO_2 released in the process of decomposition because most of their oxidative reactions are complete, unlike bacteria which often liberate organic acids, alcohols, aldehydes, and other compounds which are used by succeeding organisms.

Multi-celled macrofauna (e.g. earthworms, mites) also play an important role in the decomposition function. They physically break down, partially digest, and transport organic materials within the soil and play an active role in facilitating the nutrient cycle. As an example, mites and collembolas feed on organic materials on the forest floor and produce fecal pellets which are innoculated with fermentative microorganisms that mineralize nutrients. Mycorrhizal fungi colonize the pellets and extract the nutrients, passing them on to higher plants.

The physical breakdown of plant material is important as it provides greater surface area to volume ratios, allowing more rapid chemical decomposition by microbes and fungi.

Decomposition rates are dependent on lignin content, moisture, temperature, pH, chemical composition, and the presence of O_2. In terrestrial communities oxygen is seldom limiting. Some generalized relationships between moisture, temperature, and decomposition rates for coniferous forest in the region have been developed by the Coniferous Forest Biome Modeling Group (1977). These relationships for foliage litter and dead roots are presented in Figures 3-12 and 3-13, respectively. Also, there is a relationship between decomposition rate and lignin content as shown for a given set of environmental conditions in Figure 3-14.

Decomposition rates are specific to the material being decomposed and the environmental conditions. Decomposition rates which do not appear to vary for Douglas fir needles in one area with a variety of types of understory vegetation are given in Figure 3-15. Table 3-9 and Table 3-10 provide evidence of differences in decomposition rates dependent on environmental conditions. Note that the maximum rate occurs under most conditions in both cases.

Rates also change depending on season, although supporting data are limited. Optimum conditions for decomposition are wet, warm conditions. Rates are reduced under cold, dry conditions. Snow pack apparently insulates the litter layer sufficiently so that decomposition occurs through the winter (Edmonds, 1975).

Changes in nutrient composition of decomposing material are given in Table 3-11. Initial litter (newly fallen cones and needles) have more rapid turnover rates, while humus decomposes at much slower rates. Note the increase of lignin in more advanced stages of log decomposition.

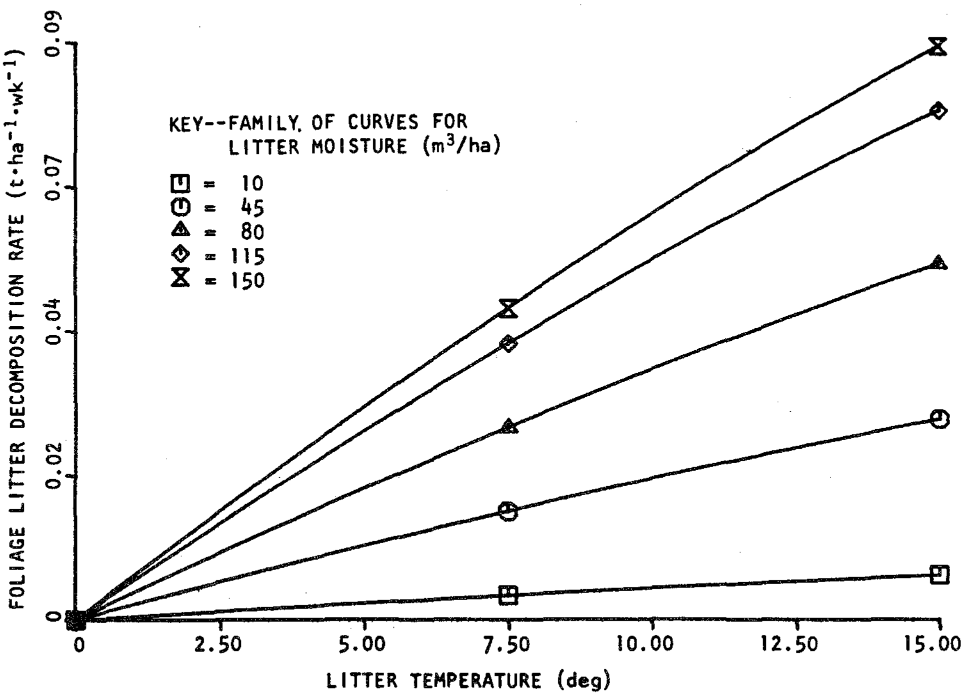


FIGURE 3-12. FOLIAGE LITTER DECOMPOSITION RATE AS A FUNCTION OF LITTER TEMPERATURE AND LITTER MOISTURE. Held constant: litter biomass = 39.5 t/ha. (From Coniferous Forest Biome Modeling Group, 1977.)

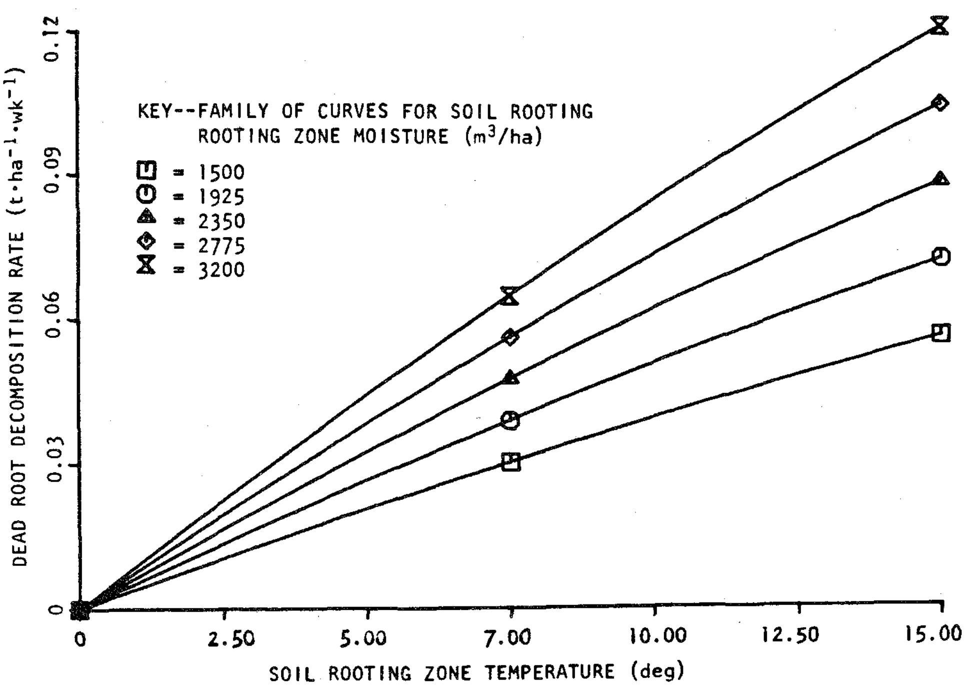


FIGURE 3-13. DEAD ROOT DECOMPOSITION RATE AS A FUNCTION OF SOIL ROOTING ZONE TEMPERATURE AND SOIL ROOTING ZONE MOISTURE. Held constant: dead root carbon = 6.197 t/ha. (From Coniferous Forest Biome Modeling Group, 1977.)

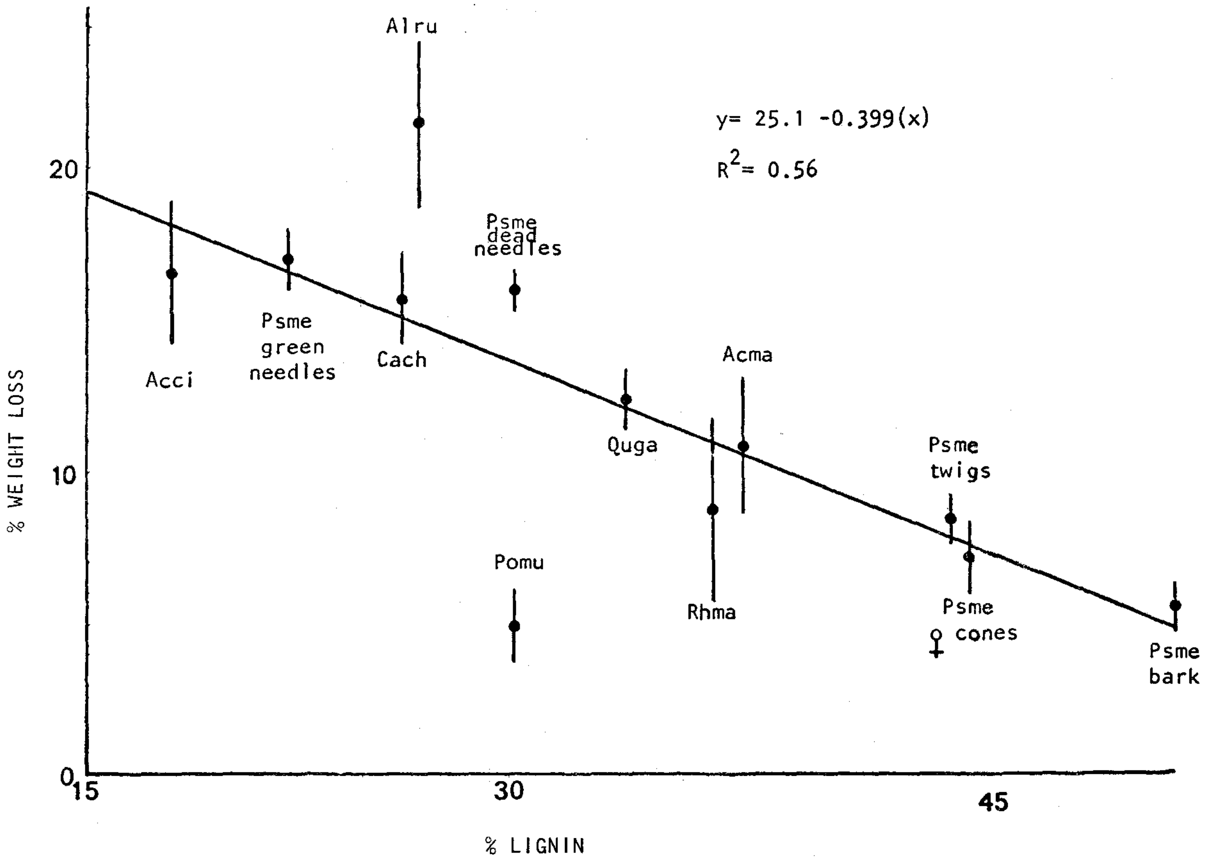


FIGURE 3-14. WEIGHT LOSS OF SUBSTRATES AS A FUNCTION OF THEIR LIGNIN CONTENT. Data are from Reference Stand 2 in the H. J. Andrews Experimental Forest, Oregon, after a six month period beginning 29 May 1973. Acci = Acer circinatum, Acma = Acer macrophyllum, Alru = Alnus rubra, Cach = Castanopsis chrysophyllum, Pomu = Polystichum munitum, Psme = Pseudotsuga menziesii, Quga = Quercus garryana, and Rhma = Rhododendron macrophyllum. Substrates are needles unless otherwise indicated. 95% confidence limits are shown. (From Edmonds, 1974.)

TABLE 3-9. DOUGLAS FIR NEEDLE DECOMPOSITION RATES ALONG AN OREGON CLIMATIC GRID (From Edmonds, 1975.)

Location	Annual rainfall (cm)	January temp. (°C)	Summer litter moisture	Percent decomposition--weight loss (300 days)
Coastal site - Cascade head	149	6	moist	39.2
Northern Cascades Bull Run	304	2	moist	33.9
Mid-Cascades H. J. Andrews - high elevation	250	0 (snowpack)	dry	30.0
Southern Cascades - Coyote Creek	79	2	dry	28.4
Eastern plateau - Pringle Butte	31	-0.5 (cold,dry)	dry	22.6

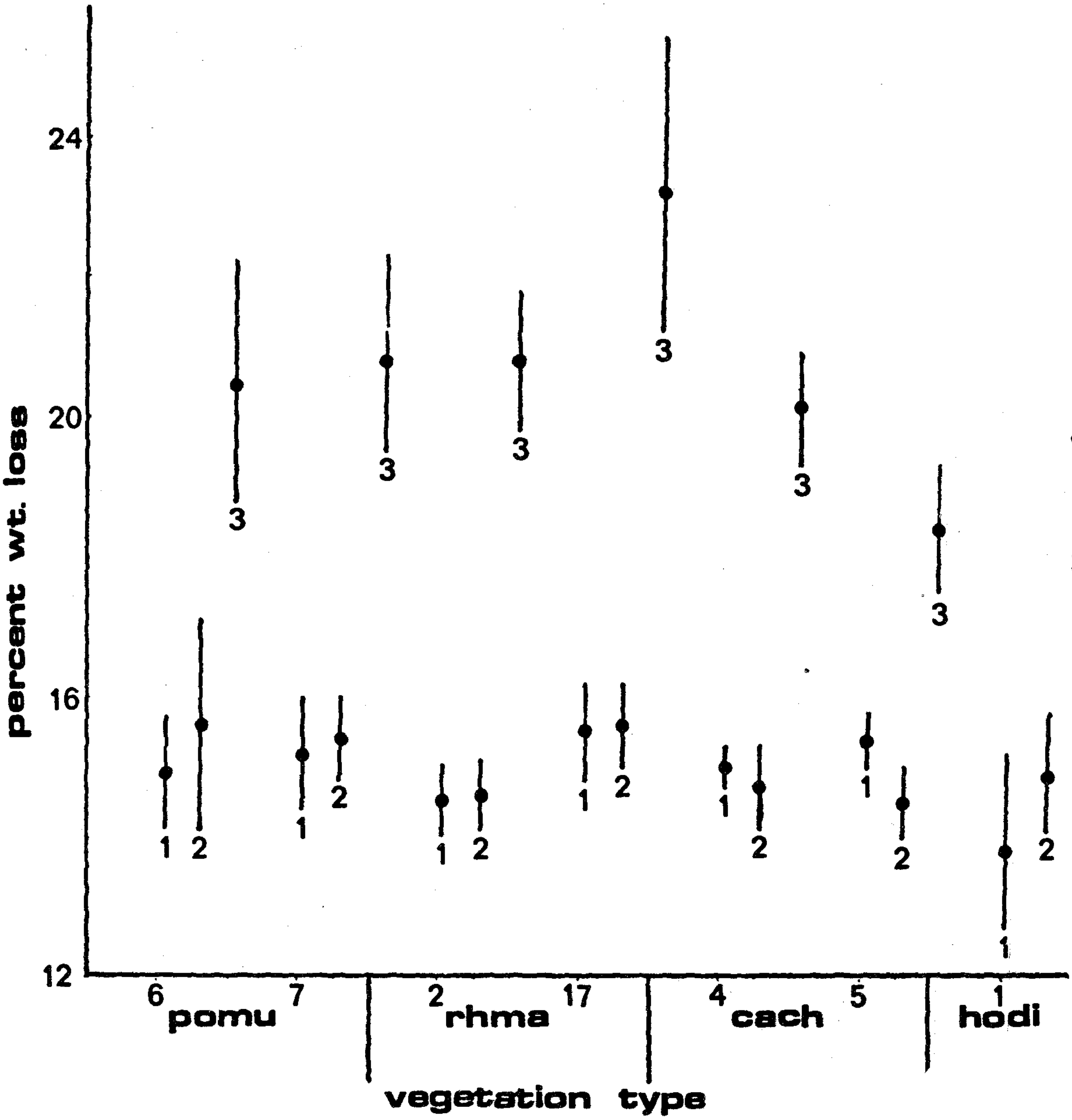


FIGURE 3-15. WEIGHT LOSS OF GREEN DOUGLAS FIR NEEDLES IN FOUR UNDERSTORY/ FLOOR VEGETATION TYPES. Data are from the H. J. Andrews Experimental Forest after 4 months (1), 6 months (2), and 9 months (3) beginning 10 March, 1973. pomu = Polystichum munitum (sword fern), rhma = Rhododendron macrophyllum, cach = Castanopsis chrysophyllum (chinquapin), and hodi = Holodiscus discolor (ocean spray). 95% confidence limits are shown. (From Edmonds, 1974.)

TABLE 3-10. FOLIAGE DECOMPOSITION OF REPRESENTATIVE SPECIES ON OREGON ENVIRONMENTAL GRID. (From Edmonds, 1975.)

Location	Species	Summer litter moisture	Percent decomposition--weight loss (300 days)
Coastal site - Cascade head	Red alder	moist	59.1
Willamette Valley - Pigeon Butte	Oregon oak	dry	22.2
Wildcat Mt. - high elevation	Silver fir	dry	25.2
H. J. Andrews - high elevation	Douglas fir	dry	29.6
Eastern plateau Pringle Butte	Ponderosa pine	dry	15.0

TABLE 3-11. NUTRIENT CONTENTS AND COMPOSITION OF LOGS IN VARIOUS STAGES OF DECOMPOSITION. Data are from the J. H. Andrews Experimental Forest, Oregon (on west slope of Cascades outside study area). (From Edmonds, 1974.)

Stage of log decay[a]	Percentage						Parts per million				
	N	C	Non-cell-wall	Lignin	Cellulose	Ash	P	K	Ca	Na	Mg
1	0.12	52.6	20.3	57.6	22.0	0.06	157	360	1041	15	61
2	0.24	56.4	6.5	86.6	6.7	0.23	155	365	1451	42	240
3	0.37	53.2	15.0	72.7	11.4	0.99	236	141	2347	44	366

[a] Decay condition where: 1 is least decomposition, bark still intact; 2 is log rotted throughout, but still retaining recognizable structure; and 3 is log integral with forest floor.

Edmonds (1974) reports 78 species of scavenger invertebrates (mostly insects) feeding on plant material and 14 feeding on animal material and feces in a Douglas fir forest. Krantz et al. (1973) reports a minimum of 50 families and 60 genera of mites (the majority are Cryptostigmata) occurring on the forest floor for the same area. Population density varies from 5,000 to 350,000 per square meter. Nematodes, many of which are saprophytic, are also found in large populations with densities varying from 400,000 to 2,000,000 per square meter.

#11. Weathering. Mineral weathering is a continuous source of elemental nutrients within old growth western hemlock ecosystems, as well as other environments. Old growth western hemlock forests do not typically have many large rocks near the surface, hence mechanical weathering is limited. Where rocks do occur, disintegration is caused by (1) differential expansion by pressure release as rocks are exposed to lower atmospheric pressures, (2) growth of foreign crystals such as ice or salts in cracks and pores, and (3) differential expansion and contraction due to temperature change (Bloom, 1969).

In the Western Hemlock Zone chemical weathering is a more important process which includes oxidation, carbonation, hydrolysis, hydration, base exchange, and chelation. Water plays an important role in all of the chemical weathering processes, while biological factors are significant in carbonation as suppliers of carbon dioxide, and in the addition of soluble organic acids to the soil which affect base-exchange. Chelation is a complex organic process by which hydrocarbon molecules establish tight chemical bonds to metallic cations. In simple terms, plants establish H^+ ions around root tips by secreting organic acids which replace metallic cations of the soil. The released metallic cations are taken up and incorporated into the plant (Bloom, 1969). Often the process is augmented by intermediary mycorrhizal fungi. (See discussion under Note #3 Uptake, as well as #12 Base Exchange and #13 Leaching, which follow.)

For additional information on weathering, see Gilluly et al. (1959) and Bloom (1969).

#12. Base Exchange. Nutrients are transformed into available ionic form through base exchange (cation exchange). Common base ions include hydrogen, calcium, potassium, magnesium, and sodium. These cations collect around clay particles in the soil which are negatively charged. Organic colloids also provide similar exchange sites. These exchange sites are locales where cation nutrients are held in the soil. Total exchange capacity of the soils of coastal areas of Washington and Oregon is high, varying from 20-35 M.E./100 gm, due to high organic content of the soils (Forest Soils Committee of the Douglas-Fir Region, 1957). Consequently the soils are able to hold considerable amounts of nutrients in reserve.

A similar exchange process is exhibited by soil colloids for anions.

Soil pH, particle size, and organic content, temperature and moisture, combine to establish the specific conditions of the equilibrium between nutrients free to be leached or taken up and those which are held in the soil, determining the total amount of nutrients the system can contain. Changes in these factors alter the equilibrium, causing leaching or an increased ability for the site to contain nutrients.

See discussions under Notes #11 Weathering and #13 Leaching.

#13. Leaching. The major carrier of nutrients in soil is water. Nutrient ions are typically taken up by vegetation or bound to electrically-charged exchange sites on soil colloids (Edmonds, 1974). For nutrients (cations) to move through the soil solution, they must be accompanied by negatively-charged ions (anions). Typically, anions are deficient in temperate forests (Nye and Greenland, 1960). Leaching occurs when decomposers generate CO_2 in the soil through respiration. A minor portion of the CO_2 hydrolyzes to carbonic acid which ionizes into hydrogen cations and carbonate anions. The ionization does not occur if pH is below 4.5.

Under these conditions, hydrogen cations can replace the nutrient cations at the colloidal exchange sites, which can then be leached out of the system in a water solution, accompanied by the carbonate ions. Consequently, storms in the summer and fall, when decomposition is active and CO_2 is abundant in the soil, establish active leaching conditions. Figure 3-16 provides a graphic presentation of the interplay of leaching, temperature, and precipitation in a second growth forest. Air pollutants HCO_3+ and SO_4- can affect the cation balance in the soil and thus increase leaching from a given site.

As indicated in Table 3-12, old growth coniferous forests approach a closed system in terms of nutrient cycling. Little elemental loss occurs through leaching and little gain occurs due to weathering or precipitation (Edmonds, 1974).

#14. Runoff and Evapotranspiration. Movement of water out of an old growth forest is controlled by input and by rate of evapotranspiration, temperature, soil depth, soil porosity, soil permeability, and organic material in the soil. In other words, loss of water is a function of input, the ability of the area to retain and hold water, losses through evapotranspiration, and the degree to which the environment was saturated at the time of input. See Figure 2-17 in Volume 1 for the general hydrologic cycle model.

Since input (precipitation and/or discharge from surrounding habitats), temperature, and evapotranspiration are strongly correlated with season, export or discharge is also strongly correlated with season. Typically, in the Western Hemlock Zone maximum annual discharge occurs during late fall, winter, and early spring. Minimum retention time occurs when the system is saturated, such as under flood or near-flood conditions. The large amounts of organic material in old growth soils may improve retention capabilities (USDA, 1975A; E. P. Odum, 1971). No discharge is to be expected from overland flow in forests within the study area (Rothacher, 1973), which in part is due to the accumulation of organic material at the soil surface. Models determining runoff in forested ecosystems of the study area have been developed by Ryan and Morison (1976) and the Coniferous Forest Biome Modeling Group (1977).

Runoff from western hemlock old growth as well as other environments is part of the hydrologic cycle as described in Volume 1 and in this volume in Section 2.5.3.

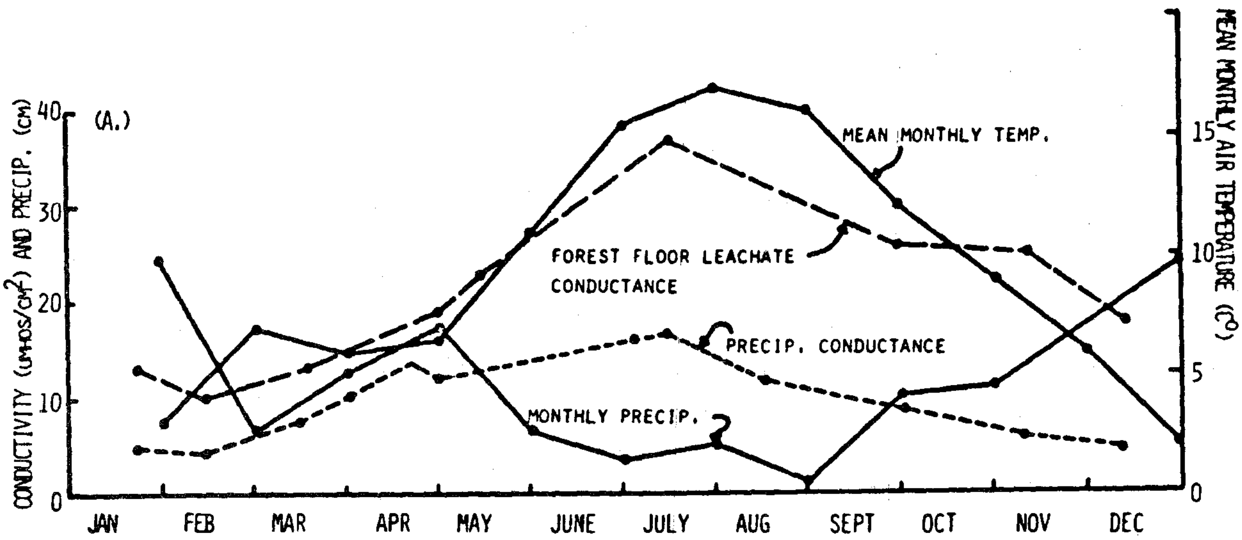


FIGURE 3-16. MEAN MONTHLY PRECIPITATION, AIR TEMPERATURE, AND SPECIFIC CONDUCTANCE OF PRECIPITATION AND FOREST FLOOR LEACHATES. Data are for 1970 from the Thompson site, Washington, which is a second growth forest; conditions may vary for old growth coastal forests. (From Grier and Cole, 1972.)

TABLE 3-12. COMPARISON OF ANNUAL INPUTS, LOSSES, AND BALANCES OF NITROGEN, PHOSPHORUS, POTASSIUM, AND CALCIUM AT THREE CONIFEROUS FOREST SITES, IN KILOGRAMS PER HECTARE. (From Edmonds, 1974.)

Site	N	P	K	Ca
Thompson site, Washington, (young-growth Douglas fir)				
Input (precipitation)	1.1	trace	0.8	2.8
Loss (leached beyond root zone)	0.6	0.02	1.0	4.5
Forest stand balance	+0.5	-0.02	-0.2	-1.7
Findley Lake, Washington, (Pacific silver fir)				
Input	1.3	0.04	0.8	0.6
Loss	2.1	1.0	5.5	11.2
Forest stand balance	-0.9	-0.96	-4.7	-10.6
Watershed 10, Andrews Forest, Oregon, (old-growth Douglas fir)				
Input (precipitation)	2.3	0.9	0.3	3.1
Loss (runoff)	1.1	1.4	1.1	61.3
Unit watershed balance	+1.2	-0.5	-0.8	-58.2

Evapotranspiration is predicted at 45.3 cm/year (18 in/yr) in an old growth forest with precipitation of 158 cm (62 in) by Rogers and Swanson, as reported by Edmonds (1975). PNRBC (1970) reports approximately 60 cm (24 in) annual evapotranspiration for inland environments of the region. Models for determining evapotranspiration have been developed by Ryan and Morison.

(1976), Coniferous Forest Biome Modeling Group (1977), Thornthwaite (1944), and Penman (1963), among others. Evapotranspiration is typically found to be dependent on plant species, canopy closure, solar energy received, wind speed, air temperature, and dew point. Proposed interrelationships among these factors are defined in the models cited above.

#15. Erosion and Mass Wasting. Old growth forests within the Western Hemlock Zone have proven to be stable and conservative in terms of movement of sediments. Fredriksen, as reported by Edmonds (1974), found (in 1971) that in stable forested areas within the region dust deposition represented 84% of sediment output for small forested watersheds. Rooting systems, protective canopy, and an organic soil layer combine to mitigate the effect of intense precipitation, the immediate cause of most erosion.

If the habitat is disturbed, however, erosional processes can be accelerated depending on the type of disturbance, mitigating measures taken, the sensitivity of the area, and climatic conditions during the recovery period. Harvesting and associated road construction have, in most cases, been documented as the major causes of erosion and mass wasting. Slope is thought to be the single most important factor (Fredriksen et al., 1973), with soil type also being important (Swanson and Dyrness, 1975; Paeth et al., 1971; Fredriksen, 1972). An extensive literature exists on the effects of clearcutting and road building on erosion and sedimentation and their effects on aquatic ecosystems. Useful literature reviews are provided by Moring (1975), Crow et al. (1976), Coats (1978), EPA (1975A), Gibbons and Salo (1973), and Fredriksen et al. (1973). Briefly, erosion, masswasting and sedimentation have in some cases been proven to appreciably increase following clearcutting and associated road building. In other areas no substantial increases have been recorded. Sensitivity is site-specific and cutting practices and road construction must be designed accordingly. Mitigating techniques have proven to be effective and are described by EPA (1975A), Lysons and Wellburn (1976), Burroughs et al. (1976), and Washington Forest Practice Board (1976). A brief bibliography is provided by Pacific Northwest Forest and Range Experiment Station (1977).

#16. Nutrient Losses. As discussed in Note #3 (Uptake) and Note #13 (Leaching), and as documented by Fredriksen (1971), the export of nutrients from an old growth forest is small compared to inputs from weathering and precipitation. The old growth ecosystem approaches a closed system. When disturbed by cutting, wildfire, or windthrow, nutrients can be removed from the site. The extent and duration of loss does not seem to be significant to the nutrient pool of most sites. Brown et al. (1973) reported a three-fold increase (5.0 to 15.7 kg/ha) in loss of nitrogen (as nitrate) the first year following clearcutting in a small sub-watershed (Deer Creek) within the Alsea watershed basin (Watershed Unit 5). He also found an increase in potassium concentration following slash burning from 0.6 to 4.4 mg/l in the watershed discharge. Partial cutting with stream buffers did not result in similar increases. Sedell, as reported by Edmonds (1974), indicates a 20- to 100-fold increase in nitrate and phosphorus concentrations in runoff for a period of one to three years following clearcutting.

Fredriksen 1971) found that nutrient cation loss increased 1.6 to 3.0 times following clearcutting and slash burning. Annual loss of nitrogen immediately following clearcutting was measured at 4.6 lb/acre compared to 0.16 lb/acre before disturbance. The Forest Soils Committee of the Douglas-fir Region (1957) states that fire and the resultant soil heating reduce nitrogen content of forest soils within the "Douglas fir region" and increase available phosphorus.

#17. Debris and Detritus Export. Rates of debris and detritis export from old growth forests are not well documented. Sedell et al. (1974) reports input into small streams from lateral movement was 1.5 times litterfall directly into the stream. Input to the stream (i.e. export from the old growth forest) was estimated at 2.5 $g/m^2/day$. There are sampling problems with this value, as log and other large debris inputs were not adequately measured. Logging residues have proven detrimental when exported to aquatic systems (Owens and Cramer, 1974). Volumes of logging residues have been estimated at 32 to 227 tons/acre for the "Douglas Fir Region" which includes the Western Hemlock Zone (Pell and Ward, 1971). An unknown portion of these materials are exported.

#18. Logging or Disturbance. An old growth forest stand in the Western Hemlock Zone, as well as other forested zones in the area, may be eliminated and the area placed into early seral communities by a decision to harvest or by some natural event such as wildfire, insect epidemic, or windthrow. The harvesting decision and its related effects are discussed in the Forestry Section (4.2) of Chapter 4 of Volume 1 and of this volume. Harvesting represents the major year-to-year means by which this habitat is disturbed (see Note #19, which follows). Extensive insect epidemics have periodically eliminated old growth stands in the study area. Likewise forest fires have resulted in the replacement of large tracts of old growth with seral communities. Windthrow which is probably more prevalent in the Sitka Spruce Zone is another means by which old growth forests are disturbed. (See Note #9 Mortality, for more information on natural disturbances.)

Bolsinger (1973) has documented significant losses of forest lands in Washington and Oregon between 1945 and 1970. Nearly a million acres of commercial forest lands were altered to other land uses with the major loss (an estimated 35%) due to road construction. Other significant losses were to urbanization and industrialization (29%), farm and pasture clearing (16%), power line clearings (5%), and reservoir and impoundments (5%). Similar trends are probable within the coastal region, including the California Watershed Units.

#19. Harvest. Old growth forests in the Western Hemlock Zone are usually harvested by clear-cutting. Some selective cutting is carried out in the more southerly portion of the Zone within the study area. Materials are sorted and trimmed following harvesting, with the merchantable timber exported from the ecosystem and the remaining slash typically burned on site, the residue of which becomes detritus in the new seral community. Based on data presented in Table 3-3, assuming that only the bole is removed, losses ofmajor nutrients from the ecosystem are 4% of the nitrogen, 8% of the phosphorus, 8% of the potassium, and 5% of the calcium. These figures do not include loss due to the slash burning (see Note #16 Nutrient Losses).

As indicated in the Old Growth Model (Figure 3-4, logging disturbance and harvesting initiate the succession sequence (#21) and have additional effects on hydrology (#14), erosion (#15), nutrient losses (#16), and detritus losses (#17).

Old growth forests in this Zone are increasingly rare. Nearly all old growth on private lands has been cut, and most old growth on Bureau of Land Management and U.S. Forest Service lands is being cut, with a relatively long rotation period. The harvest of old growth timber is of considerable socioeconomic importance to the region and is discussed in Chapter 4.

A succession series initiated by harvesting adds diversity to the landscape, providing habitat and forage for successional species such as black bear, black-tailed deer, and Roosevelt elk (Brown, 1961; Maser et al., 1977). See the Species of Concern accounts of the latter two mammals in Part 2 of this volume for more information on this aspect of forest harvesting.

#20. Recreational Use of Habitat. Harvest, excluding forestry, of understory and canopy species in this habitat is minimal. Some berry picking, floral greenery harvesting, native transplants, mushroom picking, taking of furbearers, and big game hunting do occur but not at great intensities. A good review of the extent of these kinds of activities is provided by Hirsch (1970). However, old growth provides aesthetic pleasures to hikers, birders, photographers, and other non-consuming recreationists.

#21. Succession. Succession following a disturbance (e.g. windthrow, clearcutting, landslide) is treated in the Succession Model for the Western Hemlock Zone and related discussion in Section 3.2.4 of Volume 1 and of this volume.

The processes used in intense forest management regimes reduce the "natural" duration of grasslands and early seral shrub stages by special planting and fertilization. However, rotation periods are more rapid, 40 to 60 years, thereby compensating for some effects (e.g. habitat loss) of shortened succession.

The major and obvious effect of intense forest management is the elimination of old growth forest and dependent fauna from areas under such management. Species dependent on old growth habitat for existence are indicated in Table 3-6, and those preferring snags, which are characteristic of old growth and uncommon in earlier seral stages, are listed in Table 3-7. The Bureau of Land Management and the National Forest Service have established some guidelines for the maintenance of snags on federal lands. However, snags are typically removed from private lands.

Natural succession after a disturbance such as windthrow or fire, as indicated in the Succession Model in Section 3.2.4, may take 500 or more years to reestablish an old growth forest.

3.2.1.2 Emergent Vegetation Ecosystem Model Notes. Compared to many other coastal areas in the U.S., the extent of estuarine emergent vegetation (salt marsh) in the study region is limited. Not only has the community been historically scarce in the region, but also much of it has been seriously altered by diking, filling, and other land use changes.

The salt marsh is an ecotonal community, standing in the transition zone between terrestrial, riverine, and estuarine environments. It contains species originating from all three environments in various densities along an inland-estuary gradient. Marine species are more common at the outer fringes of the marsh and channels, while terrestrial species are found in greater numbers inland. Many of the species move in and out of the area with the tide (e.g. fish). The vegetation is principally vascular, although marine algae are also common and play an important role in productivity.

Many workers believe that this community acts as a nutrient and sediment trap. There is conflicting information on its role as a source of energy and food, through detrital export, for the estuary at large.

Net productivity in salt marshes is high, but in this region does not appear to be significantly different from the inland seral forest production. Producer biomass is considerably less than inland forest communities yet greater than most marine or estuarine communities. The condition of a relatively small biomass and high productivity is evidence for the rapid nutrient cycling and exchanges of this community.

The salt marsh is subject to pulsating environmental conditions based on tidal cycles, daily and seasonal cycles, and periodic storms and floods. Such patterns require the inhabitants of the marsh to be either adapted to fluctuating salinity, temperature, gaseous conditions and periodic inundation or able to migrate in and out of the area.

Productivity and detrital export are modulated by daily, seasonal, and tidal cycles. Community composition is affected by seasonal visitation by vertebrate species, and seasonal shifts of abundance and biomass of the producers and invertebrate consumers.

Little direct human use with a measurable marketable value is made of the community. Some grazing and activities associated with waterfowl hunting occur in the habitat, along with some recreational uses such as bird watching. In an altered state the sites are used for agricultural production (diked marsh) and/or development of shipping, housing, or similar facilities (human activity zones).

Indirectly the community may be of considerable significance as a primary producer in the estuarine system. It may have additional utility in mitigating floods and sedimentation as well as some potential value in waste treatment, thus protecting the estuary from waste products and oil spills. Protection of the emergent vegetation habitat is required to maintain environmental diversity in the estuaries of the region.

Major components, processes, and relationships in the emergent vegetation ecosystem are modeled in Figure 3-17 and discussed in detail, as notes to the model, in the following sections. The physical processes of precipitation and evaporation (1) are discussed first, followed by information on the input and output of (2) water, (3) nutrients, (4) detritus, and (5) sediment. The increase of salt marsh habitat (6) is presented next, along with a discussion of marsh soil (7). The biological processes follow: (8) photosynthesis/primary productivity, (9) nitrogen-fixation, (10) ion exchange, (11) secondary productivity, (12) community composition, (13) migration, and (14) decomposition. The notes conclude with discussions of (15) human use of the habitat, (16) pollutant input, and (17) loss of the habitat by human activities.

#1. Precipitation and Evaporation. Precipitation within the coastal region is documented in the section on meteorological conditions in this volume (see Section 2.3.1). Evaporation is similarly discussed in Section 2.4. An analysis of the seasonal pattern of precipitation shows maximum temperature and solar energy input along with minimum precipitation in summer. Although generally undocumented in the region, these combined conditions, along with low summer riverine flows, will result in increased saline conditions during summer periods in some marshes and estuaries. This phenomenon has been observed in Humboldt Bay (Skeesick, 1963). Small depressions called pannes, which repeatedly evaporate and concentrate salts can establish salt flats which resist vegetation invasion and exist on a semi-permanent basis (Ranwell, 1972; Daiber, 1974; Eilers, 1975).

ECOSYSTEM MODEL- EMERGENT VEGETATION

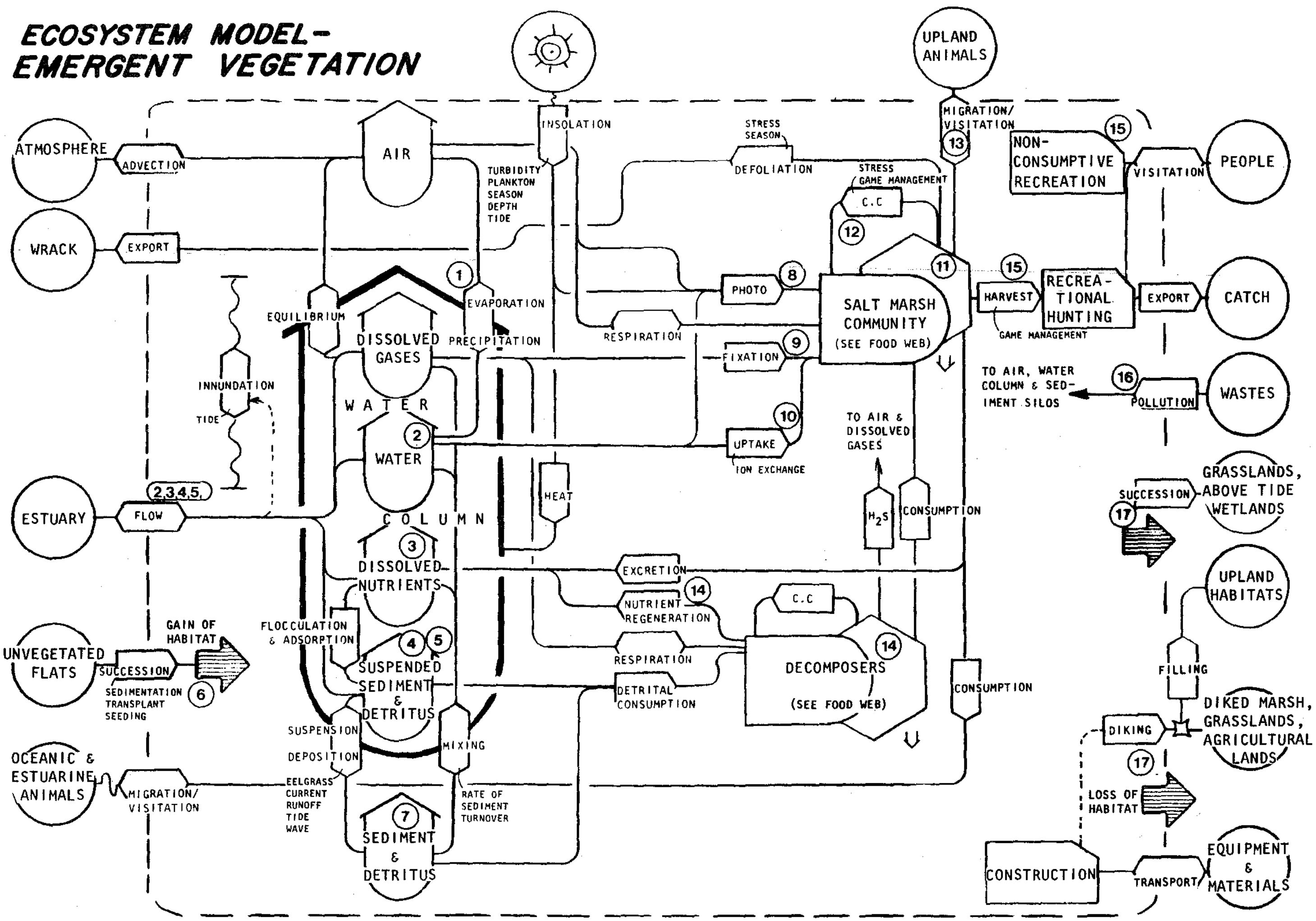


FIGURE 3-17. EMERGENT VEGETATION ECOSYSTEM MODEL.

#2. Water Input and Output. Semi-aquatic emergent marshes have a rapid exchange of water (and suspended and dissolved materials) with adjacent aquatic environments as well as principal sources (rivers and the ocean). This rapid exchange of water has significant effects on productivity and decomposition. Water is the principal agent by which materials are moved in and out of the marsh. In combination with riverine discharge, water conditions in a salt marsh are strongly related to tidal conditions. Figure 3-18 provides some indication of tidal conditions within a salt marsh of the region. Maximum tidal fluctuation typically occurs in June and December (U.S. Department of Commerce, 1977A). Excluding the Columbia, which peaks with the spring melt, maximum river discharge typically occurs in winter (Roden, 1967). Morphology of adjacent river and stream bottoms and atmospheric pressure conditions also play an important role in water exchange and currents. In addition, long term changes in sea level and sedimentation play a role in water exchange. Some wetland studies outside the region have documented a strong correlation between tide strength and net primary productivity (E. P. Odum, 1974). As indicated in the model (Figure 3-17), marsh vegetation physically resists current flow and buffers movement of water in and out of the environment, reducing local currents (Eiler, 1975; Ranwell, 1972) and enhancing sedimentation. At times of flood and stormtides, this buffering can mitigate both erosion and property damage (Akins and Jefferson, 1973).

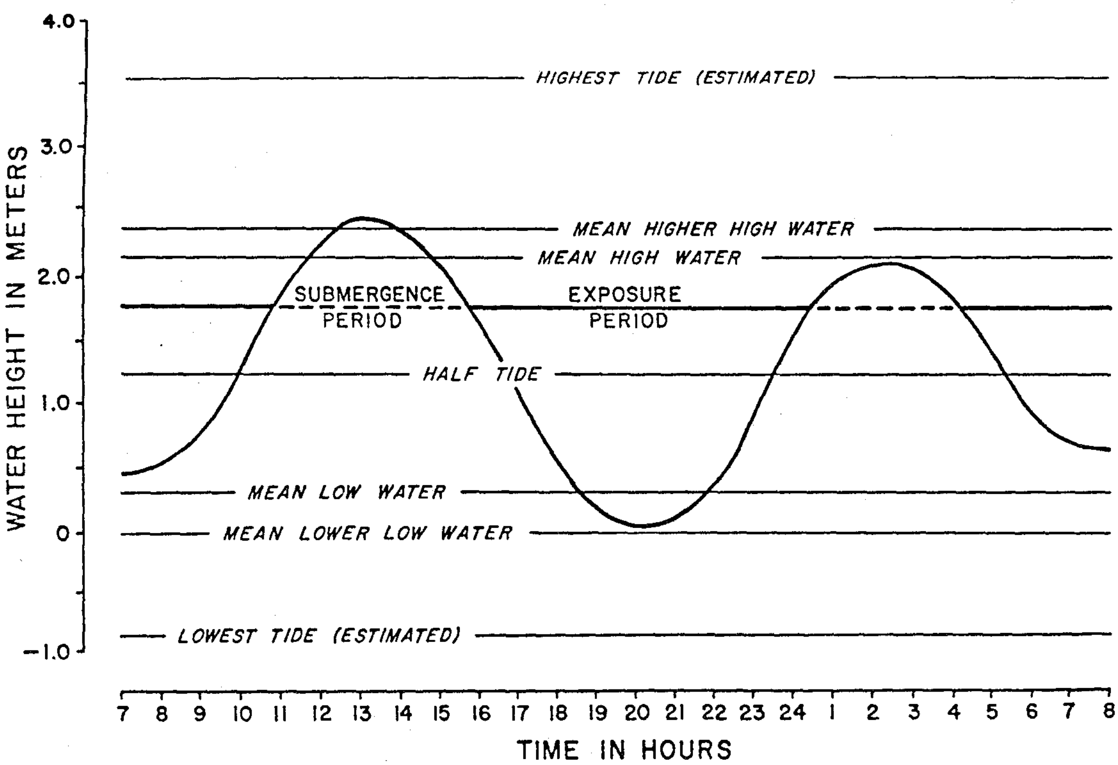


FIGURE 3-18. TIDAL MODEL FOR COASTAL OREGON. This figure presents the general tidal cycle at Wheeler, Nehalem Bay, Oregon; tides in other areas of the region will vary with latitude and local conditions. Exposure period and submergence perods shown are for a low marsh elevation. (From Eilers, 1975.)

Water is moved in and out of salt marshes by creek systems. Eilers (1975) describes the salt marsh creek systems on the North American Pacific Coast to be typically of the dendritic type - a well defined trunk channel with numerous minor branches and sub-branches. Salt marshes of higher gradient estuaries have simple drainage patterns. The drainage pattern infrequently penetrates into the high marsh higher than 2.76 meters (9.05 ft) above Mean Lower Low Water (Eilers, 1975). Creek density related to elevation, marsh type, and drainage have been reported for Nehalem Bay and are presented in Table 3-13. As indicated by these data, most tributaries occur between 2.06 and 2.76 meters (6.75 and 9.06 ft) above MLLW.

TABLE 3-13. SUBDIVISIONS OF A SALT MARSH IN NEHALEM BAY, OREGON, BASED ON RELATIVE CREEK DENSITY ASSOCIATED WITH ELEVATION. (From Eilers, 1975.)

Subdivision	Elevation Above MLLW	Relative Creek Density	Length/Area Ratio (m/m^2)
Mudflat	below 1.40 m	low	<.043
Low marsh	1.40 - 2.06 m	low	<.043
Middle marsh	2.06 - 2.76 m	high	>.043
High marsh	above 2.76 m	low	<.043

Salt marsh creeks can be divided into two major hydrologic types: the major, higher order creeks of the lower marsh which have high velocities in both directions; and the minor, lower order creeks of the higher marsh which have significant flow velocities in only one direction (Pestrong, 1965). Uni-directional flow occurs during the ebb tide cycle since a greater hydraulic gradient is caused by a delay in drainage of the marsh surface due to friction and a rapid decline in the height of bay waters (Pestrong, 1965). Additional information on profiles and cross sections of salt marshes is given by Eilers (1975).

Ditching in salt marshes outside the study area has been reported to cause a drop in the water table with consequent vegetational changes (Cottam et al., 1938), and/or intrusion of salt water into fresh water marshes (Stearns et al., 1940; Cory and Crosthwait, 1939), also with vegetational changes.

In salt marshes outside the region dropping of the water table following ditching has caused significant reduction of abundance and diversity of invertebrate species (U.S. Department of Interior, 1970, Volume 2), with reductions of 44% and 93% measured depending on specific community (see Note #12 Community Composition). A reduction of the water table may also result in substantial changes in chemcial conditions of the marsh soil as described in the chemical equilibrium note (#7).

#3. Nutrient Input/Output. Estuarine marshes are thought to trap and recycle nutrients (Ranwell, 1972), in part through the many exchange sites typical of the fine clay particles of salt marshes (W. E. Odum, 1970). Periodically, nutrient-laden sediments are physically trapped in salt marshes, thereby increasing nutrients (see Note #5). The high organic content of salt marshes also results in formation of organic colloids which have high adsorptive capabilities for trapping nutrient cations (Albrecht, 1941). Much of the nutrient material so captured is accumulated and incorporated into biomass. Some nutrients flow through on-site food webs but a large portion is exported to adjacent habitats as detritus. (See Detritus discussion, Note #4 and Note #10.)

Stevenson et al. (1976) found that brackish marshes in Chesapeake Bay were exporters of nitrogen and phosphorus over an eleven month sampling period. Nitrogen flux was measured at 4.14 g/m^2/yr or about 18-82% of the estimated nitrogen in the standing biomass of marsh vegetation, while a net annual export of dissolved phosphorus was 0.19 g/m^2/yr or 8-23% of the estimated phosphorus in the standing biomass of the marsh vegetation.

Estuarine marshes in other regions (East Coast and Gulf of Mexico) have proven to have valuable capabilities as natural tertiary treatment sites for pollution (Gosselink et al., 1973). In Florida a 1500 acre salt marsh was shown to remove all of the nitrogen and one-quarter of the phosphorus from the domestic sewage of 64,000 people per year (Jahn and Trefethen, 1973). Gosselink et al. (1973) estimated the cost of duplicating the tertiary treatment and fisheries facilities of a salt marsh to be at $205,000 per hectare. No similar evaluations have been completed in the study area, although Martin (1976) has completed some preliminary work.

See discussion of pollutant input in Note #16.

#4. Detritus and Other Dead Organic Material Input/Output. Estuarine salt marshes are widely agreed to be (see p. 3-39) net exporters of organic material and have been documented to provide an important contribution to the energy base of adjacent estuarine habitats (E. P. Odum and de la Cruz, 1967; Eilers, 1975). Some preliminary work on detritus input-output has been completed within the study area at Coos Bay (Gnat et al., 1976) and at Nehalem Bay (Eilers, 1975).

Gnat et al. (1976) found that algae made up a large part of the materials leaving and entering Coos Bay salt marshes during spring and summer, with a net input of detritus in neap and spring tides. Little data were collected during fall and winter. Spring, in studies outside the study area, is the period when dead standing biomass is most rapidly removed (Kirby, 1972) corresponding to biomass peaks of invertebrates (Day et al., 1973).

In areas outside the region, approximately one-half of net productivity is utilized on site and one-half is exported as detritus (Teal, 1962; Day et al., 1973). Eilers (1975) reports 56% of net aerial (above ground) production is similarly exported from his study site in the intertidal areas of Nehalem Bay. He reports further that 90% of the net annual aerial production was exported as detritus to adjacent habitats in the lower portions of the marsh. Day et al. (1973) report 764 g/m^2 is exported from the marsh and 594 g/m^2 is exported by the water column over the marsh in Louisiana. If the one-half net primary production exported assumption held for the study region, export would be from 180 to 560 g/m^2/year, dependent on marsh type, based on data from Coos Bay by Vanderzanden et al. (1976). With the same assumption, data of Burg et al. (1975) for the Nisqually salt marsh (Southern Puget Sound) would indicate a range of 45-700 g/m^2 with an average of 375 g/m^2 for the total salt marsh. Eilers (1975) reports a mean of 777 g/m^2/yr exported from Nehalem marshes. Hoffnagle and Olson (1974) report an estimated 280 g/m^2 are exported from salt marshes in Coos Bay. None of these data include root production (thought to be equivalent to aerial productivity of phytoplankton or benthic algae, which in Louisiana comprised around 43% of the detritus exported [Day et al., 1973]) Other authors (Pomeroy, 1959) have found benthic producers to be important in salt marsh productivity. In the period from May to September, Harding et al. (1978) found phytoplankton net primary productivity in Humboldt Bay to range between 1 and 1.5 g carbon/m^2/day.

Eilers (1975) concludes that the intertidal marshes (mean high water and lower) contribute almost all of their net aerial productivity to adjacent estuarine environments, while the high marsh (above mean higher high water) productivity decomposes primarily on site.

However, Pickeral and Odum (1976) indicate that a large flux of detritus occurs out of salt marshes during periodic storms. The export is, in part, derived from high marsh and is thought to represent a substantial portion of detritus export to the estuary.

Recently the salt marsh detritus export paradigm has been challenged by studies reviewed by Haines et al. (1976) which indicate that salt marshes may be a net importer of particulate organic matter. The significance of the reported flux of detritus and carbon is therefore uncertain, and requires additional study.

#5. Sediment Input/Output. Salt marshes are sediment traps. They are typically found in low energy environments with a low gradient, allowing settling of imported sediments. Examples in the study area include Willapa Bay, Grays Harbor, Coos Bay, and Humboldt Bay. The emergent vegetation physically reduces currents, thereby increasing sedimentation. Relationships between current, sediment size, and deposition are given in Volume 1, Section 2.5.4. Salt marsh sediments of the region are of both coastal (oceanic) and alluvial (riverine) origins (Kulm and Byrne, 1966; Avolio, 1973; Phipps and Scheidegger, 1976).

Sedimentation and erosion are strongly associated with seasonal tidal and current patterns. Accreting periods frequently occur during flood tides especially when associated with high sediment discharge. Accretion rates of 0.5 to 1.7 cm/year (0.2 to 0.7 in/yr) are documented by Jefferson (1974) for low silty marshes in Oregon. In salt marshes outside the study area, accretion has been measured at rates between 0.2 and 1 cm/year (0.1 and 0.4 in/yr) (Ranwell, 1972). See discussion in Note #6 on Gain of Habitat.

Settlement, compaction, and decomposition of organic bulk can in some cases occur in the study area resulting in semi-permanent salt marsh with a near stable elevation (Stearns and McCreary, 1957).

Deposition of sediments in channels raises the elevation of the water surface, thus imposing an increased hydraulic gradient with regard to downstream or adjacent estuarine areas. Such a gradient, causes the flow to take the most direct route, thereby invariably causing a migration of the channel (Percy et al., 1974). Shifting channels through salt marshes can, in turn, cause a significant turnover of sediments. Eilers (1975) and Pestrong (1965) report that channel migration is largely restricted to lower portions of the marsh and adjacent mudflats, as vegetation stabilizes the meanders in upper reaches. Eilers reports some caving and undercutting occurring within the marsh, but that the channel remains fixed.

#6. Gain of Habitat. Salt marshes within the region's estuaries (Tillamook, Umpqua, Coos, Coquille, Nehalem, Grays Harbor) have been documented to be prograding (Johannessen, 1964; Andrews, 1965; and Eilers, 1975), the result of accretion (see Figure 3-19). Progradation of salt marsh has been measured in Nehalem Bay at a maximum of 2.4 meters per year (8 ft/yr) with a range of 0.3 to 1.5 meters per year (1 to 5 ft/yr) (Eilers, 1975). In Massachusetts, progradation in salt marshes has been measured at rates up to 2.4 feet per year (0.73 m/yr) with an average rate at 1.2 feet per year (0.35 m/yr). Progradation rates are site-specific and vary with discharge, sediment supply, and other local conditions.

The cause of the salt marsh accretion in many of the study area's estuaries is thought to be, in part, increased sediment input from riverine habitats, principally caused by logging activities, erosion after forest fires, and agriculture (Akins and Jefferson, 1973), and has accelerated since 1850 (Johannessen, 1964). Low gradient estuaries fill in at a natural rate, but some authors believe that rates have been increased by erosive land use practices. Note that losses of estuarine habitats have been documented to exceed the recent progradation in most of these estuaries (e.g. Coos Bay, Humboldt Bay, Grays Harbor) (Hoffnagle and Olson, 1974; Koebig and Koebig, 1975; U.S. ACOE, 1976C). See further discussion in Note #17.

#7. Marsh Soil. In contrast to high (infrequently submerged) marsh soils, the aerobic layer of frequently submerged low marsh soils typically consists of a surface zone which is three centimeters (1.2 in) or less thick, because oxygen and other gases enter primarily from the water above, as diffusion in interstitial water is a thousand times slower than in the gas-filled pores of upland soils (Darnell et al., 1976). Table 3-14 presents characteristic conditions of these two extremes. The typically fine, low-bulk submerged soils of salt marshes are largely anaerobic, as oxygen is removed by the decomposition of organic matter faster than it can be replenished. These anaerobic soils establish conditions which maintain chemicals in a reduced state. Decomposition within the soil proceeds slowly with a large variety of intermediate unoxidized decomposition compounds (e.g. organic acids, aldehydes, alcohols, amines, mercoptans, methane, hydrogen sulfide, and others) (Darnell et al., 1976). Some of these products (e.g. hydrogen sulfide, methane) are toxic to many organisms (Smith and Oseid, 1971; Smith, 1971; Darnell et al., 1976; OSU, 1977A). For more information on decomposition, see discussion in Note #10.

Typically, reduced compounds are water soluble and could be expected to diffuse to the overlying water. However, the surface layer oxidizes the reduced chemicals before they can reach surface waters, thereby making them insoluble. Root systems are able to extract nutrients under these conditions.

TABLE 3-14. CHARACTERISTIC CONDITIONS OF UPLAND (INFREQUENTLY SUBMERGED TO ABOVE TIDE) AND FREQUENTLY SUBMERGED MARSH SOILS. A gradient exists in marshes ranging from edge of above tide (upland) to edge of below tide (submerged). The characteristics of the marsh soils vary along this gradient, being fairly uniform with depth at the upland end and varying between surface and subsurface at the other. (From Darnell et al., 1976.)

Characteristic	Upland Soils (Surface & Subsurface)	Frequently Submerged Soils	
		Surface	Subsurface
Appearance	variable	variable	finer-grained[1]
Decomposition	aerobic	aerobic	anaerobic
pH	high	high	high
Free oxygen	high	high	absent
Carbon	carbon dioxide	carbon dioxide	methane and other reduced carbon compounds
Nitrogen	nitrate	nitrate	ammonium
Sulfur	sulfate	sulfate	hydrogen sulfide
Iron	ferric	ferric	ferrous

[1] Eilers (1975), in core samples within Nehalem Estuary, found large grain sands in the subsurface areas which were deposited during earlier successional sequences.

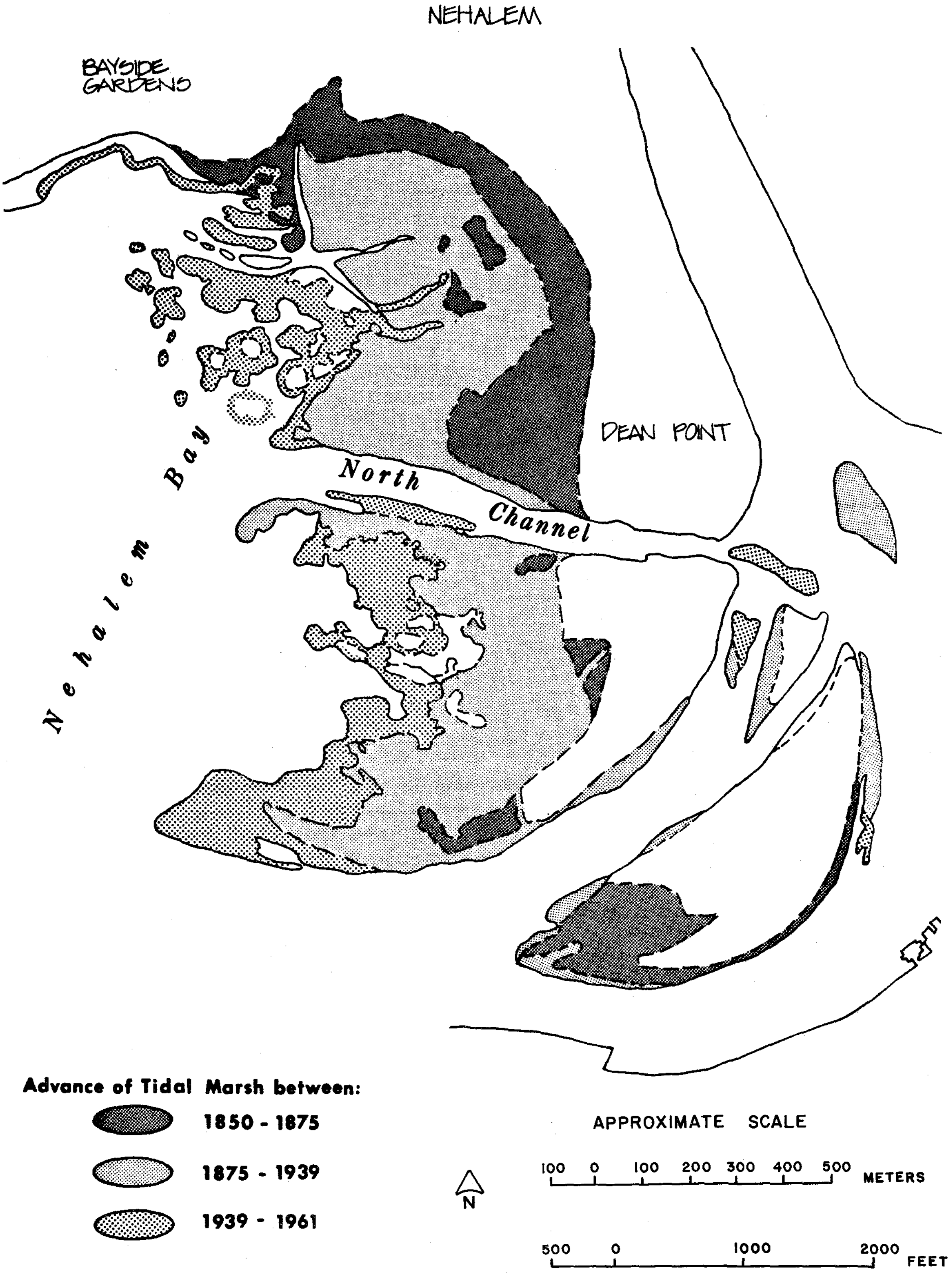


FIGURE 3-19. MARSH EXPANSION IN NEHALEM BAY, OREGON, OVER 100 YEARS. (From Johannessen, 1964.)

Increased elevation, or lowered water table, enhances leaching and oxidation. The resultant acid conditions adversely affect crustaceans and molluscs which depend on alkaline conditions for shell building. Under anaerobic conditions, sulfates are reduced to sulfides in the presence of organic matter. The sulfides combine with iron in the clay to form polysulfides where they remain if the soil remains wet. If the soil drys and becomes aerobic, the sulfides oxidize to form sulfuric acid and can lower the pH to 2.5 or below (Neely, 1962). Such a drop in pH (3-6 units) has been documented in Siletz estuary during extremely low tides of spring and winter (Rauw, 1974) and may be due to the same phenomenon.

Note that emergent marshes under natural conditions are an environment with gradient conditions. For example, salinity across a salt marsh is typically equal to sea water at the lower and middle ranges and rises to a peak at the upper extremity of the marsh during dry seasons, before dropping to near zero above tidal influences (Hedgpeth, 1957). Similarly Eilers (1975) reports a decline in soil salinity with depth in the high marsh, thought to be caused by the upward movement of water due to evapotranspiration. Likewise, soil oxygen decreases with depth. Table 3-14 provides the extreme ranges of conditions which can be expected on an emergent marsh. The gradient conditions vary with tidal fluctuations in daily, monthly, and annual cycles, as well as flooding (see Figure 3-18). Where salt marshes are diked, the gradient is altered and soils show a marked change in conditions at the dike.

#8. Photosynthesis/Productivity. Estuarine emergent marshes are generally considered to be highly productive communities (E.P. Odum, 1971) and are typically more productive than the adjacent sea or uplands. The causes of their relatively greater productivity, as summarized by E.P. Odum (1971), include replenishing and recycling of nutrients, multiple producers programmed for year-around productivity using substrate and water as nutrient sources, and tidal actions which subsidize productivity by transporting food and nutrients. Additional factors described by other authors include a long growing season (Keefe, 1972) caused by buffering of thermal effects by estuarine water; vertical orientation of the leaves of salt marsh species which maximizes the leaf surface to sunlight ration, reduces shading, and decreases intense heating of the leaf surface (Jarvis, 1964; Palmer, 1941), and availability of moisture and high concentrations of organic colloids which aid in the nutrient uptake process (Keefe, 1972; Albrecht, 1941).

There are some negative aspects in the salt marsh environment. Producers have adapted to the rigorous environmental conditions of the intertidal estuary, which include anaerobic soil conditions, changing salinities, and submergence.

Estuarine emergent vegetation (salt marsh) productivity studies have been completed by Eilers (1975), Hoffnagle and Olson (1974), and Hoffnagle (1976) within the study area, with additional studies by Northwest Environmental Consultants (1975) and Burg et al. (1975) for nearby marshes within Puget Sound. Values are summarized in Table 3-15. Productivity of salt marshes in areas outside the region has been summarized by Eilers (1975) and, with some additions, is presented in Table 3-16.

Eilers (1975) reports a direct correlation between elevation and productivity as indicated in Figure 3-20. However, other studies (Vanderzanden et al., 1976; Burg et al., 1975; Northwest Environmental Consultants, 1975) have indicated an opposite trend, with the mature high marsh (or diked marsh) being less productive and Carex or Juncus marshes with lower elevations being typically most productive.

Review of these studies indicates that productivity of different portions of an emergent marsh differ markedly, that there is a considerable differential in the value of production of each estuary, as some species have different nutritional qualities, and that export to the estuary differs widely from one area of marsh to another.

One of the most productive portions of the salt marsh appears to be the Carex marshes (Vanderzanden et al., 1976; Northwest Environmental Consultants, 1975; Eilers, 1975; Burg et al., 1975). Carex occurs in the intertidal areas where detrital materials can be readily exported, decomposes rapidly, and compares favorably to other salt marsh species as a food source (as seston) in controlled experiments with mussels and oysters (Eilers, 1975; Hall, 1976; Stunz, 1976; Gnat et al., 1976). Productivity data for selected associations of marsh plants for salt marshes in and near the region are given in Tables 3-17, 3-18, and 3-19.

There is also a seasonal component to productivity. Biomass increase over time, as indicated in Figures 3-21 and 3-22, provides evidence of differential productivity as well as different peaking periods for different associations. However, the biomass of most species peaks in July; bent grass (Agrostis spp.) and seashore salt grass (Distichlis spicata) have later peaking dates.

TABLE 3-15. NET AERIAL PRODUCTION OF DRY MATTER (IN g/m^2/YEAR) BY SALT MARSHES IN THE PACIFIC NORTHWEST.

Site	Type of Marsh	Productivity		Source
		Range	Mean	
Hood Canal, WA[1]	--	283-2,000	--	Northwest Environmental Consultants (1975)
Hood Canal, WA	low, sandy	738	--	"
Hood Canal, WA	sedge spp.	2,000	--	"
Hood Canal	immature, high	1,041	--	"
Hood Canal, WA	mature, high	283	--	"
Nisqually Delta, WA[1]	--	90-13,900	750	Burg et al. (1975)
Nehalem Bay	intertidal	227-2,629	1,174	Eilers (1975)
Nehalem Bay	transitional	741-2,612	1,410	"
Nehalem Bay	above tide	839-2,820	1,710	"
Nehalem Bay	all/combined	227-2,820	1,364	"
Coos Bay	(intertidal-transitional)	379-11,119	--	Vanderzaden et al. (1976)

[1] Hood Canal and Nisqually Delta are in Puget Sound area of Washington, outside the study area.

The preceeding data have not included root production which makes up the majority of the standing biomass of the salt marsh species of the region (Vanderzanden et al., 1976). A study in Mississippi by de la Cruz and Courtney (1977) measured root production (970-1240 g/m^2/year) comparable to annual aerial production in an emergent salt marsh, with the majority of the production occurring in the top twenty centimeters (8 in) of soil.

In addition to the productivity of the macrophytes which are discussed above, periphyton and benthic diatom productivity make up a significant but regionally undocumented portion of the salt marsh net primary productivity. In a study in Louisiana, benthic diatom, phytoplankton, and epiphyte production made up nearly forty percent of the net primary productivity of a salt marsh (Day et al., 1973).

In summary, salt marshes of the region are at least as productive as salt marshes of equivalent latitudes of other areas (Eilers, 1975; Vanderzanden et al., 1976); they may, in fact, be more productive. Vanderzanden et al. (1976), suggests the causal factors may include longer growing season, more moderate temperatures, and lack of ice scouring. Eilers (1975) proposes an uncharacteristic decreased productivity southwardly due to summer dessication.

Salt marsh primary production in the region is a little less than, although comparable to, the inland seral forests, and is twice that of the upwelling regions of the oceanic shelf.

#9. Nitrogen-Fixation. Although not documented within the region, nitrogen-fixation in Spartina salt marshes has been documented in Georgia (Van Raalte, 1977; Haines et al., 1976). The fixation is carried out by bacteria inside Spartina roots, on the soil surface by bluegreen algae, and on pans and in the soil by photosynthetic bacteria. Nitrogen-fixation has also been documented in other marsh environments including cattail (Typha) marshes and rice paddy fields (Balandreau et al., 1976). Consequently, it is probable that nitrogen-fixation occurs in estuarine salt marshes within the region. Rates of fixation in marsh environments in Georgia have been measured at 1.2-17.1 g/m^2 (Haines et al., 1976).

The characteristic anaerobic conditions of low marsh soils allow denitrification to take place (Haines et al., 1976). In face, N_2 production by denitrifying bacteria is greater than by nitrogen-fixation. In situ mineral recycling is probably the most important way nitrogen becomes available to primary producers (Haines et al., 1976).

TABLE 3-16. NET AERIAL PRODUCTION (IN g DRY/m^2/YR) FOR COASTAL SALT MARSHES OUTSIDE THE STUDY AREA, AS REPORTED BY VARIOUS AUTHORS. (After Eilers, 1975.)

Net Aerial Production (g dry/m^2/yr)	Locale	Dominant Species	Source
Intertidal Low Marsh			
445	Delaware	*Spartina alterniflora*	Morgan (1961)[a]
596	Rhode Island	--	Nixon & Oviatt (1973)
973	Georgia	--	Smalley (1959)
1,000	N. Carolina	--	Williams & Murdock (1966)[a]
1,296	N. Carolina	*Spartina alterniflora*	Stroud & Cooper (1969)
1,675[b]	Georgia	--	Teal (1962)
1,700[c]	California	*Spartina foliosa*	Cameron (1972)
2,000	Georgia	--	Odum (1961)
Extra tidal High Marsh			
230	Sweden	*Juncus gerardi*	Tyler (1971)
343	Sweden	--	Wallentinus (1970)[d]
560	N. Carolina	*Juncus roemerianus*	Foster (1968)[a]
796	N. Carolina	--	Stroud & Cooper (1969)
849	Florida	--	E. J. Heald (1969)[a]
850	N. Carolina	--	Williams & Murdock (1968)[a]
993	Long Island	*Spartina patens*	Harper (1918)
1,200[c]	California	*Salicornia subterminalis*	Cameron (1972)
1,296	N. Carolina	*Spartina patens*	Waits (1967)[a]
1,360	N. Carolina	*Juncus roemerianus*	Waits (1967)[a]

[a] Cited in Keefe (1972).

[b] kcal ÷ 4.

[c] Maximum standing crop biomass.

[d] Cited in Tyler (1971), not in bibliography.

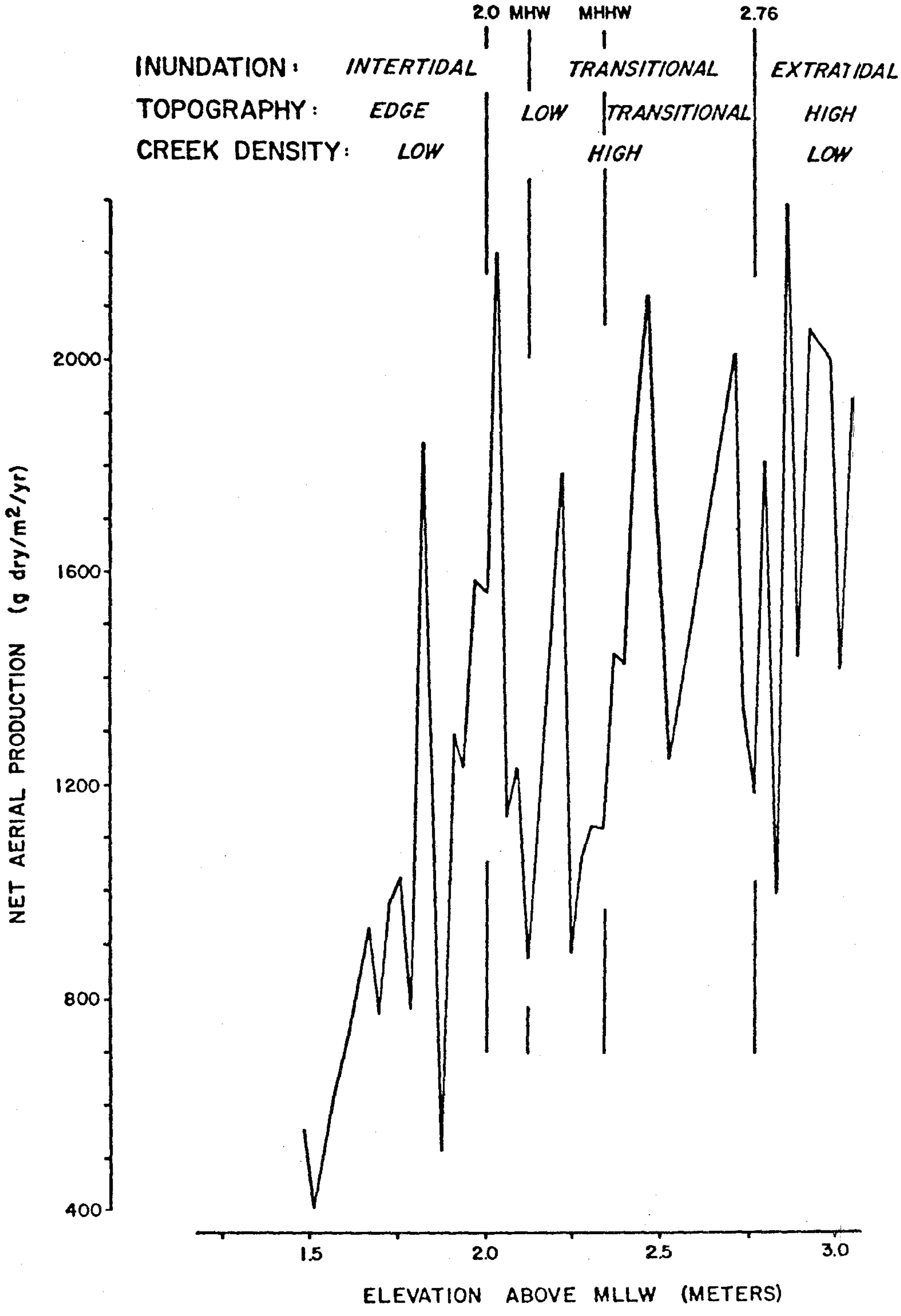


FIGURE 3-20. NET AERIAL SALT MARSH PRODUCTION BY ELEVATION. Data from Nehalem Bay, Oregon, are averaged for three centimeter elevation increments and related to inundation, topography, and creek density. MLLW = Mean lower low water. (From Eilers, 1975.)

TABLE 3-17. SUMMARY OF SALT MARSH PRODUCTIVITY DATA BY PLANT ASSOCIATION FOR THE NISQUALLY DELTA IN LOWER PUGET SOUND, WASHINGTON. Plant associations are: SPMA = *Spergularia marina*, SAVI = *Salicornia virginica*, FERU = *Festuca rubra*, CALY = *Carex lyngbyei*, DISP = *Distichlis spicata*, POPA = *Potentilla pacifica*, JUBA = *Juncus balticus*, JACA = *Jaumea carnosa*. (From Burg et al., 1975.)

Association	Annual Net Productivity	
	g/m^2	kg/ha
SPMA	90	900
SAVI	730	7,300
FERU - CALY	640	6,400
CALY - DISP - POPA	720	7,200
DISP - JUBA	470	4,700
DISP - SAVI	930	9,300
JACA - DISP	610	6,100
CALY	1390	13,900

TABLE 3-18. NET PRIMARY PRODUCTION[1] IN SIX SALT MARSHES OF COOS BAY, OREGON. (From Vanderzanden et al., 1976.)

Marsh	Net Primary Production	
	g/m^2/year	g/m^2/4 mos.
North Slough (bullrush, *Scirpus validus*)	1118.89	1118.89
Bull Island (Immature high marsh)	1007.86	816.60
South Slough (Immature High marsh)	764.81	664.40
Pony Slough (low marsh)	599.103	538.56
Salicornia marsh	560.346	423.16
Coalbank (diked marsh)	378.867	263.34

[1] Net primary production was determined for each marsh during a four month sampling interval (April to July). Yearly estimates were projected based on individual species growth curves. Values are grams dry weight.

TABLE 3-19. NET AERIAL PRODUCTION (IN g DRY/m^2/YR) FOR SALT MARSH PLANT COMMUNITIES ON WEST ISLAND, NEHALEM BAY, OREGON. (From Eilers, 1975.)

Community[b]	Mean	Range	Community Total	Community %	Marsh Area %	Deviation %
S	609	347 - 1,164	10,874,304	1.0	2.3	- 1.3
T	518	227 - 857	26,136,726	2.4	6.5	- 4.1
C (Short)	875	533 - 1,051	69,148,625	6.4	10.1	- 3.7
C (Tall)	1,746	1,276 - 2,629	131,746,176	12.2	9.6	+ 2.6
CDT	1,076	657 - 1,767	170,252,252	15.8	20.2	- 4.4
TD	1,468	947 - 2,204	31,877,620	3.0	2.8	+ 0.2
CDTAg	1,693	1,031 - 2,612	199,811,246	18.5	15.1	+ 3.4
JAg	1,479	746 - 2,180	178,985,622	16.6	15.4	+ 1.2
JAgF	1,574	943 - 2,709	27,471,022	2.6	2.3	+ 0.3
APO	1,936	839 - 2,820	222,390,256	20.7	14.7	+ 6.0
CAO	1,756	1,131 - 2,217	6,978,344	0.7	0.5	+ 0.2
PS	1,936[a]	---------	799,568	0.1	0.5	- 0.4
MARSH	1,388	227 - 2,820	1,076,471,761	100.0	100.0	0.0

[a] Estimated as identical to that of APO.

[b] Communities are named for dominant vegetation, as follows:

S = *Scirpus*
T = *Triglochin*
C = *Carex*
CDT = *Carex*, *Deschampsia*, *Triglochin*
TD = *Triglochin*, *Deschampsia*
CDTAg = *Carex*, *Deschampsia*, *Triglochin*, *Agrostis*
JAg = *Juncus*, *Agrostis*
JAgF = *Juncus*, *Agrostis*, *Festuca*
APO = *Aster*, *Potentilla*, *Oenanthe*
CAO = *Carex*, *Aster*, *Oenantha*
PS = *Picea*, *Salix* (shrub).

3.2.1.2 Emergent Vegetation Ecosystem Model Notes (continued)

#10. Ion Exchange. Salt marsh plants have special problems that include not only extracting nutrients in desired quantities but also coping with high sodium ion concentrations. Where salt water concentrations are in the order of 0.05 (or about two bars of osmotic potential), maintenance of osmotic pressure becomes a serious problem.

High external osmotic pressure from salt water has the following effects upon plants in general (Slatyer, 1967):

1) depression of growth,
2) depression of transpiration,
3) reduction of water availability, and
4) excess accumulation of ions which may interfere with the uptake of essential nutrients.

Salt marshes have evolved at least four ways by which they cope with high sodium environments (Ranwell, 1972). Some salt marsh species (e.g. halobacteria, many species of algae, glasswort (*Salicornia virginica*), and seaside arrowgrass (*Triglochin maritimum*)) have evolved a selective ion uptake mechanism that can discern between sodium ions and the ions of desirable nutrients (Parham, 1970). Other salt marsh plant species (e.g. sea-milkwort (*Glaux maritima*) and *Spartina*) have evolved special salt glands which excrete sodium. Some species accumulate salts in parts of the plant where little metabolic activity occurs, then slough off the material annually. Others (e.g. *Jaumea* and salt bush (*Atriplex patula*)) have evolved succulence which allows water storage in upper portions of the plant when roots are in highly saline conditions.

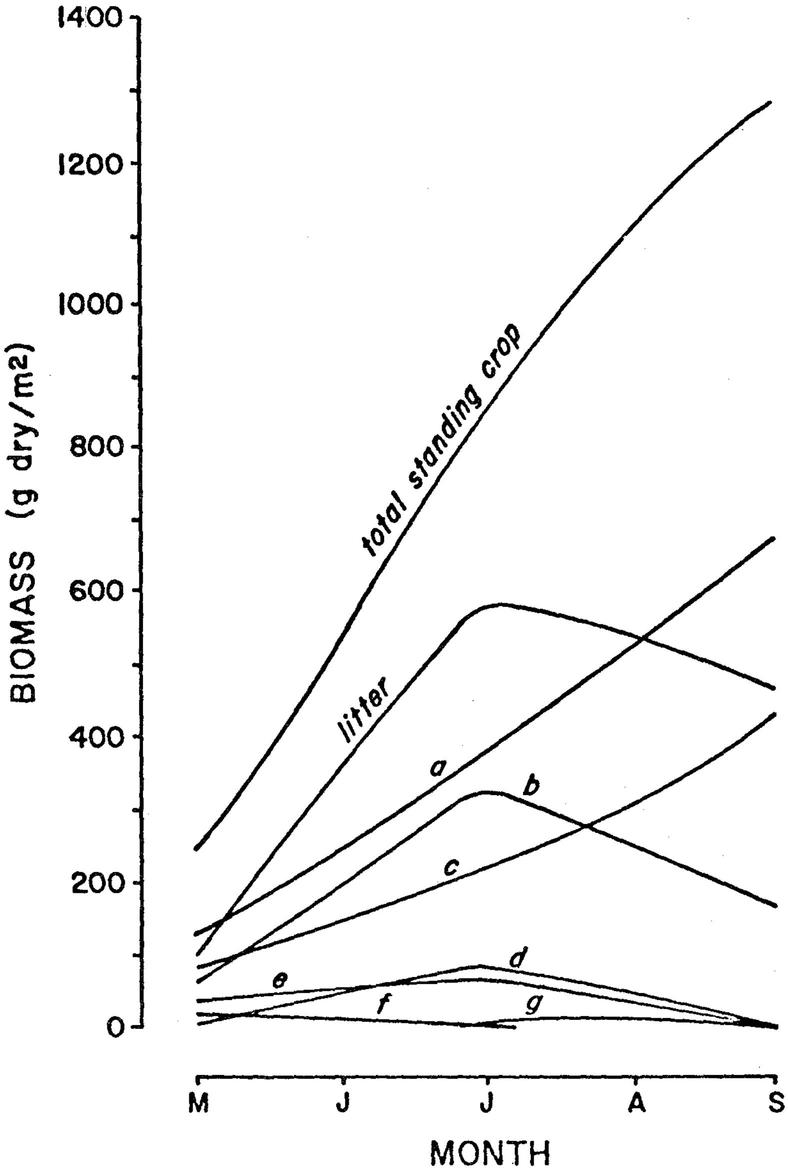


FIGURE 3-21. BIOMASS OVER TIME OF INDIVIDUAL SALT MARSH SPECIES AND LITTER. Data are from West Island, Nehalem Bay, Oregon, May, July, and September, 1972. Plant species are: a) Aster subspicatus, b) Oenanthe sarmentosa, c) Achillea millifolium, d) Lathyrus palustris, e) Potentilla pacifica, f) Galium trifidum, g) Agrostis alba. (From Eilers, 1975.)

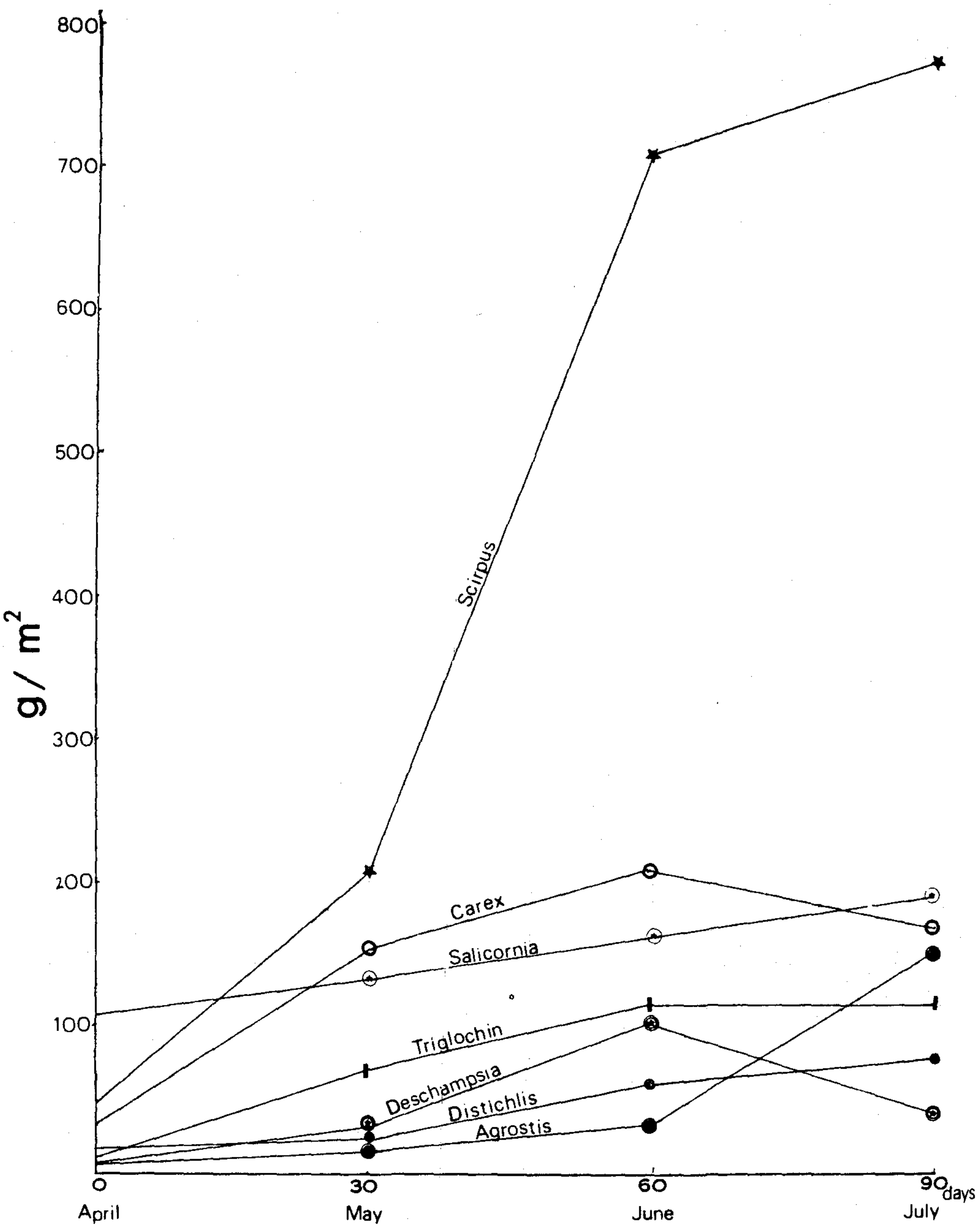


FIGURE 3-22. PLANT BIOMASS OF SEVEN SALT MARSH SPECIES IN COOS BAY, OREGON, OVER TIME. (From Vanderzanden et al., 1976.)

MacNae (1966) presents evidence from Australia indicating that calcium is essential to this selective ion transport mechanism which allows plants to selectively take up required nutrient ions under conditions of high sodium concentrations.

There is some evidence that salt marsh species are better able to take up iron in a reducing root condition where anaerobic iron-reducing bacteria are present. Iron deficiency is apparent at higher elevations where the soil is aerated. However, little work has been reported on the mechanics of uptake under reduced conditions.

#11. Secondary Productivity. There is little documentation of consumption within salt marsh communities of the West Coast, and more specifically within the study area. Recent work by Koplin (1978, personal communication, Department of Biology, Humboldt State University, Arcata, California) documents trophic relationships for the Arcata Bottoms, Arcata, California, diked marshlands which have been transformed into pasture/agricultural uses.

The only data on secondary consumption in marshes of the study area are those of Schrag (1976). He records that leafhoppers consumed approximately 7% of net primary productivity in the Coos Bay saltgrass.

This figure is slightly higher than secondary consumption (general) reported by most authors in other salt marsh studies (Odum and Smalley, 1959; Smalley, 1960; Day et al., 1973; Teal, 1962). Additional grazing is done by larger herbivores such as waterfowl, muskrats, and (locally) cattle, but quantities are undocumented. The principal grazing group in salt marshes, however, is thought to be the insects; their principal predators are spiders (Cameron, 1972).

#12. Community Composition. The emergent vegetation (salt marsh) community is an edge community that occurs where a low relief shoreline interfaces with a low energy estuarine condition. Organisms present are either characteristic of both environments, or have adapted to the special conditions (e.g. halophytes) and are specific to the community.

Unlike salt marshes of many areas, the salt marshes of the region are not monocultures of single species. A wide range of salt marsh types, many of them having several co-dominant species, are typical of the area (Eilers, 1975; Hoffnagle, 1076; Vanderzanden, 1976; Jefferson, 1974). Instead of the extensive Spartina (cordgrass) marshes of the Eastern seaboard, salt marshes of the region are more typically a mixture or a mosaic of species, including such species as saltbush (Atriplex patula), glasswort (Salicornia virginica), seaside arrowgrass (Triglochin maritimum), Baltic ruch (Juncus balticus), Lyngby's sedge (Carex lyngbyei), Jaumea (Jaumea carnosa), tufted hairgrass (Deschampsia caespitosa), and others. A more extensive list is provided in the community composition section of the Emergent Vegetation habitat (2.1.2 C) in Volume 3. The same list or variations thereof can be generated from review of the Annotated Species List.

The subclassification of marsh types most often utilized within the region is the one proposed by Akins and Jefferson (1973) and Jefferson (1974). The marsh types, along with brief descriptions are as follows:

Low Sandy Marshes. These marshes are usually located on a sandy substrate on the inland side of baymouth sand spits or on islands in sandy bays. In the east side of the Coquille estuary (Watershed Unit 7), the large area of this type is, however, on a silty substrate opposite the sand spit, indicating that another factor(s) besides sand influences formation of this marsh type. The marsh surface is slightly elevated above the tideflat and has a gentle upward slope toward higher land.

These areas are flooded by nearly all high tides and tidal drainage is diffuse. The lowermost vegetation is dominated by glasswort (Salicornia virginica) or three-square rush (Scirpus americanus), and the higher vegetation is mainly saltgrass (Distichlis spicata), Jaumea (Jaumea carnosa), and seaside plantain (Plantago maritima). Lesser quantities of the sand spurries (Spergularia canadensis, S. macrotheca), alkali grass (Puccinellia maritima), sedge (Carex lyngbyei), and milkwort (Glaux maritima) appear frequently.

Low Silty Marshes. These marshes are usually located on a silt or mud substrate wherever sedimentation occurs rapidly. The marsh surface is relatively flat but is interrupted by slightly elevated circular islands of colonizing seaside arrowgrass (Triglochin maritimum).

Nearly all high tides inundate these marshes and tidal runoff is diffuse but somewhat channelled around the plant colonies. The smaller plants, spike rush (Eleocharis parvula) and sand spurry (Spergularia marina), are scattered on the marsh surface.

Sedge Marshes. Sedge marshes occur usually on silt between the low silty type marshes and more mature marshes, or on the edge of islands, deltas and dikes. The surface is relatively level but may abruptly rise a third of a meter or more above the tideflat surface.

Most high tides inundate the sedge marshes. Tidal runoff is diffuse on lower sedge marshes and well contained in deep ditches on older, higher marshes. The vegetation is almost exclusively sedge (Carex lyngbyei, Carex obnupta, Carex sp.).

Immature High Marshes. Immature high marshes usually occur in substrates high in organics and silts, and inland of sedge and low sandy marshes. The marsh surface is relatively level, but is interrupted with shallow bare depressions and drainage ditches. The marsh usually rises abruptedly nearly a meter above the tideflat or several centimeters above the surrounding lower marsh. Immature high marshes are inundated by many higher high tides. Tidal runoff flows in deep, well defined ditches.

The vegetation present is mixed, because this marsh type is a transition type between lower, immature marshes and mature salt marshes. The vegetation cover is continuous. Tufted hairgrass (Deschampsia caespitosa), a tall grass, is often mixed with saltgrass (Distichlis spicata), a shorter grass, as a codominant. Lesser quantities of seaside arrowgrass (Triglochin maritium), glasswort (Salicornia virginica), and sedge (Carex lyngbyei) are also present.

Mature High Marshes. Mature high salt marshes occur on highly organic substrates that often lie over old clays. The marsh surface is relatively level but is interrupted by shallow depressions and deep ditches and potholes. The marsh rises a meter or more above the tideflat. Many high tides just cover the surface of the marsh. Tidal runoff follows the tidal channels. Fresh water may seep through the soil.

The plant cover is continuous and is characterized by grasses, rushes, and forbs. Tufted hairgrass (Deschampsia caespitosa), salt rush (Juncus lesueurii), and creeping bentgrass (Agrostis alba) dominate. Remnants of earlier plant populations remain scattered across the surface and along ditches. Gum plant (Grindelia integrifolia), Pacific silverweed (Potentilla pacifica) and orache (Atriplex patula) are forbs found on the highest elevations.

Bulrush and Sedge Marshes. Bulrush (Scirpus validus) and sedge (Carex) characterize this type of salt marsh. Such marshes occur along tidal creeks and dikes or on islands where fresh water largely dilutes the salt water. As the water becomes fresher upstream, the sedge disappears. Bulrush and sedge marshes occur on silt or sand that is inundated by most high tides. Tidal runoff is diffuse.

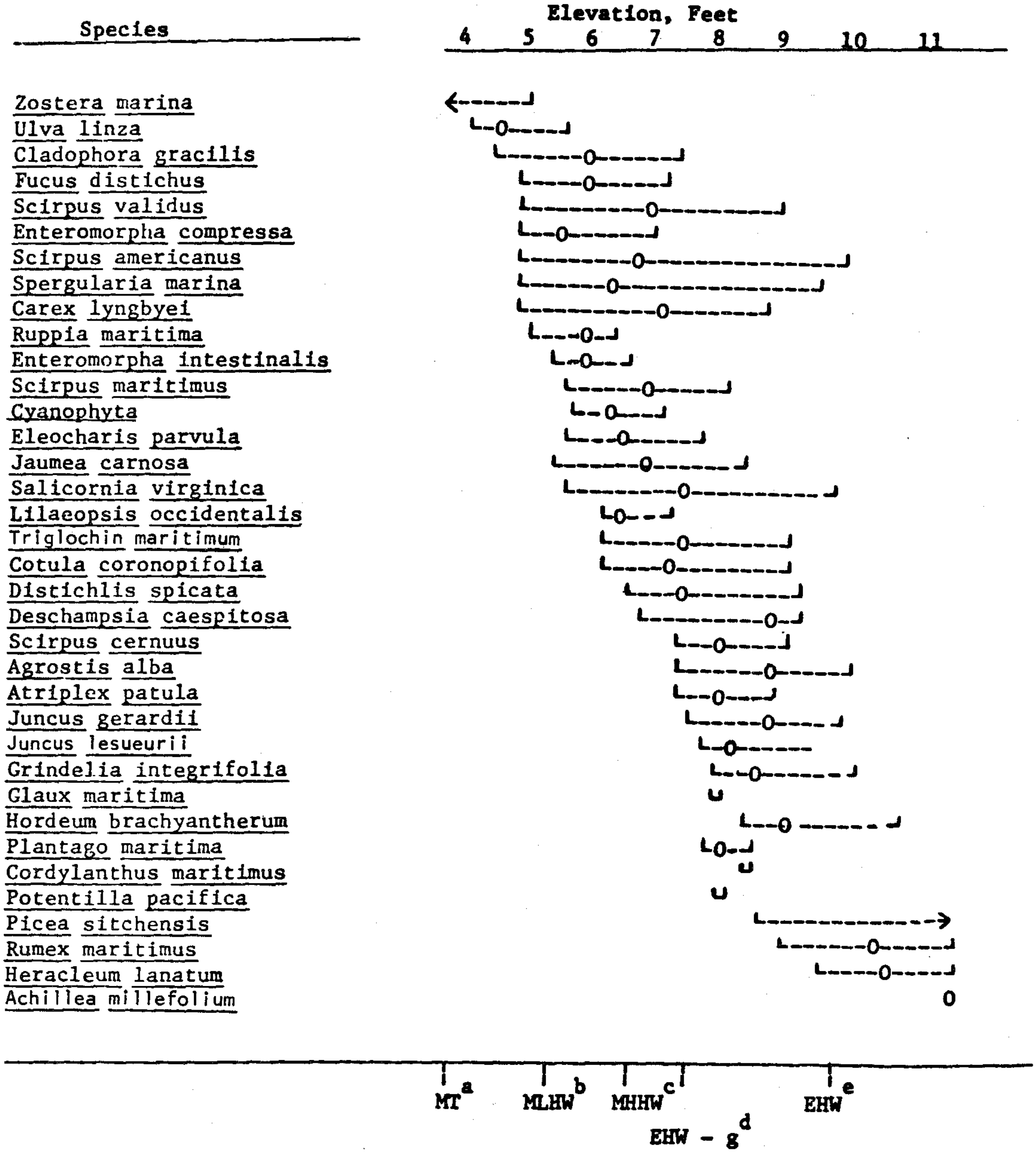
Intertidal Gravel Marshes. This type of marsh is rare in the study area, occurring only near the mouths of the Rogue and Coquille Rivers. Patches of spike rushes (Eleocharis macrostachya, E. parishii, E. parvula) and scattered forbs grow on gravel bars and beaches subject to tidal inundation. However, the type of plants present indicate that water salinity is probably very low.

J. L. Smith et al. (1976) have reported changes in community composition using this classification system in Grays Harbor. Northwest Environmental Consultants (1974) similarly found the classification usable in Willapa Bay.

Within the region, community composition is largely dependent on elevation, salinity, and substrate type (Jefferson, 1974; Eilers, 1975). Distribution of salt marsh species along an elevation gradient is given in Figures 3-23 and 3-24 for salt marshes of Oregon while Figure 3-25 indicates vegetation gradation in Grays Harbor, Washington. Similar gradation is to be expected in more northerly and southerly areas of the study region.

Faunal community composition is provided in the community composition list for the estuarine Emergent Vegetation habitat (2.1.2 C) in Volume 3. Within the salt marsh there is also a gradient of species use as is indicated in Figures 3-26 and 3-27 for insects. Schrag (1976) reports a shift from insects to marine invertebrates along an elevation gradient for the Coos Bay salt marshes. Figure 3-28 demonstrates the differential use of portions of a salt marsh by the two major small mammals of the community. Outside of the region Diaber (1974) has documented a preference for the less saline portions of the marsh by muskrat. Yocum (1951) and Martin et al. (1961) report use of some marsh plants over others by migratory waterfowl.

Community composition in the region's emergent marshes is strongly influenced by tidal and seasonal patterns. During high tides motile estuarine aquatic species move in, while during periods of lower tides terrestrial species forage.



[a]Mean tide.
[b]Mean lower high water.
[c]Mean higher high water.
[d]Extreme high water, growing season 1971.
[e]Extreme high water.

FIGURE. 3-23. RANGES OF OREGON SALT MARSH PLANTS RELATIVE TO MEAN LOWER LOW WATER. (Directly from Jefferson, 1974.)

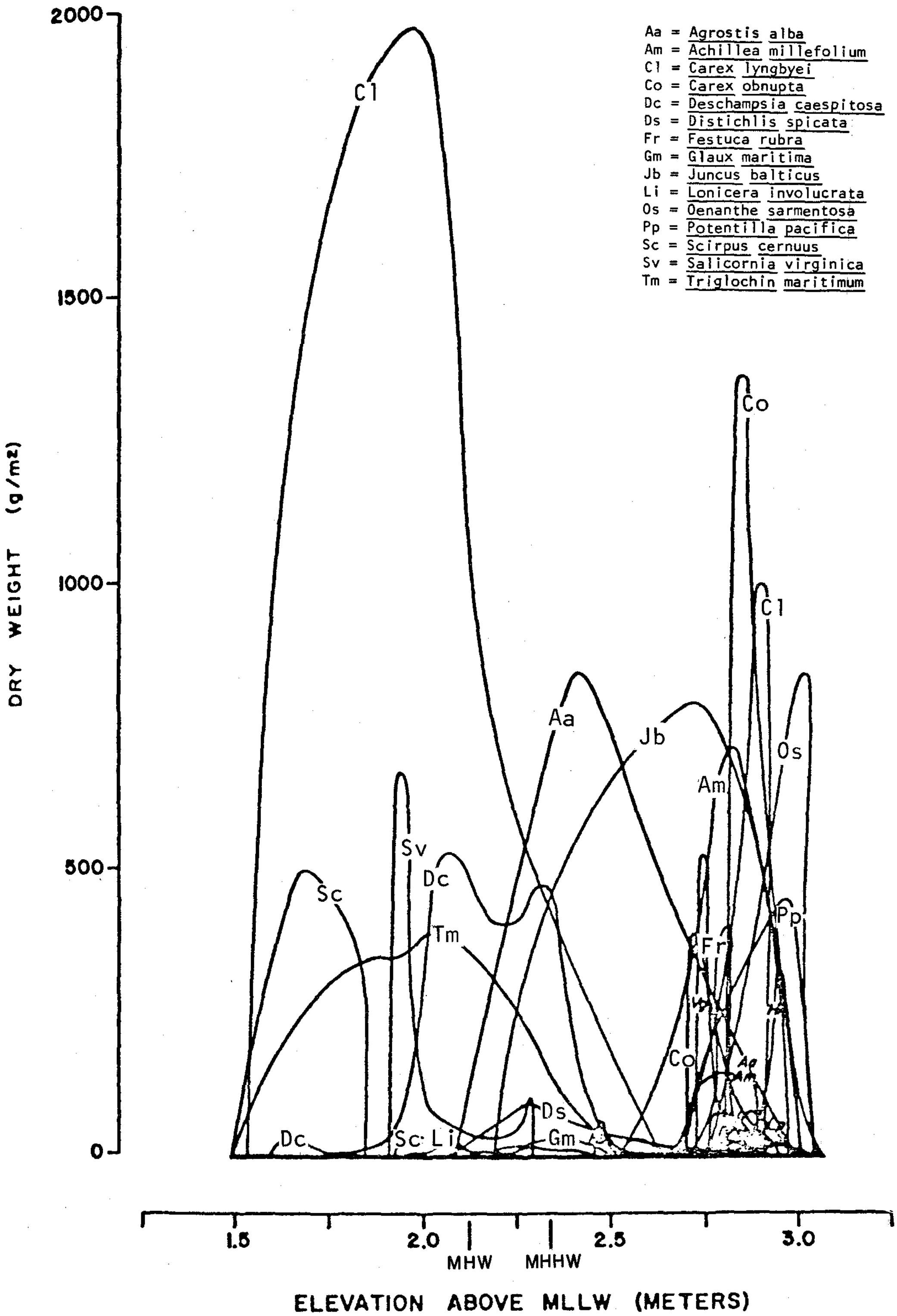


FIGURE 3-24. DISTRIBUTION OF SALT MARSH PLANTS (BY ABOVE GROUND DRY WEIGHT BIOMASS) ALONG AN ELEVATION GRADIENT. Data are from West Island, Nehalem Bay, Oregon, July, 1972. (From Eilers, 1975.)

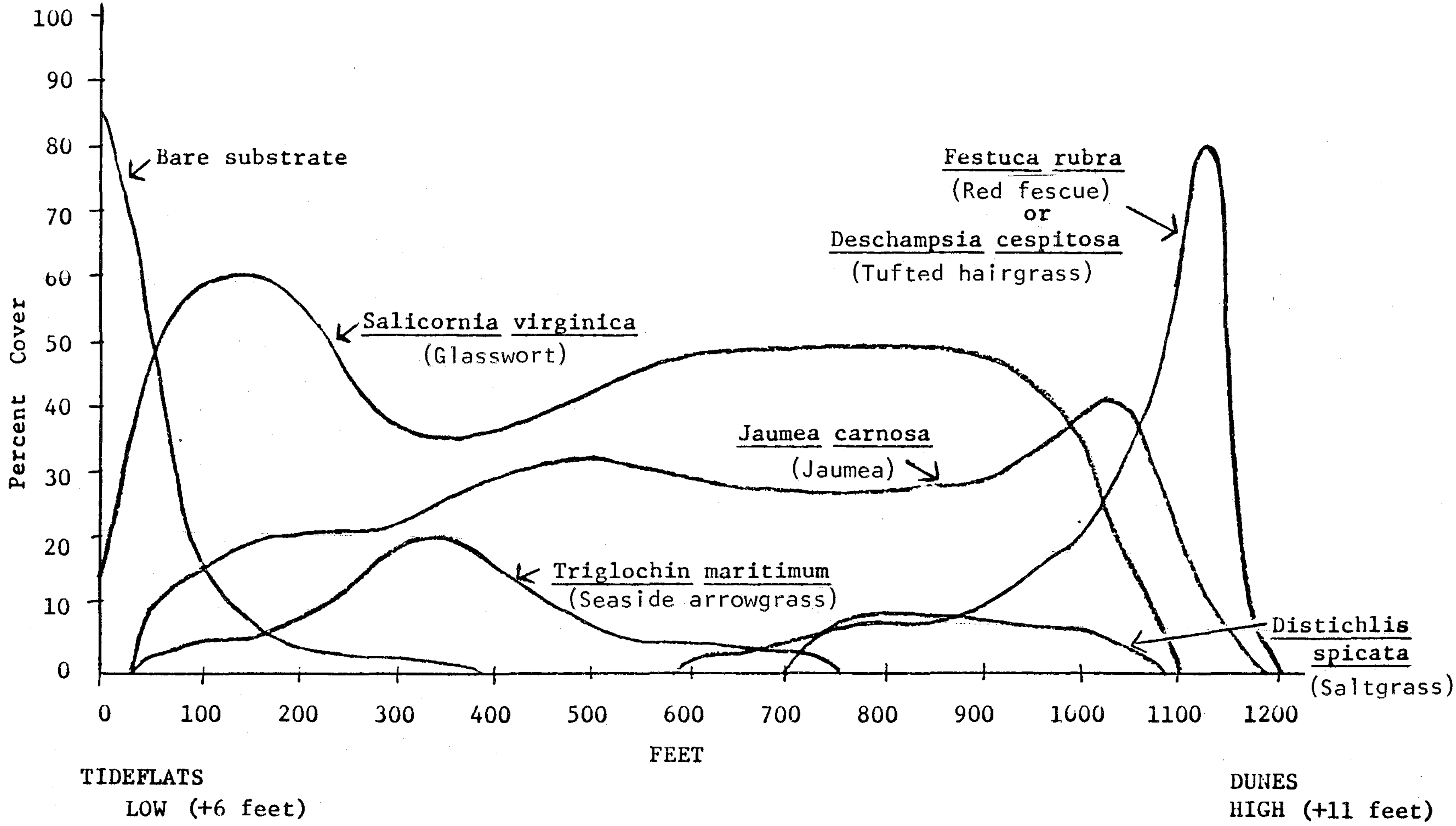


FIGURE 3-25. PERCENT COVER RELATIONSHIPS OF CHARACTERISTIC PLANT SPECIES ALONG AN ELEVATION GRADIENT AT THE WESTPORT SALT MARSH, GRAYS HARBOR, WASHINGTON, 1975. (From J.L. Smith et al., 1976.)

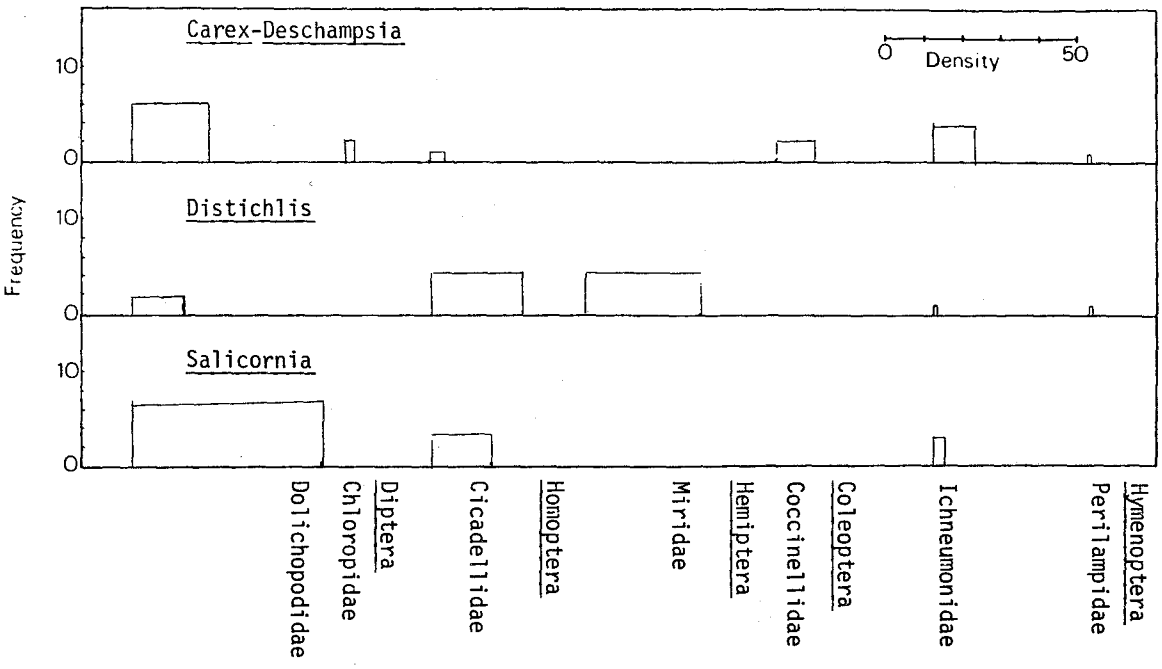


FIGURE 3-26. FREQUENCY-DENSITY DIAGRAM OF THE COMMON INSECT FAMILIES IN LOW SALT MARSHES (COOS BAY, OREGON) IN RELATION TO DOMINANT PLANT TYPES. (From Schrag, 1976.)

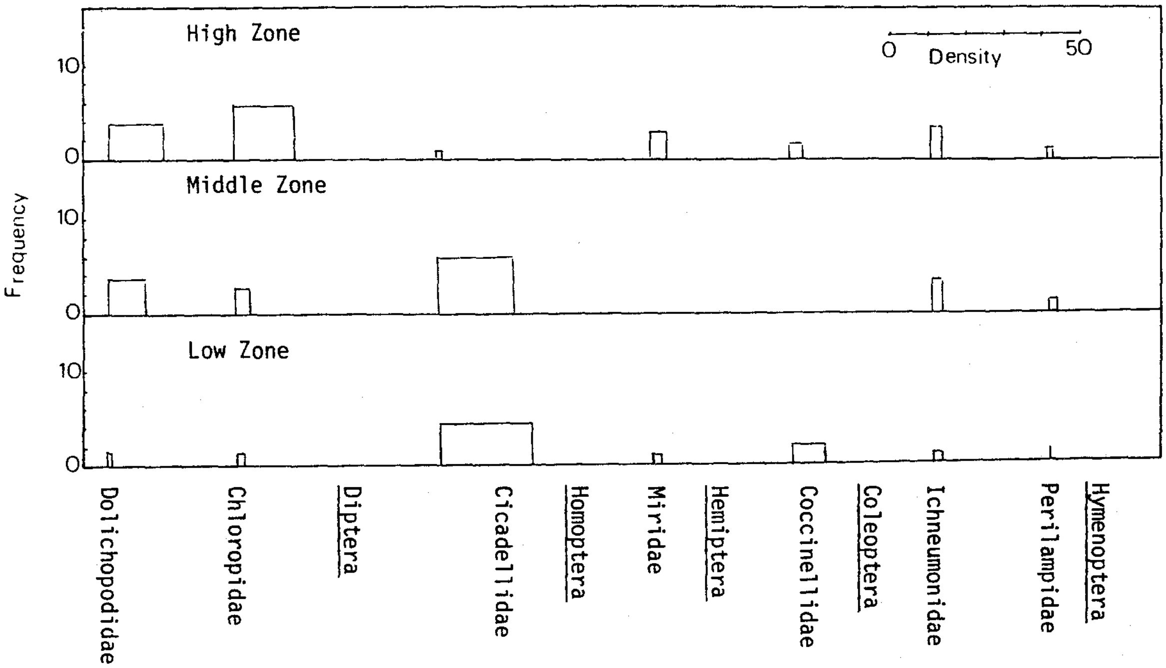


FIGURE 3-27. FREQUENCY-DENSITY DIAGRAM OF INSECTS IN IMMATURE HIGH SALT MARSHES IN RELATION TO LOW-MIDDLE-HIGH ELEVATION GRADIENT (COOS BAY, OREGON). (From Schrag, 1976.)

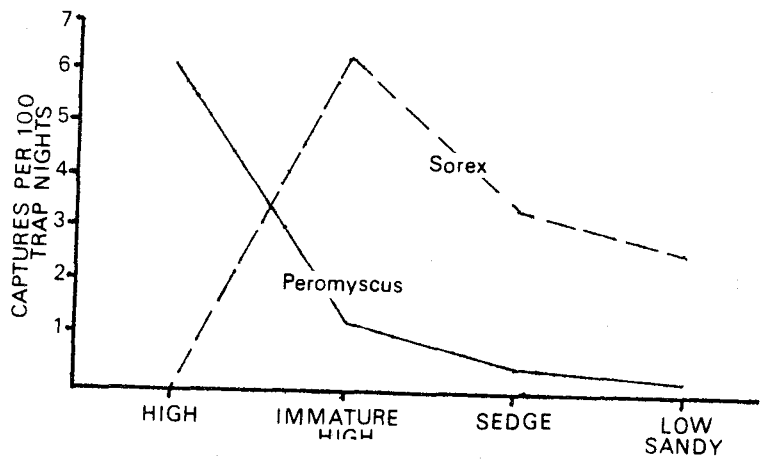


FIGURE 3-28. USE OF DIFFERENT SALT MARSH TYPES (COOS BAY, OREGON) BY TWO SMALL MAMMALS, THE DEER MOUSE (PEROMYSCUS) AND THE VAGRANT SHREW (SOREX). (From Magwire, 1976B.)

3.2.1.2 Emergent Vegetation Ecosystem Model Notes (continued)

In a salt marsh in San Francisco Bay, Cameron (1972) found Diptera, Coleoptera, and Hymenoptera to comprise 75% of the insect species present. Of the insects present, 50% were herbivores, 9-13% were saprovores (detritivores) and 13-16% were predacious or parasitic. The population showed considerable seasonal variability with populations peaking in October and in June and July. Spider abundance ($\sim 40/m^2$) peaked in May through August. Herbivore diversity was strongly correlated with standing crop biomass, saprovore diversity with amount of litter, and predators and parasites with diversity of prey species.

MacDonald (1969), in his review of salt marsh molluscs within the study area found two distinctive communities - one found within the salt marsh proper dominated by a few species of gastropods (Assiminea californica and Littorina newcombiana) and the other found in the salt marsh creeks and channels, dominated by a few species of bivalves (e.g. Cryptomya californica, Macoma nasutu, Macoma inconspicua, and Mya arenaria). Other species were in low densities and patchy. Abundances in the salt marsh were 600 per square meter at Grays Harbor, 250 per square meter at Coos Bay, and 900 per square meter at Arcata. The creek community abundances were lower with 172 per square meter at Grays Harbor, 26 per square meter at Coos Bay, and 14 per square meter at Arcata, where the individual bivalves were larger. Biomass for either community was less than three grams dry weight per square meter. Biomass farther south was considerably greater.

Waterfowl are seasonally abundant. The most abundant birds are the long-billed marsh wren, swallows, song sparrow, and the great blue heron (Magwire, 1976A). Most abundant mammals are white-footed deer mouse, vagrant shrews, and microtines (Magwire, 1976B; U.W., College of Forest Resources, 1974). Seasonal concentrations of raptors (birds of prey) occur during migration and wintering periods (U.W., College of Forest Resources, 1974), the most abundant of which is the marsh hawk.

#13. Migration. Many of the consumer species which utilize the salt marsh are migratory. Some (e.g. shiner perch and staghorn sculpin) utilize the marsh in a cycle following tidal conditions, i.e. they enter and leave with tidal waters (Hoffnagle, 1976). Other species (e.g. the nocturnal raccoon) utilize the marsh according to photic conditions, leaving for shelter during daylight hours. Others are seasonal visitors; waterfowl and raptors are the most obvious (U.W., College of Forest Resources, 1974). Still others (e.g. juvenile salmonids, and Dungeness crabs) may utilize the marsh during only a portion of their life cycle.

#14. Decomposition. In the high marsh, decomposition is primarily aerobic in surface and sub-surface soils with organic materials decomposed rapidly on site (Eilers, 1975). Periodically, oxygen levels may become reduced during seasonal high tides and/or flooding.

In the lower, more frequently inundated portions of the marsh , decomposition on the soil surface is aerobic and rapid. Organics are degraded by generalistic, heterotrophic bacteria and fungi using oxygen as an electron acceptor. As discussed in Note #7, sub-surface decomposition is typically anaerobic. Under estuarine conditions the principal method of anaerobic decomposition is by bacterial sulfate-reduction (Rickert, 1969), since saltwater sulfate concentrations greatly exceed other electron acceptors (e.g. oxygen, nitrates, and carbon dioxide) and are readily transported to the anaerobic layer (Bella and Williamson, 1977). Under these conditions bacterial reaction results in production of hydrogen sulfide, various organics, and carbon dioxide.

Hydrogen sulfide (H_2S) reacts with iron where available to form insoluble ferrous sulfide. Where iron is not available, or is saturated, the toxic hydrogen sulfide can be released.

This form of decomposition can be altered by the depletion of organics which are degraded through the sulfate reduction process. (Some organic compounds are refactory to this process but not to others.) Or, through a reduction in available sulfates, anaerobic decomposition can be altered by lowering of salinity (thus sulfates) in overlying waters, resulting in reduced availability of sulfates in below-surface sediments. When sulfates are depleted an alternative decomposition process using a carbon dioxide as the electron acceptor and producing methane gas can be expected Bella and Williamson, 1977). Freshwater portions of estuarine marshes associated with cattails probably exhibit the latter subsurface form of decomposition. Other anaerobic forms of decomposition considered important in salt marshes are fermenting and dissimilatory nitrogenous oxide reducing by bacteria (Pomeroy et al., 1976).

Eilers (1975), Figure 3-29, shows the proportion of net aerial production which is exported (see Note #4) for surface litter versus elevation.

Accumulation of litter appears to occur in the transitional areas between the lower marsh where detritus is thought to be exported and the upper marsh where aerobic dryer conditions allow for more rapid decomposition. Agrostis alba and Junca balticus are typical of the lower and upper marsh, the litter from both of which resists rapid decomposition. Gnat et al. (1976), report rapid rates of decomposition measured by litter bag techniques for some major salt marsh species of the study area (Figure 3-30). The decomposition rates in litter bag experiments are greater than those indicated for marshes outside the study area. On the average, 60% of the material was decomposed in 90 days for Salicornia, Deschampsia, and Juncus lesueurii compared with annual rates of 35%, 47%, and 37% reported by de la Cruz (1965), Waits (1967), and R. J. Heald (1969), respectively, for Juncus roemerianus.

Laboratory studies by Stunz (1976), as shown in Figure 3-31, indicate decomposition trends corresponding to those reported by Gnat et al. (1976). Similar studies for salt marsh species have shown a 25% gross loss in seven days for Spartina alterniflora, and a similar loss in ten days for Juncus roemerianus (Gosselink and Kirby, 1974; de la Cruz and Gabriel, 1974). However, comparison of these studies may not be meaningful as different techniques were used.

The principal flow of energy in a salt marsh is through decomposition of vegetable litter and is thought by many authors to make significant energy and nutritional contributions to adjacent estuarine habitats (de la Cruz, 1965; de la Cruz and Gabriel, 1974; E.J. Heald, 1969; Stunz, 1976). Decomposers take the salt marsh cellulose, which is largely unusable by most estuarine organisms, and transform portions into usable microbial protein (Stunz, 1976; Pomeroy et al., 1976; Heinle et al., 1976). This seston protein is an important food source for estuarine filter-feeders, zooplankton and deposit-feeders (Heinle et al., 1976).

In a situation where the detritus remains in an aquatic environment, it is attacked by microorganisms, fungi, and bacteria which oxidize, hydrolize, and assimilate portions of the basic carbon structure. Simultaneously these decomposers are grazed by protozoans. The complex of decomposing plant material, bacteria, fungi and protozoans (seston) has considerable nutritional potential. Newell (1964) has presented evidence indicating nitrogen-fixation by bacteria as one significant means by which bacteria add nutritional value to seston. Seston is consumed by filter-feeders, deposit-feeders, and fishes. The bacteria, fungi, and protozoans are digested and the plant materia is returned to the environment virtually intact. Some estuarine consumers have intestinal symbiotic microbes which can also extract energy and nutrition from the plant particle. The fecal material is deposited, and the material is recycled until most biologically available energy and nutritional value have been extracted (Hall, 1976).

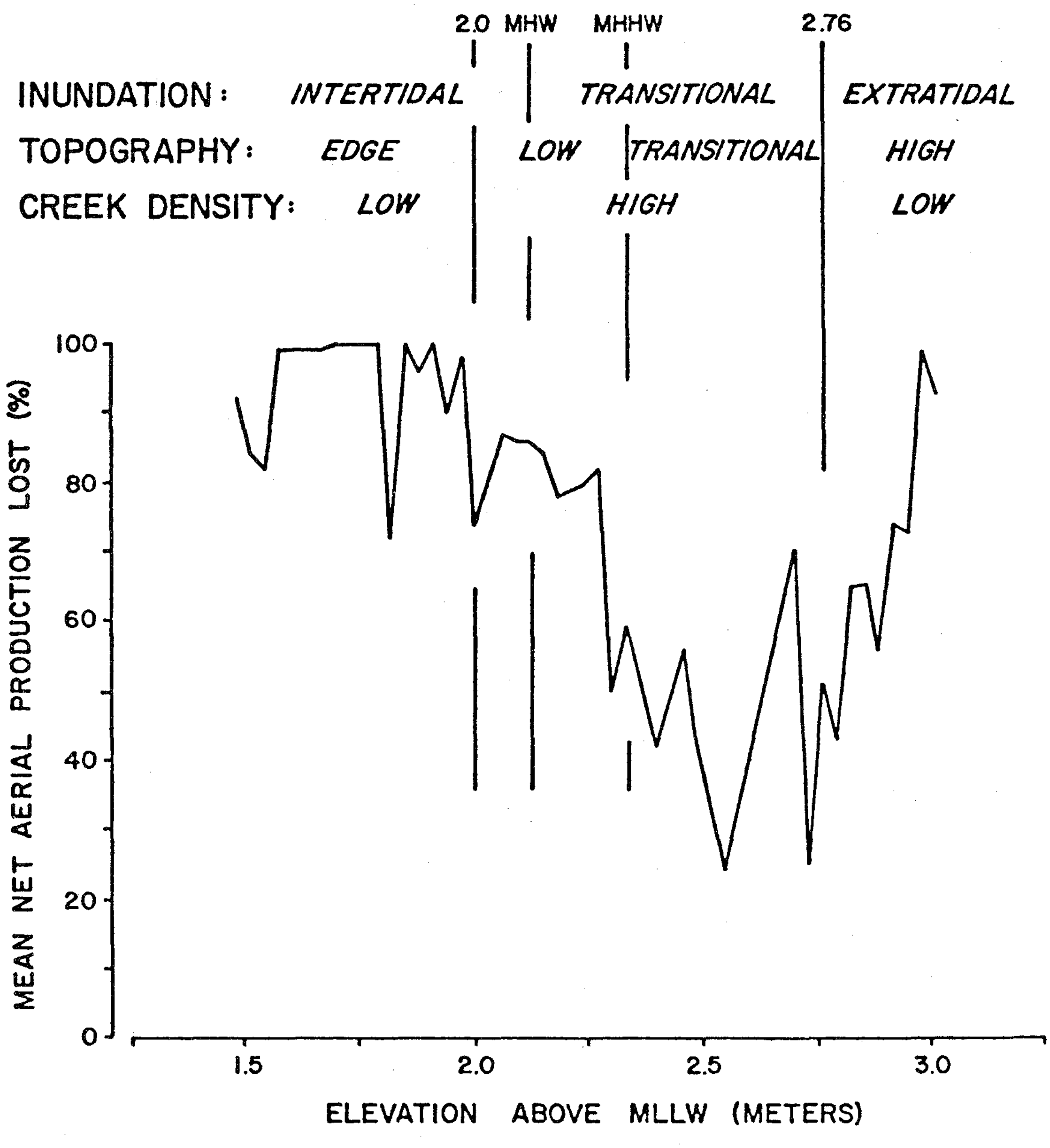


FIGURE 3-29. PERCENT OF SALT MARSH PRODUCTION LOST TO SOIL AND ESTUARY RELATED TO ELEVATION. Data are from West Island, Nehalem Bay, Oregon. (From Eilers, 1975.)

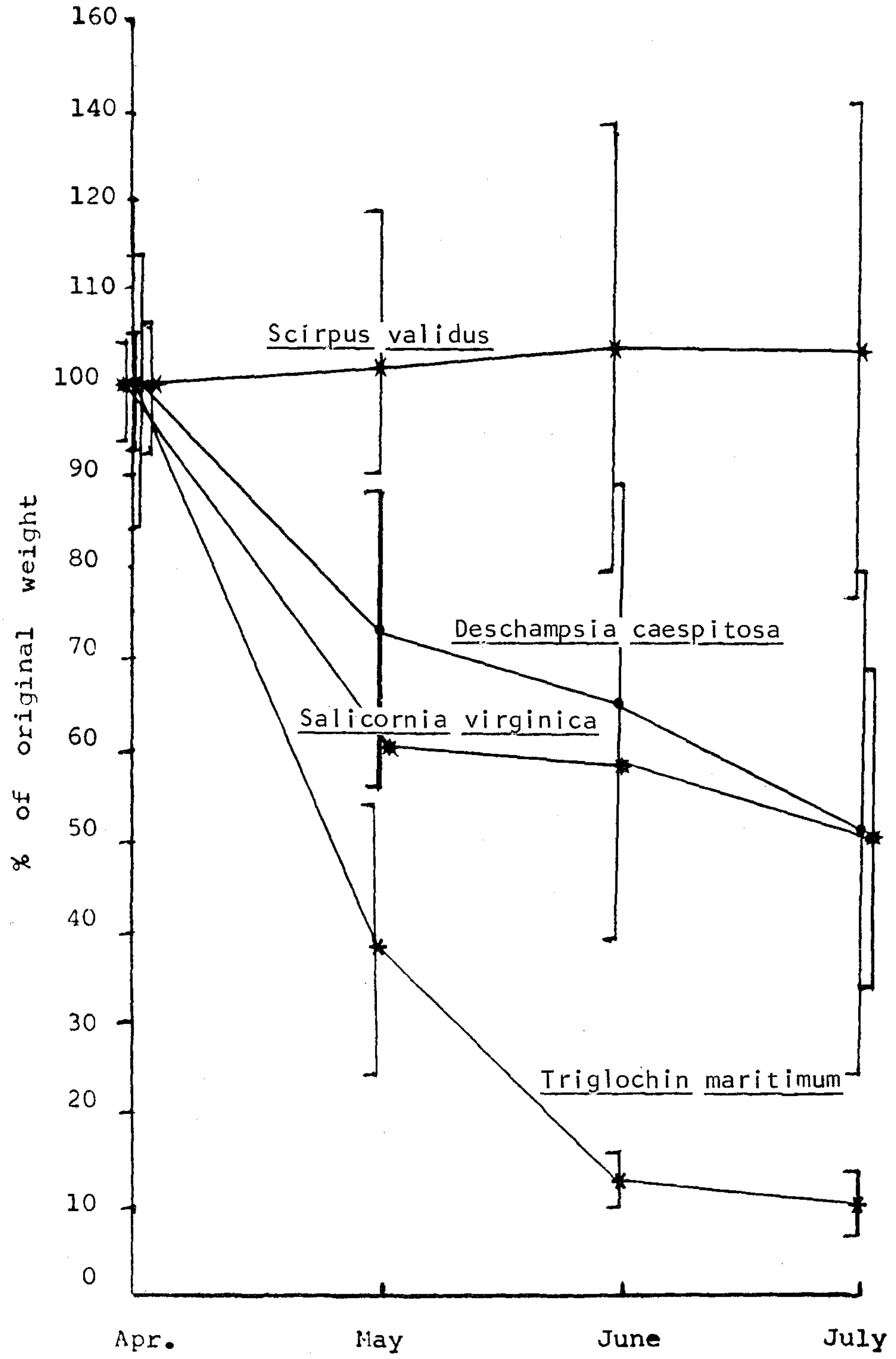


FIGURE 3-30. DECOMPOSITION OF FOUR SALT MARSH PLANTS. Vertical lines equal plus or minus one standard deviation. (From Gnat et al., 1976.)

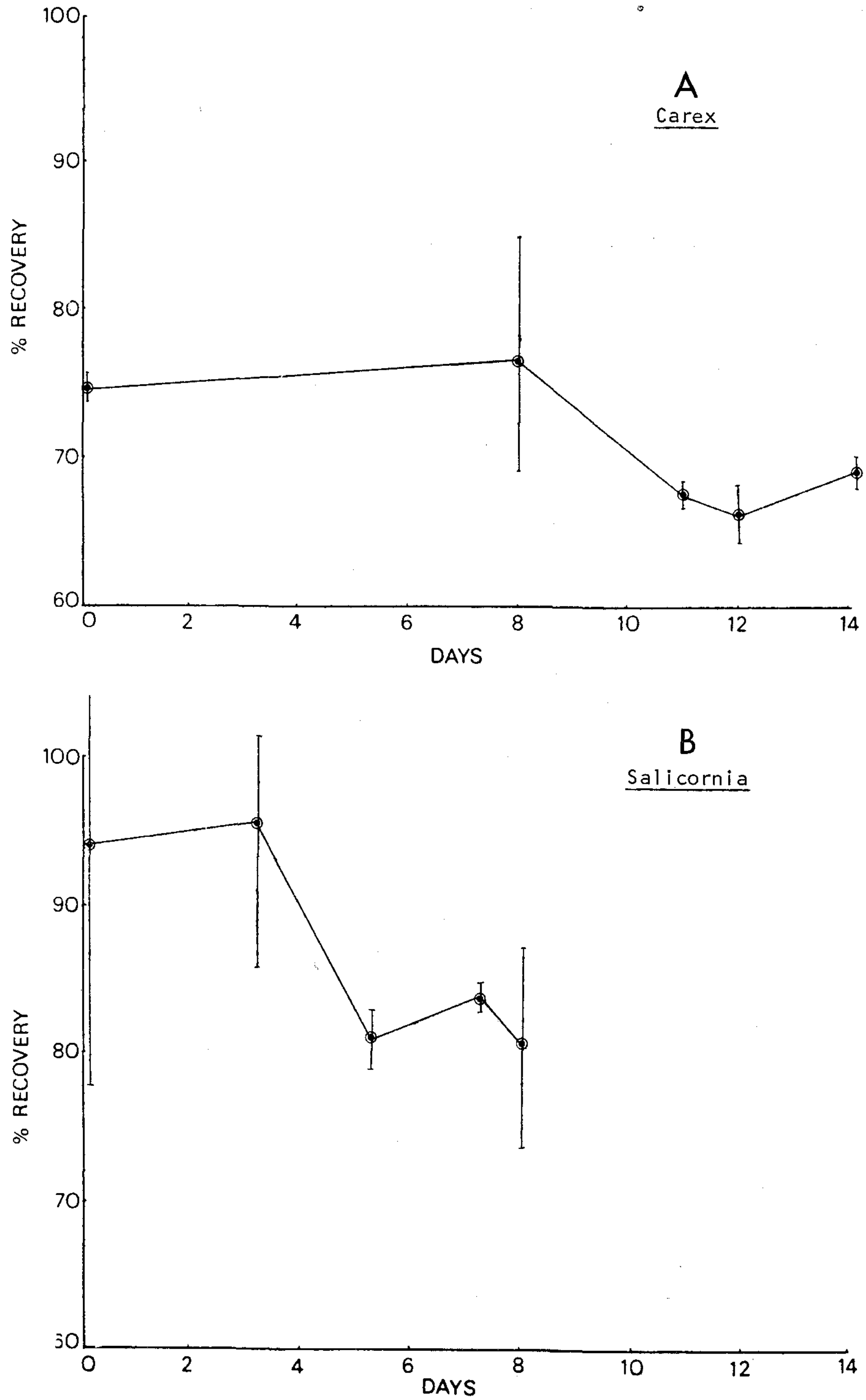


FIGURE 3-31. LABORATORY RESULTS DEMONSTRATING DECOMPOSITION OF TWO SPECIES OF SALT MARSH PLANTS COLLECTED FROM COOS BAY, OREGON. (A) Carex decomposition. (B) Salicornia decomposition. (From Stunz, 1976.)

#15. Human Use. There is only limited direct human use of salt marshes of the study region. Although very little data is available, most of the waterfowl hunting of the coastal area occurs in this habitat. Bird watching and natural study follow closely in amount of use. See Recreational Species of Concern discussion (Section 3.4.2) for more information. Some grazing by domestic cattle occurs in intertidal estuaries (e.g. Sand Island in the Columbia River Estuary). Salt marsh detritus may be of particular importance to the commercially valuable oysters in Willapa and Humboldt Bay. De la Cruz (1976) has reviewed various values which salt marshes can provide, e.g. sewage assimilation, aquaculture.

#16. Pollutant Input. Estuaries, and salt marshes in particular, are considered to be sites where pollutants accumulate (Ohlendorf et al., 1974; Woodwell et al., 1967). The accretion of sediments and materials, much of which originated from adjacent uplands (see Notes #3, #4, and #5), and the intensive biochemical cycling within the estuary, as well as the intertidal nature of salt marshes, establish this habitat as a location where persistant pollutants are likely to be found.

No serious pollution levels have been measured in the marshes within the study area. In more southerly parts of California, however, eggshell thinning has been measured in great blue heron and common egret populations and associated with DDE residues (Faber et al., 1972). In a survey on the East Coast in 1972, DDT occurred in measurable amounts in 24% of the eggs of salt marsh birds sampled, while DDE occurred in all eggs measured and PCB's occurred in 76% of the eggs measured (Ohlendorf et al., 1974); other chemicals were also found. No eggshell thinning was documented with these concentrations, but the potential danger was evident. No studies of eggshell thinning have been done in the study area.

#17. Loss of Habitat. Salt marshes in this region, as well as world wide, have been considerably reduced in size (and in many places completely eliminated) through diking, filling, spoil disposal, and ditching, or some combination of these activities. Much of these lands have been converted to agricultural use, some to waterfront development, and others to spoil sites. U.S. Department of Interior (1970, Volume 1) reports 13% of the estuarine area in the Pacific Northwest has had slight modification, 50% has had moderate modification, and 37% has had severe modification. A substantial but undocumented portion consists of wetland losses.

Grays Harbor. The Army Corps of Engineers (1976C) reports 3,840 acres (1,550 ha) of intertidal land within Grays Harbor have been utilized for disposal of dredged material. The figure represents 11.4% of the total intertidal lands (33,600 acres or 13,600 ha), with an average annual usage of 110 acres (45 ha). The amount of spoil disposal on salt marshes is unknown. However, today, the emergent marsh comprises only 16% of the intertidal area indicating an overall loss due probably to spoil disposal. Since the early 1900's some 1,540 acres (625 ha) of wetlands, presumably mostly emergent marsh, have been permanently committed to upland usage. The rate of salt marsh removed increased following 1950, as 1,280 acres (500 ha) have been altered to uplands since that date. Permanent loss represents approximately 1/2 of the previously existing wetlands, with an additional unknown quantity affected by spoil disposal.

Willapa Bay. Of the estimated original 15,300 acres (6,100 ha) of emergent marsh, an estimated 6,200 acres (2500 ha) or about 40% have been diked and altered to other habitats, predominantly agricultural (ACOE, 1976H). Some 300 acres (120 ha) have been diked and filled from dredge disposal since 1962. In addition, a lesser (but undocumented) amount of salt marsh has been filled and transformed into developed (commercial, industrial, residential) land (ACOE, 1976H).

Prior to 1962, the disposal of spoil did not include diking; disposal of materials was typically adjacent to dredged areas. Quantity disposed is estimated at 2.5 million cubic yards (1.9 million m^3).

Columbia River. Seaman (1977) estimates 700 acres (300 ha) have been filled in the Columbia estuary. Recent disposal sites to river mile 34 are given in Table 3-20. In addition, of the 170,000 acres (68,000 ha) of flood plain bordering the lower Columbia River (mouth to river mile 125), 65% or 110,500 acres (44,000 ha) are protected by dikes or levees. Obviously, a large area of wetlands (emergent marsh) has been affected, but precise quantities are unknown. Continued dredging of the lower Columbia River will maintain a demand for spoil sites, some of which are likely to be emergent marshes.

Oregon Emergent Salt Marshes. The extent of disturbance to Oregon's coastal marshes has been summarized by Eilers (1975), in Table 3-21. Additional information on landfills for selected Oregon estuaries is summarized (Percy et al., 1974) from surveys by the Oregon Division of

TABLE 3-20. LAND DISPOSAL SITES IN THE COLUMBIA RIVER ESTUARY. RM = river mile from mouth. (From Seaman, 1977.)

Site	Habitat	Wildlife	Size (acres)
Rice Island (RM 21.0)	fill/sand, grass	occasional waterfowl, shorebird and aquatic mammal use	130
Miller Sands Island (RM 23.5)	fill/sand, grass	waterfowl, shorebirds, aquatic mammals (within wildlife reserve)	240
Altoona, Wa. (RM 24.3)	sand beach		10
(RM 24.8)	fill/sand, grass	shorebirds	10
Pillar Rock (RM 27.1)	fill/sand, grass	little use	10
Jim Crow Sands (RM 27.2)	fill/sand, grass, pines	waterfowl, shorebirds	70
Jim Crow Point (RM 28.2)	fill/sand	waterfowl resting area	10
Pile dikes off channel (RM 29.1)	open water/pile dikes	possibly some fish use	20
Woody Island (RM 29.1)	75% - fill/sand 25% - tideland/willow	waterfowl and shorebird resting	20
Upstream of Brookfield, Wa. (RM 29.5)	80% - fill/sand 20% - tideland/alder, willow	some waterfowl and mammal use	10
Fitzpatrick Island (RM 31.2)	90% - fill/sand 10% - tideland/marsh	important waterfowl and shorebird resting and feeding	30
Downstream of Skamokawa, Wa. (RM 33.4)	fill/sand, snags, spruce, willow, grass	within wildlife reserve songbirds, small mammals	60
Between Brooks Slough and Skamokawa Slough (33.7)	tideland/spruce, alder, willow, sedge, grass	important wetland habitat for deer, invertebrates, birds	20
Welch Island No. Bank (RM 34.0)	fill/sand	little use	20

TABLE 3-21. AREA, NATURE OF DISTURBANCE, AND DISTURBANCE RATING FOR SALT MARSHES IN OREGON ESTUARIES AND BAYS. (From Eilers, 1975.)

Location	Area[1] of Existing Salt Marsh		Nature of Disturbance															
	Square Meters	Acres	Agriculture Dike	Road Fill	Drift Logs	Urban-Industrial Fill	Log Mill	Dredge Spoil	Railroad Fill	Power Lines	Cattle Grazing	Navigation Dike	Fence(s)	Log Storage	Billboard(s)	Refuse Dump	Total	Overall Disturbance Rating[3]
Umpqua	3,261,308	805	X	X	X	X	X	X	X	X							8	3
Siuslaw	3,182,108	785	X	X	X	X	X	X	X	X		X					9	3
Coos Bay	9,065,375	2,239	X	X	X	X	X	X	X					X	X	X	10	5
Yaquina	4,464,591	1,102	X	X	X	X	X	X	X				X	X			9	3-4
Nehalem	2,433,600	601	X	X	X		X[2]		X		X[2]	X					7	2
Siletz	1,460,991	360	X	X	X	X	X[2]	X		X							7	4-5
Coquille	1,592,987	393	X	X	X	X	X	X			X		X		X		9	3
Tillamook	3,637,168	898	X	X	X	X	X		X								6	3
Salmon River	746,061	184	X	X	X	X					X		X				6	3
Alsea	2,640,405	652	X	X	X	X					X	X					6	2-3
Sand Lake	2,712,729	670	X	X	X						X		X				5	2
Netarts	1,108,170	273	X							X	X		X				4	1
Nestucca	913,825	225	X	X	X	X											4	2
Necanicum	123,728	30		X		X											2	1
Total	37,343,046	9,223	13	13	12	11	8	6	6	4	6	3	5	2	2	1		

1 Determined by planimeter from aerial photographs.

2 Historically significant.

3 Range is 1 to 5 where 1 = minor disturbance and 5 = severely disturbed.

State Lands (see Table 3-22) but do not differentiate salt marsh from other intertidal habitats. Hoffnagle and Olson (1974) report 90% of the original salt marsh environment within Coos Bay has been changed to other habitats through diking and filling. Figure 3-32 indicates salt marsh area changes in Coos Bay between 1892 and 1972.

Humboldt Bay. Koebig and Koebig, Inc. (1975) report that of Humboldt Bay's original 7,000 acres (3000 ha) of salt marsh, 600 acres (250 ha) remain. Like Coos Bay, Oregon, approximately 90% of the emergent marsh environment has been transformed to other habitat types, predominantly diked marsh agricultural areas which now make up much of the Arcata Bottoms.

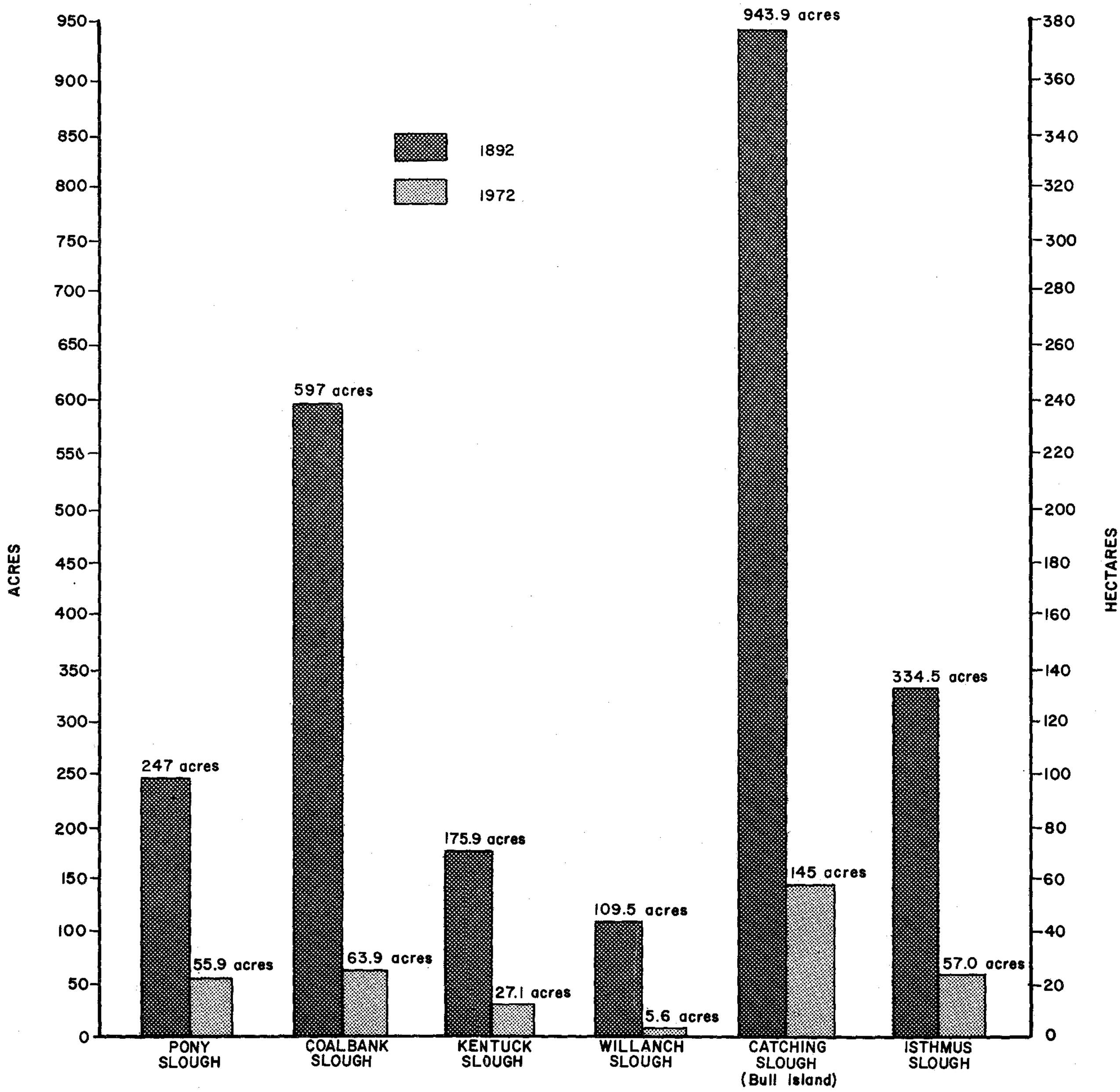


FIGURE 3-32. CHANGE IN AREA OF EMERGENT VEGETATION (SALT MARSH) HABITAT IN COOS BAY, OREGON, FROM 1892 TO 1972 THROUGH DIKING AND LANDFILL. (From Hoffnagle and Olson, 1974.)

TABLE 3-22. LANDFILLS IN SELECTED OREGON ESTUARIES. (From Percy et al., 1974.)

Estuary	Landfill Area (Acres)			Use/ownership	Main Location
	On Submerged Lands[1]	On Submersible Lands[2]	Total		
Alsea	0	24.75	24.75	marine oriented; heavy emphasis on recreation	east side of Waldport
Nehalem	20.11	7.27	27.38	residential or recreation oriented; generally small fills	Brighton, Wheeler, and Nehalem areas
Nestucca	0.15	0.68	0.83	erosion control on residential property; mainly state owned	Pacific City; Woods area; between miles 1.5 and 2.5
Salmon	0	0.12	0.12	one fill; parking area, boat launch; state owned	north side near mile 1.8
Sand Lake	no landfills; 4.1 acres of diking of which 3.0 acres is on submersible land				
Siuslaw	0.12	40.63	40.75	used mainly by the city of Florence; some marine oriented with heavy emphasis on industry; 36.28 acres are dredge spoils	Florence area
Tillamook	0.57	102.06	102.63	industry oriented; no particular emphasis on navigation	Garibaldi area
Umpqua	8.50	97.54	106.04	80 acres used for marina and harbor at Winchester Bay; remainder mainly marine oriented with heavy emphasis on deep water navigation and industry	Winchester Bay and Reedsport
Yaquina (below Toledo	55.06	202.06	257.12	are only 3 fills over 5 acres - all marine oriented with heavy emphasis on deep water navigation and industry	Newport and Marine Science Center areas and north side of river between miles 4 and 5

1 Submerged lands are those lying below the line of ordinary low water of all navigable waters.

2 Submersible lands are those lying between the line of ordinary high water and the line of ordinary low water.

3.2.1.3 Eelgrass Ecosystem Model Notes. Eelgrass is a submergent vascular plant of particular importance in the shallow waters of the estuarine environment. Its growth is desirable, because it stabilizes the bottom on which it grows, provides food, shelter, and attachment surface for marine organisms, and, in general, increases the biological productivity and diversity of the estuary. It is important to the feeding, spawning, and rearing of migrant populations of fish, shellfish, and wildfowl. Phillips (1978) provides a general description and summary of the eelgrass ecosystem. (See also Seagrass Ecosystems, 1977. C. P. McRoy and C. Helfferich, eds. Mareel Dekker, Inc. N.Y. 314 p.)

Eelgrass, also called grass wrack, is the common name generally given for the genus Zostera which contains eleven species. all marine plants found rooted on soft bottoms in shallow waters (Setchell, 1933). Two species occur in the study area: Z. marina and Z. noltii.[1] Variations in leaf length and width are known to occur in response to environmental conditions. Besides a difference in appearance between the two species, they differ in the tidal elevation at which they are found, with Z. noltii occurring only intertidally (+3 feet MLLW and above) and Z. marina occurring at lower elevations (Hitchcock and Cronquist, 1973). Most of the research on eelgrass has considered only Z. marina. The following descriptions apply specifically to Z. marina and the habitat it occupies, but the discussion of the importance of eelgrass beds in the estuarine ecosystem and the effects that human activity may have upon them apply generally to both species.

Eelgrass is a rooted, perennial plant that reproduces (1) vegetatively, producing a new set of leafy shoots (turions) every two years, and (2) sexually, by flowering annually unless retarded by environmental conditions (Setchell, 1929). It is distributed by the drifting of detached plants which can reestablish themselves when they come to rest, and by dispersion of seed, either through water-borne drifting or the migration of the animals that eat them. Locally, this plant forms a dense bed by vegetative growth of a prostrate stem, or rhizome, across the surface of muddy flats. A single plant can cover thirty square centimeters the first year, one square meter the second year, and two square meters the third (Phillips, 1974). Figure 3-33 shows the roots, rhizome, turions (each consisting of several branched leaves), and flowering spathes of a mature plant of Z. marina. The manner in which a single plant branches to form extensive, dense beds is diagrammed in Figure 3-34. Densities of some West Coast eelgrass beds are given in Table 3-23. The abundant roots and rhizomes have a binding effect on the bottom sediments, while the long tape-like leaves, by absorbing the energy of waves and currents, increase the rate at which sediments accumulate and reduce erosive forces. This effect is important in the natural succession of estuarine areas from sandy subtidal flats to muddy intertidal flats.

Eelgrass is significant as an ecological link between habitats and biological zones because of its high export of wrack and detritus. This plant produces a great amount of vegetable matter, much of which is exported from the immediate habitat as detritus. Slowly decaying particles of eelgrass can be found all through the estuary, in tidal marshes, along the coastal beaches, and across the bottom of the continental shelf, providing a rich source of food for detritivores in many different habitats during the unproductive winter period.

Species of concern associated with eelgrass beds are the waterfowl, black brant and widgeon, whose diet is composed largely of the leaves, and the Dungeness crab (Cancer magister), attracted by the large number of clams which inhabit eelgrass beds. Herring and smelt use the beds for spawning and rearing their young.

---

[1] The name eelgrass generally refers specifically to Zostera marina, with the other species in the genus using some adjective with eelgrass as the common name. However, in this section and throughout this study, eelgrass is used synonymously with the genus Zostera, although for the most part referring to Z. marina.

FIGURE 3-33. EELGRASS - ZOSTERA MARINA. Shoots of branched leaves, called turions, rise from the spreading rhizome. The terminal leafy shoot in the illustration is fertile, bearing three flowering spathes. (After Setchell, 1929, in Phillips, 1974.)

The extent of eelgrass habitat in the study area, summarizing several estimates, is indicated in Table 3-24.

Figure 3-35 is an ecosystem model for the eelgrass bed habitat. Discussion and data pertaining to the important components and processes of the model are found in Notes which follow, beginning with (1) the sediments in which the plant is rooted, and continues with (2) the metabolic processes of photosynthetic production, respiration, and growth, (3) uptake and excretion, (4) defoliation and export, (5) decomposition, (6) the community composition, (7) the use of eelgrass by migrating populations of birds and fish, (8) human uses of the habitat, (9) human activities that pollute this habitat, (10) the loss of habitat, and (11) the gain of habitat.

TABLE 3-23. EELGRASS DENSITIES DETERMINED FOR SOME WEST COAST LOCATIONS. (From J.L. Smith et al., 1976.)

DENSITY				
turions/m²	turions/ft²	Comments	Location	Source
200.2	18.6		South Bay, Humboldt Bay, California	Keller (1963)
31.2	2.9		Arcata Bay, Humboldt Bay, California	Keller (1963)
92.6	8.6	undredged plots, 1962	"	Waddell (1964)
47.4	4.4	oyster dredging, 1962	"	"
43.1	4.0	undredged, 1963	"	"
14.0	1.3	oyster dredging, 1963	"	"
710	66.0	"low" density	Izembek Lagoon, Alaska	McRoy (1966)
1497	139.1	"intermediate" density	"	"
2101	195.2	"high" density	"	"
80.6	7.5	weighted mean of all areas, 1971	Samish & Padilla Bays, Washington	Parker (1975)
161.3	15.0	" , 1972	"	"
108.6	10.1	" , 1974	"	"
74.1	6.9	weighted mean of all areas, 1975	Grays Harbor, Washington	J.L. Smith et al. (1976)
839	78	mean on an annual basis, 1963-64	West side of Whidbey Island Washington (intertidal)	Phillips (1978, pers. comm.)
189	18	mean on an annual basis. 1963-64	West side of Whidbey Island Washington (subtidal)	Phillips (1978 pers. comm.)

TABLE 3-24. AREA OF EXTENSIVE EELGRASS HABITAT IN PACIFIC NORTHWEST COASTAL REGION.

Location	Approximate Area (Estimated in Acres)	Source
Washington		
Willapa Bay	15,520	ACOE, 1976 H
Grays Harbor	5,540	ACOE, 1976 C
Oregon	5,019	ACOE, 1976 B
California		
Humboldt Bay	3,800	Monroe, 1973
TOTAL	29,879	

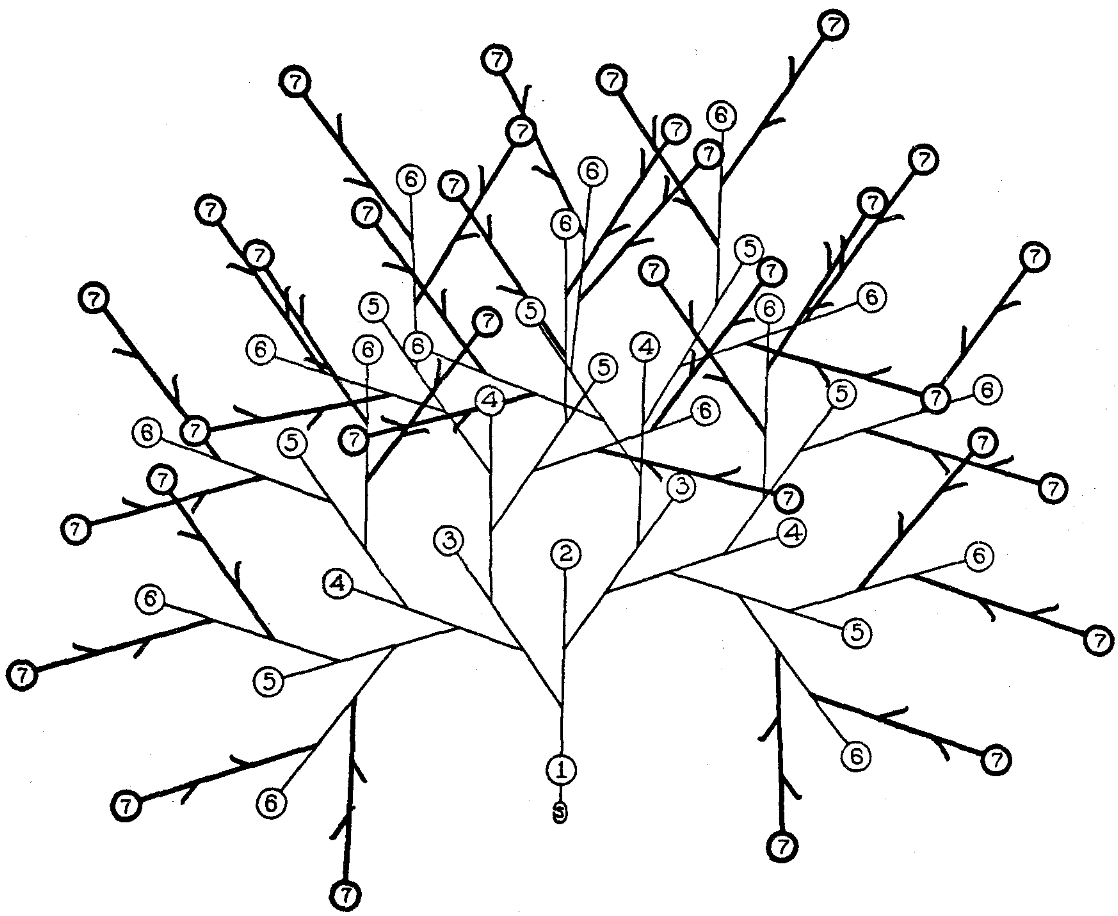


FIGURE 3-34. DIAGRAM OF EELGRASS BRANCHING AND FRAGMENTING AFTER SEVEN SEASONS. Arabic numerals indicate successive terminal buds or turions, from the first season (single plant #1) to the seventh season (31 turions). Lateral spurs indicate lateral buds and branches of the season. S indicates the original seed. The light lines represent rhizome fragments and plants which have disappeared. The heavy lines represent the living rhizomes and plants. (After Setchell, 1929, in Phillips, 1974.)

3.2.1.3 Eelgrass Ecosystem Model Notes (continued)

#1. Sediments. Eelgrass has been observed on a wide variety of substrates ranging from soft mud to gravel mixed with coarse sand. Growth is patchy where it is exposed to wave action with substrates mostly of gravel. Eelgrass beds are usually found on muddy sand substrate and are seldom found on pure sand or where extensive solid surfaces support macroalgae such as Ulva (Phillips, 1974). Figure 3-36 shows the sediment size composition of the substrate in an eelgrass bed, an adjacent channel, and an adjacent sand flat in an Alaskan lagoon. Figure 3-37 compares the sediment composition of four different eelgrass beds in the same lagoon. McRoy (1966) suggests that the variability of particle size distribution depends more on water movements than on plant characteristics. A recent study (J.L. Smith et al., 1976), which analyzed grain size in Grays Harbon sediments, shows that fine sand (62-500μ) predominates on the flats where eelgrass is abundant.

ECOSYSTEM MODEL — EELGRASS

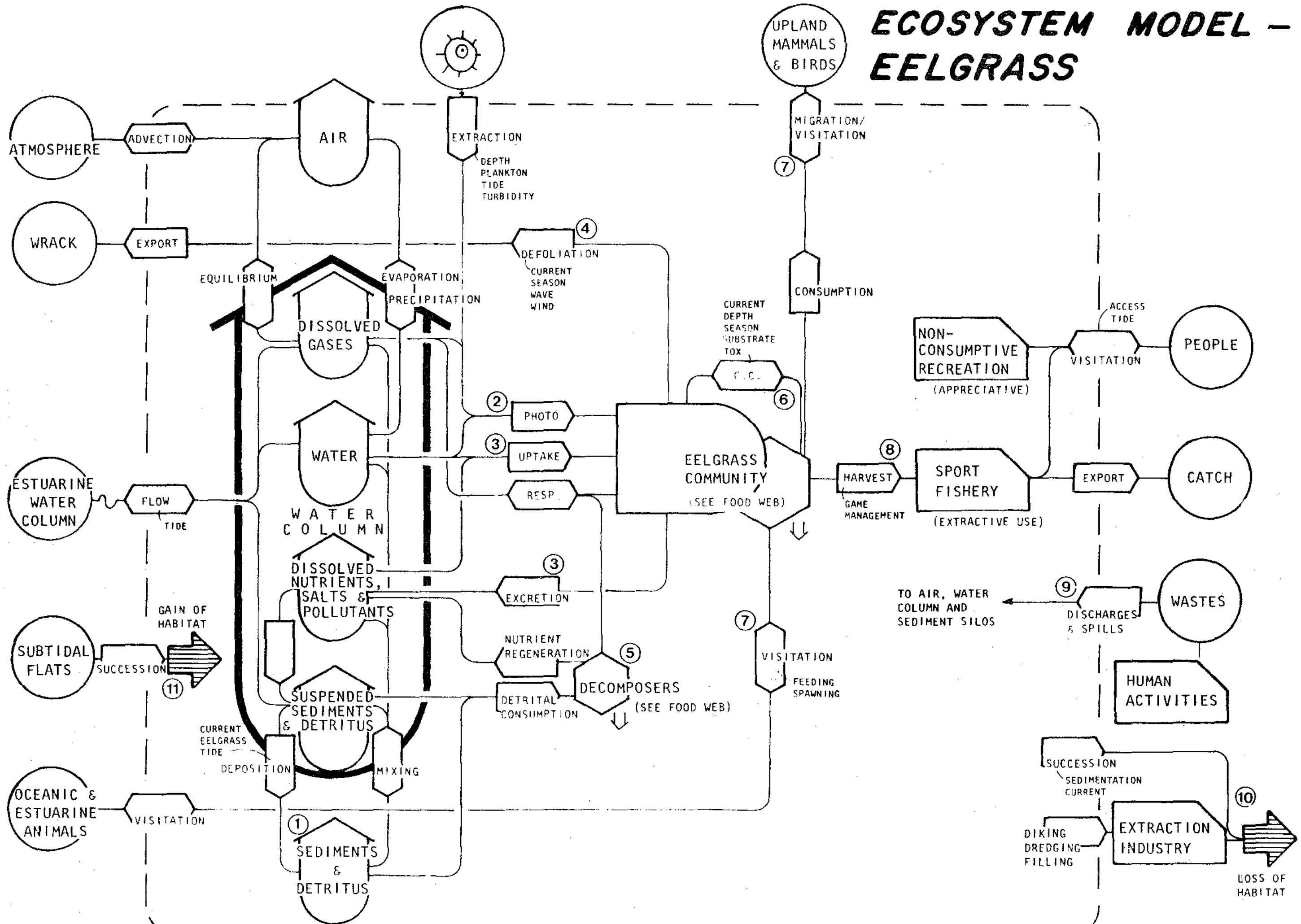


FIGURE 3-35. EELGRASS ECOSYSTEM MODEL.

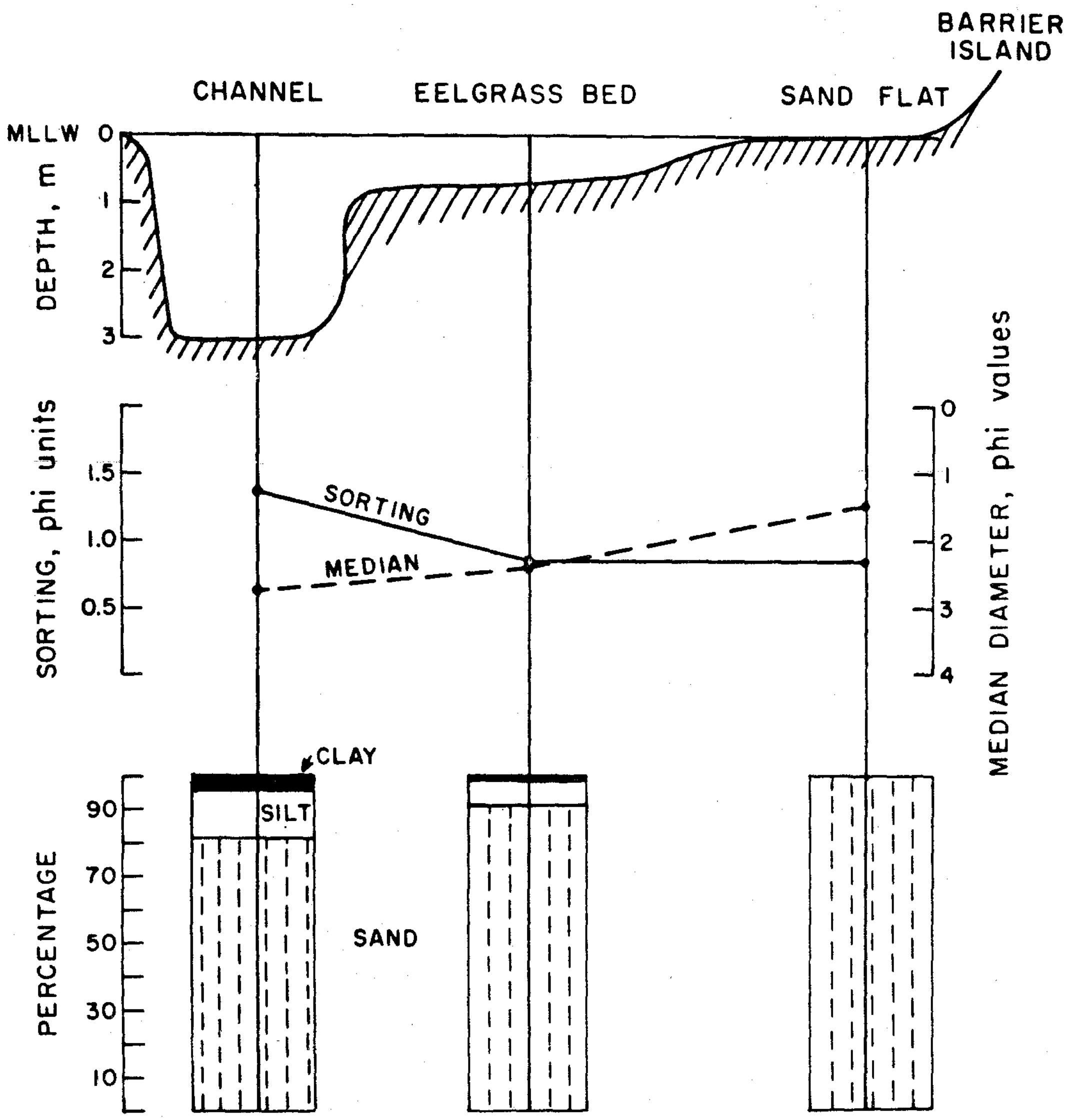


FIGURE 3-36. SEDIMENT COMPOSITION OF EELGRASS BED COMPARED WITH ADJACENT CHANNEL BOTTOM AND SAND FLAT. Depth, sorting coefficient, median particle diameter, and sand, silt, and clay distribution are shown. Data are from an Alaskan lagoon. (After McRoy, 1966, in Phillips, 1974.)

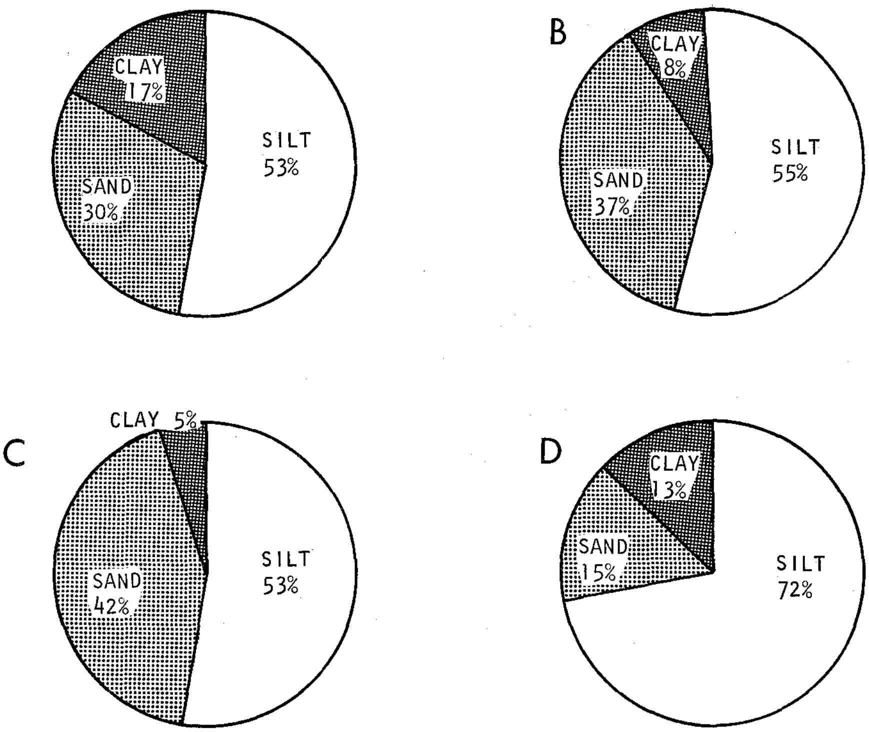


FIGURE 3-37. SEDIMENT COMPOSITION OF FOUR EELGRASS BEDS IN AN ALASKAN LAGOON. Percentages are by weight. (From McRoy, 1966.)

3.2.1.3 Eelgrass Ecosystem Model Notes (continued)

A study examining the environmental effects of dredging in Coos Bay, Oregon, related eelgrass occurrence to two sediment factors: organic content of sediments (OCS) and rate of sediment turnover (RST). This relationship is shown in Figure 3-38 along with some of the other biological characteristics related to these two parameters, in a dimensionless display. (See Section 2.6.4 in Volume 1 for more information about this OSU system.)

#2. Eelgrass Productivity, Growth, and Reproduction. Eelgrass is a submergent plant limited to substrates where at least one percent of the incident light remains (Burkholder and Doheny, 1968). The rate of extinction of light with depth is a function of angle of incidence (latitude and season) and water quality (Sverdrup et al., 1942). In the shallow waters of an estuary, the most important water quality parameter related to eelgrass is turbidity (OSU, 1977A). In addition, the amount of light reaching photosynthetic tissue is limited by shading, to a degree dependent on the density of turions (number per unit area), the length and width of leaves, and the age of the leaf surface, as it accumulates epiphytic growth.

The depth to which eelgrass beds grow varies on the West Coast of North America from fifty feet (15 m) at La Jolla, California (Cottam and Munro, 1954) to just a few meters at the Izembek Lagoon on the Alaska peninsula (McRoy, 1966), the gradient probably affected by latitude and cloud cover. Phillips (1974) has found eelgrass growing at about 22 feet (6.6 m) in Puget Sound. Jefferson (1974) reports *Zostera marina* as extending up to an elevation of five feet (1.5 m) above MLLW, just below the level of mean lower high water (MLHW) along the Oregon coast. J.L. Smith et al. (1976) found *Z. marina* growing sparsely at an elevation of six feet (2 m) above MLLW at *Z. noltii* growing on small mounds above the +3 feet (1 m) tide level and only abundantly above +5 feet (1.5 m). However, the dense eelgrass meadows observed in Grays Harbor, Washington, lie between -1 and +3 feet (-0.3 to +1 m). Eelgrass beds on exposed flats are situated in tide pools or areas that remain wet throughout the low tide (McRoy, 1966).

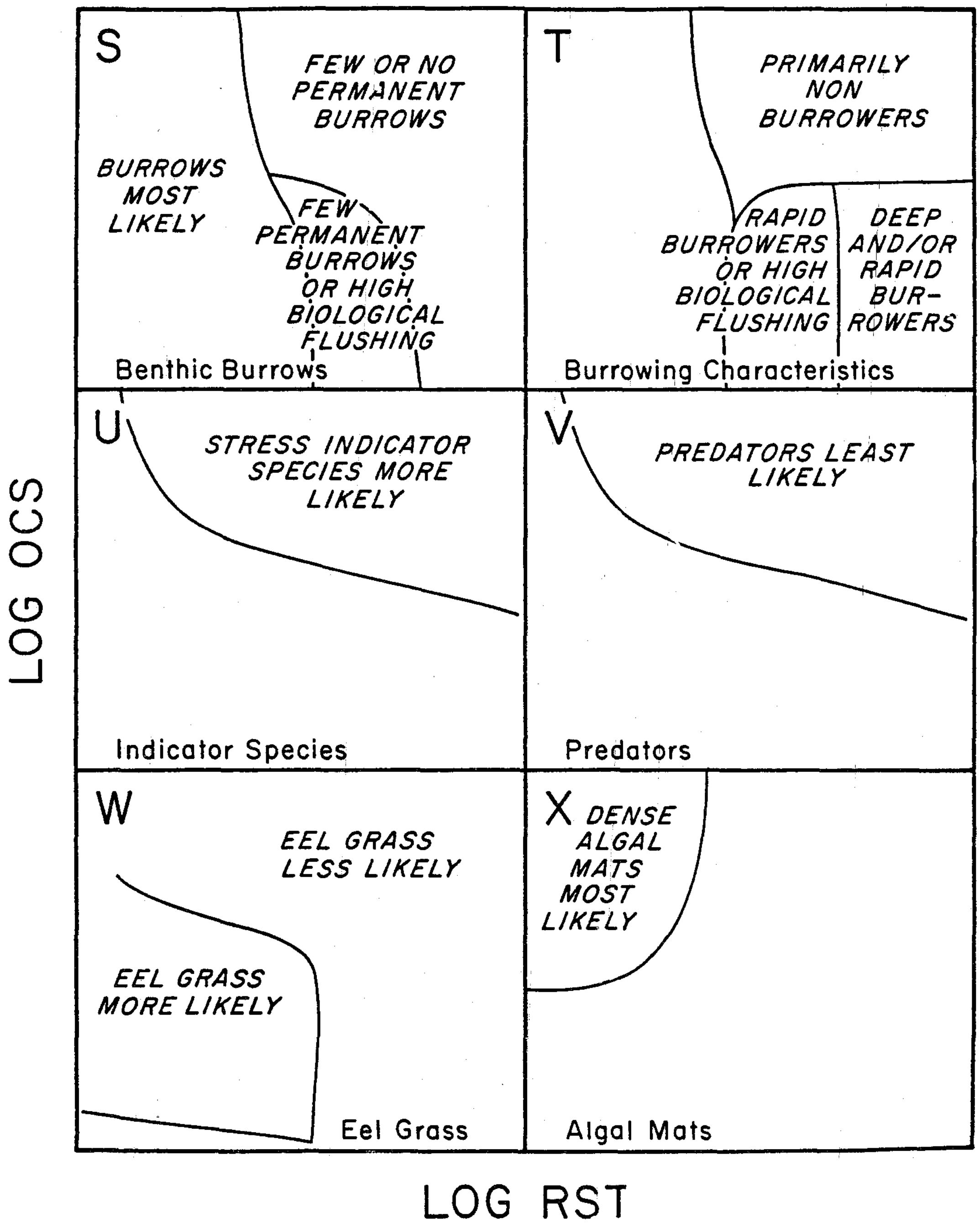


FIGURE 3-38. EELGRASS OCCURRENCE AND OTHER BIOLOGICAL CHARACTERISTICS RELATED TO THE RATE OF SEDIMENT TURNOVER (RST) -- ORGANIC CONTENT OF SEDIMENT (OCS) PLANE. See Section 2.6.4 in Volume 1 for details of this system. (From OSU, 1977A.)

There are no studies directly examining the effects of turbidity on the production and distribution of eelgrass, but Backman and Barilotti (1976) experimentally shaded eelgrass beds with a canopy which reduced light intensities by 63%. After nine months, turion density in the shaded plot was five percent of that in control areas. The relationship between turbidity and rate of light extinction is similarly direct but difficult to measure quantitatively.

Turbidity of water is modified by both physical and biological processes. Seasonal blooms of phytoplankton may reduce naturally the depth to which light sufficient for eelgrass growth can penetrate. Phytoplankton density might be maintained at high levels by the artificial nutrification of estuary waters by sewage or industrial effluents. Waves generated by strong winds may temporarily resuspend bottom sediments within the estuary. Upstream activities which increase the suspended sediment load in runoff entering an estuary may increase turbidity over a long enough period to reduce, by increasing the extinction rate of light energy entering the water column, the depth and, therefore, the area in which eelgrass can grow.

Optimum light intensity for eelgrass production lies between 0.42 and 0.92 Langleys per minute (Short, 1975). McRoy (1974) and Burkholder and Doheny (1968) in studies at Long Island, New York, found the optimum light level for growth to be about fifty percent of the maximum incident light occurring during the growth period (Elder, 1976). Incident light intensity varies seasonally and latitudinally in the study region (U.S. Department of Commerce, 1968). Table 3-25 shows a sixteen-year record of average daily solar radiation by monthly periods. Trigonometric conversion of these data to Langleys per minute at local apparent noon indicates that the maximum values (July) seldom exceed 0.9 ly/min, and that light intensity at noon drops below 0.4 ly/min from late October until late February (Phillips and Donaldson, 1972).

The tidal change of depth influences the amount of light available for photosynthesis. Maximum turbidity in a river estuary is at high slack tide (Seaman, 1977) coincident with the greatest depth of water over the eelgrass beds.

Eelgrass production responds to variation in water temperature, as shown in Figure 3-39, a curve derived by Short (1975) from temperature productivity studies by Biebl and McRoy (1971).

Eelgrass survives temperatures to 0°C (32°F) in Greenland and 40°C (104°F) on exposed flats in Japan, but grows best between 10° and 20°C (50-70°F) in most areas of the world. Optimum temperatures range from 7.5°C (45°F) to 12.5°C (55°F) in Puget Sound where waters ordinarily do not exceed these limits (Phillips, 1974). Phillips (1974) reviews the controversy over the relative effects of light and temperature in controlling eelgrass growth and reproduction.

TABLE 3-25. AVERAGE DAILY SOLAR RADIATION (IN LANGLEYS) BY MONTHLY PERIODS AT ASTORIA, OREGON. (From Phillips and Donaldson, 1972.)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1953	-	214	328	403	472	489	603	439	365	238	94	73	-
1954	90	158	289	362	585	405	488	360	312	229	93	79	288
1955	95	181	268	375	478	449	442	539	342	169	97	79	293
1956	88	160	279	473	578	479	592	495	390	214	114	88	329
1957	128	163	265	386	446	557	545	458	392	224	139	67	314
1958	77	119	267	355	498	429	512	544	337	237	106	67	296
1959	85	121	220	380	503	444	568	-	-	192	136	83	-
1960	79	200	271	305	427	550	603	430	371	189	118	104	304
1961	106	104	246	338	472	586	508	424	388	227	135	68	300
1962	115	202	279	379	433	528	494	458	340	195	99	84	301
1963	115	147	272	408	560	500	487	431	387	172	98	71	304
1964	73	215	261	427	504	486	492	449	-	256	140	86	-
1965	85	129	351	360	460	527	524	416	310	203	89	-	-
1966	70	128	215	384	548	510	452	494	341	205	101	52	292
1967	65	154	235	415	504	514	575	503	384	198	144	71	319
1968	97	191	243	427	496	529	535	410	330	210	104	-	-
AVERAGE	91	162	268	386	498	499	526	457	356	210	113	77	304

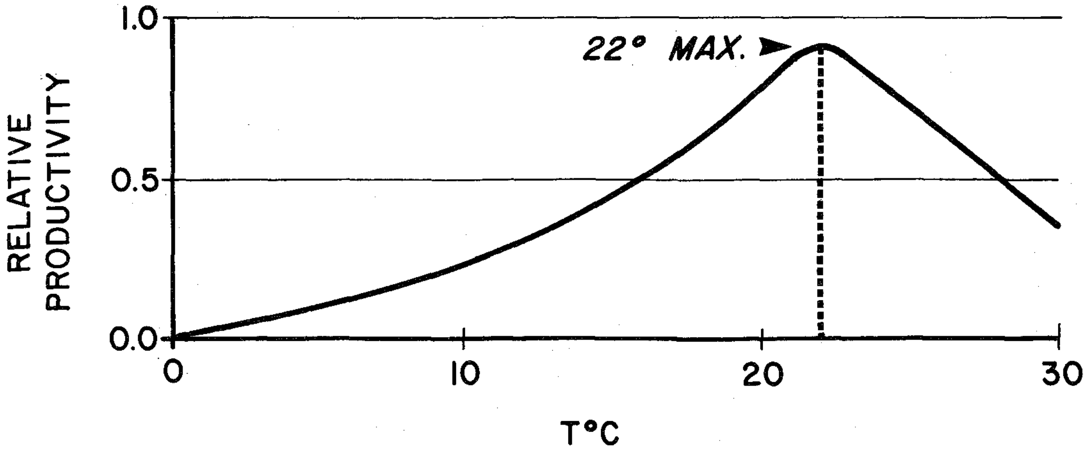


FIGURE 3-39. RELATIVE PRODUCTIVITY OF EELGRASS AT VARYING TEMPERATURES. (From Short, 1975, after Biebl and McRoy, 1971.)

Current velocity plays a major role in the productivity of eelgrass, and probably is the factor most important in determining whether flats will support eelgrass beds or macroalgae. If currents are too slow, eelgrass grows poorly and algae are likely to dominate. This is not entirely understood, but it is theorized that molecular diffusion across the surface membrane of the leaf blades is enhanced by replenishment of nutrients brought by the current (Elder, 1976). Too much current and the leaves are torn loose from the plant or the substrate is eroded, exposing roots and rootstock. Optimum current speeds were found to be about the average neap and spring tidal current speed in the eelgrass areas, in the range of 0.6 to 0.8 knots (30 to 40 cm/sec) (Conover, 1958).

The reciprocal relationship between photosynthesis and respiration is shown in the model (Figure 3-35) as alternate pathways connecting the substrate dissolved gases with the eelgrass community. Although respiration is continuous even during periods of photosynthesis, photosynthesis, as shown, is the switching factor for the net production of oxygen. Suda (1974) measured oxygen production and respiration of the eelgrass community during the summer and found gross oxygen production to be 5.49 to 10.87 g O_2/m^2/day (mean = 8.07), while respiration was 3.92 to 7.99 g O_2/m^2/day (mean = 5.70). Mean net production during the 24-hour day would then be 2.37 g O_2/m^2. Figure 3-40 shows the variation of eelgrass production over the period of a year (Short, 1975). Production, the product of productivity and biomass, may vary as much as 100% from year to year (Waddell, 1964).

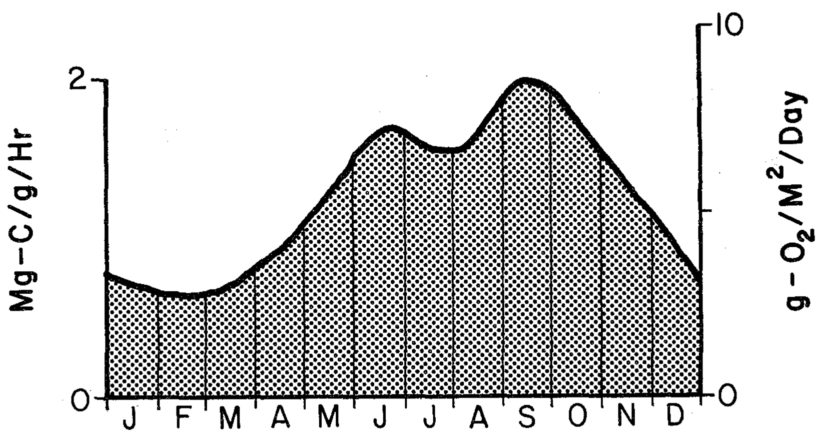


FIGURE 3-40. PRODUCTION OF ORGANIC CARBON AND RELEASE OF OXYGEN BY EELGRASS IN CHARLESTOWN POND, R.I. (From Short, 1975.)

Even though there is positive daily net production and dissolved oxygen levels may exceed saturation during daylight in the eelgrass areas, there is a diurnal decrease in oxygen to levels that may cause fish and arthropods to leave the bed temporarily. Figure 3-41 demonstrates that the dissolved oxygen can range from 0 to more than 260% saturation in less than 10 hours (Broekhuysen, 1935). Hedgpeth (1976) suggests that eelgrass beds could be important sources of food for fish in neighboring habitats. Animals living within the beds must be adapted to low oxygen levels and the lowered pH levels coincident with them. McRoy (1966) demonstrated experimentally that eelgrass is capable of anaerobic respiration.

Salinity has little effect on production, and net production has been reported for salinities ranging from 0 to 50 °/oo (Short, 1975). Phillips (1974) reported the salinity range for eelgrass as 8 to 40 °/oo. Whether discrete physiological forms of this species exist at each end of the salinity range is not known (Elder, 1976).

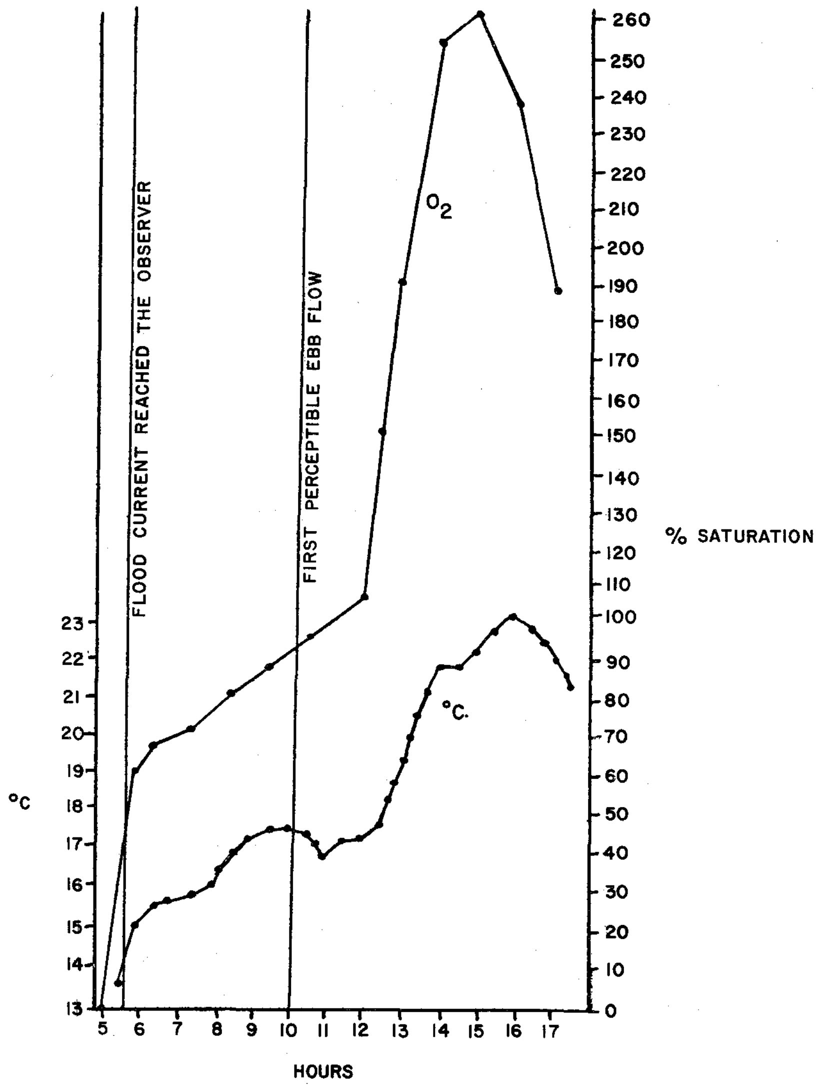


FIGURE 3-41. OXYGEN CHANGES IN AN EELGRASS BED OVER TIME. Data are from a study in Holland. (After Broekhuysen, 1935, in Phillips, 1974.)

The determination of Zostera primary productivity (gC/m^2) is complicated by the wide ranges of turion densities encountered in eelgrass beds. Phillips (1974) compared the standing stock (g dry/m^2) of eelgrass in Puget Sount to that of cultivated crops and terrestrial grasses (Table 3-26. These data show eelgrass standing stock of 581 and 277 grams (dry weight) per square meter per year. Other data on eelgrass standing stock include 1002 grams per square meter per year in Nova Scotia (Mann, 1973), 340 grams per square meter per year in Denmark (Mann, 1973), and 150 to 290 grams per square meter per year in Coos Bay, Oregon (McConnaughey, 1973). The average of these values is 480 grams per square meter per year (350 g/m^2/yr if the Nova Scotia figure is excluded). Thayer et al. (1975), in their discussion of eelgrass and other "seagrasses," give a general range of Zostera marina production of 300 to 600 grams (dry weight) per square meter per year.

McRoy (1966) estimated the net productivity of Zostera in Izembek Lagoon (Alaska) to be 2.0 grams carbon per square meter per day during the growing season, a figure he says is higher than that for Thalassia sp. (a tropical seagrass) and comparable to some species of marine algae. He gives the daily turnover rate of standing stock of eelgrass biomass as about 1.5%, with a turnover time of about 69 days. (However, the Alaskan growing season has significantly longer daylight hours; and the turion densities (in Table 3-23) are extremely high; caution must be exercised in using these data to characterize the study area.) Phillips' data from Puget Sound, Washington, closer to the Pacific Northwest Coastal Region, yield a primary productivity range of 0.7 to 4 grams carbon per square meter per day, with a 250 day growing season (Phillips, 1978, pers. comm.).

The above productivity figures indicate that eelgrass is significantly less productive over the entire year than salt marshes or seral forests of the region (only about 1/3 to 1/5 of these other systems' annual primary productivities), and is generally less than the upwelling area's phytoplankton production, although comparable.

However, as shown in Figure 3-42 for one particular estuary on the East Coast, eelgrass production may be more important to the estuary than the relative size of its biomass or annual productivity would indicate. Its annual turnover (which includes most of its biomass) is intermediate between phytoplankton (higher) and marsh plants (lower), thus adding a significant output of detritus to neighboring habitat food webs. In this sense, eelgrass beds are highly productive in amount of biomass that supports consumers and detritivores in other habitats

The epiphytes growing on mature leaves of eelgrass may have a biomass approximately equal to that of the eelgrass itself. These producers increase the primary productivity of the entire eelgrass bed by a significant amount

TABLE 3-26. COMPARISON OF NET PRODUCTIVITY OF CULTIVATED CROPS AND TWO MARINE SYSTEMS.[1] (From Phillips, 1974.)

Crop	Grams/Meter^2 (Dry Matter) Per Year	Per Day
Wheat, world average	344	0.94
Oats, world average	359	0.98
Corn, world average	412	1.13
Rice, world average	497	1.36
Hay, U.S. average	420	1.15
Sugar cane, world average	1725	4.73
Tall grass prairies, Oklahoma and Nebraska	446	1.22
Short grass prairies, Wyoming	69	0.19
Seaweed beds, Nova Scotia	358	0.98
Eelgrass (Zostera marina),		
Puget Sound, Washington	581	1.59
Denmark (Grøntved, 1958)	277	0.83

[1] All data except for eelgrass are taken from data reported by Odum (1959). Eelgrass data are from Phillips (1974).

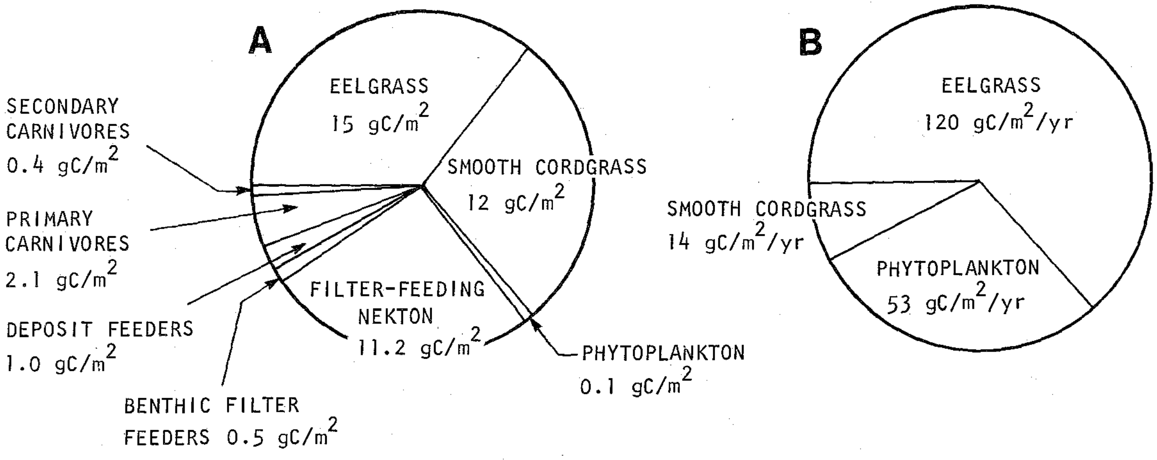


FIGURE 3-42. PROPORTIONAL RELATIONS OF STANDING CROPS AND PRODUCTIVITY IN AN ESTUARY. (A) Relation among standing crops (in terms of carbon) of organisms in the 400 square kilometer estuarine system near Beaufort, N.C. (B) Organic production (in terms of carbon) by the major plants in the Beaufort, N.C. estuarine system. N.B. Salt marsh productivity varies greatly with type and location (see Section 3.2.1.2). These data present an example of one East Coast estuary. The few data of the study area do not support the trends implied in this figure. (From Thayer et al., 1975.)

3.2.1.3 Eelgrass Ecosystem Model Notes (continued)

Table 3-27 summarizes the optimum and range of habitat factors affecting vegetative growth, flowering, and seed germination of eelgrass.

The seasonal pattern of vegetative and reproductive activity has been observed by several investigators whose findings are summarized in Table 3-28. The data of Phillips from Puget Sound probably indicate the general timing of eelgrass growth and seeding in the study area.

<u>#3. Uptake and Excretion</u>. McRoy and Goering (1974) have shown that eelgrass can absorb nutrients from sediment through the roots as well as from the water column through the surface of the leaves.

Later work by McRoy and colleagues has shown that about 90 percent of the nutrient-mineral uptake occurs via sediments-roots. If the concentration of a nutrient in the leaf falls with respect to the water, uptake occurs via the leaf, but the predominant pathway is sediments-roots-leaves (Phillips, 1978, pers. comm.).

Phillips (1974) reviews the three mineral cycles of note in eelgrass literature: nitrogen, sulfur, and phosphorus (see Section 2.2.6 in Volume 1.)

No experimental work to determine nutrient requirements and limits has been reported. Analyses of eelgrass leaves vary considerably in the percentages of nutrient elements found, but even the minimum values for nitrogen (1.5% of dry leaf weight; Boysen-Jensen, 1914) indicate that the nitrogen content of eelgrass is high compared to other aquatic plants (Elder, 1976). However, nitrogen-fixation in the roots is questionable. McRoy et al. (1973) found little indication that nitrogen was fixed in the root system, but Mann (1973) reports fixation of large amounts of atmospheric nitrogen in the anaerobic mud surrounding the roots. This would make eelgrass independent of dissolved nitrate supplies which sometimes limit production in coastal waters.

Table 3-29 gives results of analysis of cast off eelgrass plants, and Table 3-30 gives the mineral levels found in <u>Zostera</u> leaves by Burkholder and Doheny (1968).

TABLE 3-27. NUMERICAL CHARACTERISTICS OF EELGRASS HABITAT FACTORS. (From Phillips, 1974.)

HABITAT FACTOR	VEGETATIVE GROWTH	PLANT ACTIVITY FLOWERING STATE	SEED GERMINATION
TEMPERATURE			
Range	0 - 40.5°C	-----	-----
Optimum	10 - 20°C	15 - 20°C (8-9°C in Puget Sound)	5 - 10°C[a]
SALINITY			
Range	Freshwater - 42 °/oo	-----	-----
Optimum	10 - 30 °/oo	Same as optimum	4.5 - 9.1 °/oo
DEPTH-LIGHT			
Range	1.8 meters above MLLW to 30 meters deep	-----	-----
Optimum	MLLW - 6.6 m below MLLW (11 m at high tide)	Effect unknown	No effect
SUBSTRATE			
Range	Pure firm sand to pure soft mud	-----	-----
Optimum	Mixed sand and mud	No effect	No effect
pH	7.3 - 9.0	Effect unknown	Effect unknown
WATER MOTION			
Range	Waves to stagnant water	-----	-----
Optimum	Little wave action. Gentle currents to 3.5 knots	Effect unknown	Effect unknown

[a] Arasaki (1950 A) found no correlation with temperature. Most reports list highest incidence of germination occurring in February and March.

Just below the surface of the sediments in an eelgrass bed there is usually a strong reducing layer in contact with the roots and rhizomes. Hydrogen sulfide whether or not it is detected is always present, and ferrous sulfide is almost always present in the muddy layer. Zostera excretes two reducing products, a sulfur compound and a nitrogen compound, which may produce ferrous sulfide directly and may result in reducing conditions that greatly accelerate sulfate reduction by Microspira (sulfur bacterium) (Phillips, 1974).

A schematic diagram of the sulfur cycle as it operates in an eelgrass bed is given in Figure 3-43.

There is little in the literature specifically relating the phosphorus cycle to eelgrass, but McRoy (1966) estimates the amount of phosphorus in the leaves dropped by eelgrass plants (8% of dry organic weight) to be about four times the amount of nitrogen (2% of dry, organic weight).

The ash weight of eelgrass was found by Boysen-Jensen (1914) to be 25% dry weight; McRoy (1966) calculated it to be 20%. Burkholder and Doheney (1968) analyzed leaves and rhizomes separately, and found the ash weights to be 9.8% and 34%, respectively, with the ash weight of the entire plant 22% of dry weight.

Penhale and Smith (1977) found that Zostera and its epiphytes excrete dissolved organic carbon (DOC). They estimate that 47% of the total production of marsh grass (Spartina), eelgrass with its epiphytes, and the phytoplankton in estuaries is excreted as DOC. Of the total, they estimate 14% is excreted by eelgrass and epiphytes, giving these plants an important role in short-term carbon cycling within the estuary on the east coast of the U.S.

TABLE 3-28. SEASONAL PERIODICITY OF EELGRASS. (From Phillips, 1974.)

Country	Vegetative Growth				Flowering Stalk Produced	Seed Germination
	New Turions	New Leaf Production	Standing Stock	Root Growth		
United States						
Northern California (Setchell, 1929)	Probably June - October				Early Spring	February
Puget Sound, Washington (Phillips, 1974)	February (Production began)	February	Maximum- June - Sept Minimum- Jan - Feb	February	May	June - July
Massachusetts (Conover, 1958)		Mid-Spring (March)	Maximum- June - Sept Minimum- Jan - Feb			
Japan (Arasaki, 1950A)	Throughout year (except July - August)		Decline from July - late Autumn		Late Jan	Late Dec - April
Denmark (Petersen, 1913)			Maximum- July - Sept			

TABLE 3-29. PROXIMATE ANALYSES OF ZOSTERA LEAVES, RHIZOMES, AND OLD SHOOTS WASHED UP ON THE BEACH. Analytic values are given as percent of dry weight. (From Elder, 1976, after Burkholder and Doheny, 1968.)

Determination	Zostera Sample		
	leaves	rhizomes	beach grass
Total solids	89.01	96.62	86.82
Moisture	10.99	3.38	13.18
Fat (ether extract)	2.29	0.91	1.04
Protein (N x 6.25)	10.63	6.14	10.55
Ash	8.80	32.62	15.68
Crude Fiber	61.70	59.94	63.50
Carbohydrate (other than crude fiber)	5.60	-	-
		calories/100g	
Caloric value[1]	85.5	32.80	51.60

[1] Based on caloric equivalents per gram of 9, 4, and 4 for fat, carbohydrates, and protein, respectively.

TABLE 3-30. MINERAL CONTENT OF ZOSTERA LEAVES.[1] (From Elder, 1976, after Burkholder and Doheny, 1968).

Mineral	Percent in ash	Percent in Zostera leaves[2]
Calcium	5.15	0.453
Magnesium	7.69	0.677
Phosphorus	4.39	0.386
Potassium	2.52	0.222
Zinc	0.031	0.0027
Iron	0.39	0.034
Manganese	0.49	0.043

[1] By atomic absorption spectroscopy.

[2] Moisture-free basis.

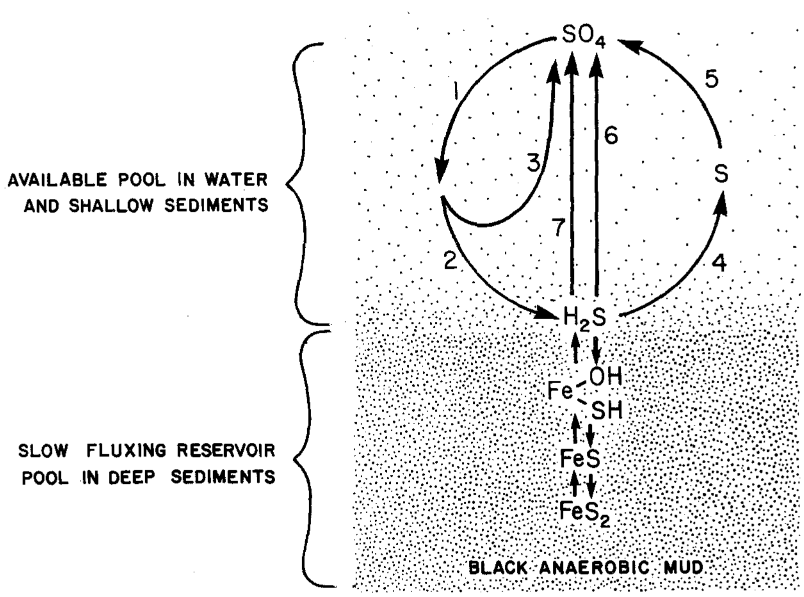


FIGURE 3-43. THE SULFUR CYCLE IN THE EELGRASS ECOSYSTEM. Processes are as follows: 1 = primary production by autotrophs, 2 = decomposition by heterotrophic microorganisms, 3 = animal excretion, 4 and 5 = steps by colorless, purple, and green sulfur bacteria, 6 = desulfovibrio bacteria (anaerobic sulfate reducers), 7 = thiobacilli bacteria (aerobic sulfide oxidizers). (Phillips, 1974.)

#4. Defoliation and Export of Biomass. Very few organisms consume living eelgrass (see Note #6), but dead, decaying leaves of these plants are an important source of organic matter and minerals in the estuarine habitat and elsewhere. Carried by currents far beyond the limits of their habitat, even out of the estuary, the eelgrass cast nourishes a wide area.

An extensive dieback occurs during the fall and winter months (October through January) in the study region. Light limitation may be involved (see Note #2). Short (1975) calculated the relationship between wind speed and vegetal erosion, but notes that susceptibility to erosion varies with season and that high wind velocities will uproot whole plants.

Thayer et al. (1975) indicate that as much as 45% of the plant production in eelgrass beds in North Carolina estuaries may be carried away to supply detrital material to adjacent habitats.

The area of dense stands of eelgrass in the Pacific Northwest Coastal Region is approximately 30,000 acres (12,000 ha): 21,000 in Washington, 5,000 in Oregon, and 4,000 in Northern California (ACOE, 1976B, -C, -H, and Monroe, 1973). If a net annual standing crop of approximately 580 grams per square meter (2.6 tons per acre) dry matter (after Phillips, 1974) and 70% seasonal defoliation (after Short, 1975) is assumed, then it is estimated that the region produces annually about 66,000 tons (dry matter) of eelgrass, of which 46,000 tons is defoliated per year to become local or exported detritus and wrack.

#5. Decomposition. Harrison and Mann (1975) found that it took approximately fifty days for detached eelgrass leaves to break down completely as the result of bacterial activity, but that about fifty percent of that breakdown occurred within the first ten days. Amphipod crustaceans play a major role in the mechanical breaking down of the dead plant tissue. Harrison (1977) compared decomposition of eelgrass leaves in an aquarium containing two adult amphipods (Gammarus oceanicus) with that in an aquarium in which only bacterial decay occurred. The amphipods increased the rate of decomposition by 32% at 5°C (40°F) and by 35% at 21°C (70°F). They markedly reduced the average size of leaf particles remaining. The microscopic plant epiphytes attached to or living on the surface of the eelgrass leaves also are significant in the decomposition process, as the amphipods were found to graze on untreated leaves but not on those from which the epibionts had been removed. Likewise, the rate at which eelgrass detritus is incorporated into the polychaete Nephtys incisa depends not only on the age of the detrital material but also on the presence of a benthic meiofauna dominated by nematodes (Tenore et al., 1977).

#6. Community Composition. Eelgrass is the dominant producer, but the epiphytic macroalgae and microbes are a significant additional photosynthetic biomass which may nearly equal that of their eelgrass substrate (Thayer et al., 1975). Besides providing primary production, the eelgrass leaves greatly increase the surface area of substrates for the attachment and grazing of those species directly associated with eelgrass. The interrelationships of this epibiotic community are indicated in Figure 3-44 which shows the general vertical distribution of plants and animals on submerged eelgrass leaves.

Some species of plants (e.g. the small epiphytic red alga, Smithora naiadum) and animals (e.g., the little sea slug, Phyllaplysia taylori) seem to be especially adapted to living in eelgrass and are seldom found elsewhere. The common inhabitants of eelgrass beds are also found in other habitats (Kozloff, 1973; Ricketts and Calvin, 1968).

An eelgrass bed can be divided into four subhabitats by substrate: (1) on leaves, (2) in water, (3) on the bottom, and (4) in the bottom.

The leaves not only form a substrate for small, epiphytic macroalgae and microscopic diatoms and other meiofauna but are covered with a rich layer of bacteria as well. The increase in bacterial biomass associated with the eelgrass leaf subhabitat is indicated in Table 3-31.

Animals such as anemones, bryozoans, and hydroids are sessile, attached firmly to the leaf surface. Protozoa, nematodes, and gastropods glide along the leaves, while small crustaceans cling and move about on hooked appendages. This subcommunity consists predominantly of microscopic organisms. The isopods of the genus Idotea and the caprellid amphipods, which are specially adapted for gripping the blades of eelgrass, are macroscopic and thus more obvious, but do not comprise a major portion of the faunal biomass (Albright and Rammer, 1976).

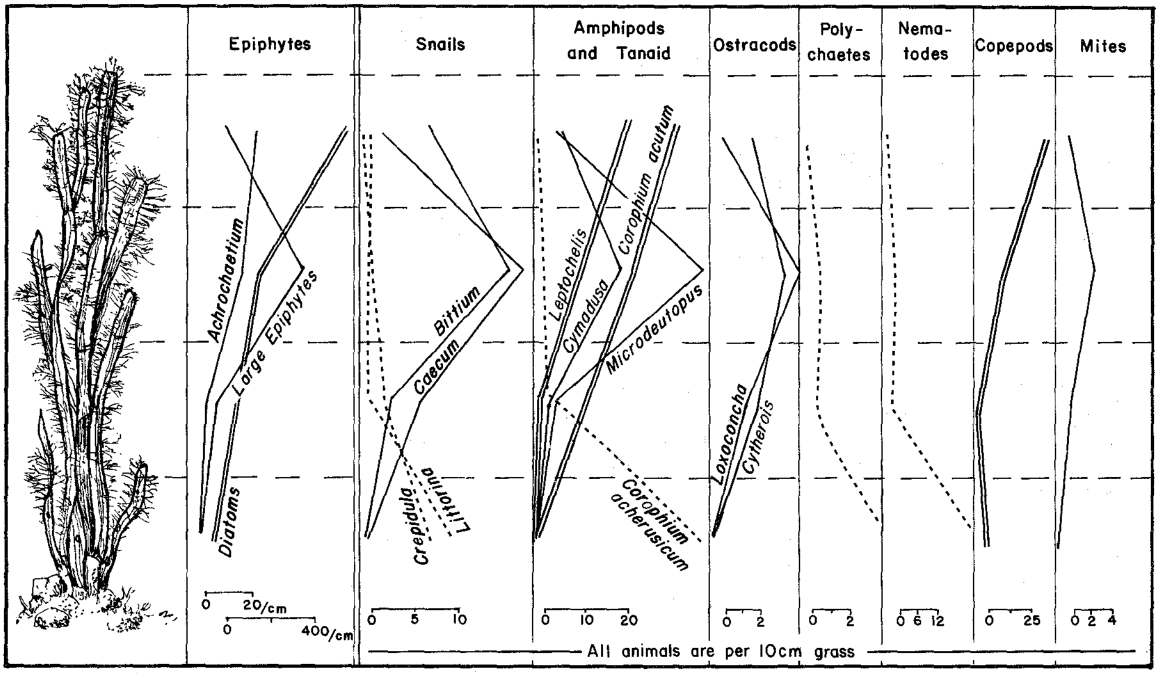


FIGURE 3-44. VERTICAL DISTRIBUTION OF EELGRASS EPIBIOTA. Data are from study done near Monument Beach, Massachusetts. Dashed lines indicate animals which generally decrease in abundance away from the bottom. Solid lines indicate variation with epiphytes, with single ruled lines signifying variance with large eqiphytes, double ruled lines signifying variance with diatoms. (From Nagle, 1965, in Phillips, 1974.)

TABLE 3-31. BACTERIA IN THE EELGRASS HABITAT. Data are from two stations in South Oyster Bay, Long Island, New York, July, 1966. (From Phillips, 1974, after Burkholder and Doheny, 1968.)

Station	Type of Sample	Bacteria per gram or ml
1	mud	1,300,000
	water	27,700
	eelgrass	68,964,000
2	mud	200,000
	water	30,000
	young eelgrass	1,680,000
	old eelgrass	28,728,000

Swimming in the water between plants are fishes and small crustaceans; some are characteristic of the general estuarine nekton and plankton, while others, such as the amphipod Photis brevipes, are usually found only in eelgrass areas (Albright and Rammer, 1976).

On the bottom live flatfish, crabs, shrimp, amphipods, sea slugs, snails, brittle stars, sea urchins, ribbon worms, polychaete worms, flat worms, nematodes, rotifers, and various estuarine benthic detritivores and their predators (Phillips, 1974). Here is the greatest number of animals among the four subhabitats. Numerically, as well as in biomass, meiofaunal nematodes seem to dominate (Tenore et al., 1977), but there are no estimates of the biomass of the microfauna, such as rotifers and protozoans, to substantiate this claim.

The surface of the bottom is rich in bacterial flora and may be covered at times with mats of diatoms which are probably important as producers in the community (Phillips, 1974).

Living in the bottom sediments, either actively burrowing through it or residing in burrows open at the surface, are worms, clams, brittle stars, and crustaceans such as Upogebia, the blue mud shrimp (Phillips, 1974). The invertebrate benthic fauna includes both deposit feeders and filter feeders. In some areas, these infauna may be the dominant animal biomass in the eelgrass community.

The species composition of eelgrass beds varies seasonally with life cycles, migrations, and physical rigors (such as the high temperatures associated with extreme low tides which occur at midday in summer); seasonal changes in the entire community have not been documented in the study region.

Both grazing and detrital food webs are present in the eelgrass habitat, but the detrital food web is predominant. Those few species of animals which utilize fresh eelgrass plant material as food are periwinkles, some crabs, certain fishes, isopods, and waterfowl (Phillips, 1974). Certain migratory fowl, such as the black brant, may be the major herbivorous consumers. Within the eelgrass bed, herbivores feed mainly on epiphytic diatoms. The principal detrital food web is based mainly on the decomposition of eelgrass and its epiphytes. Figure 3-45 shows the proportion of detritus to fresh eelgrass and of detritivores to herbivores.

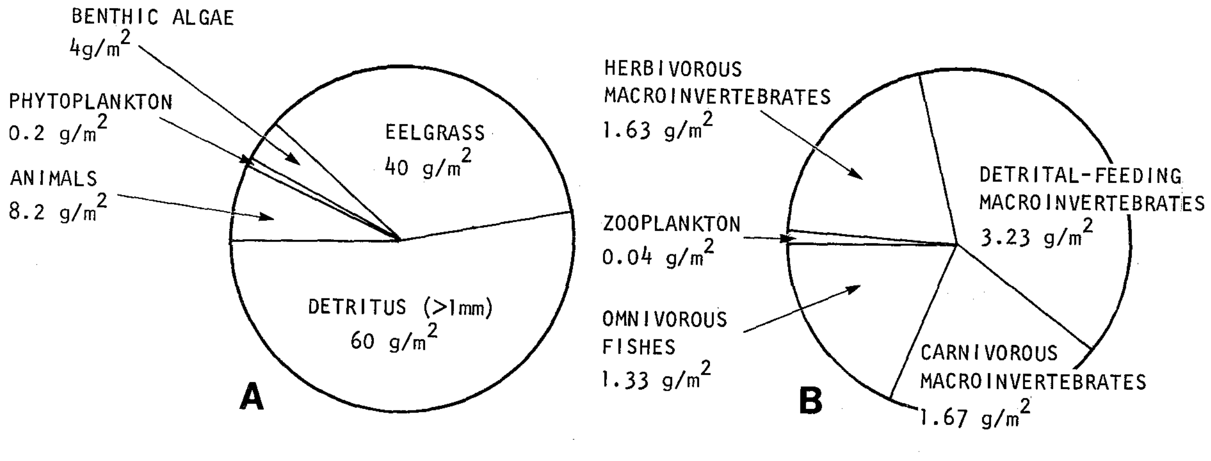


FIGURE 3-45. PROPORTIONAL RELATIONS OF VARIOUS TROPHIC COMPONENTS IN THE EELGRASS HABITAT. (A) Relation among standing crops and detritus in a 20,000 square meter eelgrass bed in the Newport River estuary, Beaufort, N.C. (B) Standing crops of animals in the eelgrass bed. Plants and detritus are in dry weights; animals in ash-free dry weight. (From Thayer et al., 1975.)

The rich supply of detritus makes this habitat richly productive and the biomass of many animal species increases within it. Table 3-32 shows the density of capetellid polychaete worms relative to eelgrass density. A cause and effect relationship is implied here - gross density: animal species density. This relationship is not well established in the literature.

TABLE 3-32. TOTAL ABUNDANCE OF ORGANISMS AND ABUNDANCE OF CAPITELLID WORMS IN RELATION TO EELGRASS (Z. MARINA) AT FOUR WHITCOMB FLATS STATIONS, GRAYS HARBOR, WASHINGTON, 1975. (From Albright and Rammer, 1976.)

Station No.	Eel grass	Bivalves, Crustaceans, Amphipods and Other/m^2	Capitellids/ m^2
W-1	None	2,805.3	181.3
W-3	Mod. dense	5,194.6	2,816.0
W-2	Mod. dense	15,583.9	10,597.3
W-1A	Very dense	29,535.8	19,621.2

Quantitative relationships of the various trophic components in the eelgrass community are shown in Figures 3-45 and 3-46, and Table 3-33. Food webs in the eelgrass habitat have been diagrammed by MacGinitie (1935), as shown in Figure 3-47.

TABLE 3-33. QUANTITATIVE RELATIONSHIPS OF EELGRASS SYSTEM. Data are weights, given in tons. (From ACOE, 1976H, after Phillips, 1974.)

	Willapa Low*	Willapa High**
Eelgrass	205,230	1,207,234
Herbivorous Animals	8,551	50,302
Starfish	214	1,258
Small Fish	86	503
Plankton	599	3,521
Herring, etc.	60	352
Cod	52	302
Flatfish	43	252
Larger Predatory Crustaceans, Gastropods, etc.	430	25,151
Ducks, Brant, Geese	42,757	251,509

*If 17 grams/square foot organic matter produced annually.
**If 100 grams/square foot organic matter produced annually.

#7. Migration and Visitation. Migratory wildfowl are major consumers of fresh eelgrass material during fall and winter. Birds not only consume plant material but bring in fecal matter from other locations, and may, seasonally, play an important role in the direct conversion of eelgrass plants to detritus.

Black brant favor this habitat, eating the floating leaves and stems. Eelgrass is a food item also for widgeon, scoter, canvasback, and coot. This habitat is used by 25 species of ducks, 3 species of geese, and whistling swans (ACOE, 1976G; Thompson and Snow, 1974; Smith and Mudd, 1976; Yocum and Keller, 1961).

The species particularly dependent on eelgrass are black brant and widgeon; Zostera makes up 80% of their diets (Phillips, 1974). Yocum and Keller (1961) concluded that eelgrass was the single most important item of food for waterfowl migrating through Humboldt Bay, California, on the basis that widgeon and black brandt constituted 47% and 20%, respectively, of the total waterfowl populations in the area and that eelgrass constituted 81% of the volume of the diet of both these species. McRoy (1966) estimated that black brant and Canada geese consumed about 17% of the standing stock of eelgrass in Izembek Lagoon, Alaska, during the summer-autumn feeding period. He estimated that each bird required about one square meter of eelgrass per day. Smith and Mudd (1976) have studied the food habits of wildfowl and shorebirds in Grays Harbor, Washington, with similar conclusions on the importance of eelgrass.

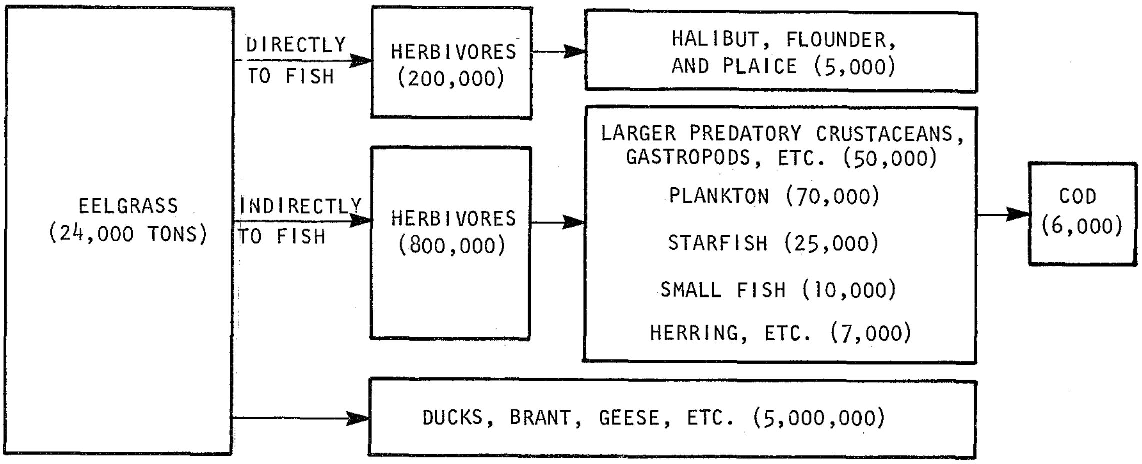


FIGURE 3-46. ESTIMATED RELATIONSHIP AMONG STANDING CROPS OF ORGANISMS SUPPORTED BY THE EELGRASS SYSTEM IN DENMARK. (From Thayer et al., 1975; data from Petersen, 1918, and Milne and Milne, 1951.)

3.2.1.2 Eelgrass Ecosystem Model Notes (continued)

Both herring and smelt attach their eggs to the leaves of eelgrass as well as algae, worm tubes, and shells. Eelgrass beds may be visited by residents of other nearby habitats. Dungeness crabs (Cancer magister) feed here and juvenile salmon commonly feed on small benthic organisms such as the amphipods and harpacticoid copepods that are abundant in eelgrass beds.

Otter, racoon, and other land animals may visit intertidal beds at night during low tides to forage. Black-tailed deer are observed as far out onto the tideflats as 500 m (1600 ft) from the high tide perimeter, presumably either feeding on eelgrass or algae or taking salt water for its mineral content (Mudd and Smith, 1976). Harbor seals land on exposed intertidal flats, and may visit subtidal eelgrass areas to feed when food fish are present.

#8. Human Use. Eelgrass has been used by man in many ways: as explosive gun cotton, a source of salt and soda, mattress stuffing and animal bedding, packing material, compost, but most extensively as insulation. A house was built in 1635 in Dorchester, Massachusetts, using dried eelgrass as insulation in the walls; the eelgrass was found to be well preserved 250 years later. In 1956, an article commending eelgrass as insulation appeared in a magazine, The Maine Coast Fisherman, and a Nova Scotia firm was producing batts of harvested eelgrass leaves for home insulation at $21-$30 per ton depending on shipping distance (Phillips, 1974). No such commercial harvesting of eelgrass is known in the study area.

The eelgrass habitat is used to an unknown extent in the sport fishery for clams and crabs, and for appreciative uses such as nature study field trips. Those beds near and directly accessible from shore during low tide are most impacted in this way. Research studies concerned with estimation of standing crop and other spatial variables in this habitat may take scientists into more remote beds. Such surveying usually revisits stations along established transects. The need for field studies on eelgrass, its community, and its role in the estuary is recognized, and intrusion of more researchers into this habitat may be expected.

#9. Pollution. Chemical pollution effects upon eelgrass are often inferred, but seldom defined. Some pollutants would increase light extinction and affect production (Phillips, 1974). Eelgrass has not been used as a test organism in bioassays of pollutant effects, but this should probably be done, using experimental and control plots of eelgrass habitat, including a representative community composition. Tests should be extended throughout the year to determine seasonal vulnerability.

#10. Loss of Habitat. The major threat to eelgrass beds within the study area is thought to be dredging and the unconfined disposal of dredged materials within the estuary (OSU, 1977A; ACOE, 1976-77). The former directly removes the substrate of this habitat by excavation, and

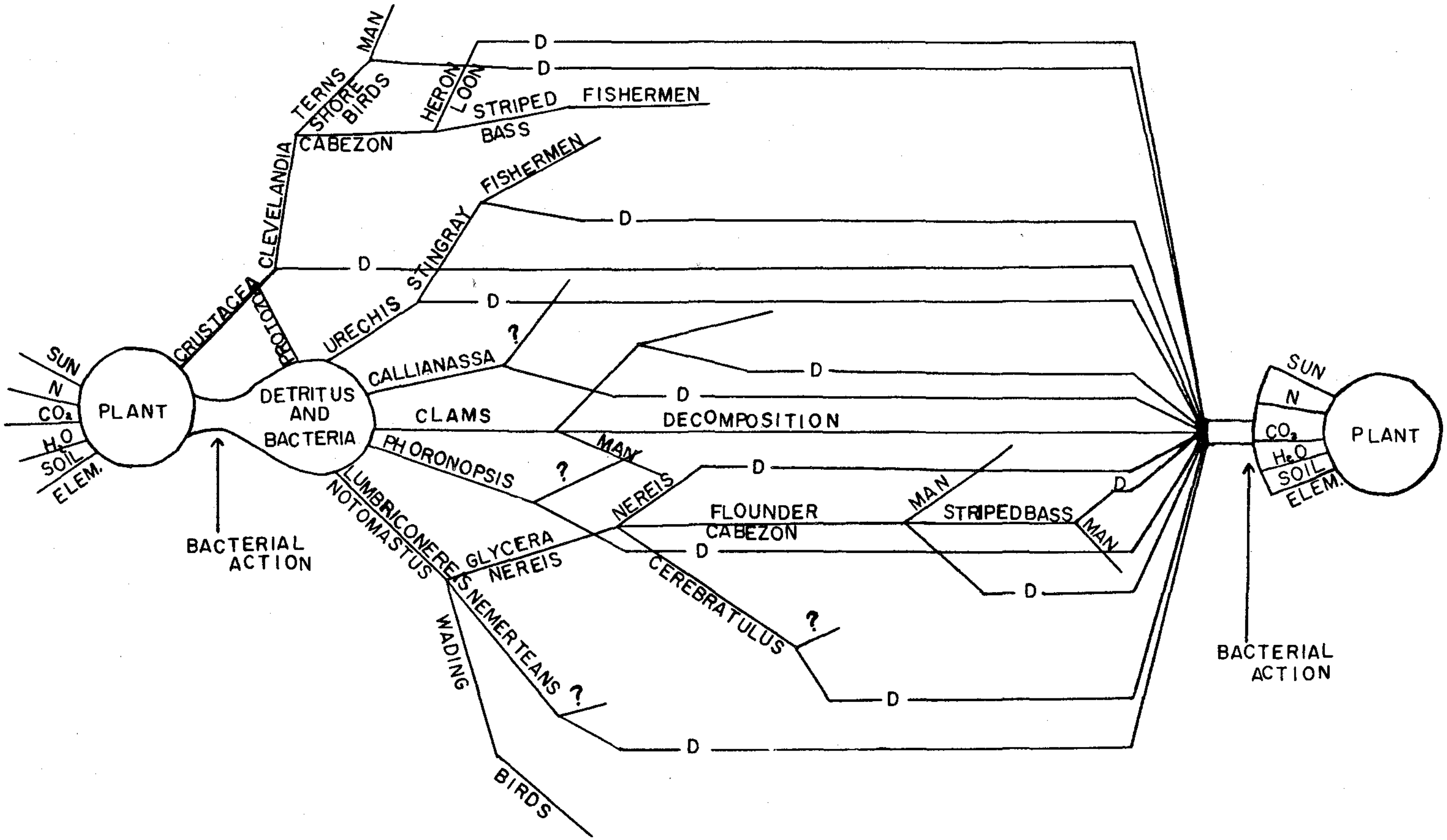


FIGURE 3-47. FOOD CHAINS IN AN EELGRASS COMMUNITY. Diagram is based on studies of Elkhorn Slough, Monterey Bay, California. (From Phillips, 1974, after MacGinitie, 1935.)

generally has not been allowed in the study area in recent years in recognition of the food value of eelgrass to migratory bird populations. Disposal of dredged material along the sides of the channels has the indirect effect of raising the substrate over a wide area beyond the disposal site, until elevation is too high to support eelgrass. This effect has now been recognized as causing a loss of eelgrass habitat and is the subject of several studies (OSU, 1977A; ACOE, 1976-77). Direct filling of eelgrass areas to expand dry land area for human development is an obvious loss of this valuable resource area. Percy et al. (1974) summarize the inventory of landfills on submerged and submersible lands in Oregon estuaries carried out by the Oregon Division of State Lands (Table 3-22). Less direct effects may result from peripheral erosion around such a fill in the vicinity of eelgrass beds. Diking, or the placement of other structures that affect changes in the pattern and strength of currents in eelgrass areas, will alter the community and its production, perhaps advantageously, probably adversely.

Disposal of dredged material is unlikely to result in an increase of habitat. Even if the dredged sediments prove to be stable, because they are poor in organic matter and do not have the subsurface reducing layer, they are not readily colonized by eelgrass (Phillips, 1974).

Sudden, extensive loss of eelgrass, as occurred in the 1930's on both sides of the Atlantic Ocean, had a damaging effect on adjacent habitats. There was much damage to oyster beds smothered by the translocation of fine sediments that had been held by the eelgrass beds. Waterfowl populations, such as black brant and widgeon that depend heavily on eelgrass for food, declined sharply, by as much as 80-90% in many locations. Phillips (1974) reviews the literature studying this phenomenon, generally referred to as the "wasting disease" of eelgrass.

According to Phillips (1974), the best documented case history of the consequences of this great and general loss of eelgrass to "wasting disease" is that of Allee (1923) and Stauffer (1937) from Woods Hole, Massachusetts. Of 138 species of animals found in the eelgrass bed, 55 were characteristic of the eelgrass system (generally, those living on or swimming among the plants). Many of these disappeared with the eelgrass, leaving mostly those animals living on or in the bottom. Table 3-34 shows the relative abundance before and after loss of the eelgrass habitat.

#11. Gain of Habitat. Phillips (1974) reports successful transplanting of eelgrass to establish new beds, but notes that horizontal spread by vegetative growth is very slow. He suggests either large numbers of transplants over an extensive area or recolonization by seed propogation in order to reclaim disturbed areas or newly created eelgrass ponds.

Allee (1934) diagrammed community development in the Woods Hole region (see Figure 3-64 in Section 3.2.4.2), showing the position of the eelgrass community in the line of succession. However, caution should be exercised in assuming eelgrass beds to be in a line of succession to salt marshes and land communities. Den Hartog, as quoted by Phillips (1978, pers. comm.) states that there "... is no evidence at all that submarine succession series form an overture to a terrestrial haloseries." Den Hartog further noted that those suggesting such a succession were only confusing succession with zonation.

In summary, Thayer, et al. (1975, p. 288) list the effects of eelgrass on ecosystem function:

1. Eelgrass has a high growth rate, producing on the average about 300-600 g dry wt/m^2/year, not including root production.

2. The leaves support large numbers of epiphytic organisms, with a biomass perhaps approaching that of the grass itself.

3. Although a few organisms may feed directly on the eelgrass and several may graze on the epiphytes, the major food chains are based on eelgrass detritus and its resident microbes.

4. The organic matter in the detritus and decaying roots initiates sulphate reduction and maintains an active sulphur cycle.

5. The roots bind the sediments together, and, with the protection afforded by the leaves, surface erosion is reduced, thereby preserving the microbial flora of the sediment and sediment-water interface.

6. Eelgrass leaves retard currents and increase sedimentation of organic and inorganic materials around the plants.

7. Eelgrass absorbs phosphorus through the leaves and the roots; it may be that the phosphorus absorbed through the roots is released through the leaves, therefore returning phosphate from sediments to the water column. Nitrogen also is taken up by the roots and transferred to the leaves and into the medium.

TABLE 3-34. RELATIVE ABUNDANCE OF CHARACTERISTIC EELGRASS HABITAT SPECIES BEFORE AND AFTER DISAPPEARANCE OF THE EELGRASS. Study documents changes as a result of the eelgrass "wasting disease" in the N.W. Gutter Lagoon in Massachusetts. (After Stauffer, 1937, in Phillips, 1974.)

I. Animals formerly growing on the plants	Occurrence[1]	
	Before	After
Coelenterata:		
Sagartia luciae	**	
Bryozoa:		
Bugula turrita	***	
Arthropoda:		
~~*Idothea baltica*~~	*	
Mollusca:		
Bittium alternatum	**	
Lacuna vincta	**	
Littorina sp.	***	**
Mitrella lunata	*	
Total number of characteristic epiphytic species	7	1
II. Animals formerly swimming among the plants		
Annelida:		
Podarke obscura	*	
Arthropoda:		
Crago septemspinosus	*	*
Gammarus sp.	**	**
Palaemonetes vulgaris	**	**
Virbius zostericola	**	
Mollusca:		
Pecten irradians	**	
Total number of characteristic swimming species	6	3
III. Animals living on the surface of the mud		
Coelenterata:		
Hydractinia echinata[2]	**	**
Arthropoda:		
Carcinides maenas	**	
Libinia dubia	*	
Libinia emarginata	*	*
Pagurus longicarpus	***	***
Pagurus pollicaris	*	*
Neopanope texana sayi	**	**
Limulus polyphemus	**	*
Mollusca:		
Crepidula convexa	**	**
Crepidula fornicata	*	*
Crepidula plana	**	*
III. Mud-surface forms (continued)		
Nassa obsoleta	***	**
Nassa trivittata	**	**
Modiolus demissus	***	
Mytilus edulis	**	
Ostraea virginica	*	*
Total number of characteristic mud surface species	16	12
IV. Burrowing forms		
Nemertea:		
Cerebratulus lacteus	*	*
Micrura leidyi	***	
Echinodermata:		
Leptosynapta inhaerens	***	*
Thyone briareus	***	**
Annelida:		
Amphitrite ornata	**	*
Arabella opalina	**	**
Cistenides gouldi	**	**
Clymenella torquata	**	***
Diopatra cuprea	*	
Glycera sp.	***	*
Lumbrinereis tenuis	*	***
Maldane urceolata	*	*
Nereis virens	***	
Scoloplos fragilis	***	***
Spio setosa	*	***
Phascolosoma gouldi	*	*
Arthropoda:		
Pinnixia chaetopterana	*	*
Mollusca:		
Cumingia tellinoides	**	
Ensis directus	*	*
Mactra lateralis	*	*
Mya arenaria	***	*
Solemya velum	**	
Tellina tenera	**	**
Venus mercenaria	**	**
Chordata:		
Dolichoglossus kowalevskyi	*	*
Total number of characteristic burrowing species	25	20
Grand total of characteristic species	55	36

[1] * Occasional: Before—found in less than 33 per cent of Allee's collections. After—forming less than 2 per cent of the 1936 population.
** Common: Before—in 33 per cent to 50 per cent of Allee's collections. After—forming 2 per cent to 5 per cent of total population.
*** Abundant: Before—in over 50 per cent of Allee's collections. After—forming 5 per cent or more of the total population.
[2] Since the hermit crabs, on whose shells this hydroid lives, are to be found on the surface of the mud, this seems the best place to classify Hydractinia.

3.2.1.4 Unprotected Beach Ecosystem Model Notes. In the Unprotected Beach Ecosystem Model (Figure 3-48) a diagonal line, represents the boundary between the beach sediment and the overlying water or air and the wave line represents the boundary between the air and the water. The unprotected beach is a zone of intense and continuous interaction between air, water, and land. The connections between materials and organisms above and below this interface are cyclical, affected by oscillating tidal forces, seasonal wave energy conditions, and the cyclical nature of the waves themselves. Not all of this habitat is intertidal, however, as the model covers the area between the berm on the landward side and the seaward limit of the surf zone. This area is regularly exposed to the force of breaking ocean waves. Although the beach strand may have isolated boulders or rock outcrops, this habitat is characterized by a deep mass of sand extending from berm to breaker depth and along the shore for distances up to several miles in the study region.

High-energy interaction is the principal physical factor determining the general character of this habitat. Indeed, wave stress with its resulting erosion, transport, and accretion, is an essential feature of the maintenance of the Unprotected Beach environment. The numbers of macrofaunal species found here are low compared to the number found in marine shore habitats protected from ocean surf. The organisms common to this environment are specifically adapted to its rapidly shifting sediments and pounding surf. For example, Chaetoceros armatum, a diatom found only in the surf zone, protects itself with an armoring coat of musilage and hardly resembles other members of the genus which are fragile in appearance.

Within this habitat, gradation of energy occur, which, coupled with the periodicity of the intertidal exposure, result in stratification of the community. A distinct biological boundary is apparent at the seaward edge of the surf zone, while the community changes only gradually shoreward from the subtidal to the intertidal beach (Lewin, 1978; Lewin and Norris, 1970).

The food web for this ecosystem is uncomplicated. The number of different species involved are few (i.e. diversity is low) due to the high energy of the waves and the periodic inundation and drying, creating conditions habitable by a limited number of organisms.

Discussion and presentation of data pertaining to the important components and processes of the ecosystem model begin with the dominant physical processes of (1) tidal inundation and (2) sediment transport, and continue with (3) the resultant cyclical suspension/deposition of sediment and detritus, (4) the percolation, adsorption, and filtration of water and waterborne materials, and (5) the aerial phenomenon of salt spray. The biological components of the system are discussed in (6) macrofaunal and meifaunal community composition, and (7) movement of macrofauna to and from neighboring habitats. Human activities in or affecting the beach are discussed last, including (8) use of the habitat for recreation and harvest, (9) direct gains (dredge spoil dumping) or losses (sand mining) of habitat, (10) indirect activities causing gains or losses of habitat, and (11) activities which may pollute the habitat.

#1. Inundation. The ocean is the immediate source for the surf zone water and waterborne materials in this ecosystem although much of the material may be terrestrial in origin. Waterborne materials in this model include dissolved and suspended organic (detritus) and inorganic (sand, etc.) materials, as well as living plants and animals. Dissolved organic carbon in the water is important in supporting the meiofauna in the Unprotected Beach ecosystem (Cox, 1976). A separate category of waterborne material is wrack and driftwood, including pieces of kelp, surfgrass, large drift logs, and other debris which floats on the surface. The waterborne materials are transported into and out of the Unprotected Beach ecosystem by a cyclical process of inundation. Inundation results from tidal processes, changes in atmospheric pressure, storms, and tsunamis. Tides, atmospheric pressure, and storms vary with time and are seasonally predictable; thus season is shown as a secondary regulating factor governing inundation.

Drift logs, deposited on the backshore and at the upper crest of the winter berm, may be large, and occupy considerable portions of the backshore in places. The driftwood line farthest inshore gives a good indication of past extreme inundations. Real estate is often subdivided and sold, and structures built within the backshore, seaward of the line of driftwood, seemingly oblivious of the tenuous, indefensible position. These structures cannot withstand the battering force of multi-ton, waterborne logs.

The tide in the Pacific Northwest Coastal Region is semi-diurnal, mixed type, with a mean diurnal (once daily) range of about seven to eight feet (2 to 2.5 m) (see Section 2.6.2 of Volumes 1 and 2). The diurnal range is more significant than the semi-diurnal range, due to the differences in

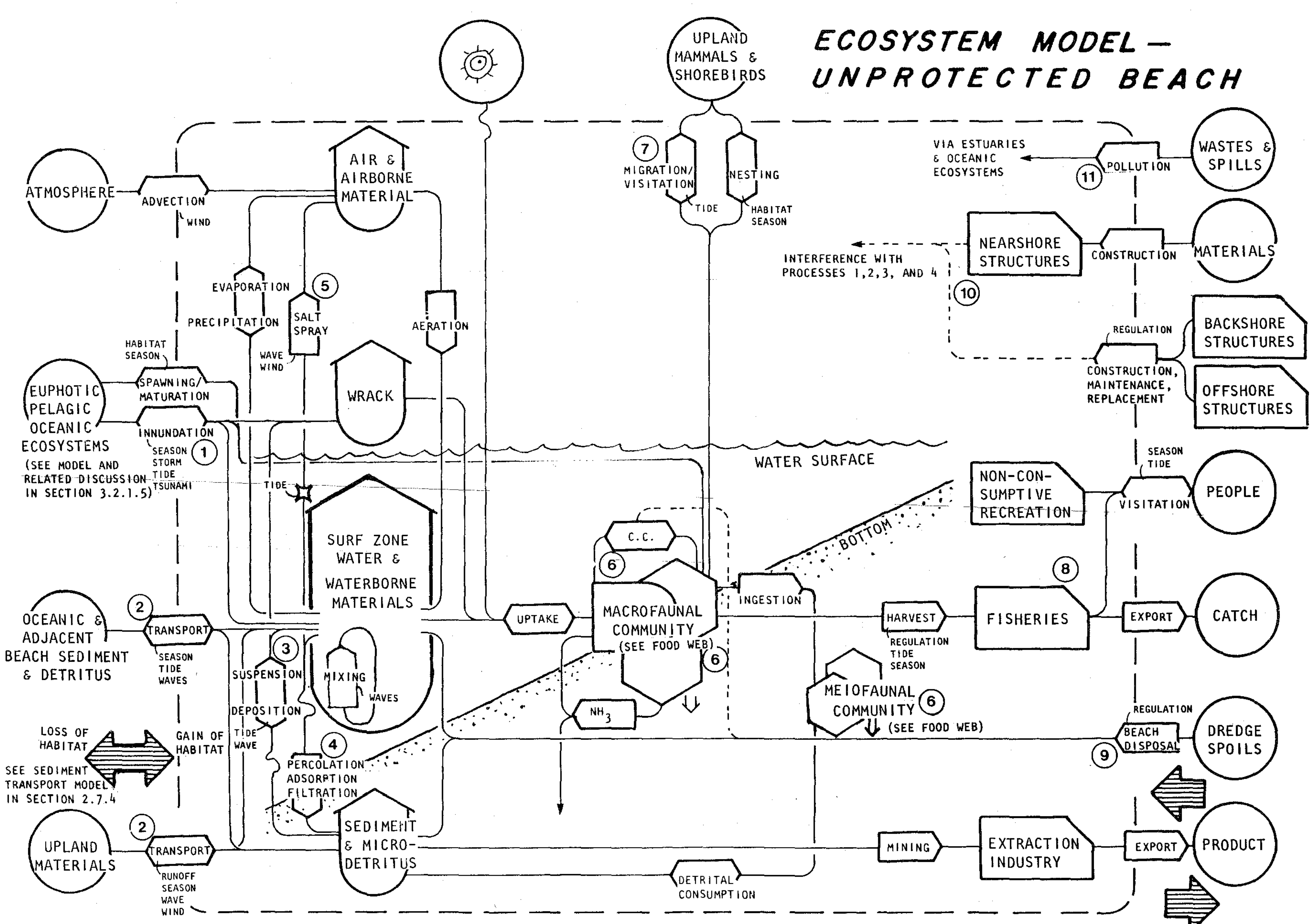


FIGURE 3-48. UNPROTECTED BEACH ECOSYSTEM MODEL.

the heights of the succeeding highs and lows. The maximum ranges occur in December and June due to astronomical factors, with highest measured tide levels as great as twelve to thirteen feet (3.5 to 4 m) above mean lower low water on beaches of the study area (Beaulieu and Hughes, 1975). Atmospheric pressure is generally lower in the winter months (see Section 2.3) and consequently sea level will be higher then. Sea level may rise approximately one centimeter per millimeter (mercury) drop in atmospheric pressure, or about one foot rise per inch drop in mercury. The maximum possible storm surge resulting directly from fluctuations in barometric pressure is about three feet (1 m) (Beaulieu and Hughes, 1975). Storms, with their strong onshore southwesterly or westerly winds, will cause a further build-up of water along the coast, and thus higher sea levels. Wave "set-up" (the retarded return of waves to the sea owing to wind friction) along the coast may approach two to four feet (1 m). Combining all factors leads to probable extremes of four to seven feet (1.2 to 2.1 m) above mean high water (Beaulieu and Hughes, 1975).

Tsunamis are not cyclical, and indeed cannot be predicted with any accuracy along the coast. The Alaska earthquake of 1964 may represent the worst case situation; wave heights above mean high water in excess of ten feet (3 m) occurred along the study area coast, reaching a high of 19.7 feet (6 m) above mean high water at Crescent City, California (see Section 2.7.2.2). Beaulieu and Hughes (1975) predict tsunami "run-ups" of 25 feet above mean lower low water in some beach areas of Oregon. The significance of these high levels of inundation is that areas in back of the winter beach berm will also be inundated, and driftwood may be deposited in drift lines well inland of the foredune (typically in the deflation plain); at such times these areas may also act as "unprotected beach." This is significant to anyone wishing to build structures in this shore process corridor. Organisms characteristic of the Unprotected Beach and dependent upon periodic inundation with salt water do not occur in the backshore, however, so this is not ordinarily considered as part of the Unprotected Beach habitat.

#2. Transport. Sediment transport is snown in the model (Figure 3-48) as a two-way valve between the Unprotected Beach and the offshore oceanic and adjacent beach sediments. This is discussed in this volume (Section 2.7.4) and in far greater detail in Section 2.7.4 of Volume 1. Sediment transport in the study region is to the north in the winter and to the south in the summer. Net transports will vary from place to place, being generally to the north for much of the area. Onshore-offshore transport is seasonal, with net-offshore transport occurring during winter months of severe wave attack, and net-onshore transport occurring during summer months of milder waves.

Upland materials provide sediment to the beaches by runoff, either directly or via the estuaries, or by wave erosion of headlands. Beach sediment may also be imported into the estuaries. This source of (beach) supply may be less than, equal to, or greater than the rate of removal by sediment transport processes. Erosion, stable beaches, or accretion will result depending upon the balance of these processes. Where accretion is great, significant quantities of sand will be available for sand dune formation, inland of the beach itself. Sand dunes form by wind transport of beach material to the upland area. The processes of transport between the upland and the Unprotected Beach are more active in winter than in summer. See Section 2.7.4 for more details.

The transport of upland materials includes freshwater as well as sediment. Dilution of the surf zone with fresh water occurs from local runoff and groundwater seepage although regionally the larger runoff through the estuaries is more significant.

In addition to sediments, waves and currents transport seaweed and seagrass cast to the beach where it is stranded as wrack at the high tide mark. The amount of wrack imported to the beach has been observed to be 1.86-2.49 kg (wet weight)/10m (1.25-1.67 lb [wet weight]/32.8 ft) of beach front (ACOE, 1976l). This is a significant import of organic material which is the main source of energy and materials for the upper beach community.

#3. Suspension-deposition. Wave action is continuously suspending and depositing sediment, and actively transporting it in the process. The active water in the surf zone contains large amounts of suspended solids: sediment, organisms, and detritus. Suspended materials are periodically deposited on the intertidal beach; the less-dense detritus and diatoms are sorted out to lie on top of the sandy sediment above the swash of the waves. Driftwood and other wrack floating in the surf zone are usually deposited high on the beach. Driftwood accumulations generally indicate storm tide water levels, while beach wrack (seaweed, etc.) usually lies along the level reached by the most recent high tide. Here, although this floating material is continually being removed and replenished at any particular location along the beach, it forms a regular part of this habitat upon which an important segment of the community depends. Occasionally, large pieces of driftwood, such as the roots and lower trunk of a large tree, become stranded lower down on the beach where they focus the energy of the surf and cause a sudden change in the depth of the sand about them. Driftwood in the surf zone is a hazard to bathers; warning signs are usually posted along the coast.

#4. Percolation, Adsorption, and Filtration. Surf zone water also contains dissolved materials: salts, nutrients, and organic matter. Under the pressures of waves and periodic innundation, this water is forced into and drained out of the beach sand. Cox (1976) describes the formation of micro-detritus, fine particles produced from dissolved organic matter (measured as DOC, dissolved organic carbon) by air bubbling through sea water, and its adsorption onto the surface of beach sand grains. Seawater usually contains at least ten times as much DOC as the carbon in particulate matter (detritus) captured by plankton nets. The foaming and filtering action of the surf on the sand is probably a major input of food energy into the ecosystem, essential for maintaining the meiofaunal component of the community (see Note #8). Similarly, uptake of inorganic nutrients needed for growth by diatoms, bacteria, and other organisms adhering to the sand grains is facilitated by adsorption of nutrients onto the vast interstitial surface area of the beach.

Rainwater at low tide also affects the beach as it percolates down and alters the salinity of the interstitial water.

The Unprotected Beach lacks a sharp oxygen gradient and sulfide layer in its sediments, such as is common to Protected Beaches. A higher amount of energy is available to overturn the sediment and re-charge the interstitial water by filtration and percolation under considerable hydraulic pressure. Figure 3-49 presents a comparison of water penetration in low and high energy beaches.

#5. Spray and Aeration. Water, salts, and other materials are propelled into the air by the intense air and water interactions that occur within the surf zone. These include the breaking of waves, the bursting of air bubbles at the surface that were entrapped by the waves, and the action of the wind against the wave faces, the surface, and the breaking wave fronts. This is the mechanism that transports salts to the backshore and further inland. Some organisms located inland of the Beach Surf Zone, (e.g. components of the Sitka Spruce Zone), are dependent on this salt supply or are tolerant of it while requiring the high moisture levels of the coastal fog.

Aeration is the entrapment and suspension of small bubbles of air in the surf zone water column which may result in supersaturation of ocean water with dissolved gases.

#6. Community Composition. The valve labeled uptake and exchanges in this model (Figure 3-48) represents all the processes of nutrient uptake, respiration, and photosynthetic utilization of CO_2. These are described in greater detail in the Euphotic Pelagic Oceanic ecosystem model (Section 3.2.1.5, which follows).

There are two relatively distinct animal groups occupying this habitat, somewhat in the same way that a canopy community and a floor community coexist in a forest habitat, the macrofaunal and meiofaunal communities.

The number of macrofaunal species that are common on these beaches is relatively small. The dominant forms are filter feeders, such as the razor clam and ghost shrimp, in the lower intertidal and subtidal beach, and detritivores, such as the beach hoppers, on the upper beach. Active predators on these dominant forms are the surf perch, flounders, and skates inhabiting the surf zone, and the shorebirds that regularly feed on the exposed beach and among its wrack.

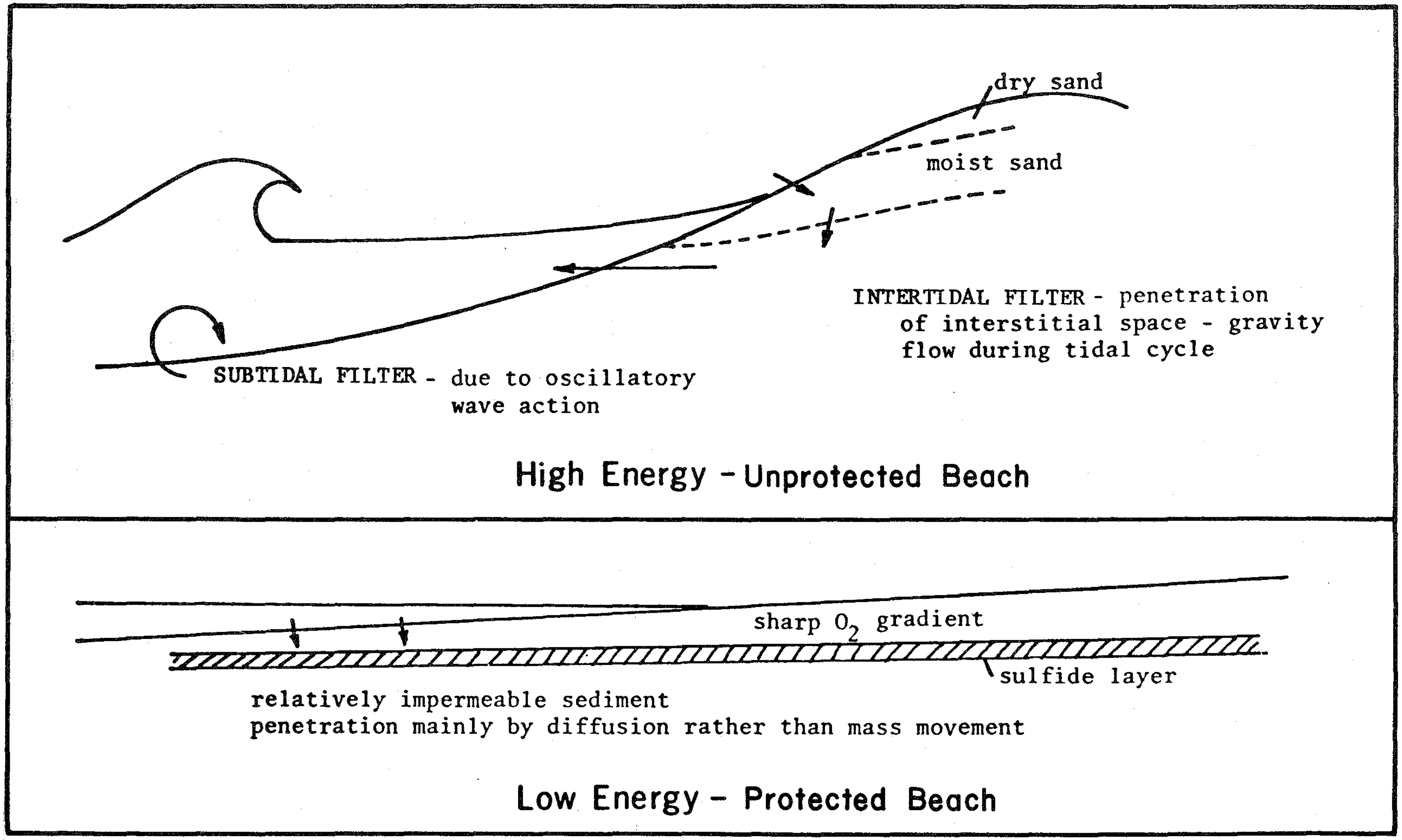


FIGURE 3-49. COMPARISON OF WATER PENETRATION IN LOW- AND HIGH-ENERGY BEACHES. (From Cox, 1976.)

All local production is by microflora, either phytoplankton or epipsammic algae. The surf zone producers are dominated by diatoms, notably Chaetoceros armatum, which seems to be specially adapted to this habitat and is closely associated with dense populations of the razor clam, Siliqua patula (Lewin, 1978; Lewin and Norris, 1970). This surf zone diatom occurs all along the coast, particularly during the winter months, wherever there is a long stretch of sandy beach, but it is most abundant and persistent north of the Columbia River and Grays Harbor on the Washington coast. This is also the center of razor clam abundance; the commercial and sport fisheries for these clams plays an important role in the local economy of this region. Lewin (1977) observed razor clam stomach contents and coincidence of abundance, and suggests C. armatum productivity is responsible for high razor clam production on the south-central Washington coast. It is not known for certain, however, why C. armatum populations are greatest in this part of the region. Lewin (1978) suggests the following factors as important to the Chaetoceros armatum/ Siliqua patula community in the area: 1) the constant silicate supply from the Columbia River, which is essential for good diatom growth, and 2) the gentle slope of the beaches and continental shelf in this part of the region (see Figure 2-3), which results in wide, gradual beaches with well-aerated surf water and fine-grained sand.

Dense "blooms" of Chaetoceros armatum appear frequently throughout the year, and high surf conditions combined with large tidal range often strand dense patches of diatoms on the beach exposed at low tide. The term "bloom", when used with diatoms, means a sudden increase in the standing crop because of increased productivity stimulated by the removal of a limiting factor, usually light or nutrients. In this case it may be a misnomer, since C. armatum is adapted to low light levels and has a ready supply of nutrients. The large coastal rivers probably provide a continual supply of the silicate needed for diatom production, and Lewin and Rao (1975) have observed the excretion of significant quantities of ammonia by razor clams, enough to account for much of the nitrogen requirement of the diatoms. The semi-closed circulation of the surf zone would tend to retain accumulations of both nutrients and producers in this habitat.

The density and productivity of surf diatoms in situ have not been reported for the region's coast, but in an almost identical habitat-community situation in New Zealand, Cassie and Cassie (1960) found concentrations of 400 cells/ml in which 80% of the cells counted were C. armatum. In New Zealand waters, they also observed net primary productivity of 400 mg C/m^3/hr.

Razor clam stocks and fisheries have been the subject of investigations by the Washington State Department of Fisheries since 1939, measured as catch statistics. While there is some evidence to indicate that the harvest of this population has declined since the first unrecorded years of commercial usage (Schaefer, 1939), there does not seem to be a significant, overall decline within the last 24 years of regular observations (Tegelberg et al., 1971). Annual catch varies about three-fold in long cycles of about ten years, from a maximum of 18 million to a minimum of 6 million clams. (See Table 3-73 in Section 3.4.2.3 for catch data 1946-1970.) The number of clams per square yard or the abundance index, varied from 0.8 to 5.8 at Copalis Beach (one of the more productive areas) during the period 1952-1970. Shell length is the other major parameter observed. Average length (and the length frequency distribution) varies from beach to beach and falls within the range of 40-148 mm. The length-to-weight ration is not reported, but data relating length to age and yearclass are given by Weymouth et al. (1925).

Ghost shrimp, Callianassa californiensis, is another filter feeder which, like the razor clam, is a consumer of surf diatoms. Burrowing ghost shrimp are usually found in relatively low numbers and, in most areas, inhabit the beach between the +4 and +7.5 foot tide levels. In some areas, however, such as that between the Copalis River and Copalis Beach, ghost shrimp are very abundant and their distribution overlaps that of the razor clam which lies seaward of the +4 foot tide level. There is no demonstrated competitive interaction between the clam and the crustacean, but the holes of the shrimp burrows look enough like the "show" of the razor clams to interfere with the fishery and reduce the rate of harvest. Washington State Department of Fisheries has used a pesticide, "Sevin", for several years to control shrimp populations in the oyster-growing areas of Willapa Bay and Grays Harbor, and were able to achieve 99.7% mortality of ghost shrimp in heavily "infested" areas of razor clam habitat (Tegelberg et al., 1971).

The meiofaunal community includes a larger number of species. The biomass of the psammic meiofauna and the extent to which it nourishes the macrofaunal community have not been evaluated quantitatively. Cox (1976) notes that meiofaunal biomass is significantly lower in unprotected beaches than that in most littoral and sublittoral bottoms, but that diversity of taxonomic groups is highest among the coarse sand grains of the outer coast and lowest in the very fine sediments of mudflats. He also described the meiofaunal food chain as based on DOC in the water column and separate from that of the macrofauna. Cox (1976) describes the variation in species diversity and relative abundance (as well as sampling error) for the major faunal groups of meiofauna on exposed sandy beaches.

Figure 3-50 includes "outside predators (birds, fish)" as part of the macrofaunal food web. Some predators, notably sandpipers and surf perch, are integral components of the surf zone community and as such are part of the macrofaunal community in the model (Figure 3-48). As the tide rises and falls, parts of the beach are periodically exposed to aquatic or terrestrial predators. This border zone is linked via the food web to both the land and the sea. Some organisms from both zones make use of the upper portions of the unprotected beach habitat for reproduction. Smelt, residents of the Euphotic Pelagic Oceanic ecosystem, come ashore at high tide during the summer to spawn in the sand. Night smelt are known to visit the surf zone to spawn in the sand at the highest tide and usually at night in the spring. The so-called surf smelt spawn in more protected beaches, avoiding excessing surf action (Hart, 1973). At such times they are easy prey to thousands of marine birds, as well as people. The snowy plover nests on the sand, just above the high tide line. Nesting and spawning activities are seasonal, and may also include migration.

#7. Migration and Visitation. Upland mammals such as raccoons or black-tailed deer visit this habitat at low tide.

#8. Fisheries and Recreational Activities. Man is a unique upland visitor to this habitat, seasonal in nature and degree of impact. Surf perch, smelt, and razor clams are harvested for human consumption as well as worms and ghost shrimp for bait.

The unprotected beaches of the Pacific Northwest region are scenic and attract thousands of people annually for non-consumptive recreation. This visitation by people is somewhat seasonal, the warmer months being preferred. Beachcombing, hiking, and scientific studies are, for the most part, non-consumptive. Some driftwood, shells, stones, sand-dollars, and Japanese fish-net floats are removed from the beach by beachcombers. Recreationists are permitted to drive automobiles on some beaches, and the debate continues as to whether or not there is any damaging impacts to the ecosystem from this activity. Clam diggers fear that cars driving close to the water line at low tide will damage valuable razor clam beds. Regulations exist regarding the driving of cars on the beach, seeking to protect both clams and recreational interests.

A commercial clam fishery exists, along with popular recreational clamming. The razor clam beaches are monitored by state fisheries authorities and regulations are imposed. The razor clams are only taken in the intertidal area, protecting the large populations in the subtidal which reseed the intertidal.

Recently it has been discovered that the extensive subtidal clam beds lying beyond the breaker zone are not populated by the razor clam, *Siliqua patula*, but rather by *S. sloatii* which, although very similar in appearance, does not inhabit the intertidal areas. This discovery has two implications now being investigated by the Washington State Department of Fisheries: (1) that reseeding populations for the intertidal areas are not as large as previously believed and must be more carefully protected, and (2) that the deeper-water species may be harvested commercially by dredging techniques adapted to the area (Simons, 1977, pers. comm.; Tegelberg, 1970).

Surf perch are harvested by sport fishermen. Clams are taken on a seasonal and low tide cycle, whereas surf perch are taken during any season and at any stage of the tide. Surf smelt are also taken along the unprotected beach seasonally by sports fishermen when they are "running" to spawn in the beach sand.

#9. Spoil Dumping and Mining. Most dredge spoils are disposed of either on land, within the estuaries, or on the continental shelf beyond the surf zone. Dredge spoil disposal directly onto the unprotected beach is practiced in some places (e.g. on the beach adjacent to Humboldt Bay), but is not common in the Pacific Northwest. Dredge spoil disposal on the beach may change the nature of the substrate, and a shift in the benthic community may accompany such disposal. The wave action along the beach may eventually re-sort the sediment until

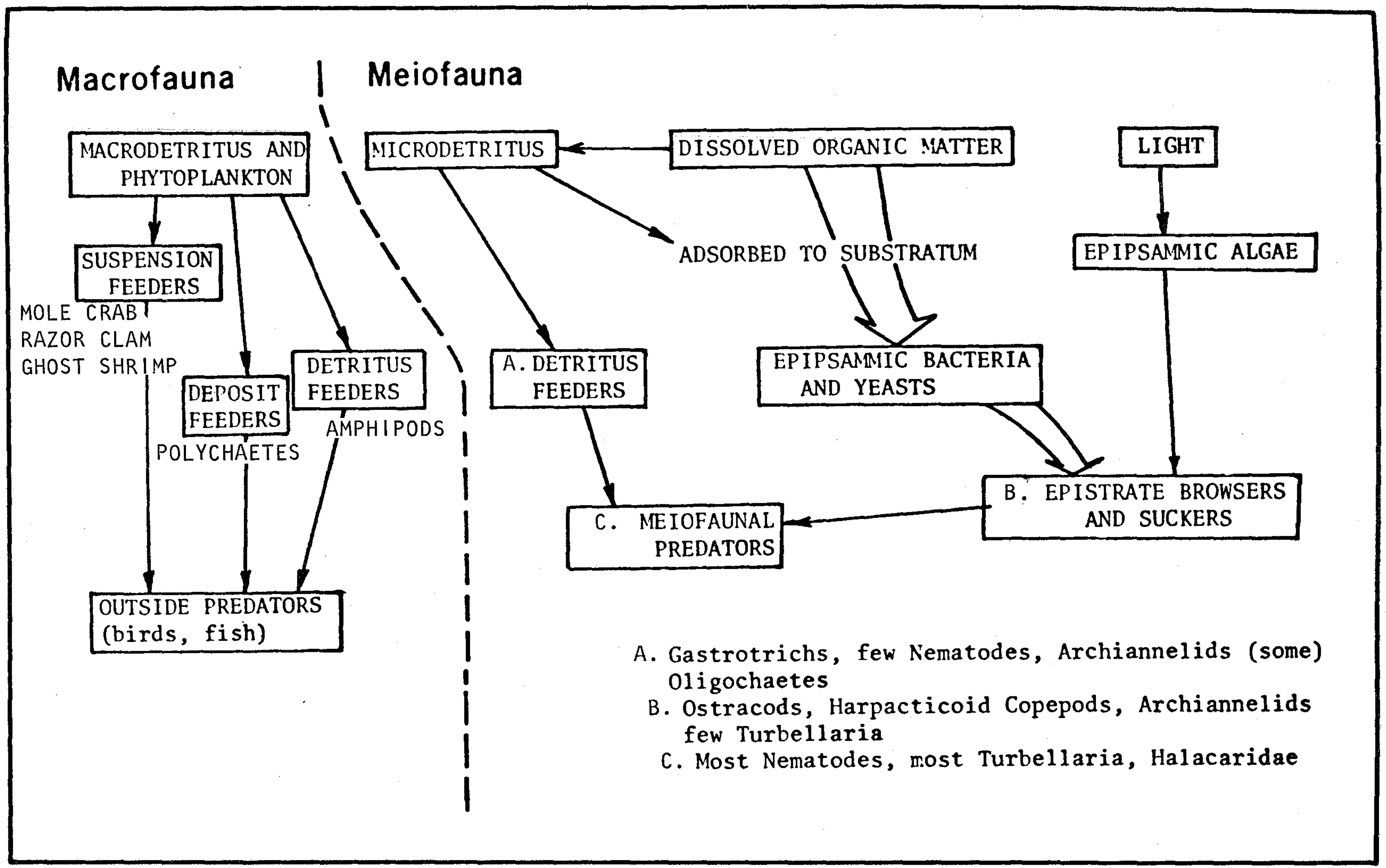


FIGURE 3-50. TROPHIDYNAMIC RELATIONSHIPS IN SANDY BEACH MACROFAUNA AND MEIOFAUNA. N.B. Although Cox considers birds and fish as "outside predators", many of them are in fact members of the beach macrofaunal community and are treated as such in the Unprotected Beach habitat. (After Cox, 1976.)

near-normal conditions are restored. Another concern about dredge spoil disposal would be the increase in concentrations of organic particles or toxic components of the sediment.

Mining of beach sand is not a major activity within the region. Rea and Komar (1975) report that mining of beach sand south of Siletz Spit may have contributed to erosion which destroyed one house in the high tide storm wave attack of 1973. Any sudden removal of beach sand upsets the natural recycling processes, resulting in wave erosion of coastal land (ACOE, 1976I). The erosion at Siletz Spit necessitated emplacement of protective rip-rap to protect houses that were built on the Spit.

#10. Construction. Construction affecting the Unprotected Beach ecosystem may take place directly in the habitat, or offshore. Such construction may take place to protect structures (such as homes) built on the backshore. Erosion areas have been identified as both critical and non-critical (see Figure 2-4; this volume), partly by the nature of the human usage in the area. A non-critical erosion area may become critical if a structure is improperly located there and human lives or property are endangered.

Structures common to the Unprotected Beach ecosystem of the Pacific Northwest include jetties, breakwaters, and rip-rap bulkheading. Piers are not common due to the extreme waves. Extensive use of groins to "stabilize" the beaches (i.e., trap sediment), such as is common on the East Coast and portions of the Southern California coast, does not occur in the Pacific Northwest region. This is largely because most of the sources of sediment have not been altered by man in this region, and the region lacks submarine canyons close to shore, which remove beach sediment from the longshore transport in other regions.

Jetties and breakwaters are used to protect harbor entrances, shielding them both from waves and from sediment transport that fills in dredged channels. These jetties affect longshore transport, and cause beach alteration. Channel entrances to estuaries that are not dredged and protected will naturally shift, with sediment transport processes causing barrier beaches on one side to grow and barrier beaches or uplands on the other side to retreat. Eventually, the barrier beach would be breached by storm events, with swash channels across the beach into the estuary forming and eventually establishing a main channel. Isolated portions of the original barrier beach may become short-lived islands, with the estuary retaining two entrances.

Seaman (1977) described this cycle for the Columbia River estuary prior to channel improvements which began in 1885. Andrews (1965) describes similar processes for Willapa Bay. Ballard (1964) reports depositional and erosional changes in the Beach Surf Zone that occurred adjacent to and off the mouth of the Columbia River from 1877 to 1958 as a result of dredging and jetty construction. Deposition occurs at the mouth of the Columbia, seaward of the jetties, forming the Columbia River Bar, a navigational hazard that has claimed many ships. Erosion occurred in the subtidal surf zone off of Clatsop Spit, south of the south jetty from 1877 to 1926, but apparently stabilized around that time, as no significant erosion was evident between 1926 and 1958. A beach formed between North Head and the north jetty between 1877 and 1958. Komar et al (1976A) discuss shoreline changes due to jetties on the Oregon Coast.

Siletz Spit, protecting the Siletz estuary in Oregon (W.U. #5), has had houses built upon it which were threatened by erosion during the winters of 1971 and 1972 (Hamilton, 1973; Komar and Rea, 1976; Komar et al., 1976B). This erosion was analyzed and correctional recommendations prepared (rip-rap bulkheading) (Komar and Rea, 1976; Komar et al., 1976B). The Corps of Engineers noted that the cost of stabilizing and maintaining the dune and spit artificially would far outweight the value of the private property in jeopardy. Rea and Komar (1975) concluded that the long-term effectiveness of attempts to rip-rap against erosion is uncertain.

Offshore structures are not significant today, but may become so in the future. Offshore oil development, or siting of offshore oil terminals may require laying of pipelines through the Unprotected Beach ecosystem, with immediate disruption during installation a certainty, and long-term alteration a possibility depending on the design. At present, the oil industry is not particularly interested in the area, and the technology is not yet available to build an offshore oil terminal in the region at a reasonable cost due to the extreme winter wave conditions.

#11. Wastes and Spills. This region has not been significantly affected by this form of pollution, although the threat is very real. The dependency of the region upon tanker delivery of fuels increased dramatically when Canada stopped supplying Washington with oil by pipeline. Oil from Alaska will be transported by tankers to some port on the West Coast of the United States for transshipment to the inland states in the near future. Possible sites for such a transshipment include Port Angeles, Washington (in the Strait of Juan de Fuca) and Long Beach, California. Spilled oil from tankers can enter the Unprotected Beach ecosystem via surface wind drift of the oceanic waters. Such surface flow will be mostly onshore during the winter months when wave conditions are likely to preclude any form of containment offshore.

Once oil or other pollutants reach the surf zone, they will become well mixed into the water column and sediments. Pollutants entrained in the sediments will move with the sediment as discussed in Section 2.7.4 of Volume 2 (Regional Synopsis). The mixing processes within the surf zone will enable some pollutants to pass into the oceanic benthic and disphotic ecosystems by physical processes. Biological uptakes and transfers may move pollutants as well, and the manner in which a pollutant may move, dissipate, or concentrate through a food web and through an ecosystem is not well understood.

As stated before, this region is unique in the lack of significant oceanic pollution. This discussion has only briefly touched on the potential problems of pollution, as befits a conceptual model approach. The consequences of major oil pollution are most visible in the Unprotected Beach ecosystems, hence the coverage here. Research is being conducted within the region by Jerry Galt of the Pacific Marine Environmental Laboratory (N.O.A.A.) Seattle, Washington on mathematically modeling oil spills. A review and analysis of models for predicting oil spill movement has been conducted by the Oceanographic Institute of Washington, Seattle.

Studies on the fate and effects of petroleum hydrocarbons in marine coastal ecosystems are being carried out by the ecosystems department of Battelle-Northwest, Marine Research Laboratory, in Sequim, Washington, and by the National Marine Fisheries Service (NOAA) in Seattle. Beak Consultants (1975) have recently completed an impact assessment of potential oil spills which is applicable to this community. They have also done an extensive literature review on the subject.

3.2.1.5 Euphotic Pelagic Oceanic Ecosystem Model Notes. The Euphotic Pelagic Zone (Figure 3-51) is that depth range in the ocean which is abundantly supplied with light sufficient for the photosynthetic processes of plants (Sverdrup et al., 1942). In the deep ocean, it is usually 80 meters (250 ft) deep, or more, depending on angle of incidence of sunlight (varying with season and time of day) and cloudiness (Gross, 1972). However, turbidity will also limit the depth of the Euphotic Pelagic Zone, and G. C. Anderson (1972), defining it as the level of one percent of surface illumination, found the depth of the euphotic zone to be less than fifty meters over the shelf off mid-Oregon throughout 1961-1962. All net production of organic matter in the ocean occurs in this habitat. The depth of this layer varies seasonally and locally, and for the Pacific Northwest Region, ranges between twenty to eighty meters (60 to 260 ft) deep (Small et al., 1972).

Solar energy powers photosynthesis in the euphotic habitat which feeds not only the local community but supports all life below it in the darker waters of the Disphotic Pelagic Zone and the Non-vegetated Benthic habitats. Solar energy also heats surface water, which in turn moderates the climate of the region. Turbidity is strongly tied to river runoff, which varies seasonally and geographically throughout the region. The Columbia River plume is detectable by its increased turbidity as well as its reduced salinity.

The upwelling areas along the Pacific Northwest coast are among the most productive oceanic areas in the world. Phytoplankton net primary production is as much as the estuarine eelgrass and, although the standing biomass is low, the rapid turnover rates indicate a significant amount of energy transfer to consumers.

The oceanic food web is predominantly a grazing one with a consumer to producer biomass ratio approaching 1:1. The oceanic web is complex, consisting of many overlapping and interdependent food chains.

The Euphotic Pelagic habitat is intricately related to the Disphotic Pelagic and the Benthic habitats of the ocean. One characteristic biological phenomenon which connects these different zones is the diel vertical migration of consumers from the lower depths to feed on the phytoplankton and its grazers in the Euphotic Zone.

The physical aspects of this habitat are treated in considerable detail in Section 2.7 of the Model (Volume 1) and the Regional Synopsis (Volume 2). Discussion of the important factors in this ecosystem model begin with summaries of the physical factors: (#1) dissolved gases, (#2) water input and output, (#3) sediment transport, (#4) dissolved nutrients, (#5) upwelling, and (#6) the compensation depth. Notes continue with treatment of the biological factors: (#7) photosynthesis/primary productivity and nutrient uptake, (#8) community composition, (#9) migration and visitation, (#10) secondary productivity, and (#11) interaction with Disphotic and Benthic Zones. Finally, human influences of (#12) harvest, (#13) waste discharge, (#14) dredge spoil disposal, and (#15) indirect effects are discussed briefly as they affect the Euphotic Pelagic ecosystem.

#1. Dissolved Gases. Unlike the terrestrial habitats, respiration and photosynthesis by most of the oceanic biological community involves dissolved gases. Marine mammals and sea birds are exceptions, frequently surfacing or remaining at or over the surface to breathe. Dissolved gas concentrations at the surface reach equilibrium with the atmosphere. Physical processes such as wind and wave mixing increase the air-water interaction. Water and air temperature and salinity alter equilibrium concentration levels.

Dissolved oxygen is of primary importance to most marine organisms. Upwelling water is lower in oxygen than water that is displaced, but high productivity can supersaturate the near surface waters with oxygen, a product of photosynthesis. Dissolved oxygen in the ocean is discussed in more detail in Section 2.7.5.1 of Volumes 1 and 2. Figures 2-43, 2-44, and 2-45 of Volume 2 present graphic information on distribution and variability of DO in the ocean over the Pacific Northwest Shelf.

#2. Water (Substrate) Input and Output. The water inputs to the study area include advection from adjacent oceanic areas (regional currents), land runoff, and precipitation. Water outputs from the region include advection and evaporation. In this region, runoff and precipitation greatly exceed evaporation, as a result, the oceanic surface waters near the coast and over the shelf are measurably diluted. (In drier regions (e.g. Southern California), where evaporation exceeds runoff and precipitation, the surface oceanic waters are more saline.) Winter winds, from the southwest, hold the river runoff close to shore; the lowest surface salinities in the nearshore region occur then. The Columbia has its peak flow in the spring and early summer, with regional effects described in Volume 2, Sections 2.4 and 2.7.1. Runoff for the entire region is discussed in Section 2.5.3 of Volume 2.

ECOSYSTEM MODEL– EUPHOTIC PELAGIC

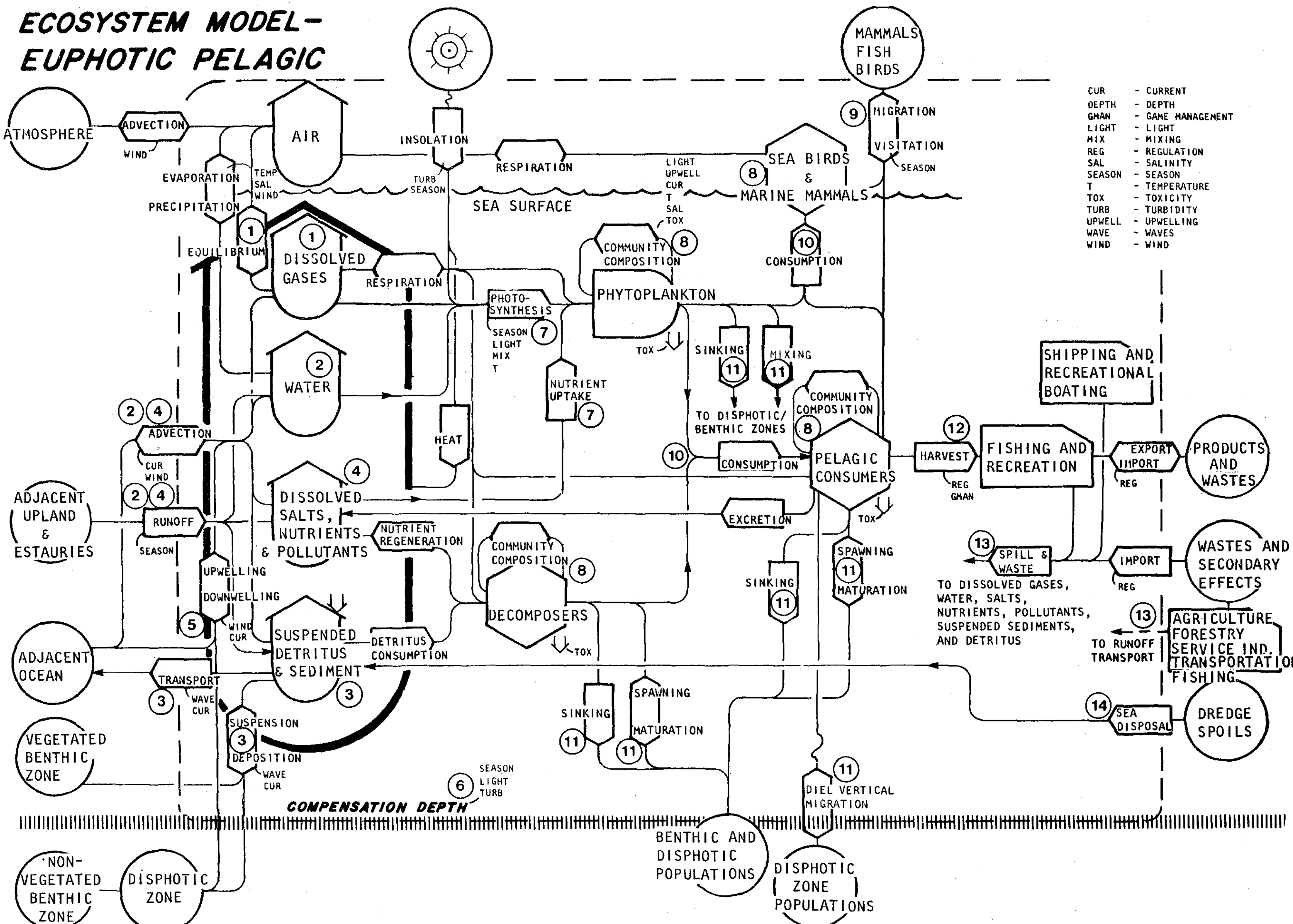


FIGURE 3-51. EUPHOTIC PELAGIC OCEANIC ECOSYSTEM MODEL.

The regional oceanic currents are the southerly-flowing California Current, and the nearshore, seasonal (winter) Davidson Current, discussed in Section 2.7.2.4 of Volume 2.

Precipitation and evaporation data for the region are presented in Section 2.3.1 of Volume 2. Elliott et al. (1971) noted that rainfall over the shelf is considerably less than in the vicinity of the coast. It must be assumed that estimations of precipitation over the shelf based on precipitation along the coast are probably in error. More data are needed to fully understand the precipitation inputs of freshwater to the Shelf Euphotic Zone.

#3. Sediment Transport, Suspension, and Deposition. Sediment transport in the ocean is modeled in Section 2.7.4 of Volume 1 (see Figure 2-34 and discussion), and sediment transport data for the region are presented in Section 2.7.4 of Volume 2. Sediment is transported in the ocean in suspended and bed loads. Pelagic models are concerned primarily with the suspended loads. Most sediment input comes from runoff from the adjacent uplands and estuaries. Much of this material is very fine sediment, and moves in suspension as turbid layers near the surface, at mid-depth, and near the bottom (see Figure 2-42 in Volume 2). Very little of this material is permanently deposited on the shelf. In the summer months, deposition on the shelf occurs, but winter waves stir the bottom and resuspend the fine sediment, which the regional circulation patterns then transport seaward. The bottom current over the shelf is predominantly to the north and net sediment transport is also to the north. The oscillatory currents at the bottom, associated with the passage of large surface waves, are an essential component of the sediment transport processes of the shelf. The regional currents, which actually transport the suspended sediments, are not strong enough by themselves to scour the bottom sediments.

#4. Dissolved Salts and Nutrients and Their Inputs and Outputs. Discussions of salts and nutrients appear in Sections 2.7.1 and 2.7.5.2 in Volume 2. In the absence of nutrient input, the available nutrients of the pelagic habitat would be consumed by phytoplankton until one of the nutrients was reduced below required levels and became severely limiting to producer growth (see Note #6 below).

Figures 2-45 and 2-46 in Volume 2 show annual variability of nutrients within the study area. The methods of presentation of the two figures differ, but in each, the effects of winter mixing and summer productivity are apparent. While nutrient values at the surface drop a little in the spring, Figure 2-45 shows that the nutrient values below the surface increase considerably because of input from upwelling of deeper water (see Note #5 below).

In Figure 2-46, nitrate concentration in the surface 10 meters (30 ft) is reduced to zero briefly during the spring. This deficit is quickly eliminated with the onset of upwelling, as is evident from the sudden increase in nitrate and phosphate concentrations throughout the water column. Dissolved oxygen is also reduced throughout the water column during upwelling, although in the surface waters photosynthetic release of oxygen supersaturates the water at times of high productivity.

The Columbia River plume enhances density stratification and water column stability, increasing productivity in the spring, but eventually resulting in nutrient depletion due to phytoplankton production. In the plume, the rapid recycling of nutrients through zooplankton excretion (released as ammonia) may provide up to 90 percent of the nitrogen needs of phytoplankton during the summer (Jawed, 1973A). Ammonia is not considered in the nitrate concentration values in Figures 2-45 and 2-46.

#5. Upwelling. In the Pacific Northwest, coastal upwelling occurs in the summer and fall, providing a supply of nutrients to surface waters from below the mixed layer. The resupply of nutrients makes this area highly productive. Coastal upwelling is generally seasonal, but occurs as a series of events correlated with northerly winds (i.e., from the north). Nearshore surface water is driven offshore, and deeper water rises to replace it. Prolonged periods of southerly winds in the summertime will halt the upwelling, with effects on the nutrient supply and productivity. Upwelling events also occur in the winter, but are less frequent and less significant biologically. Upwelling of this type is strongest in the southern half of the study area (Cape Mendocino to Mid Oregon). In Northern Oregon and Southern Washington, the rapid outflow of the Columbia

River Plume may cause river-induced upwelling as it entrains near-surface marine waters, but it also forms a barrier, masking some of the physical effects of the upwelling. This river-induced upwelling not only brings nutrients up into the euphotic zone, but carries them out to sea with the plume ("outwelling," E.P. Odum, 1971). Off Washington, upwelling is less pronounced than farther south, but is still significant.

Upwelling strongly influences the climate of the Pacific Northwest. Upwelled water is cooler than the offshore water. As a result, the summer temperature is cool along the coast and fog occurs frequently.

In most other upwelling areas in the world, evaporation exceeds runoff and precipitation and the surface waters are higher in salinity than the upwelled water. Over the Pacific Northwest Shelf, however, the upwelled water is higher in salinity than the surface water. It is also lower in dissolved oxygen and denser, a fact which is important in the replacement of bottom water in the inland salt water bodies of Washington and British Columbia (Strait of Juan de Fuca, Puget Sound, and Strait of Georgia). Some of the coastal estuaries experience decreases in oxygen concentration during summer months as a result of a tidal inflow of lower-oxygen upwelled water from the ocean. Waste discharges with their concomitant high biological oxygen demands must be controlled to accommodate this natural seasonal decrease.

Just as northerly winds generate an offshore current at the surface, resulting in upwelling of deeper water, southerly winds, more common in the winter, generate an onshore surface current with resultant downwelling of nearshore surface water. The downwelling phenomenon is not conducive to high productivity, but occurs normally during the relatively unproductive winter season, when sunlight levels are low and mixing great.

Upwelling is further discussed in Section 2.7.2.6 of Volumes 1 and 2.

#6. Compensation Depth. Compensation depth (see Figure 3-51) is defined as that depth at which oxygen production by phytoplankton just equals oxygen consumption by plant respiration during a 24-hour period (Gross, 1972) and may vary from species to species of phytoplankton. The illumination at this depth is the minimum intensity at which the plant could survive, but is too low for any crop increase (Jenkin, 1937). Compensation depth is used in this model as the bottom of the Euphotic Zone; all the water above this depth receives ample sunlight, and is a net producing (autotrophic) area. The compensation depth is not fixed, but rather varies with season, latitude, and turbidity in the overlying water column. It is not a precise depth, but rather an approximate range.

#7. Photosynthesis, Primary Productivity, Nutrient Uptake, and Exchanges. Primary productivity is controlled by nutrient availability, light availability, and mixing. Light and mixing vary seasonally. Phytoplankton are the dominant plantlife in the pelagic habitat, and are the basis for all food webs in oceanic habitats. Phytoplankton are dependent on turbulent mixing processes from waves, winds, and currents to keep them suspended in the Euphotic Zone. While phytoplankton are in the Euphotic Zone, net productivity is positive. Phytoplankton at the bottom of the Euphotic Zone (the compensation depth) experience no net productivity, and phytoplankton driven below the compensation depth either by turbulence or sinking experience a negative net productivity. When mixing processes are not active below the compensation depth, phytoplankton that sink below it are not returned to the Euphotic Zone and no longer contribute primary productivity. When mixing processes are active below the compensation depth, sinking phytoplankton can be returned to the Euphotic Zone again and again, experiencing gains and losses in productivity.

The depth above which the net effective plant production in the water column occurs is called the critical depth (Gross, 1972). The critical depth will be greater (deeper) than the compensation depth, as it indicates a net productivity of zero averaged over the entire water column above it, whereas compensation depth indicates a net productivity of zero at a particular depth. Both the critical depth and the compensation depth are conceptual in nature. Phytoplankton do not remain stationary at the compensation depth, but are actively mixed over a range of depths, eventually sinking out of the mixed zone. The critical depth and the compensation depth both vary seasonally, being shallowest in the winter low-light months, and deepest in the summer months when light intensity is higher.

A more tangible, more easily measured factor is the mixed depth. The mixed depth is a range in which there is little or no difference in salinity or temperature (essentially isothermal and isohaline). The mixed depth extends down to the top of the seasonal pycnocline (depth of maximum density change) and may be approximated by the depth of the seasonal thermocline (depth of maximum temperature change). The relationship between mixed depth and critical depth is important in understanding phytoplankton productivity. The seasonal response of the mixed depth is opposite that of the critical depth, i.e. the mixed depth is greatest in the winter and least in the summer and early fall. In the spring, as the critical depth increases and the mixed depth decreases, there is a time when the two become equal. At that time, the water column above this depth is capable of maintaining the standing stock of phytoplankton (disregarding grazing pressures). As the mixed depth becomes less than the critical depth, phytoplankton reside longer in the Euphotic Zone and there is potential for an increase in standing stock. At this time there is an abundant supply of nutrients in the water column remaining from the earlier, deeper mixing. Conditions are right for a rapid growth of phytoplankton referred to as a "bloom." This normally occurs in the spring. The productivity is said to be high, and the standing stock of phytoplankton is also high. Eventually one of the necessary nutrients may become limiting and the rapid growth will slow or stop. In the Pacific Northwest, coastal upwelling during the summer months resupplies nutrients to the Euphotic Zone, and productivity remains high throughout the summer. Standing stock will decrease, however, after the initial bloom, as the zooplankton population increases and grazing takes its toll.

The Columbia River plume during the summer effectively reduces the mixing depth, due to the density difference associated with the reduced salinity in the plume. This permits the spring bloom to occur earlier in the plume than in the surrounding oceanic waters. The plume also effectively masks the effects of coastal upwelling at the surface, however, and nutrient depletion does occur. As noted earlier, phytoplankton within the plume may receive as much as 90 percent of their nitrogen nutrient requirements from the excretion of ammonia by zooplankton.

Anderson (1972) estimates annual primary production as exceeding 125 grams carbon per square meter in the Columbia River plume and the adjacent oceanic areas. Primary production in the upwelling areas is well over 300 g C/m^2 per year, according to Anderson. (For comparison purposes, 1 g C = 2+g dry matter for phytoplankton production, according to E.P. Odum, 1971.) This amount of primary production is about half that of the terrestrial seral forest and estuarine salt marshes of the region. As discussed in Notes #8 and #10, however, the oceanic food web includes a much larger energy flow to consumers than do the forest or salt marsh food webs.

Wroblewski (1977) used a model study to relate wind, upwelling, and daily primary productivity for the upwelling regions off the Oregon coast. He found that primary production increases soon after an increase in northerly wind stress (which generates the upwelling). Highest phytoplankton concentrations occurred, however, with slackening of winds after a major upwelling event. The high winds cause high mixing and phytoplankton experienced a shorter Euphotic Zone residence time. The phytoplankton remained longer in the Euphotic Zone after the winds died down.

Modelling studies at the University of Washington Department of Oceanography (1977) consider the physical and biological processes that govern the seasonal variation in distribution of nutrients, phytophankton, and zooplankton offshore. Studies are designed to assess the proportionate uptake of nitrate and regenerated nitrogen compounds in coastal waters, as past work in nutrient-poor waters has shown that ammonia is an important source of nitrogen. Although not focused directly on the waters over the shelf, this ongoing work should yield new perspectives as well as data useful in understanding the Euphotic Pelagic ecosystem modeled here.

#8. Community Composition. The Euphotic Pelagic community is composed of microscopic producers (mostly diatoms) and a complex food web of microscopic to huge macroscopic consumers (from zooplankton to whales). The high productivity and turnover rates of the phytoplankton support a large consumer biomass; the consumer to producer ratio may even exceed 1:1.

Phytoplankton are the only significant producers in this habitat, but the distribution of species is not well known. Some species, such as *Skeletonema costatum*, are ubiquitous, while others, such as *Dactyliosolen mediteraneus*, may be found commonly only in waters of certain characteristics. Hobson (1966), examining samples collected in winter (January), distinguished assemblages of species related to waters of distinct characteristics which he classified as the offshore (e.g., salinity of 32.5 $^{o}/oo$ or more), inshore, and transition communities. His work was extended by Koga (unpublished) into the spring and summer months, and their combined findings are summarized by G. C. Anderson (1972). This distinction of species into community associations related to hydro graphic regime and season is noted in the Annotated Species List. Each assemblage is dominated by two or three species of diatoms in the winter. Species diversity increases in the spring and is relatively lower in the transition community.

Living diatoms have some control over their buoyancy, and thus can maintain their position to a degree dependent on physical conditions in the Euphotic Zone. Many phytoplankton species are adapted to certain light intensities and, in a stable water column, populations are often found to be highly stratified. This stratification is not evident in a well-mixed euphotic layer. G. C. Anderson (1972) reports the chlorophyll maximum that develops each summer off the Pacific Northwest coast at a depth that is typically 60 meters (200 ft) or less but always just below the seasonal pycnocline and at about the 1 percent incident light level (the bottom of the Euphotic Zone). Associated with an oxygen maximum and a sudden increase of nitrate concentration with depth, this chlorophyll maximum indicates the concentration of diatom populations in a layer at the bottom of the Euphotic Pelagic habitat. Studies in other areas have shown that the community assemblage of diatom species in this "chlorophyll layer" is distinct from that in the upper mixed layer (G.C. Anderson, 1972).

The dominant fraction of phytoplankton in this habitat is the nanoplankton (50 to 60 microns), but almost nothing is known about the species composition of this group of organisms that are too small to be sampled quantitatively by plankton nets. Most of the nanoplankton is thought to be composed of microflagellates (G. C. Anderson, 1972).

Pelagic consumers comprise the zooplankton and the nekton (sea birds, although nekton while feeding in the water, are most often considered separately, residing primarily on (and above) the ocean surface.) Zooplankton occupy the first few levels of the trophic pyramid above the producers: herbivores and primary and secondary carnivores. The zooplankton include a wide variety of forms and taxa: jellyfish, polychaete worms, arrow worms, cladocerans, copepods, ostracods, mysids, amphipods, euphausids, shrimps, pteropods, larvaceans, salps, lantern fish, and the larval forms of these and many more species whose adults are found only in other habitats. Of these groups, the copepods, jellyfish, and euphausids (in order of abundance) comprise over one-half of the animal biomass in this habitat within the study area (Pearcy, 1972). By far the most abundant of the zooplankton in neritic waters are the copepods. This order of arthropods has the largest number of taxa present. Species diversity is usually high. Species include Oithona spp., Pseudocalanus minutus, Paracalanus parvus, Acartia longiremis, and Calanus finmarchicus which make up most of the copepod biomass (Peterson, 1972). Figure 3-52 shows the average biomass of pelagic animals collected in plankton nets and mid-water trawls at a station 72 kilometers (45 mi) off Newport, Oregon. This location is beyond the edge of the shelf by 30 kilometers (20 mi), and probably does not represent conditions over the shelf. Note the abundance of copepods.

One of the most remarkable features of the zooplankton community is the change in community composition between mid-day and midnight. This subject is of such significance as to warrant discussion in a separate note (#11) on diel vertical migration. Table 3-35 in that note provides some data on this daily community composition change.

Little is known about the differential toxicity of various agents for pelagic species, so the effect of toxic agents (e.g., heavy metals, petroleum hydrocarbons, chemical and nuclear wastes, pesticides) upon community composition can only be surmised. Studies of the distribution of radionuclides in the marine environment of the study area indicate that physical and biological transport processes and biological concentration factors must be considered for each toxic substance that may enter the regional ecosystem, even if introduced indirectly as far away as the sagebrush deserts of Eastern Washington (Alverson, 1972).

Marine bacteria are the principal agents of decomposition in the pelagic habitat. Other microorganisms may be important agents in decomposition, but the yeasts, molds, and protozoans of the ocean are poorly known.

Numerically, bacteria are more abundant than the suspended particles (diatoms, detritus, etc.) to which they are attached. The distribution of bacteria closely follows that of the phytoplankton. The concentration of bacteria is sea water is given in hundreds per gram as compared to the millions per gram of bottom mud (Zobell, 1946). As important as their decomposition (consumption) of non-living organic matter may be the uptake of dissolved organic matter by marine bacteria. As a complement to the phytoplankton diet of copepods and other herbivores, bacteria may play an immediately important role in recycling organic nutrients. Zooplankton grazing is thought to be the main restriction on pelagic populations of marine bacteria.

The nekton include two important biomass groups, the invertebrate squids and the vertebrate fish, as well as marine mammals and sea birds, which are of significance in the food web if not in total biomass. Although these groups are shown in Figure 3-52 (from Pearcy, 1972), those data are for the animals captured in midwater trawl nets and include only small squid and fish, principally lantern fish that make large vertical migrations from great depths to the surface but are small enough to be classified with the plankton.

Biomass estimates of or other data about the invertebrate squids in the oceanic shelf region are not available.

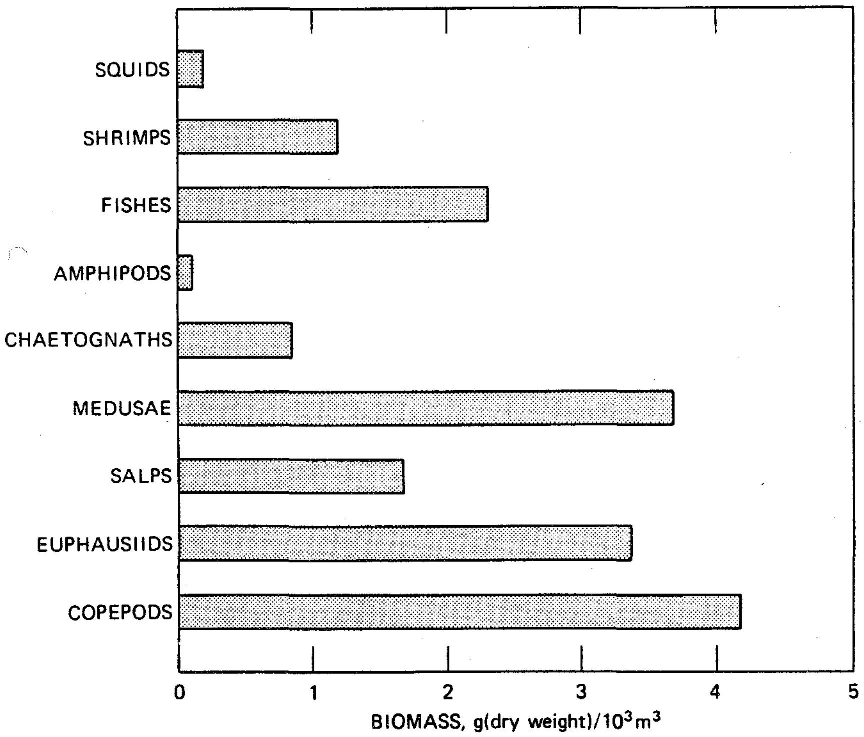


FIGURE 3-52. AVERAGE BIOMASS OF SOME GROUPS OF PELAGIC ANIMALS 72 KILOMETERS (45 MI) OFF CENTRAL OREGON. Animals were collected in 1 m nets (amphipods, chaetognaths, medusae, salps, euphausiids, copepods, and small shrimps) and in mid-water trawls (squids, shrimps, and fishes) at a station 30 kilometers (20 mi) beyond the edge of the shelf; collections closer to the coast would vary from the above data. (From Pearcy, 1972.)

The vertebrate fish nekton includes the following pelagic fish populations of significant biomass; northern anchovy, smelt, herring, sardine, hake, and the salmonid species. Seasonally important is the albacore (tuna). The biomass of most of these populations has not been estimated. The only data available are from fishery statistics. These are summarized in Section 3.4.1.2 of this volume (commercial fishery Species of Concern). Tables 3-47, 3-48, 3-49, and 3-50 provide catch data in pounds. Salmon catch is reported in millions of pounds, with chinook and coho making up over 95 percent by weight. Albacore (tuna) frequent the edge of the shelf and account for nearly half the finfish landings (by weight) in Washington and Oregon. Smelt (eulachon) are caught in quantities of about a million pounds annually. Sardines were caught in quantities of several million pounds per year through 1950, but have not been fished subsequently in any significant quantity. Although anchovies are not the object of a fishery in the study area, they are present in significant numbers, as observed by exploratory fishing surveys. Only small quantities of herring, counted as several thousands of pounds, are caught off the Oregon Washington coast, mainly as bait for the salmon fishery.

Also significant nekton in the food web if not in biomass are sharks which frequent the Euphotic Pelagic Shelf. A number of species are found in the region, most of which are the top carnivores in their food chains.

Sea birds and marine mammals, with the exception of the baleen whales, share positions as top carnivores in this habitat with the sharks. See the Species of Concern accounts for Sea Birds (page A-61) and Marine Mammals (page A-111) in Part 2 of this volume for discussion of these important populations. Little is known about the quantitative significance of these populations in the Euphotic Pelagic food web.

#9. Migration and Visitation. The Euphotic Pelagic habitat is visited seasonally by migratory populations of marine mammals (e.g. northern fur seal, California sea lion, grey whale) and marine birds (e.g. shearwaters, petrals, auklets, and murrelets). Some of these populations, such as the grey whale, are transitory and only interact with local communities in a superficial fashion. Others, such as the sea birds and pinnipeds (seals), become integral parts of local Euphotic Zone communities when present in sufficient numbers.

Generally sea birds are found in greater numbers in summer, although species from northerly waters, such as the alcids (auks and relatives), increase in numbers during winter (Sanger, 1972). Fur seal populations on the other hand, are very low in summer and peak from March to May in this region (North Pacific Fur Seal Commission, 1975). The California sea lion displays a sex-dependent migration behavior which sends nonbreeding males north to the coast of this region during fall and winter.

Being anadromous, the salmonids found in this community (e.g. chinook and coho salmon, steelhead) migrate through estuaries to inland freshwater bodies to breed. Juveniles return to the ocean community for feeding and growth. Once the young fish have entered the marine environment, migration is generally northerly, with a reciprocal southerly migration occurring as the salmon mature and return to the waters of their origin to spawn. Further treatment of salmonid migration is provided in Section 3.4.1.2 and in Part 2 (Species of Concern) of this volume.

Additional visitation to this community occurs from the Disphotic Zone and is treated in a separate note (#11)

#10. Consumption-Secondary Productivity. High phytoplankton productivity is supportive of high zooplankton productivity which, in turn, provides food for successively higher trophic levels, as discussed in Note #8. Because the Euphotic Pelagic food web is grazing-based rather than detritus-based, more of the energy "produced" by the phytoplankton flows through the complex consumer food webs and supports a larger proportional biomass of consumers than the terrestrial or estuarine ecosystems. Although primary productivity of the oceanic region is less than that of the region's forests or salt marshes, secondary productivity is probably greater.

Unfortunately no data or even comprehensive estimates exist for the region regarding secondary productivity. Hedgpeth (in Ricketts and Calvin, 1968) estimates total annual production of phytoplankton and zooplankton (in Southern California waters) to be 4,500 pounds per acre (500 g/m^2) dry weight, the zooplankton conversion or ecological efficiency (see Lindeman, 1942) to be about 7.5 percent of the phytoplankton production. Hedgpeth further "guesses based on all sorts of assumptions" that the fish conversion is about three percent of the zooplankton.

Ryther (1969), as quoted by Colinvaux (1973), suggests a twenty percent ecological efficiency rate (see Lindeman, 1942) for fish in upwelling areas, fifteen percent in coastal regions, and ten percent in the open ocean.

Douglass and Stroud (1971) estimate the total annual production of fish on the Pacific Continental Shelf to be 168 pounds per acre (19 g/m^2), while Rounsefell (1975) estimates a potential annual commercial yield of demersal fish and shellfish of three metric tonnes per square kilometer (3 g/m^2). These estimates, although giving some idea of how production is distributed between the pelagic and benthic habitats, cannot be related mathematically (i.e. $19-3 \neq 16$).

Catch statistics for commercial fish species of the region are given in Section 3.4.1.2 of this volume. Biomass estimates (in metric tonnes) for demersal fish species on the shelf are given in Table 3-56 of that section.

11. Interactions of Pelagic with Disphotic and Benthic Zones. Significant biological interactions take place between this habitat and the Disphotic and Benthic Zones below, and provide important pathways for the exchange of both energy and nutrients. These include, 1) sinking and mixing processes affecting primarily the non-swimming planktonic organisms, 2) spawning and maturation, and 3) diel vertical migration of the more mobile swimming organisms (nekton).

Phytoplankton are non-swimming plants. They are continuously, slowly sinking from the Euphotic Zone to the bottom. They are a source of food for disphotic consumers as they sink. Mixing processes also drive phytoplankton below the Euphotic Zone, but also return many back up again. Rapid reproduction of phytoplankton while in the Euphotic Zone maintains the stock, with considerable fluctuations from seasonality, upwelling, and grazing.

Various life history stages of benthic species found on the continental shelf, and in the coastal intertidal zones, affect the community composition of the Euphotic Pelagic habitat. Flatfish, starfish, clams, and many other animals of the benthos begin life as floating (planktonic) eggs and develop through several distinct larval stages in the plankton of the pelagic habitat before sinking to the bottom to reside as adults. Swimming organisms from the Disphotic Pelagic Zone may also hatch and develop within the Euphotic Zone. Hardy (1956) presents a descriptive discussion of the pelagic larval organisms in his book, The Open Sea: The World of Plankton. Distribution of benthic species is facilitated by the movements of the larval forms of these species while in the plankton. The process valve in the Euphotic Pelagic model (Figure 3-51) that deals with this interaction is labeled "spawning and maturation."

Another important interaction between Disphotic and Euphotic communities occurs daily (diel) rather than seasonally: the vertical migration of great numbers of pelagic consumers, including tiny copepods, macroplanktonic euphausids, shrimps, and lantern fish, and demersal shrimps and fish. During the daylight period, these organisms stay at deeper levels, often as a distinguishable layer on echosounding traces. As daylight fades, they rise and disperse toward the surface where they feed actively on smaller planktonic organisms. These diurnal migrations may contribute significantly to the rate of transport of surficial pollutants (e.g. oil) to depth. Many species of zooplankton make these diel vertical migrations over hundreds of meters of the water column. One of the most remarkable features of the zooplankton community in general is the change in community composition between mid-day and midnight. In terms of biomass and species diversity, this change is less in waters over the shelf and closer to shore than inthe waters just beyond the shelf edge. The most abundant species of copepods (microplankton) do not migrate vertically out the Euphotic Zone (Peterson, 1972). Some species of copepods and larger forms (e.g. macroplankton, such as euphausids, shrimps, squids, and lantern fish) migrate downward, out of the Euphotic Zone in the daylight, and upward at evening to feed throughout the entire Euphotic layer.

The average biomass of mid-water trawls off the Oregon Coast at night was almost six times that of daytime trawls, as shown in Table 3-35. These trawl catches consisted mostly (about 80-90%) of euphausid plankton (Pearcy, 1972). This vertical movement of biomass is a mechanism for the transfer of production from the Euphotic to the Disphotic habitat.

TABLE 3-35. DIEL CHANGES IN BIOMASS OF FOUR GROUPS OF MACROPLANKTON IN THE TOP 150 M (500 FT) OF THE PACIFIC OCEAN AT THE SHELF EDGE. Data are in grams per 1000 cubic meters net weight biomass, collected by 56 mid-water trawls 80 kilometers (50 mi) off Newport, Oregon, 1962-1964. (From Pearcy, 1972.)

	Fishes	Shrimps	Squids	Other Macroplankton	Total	Night/ day
Night	9.44	2.07	0.44	51.86	63.81	5.60
Day	0.64	0.57	0.05	10.14	11.40	

In addition to this vertical variability, evidence suggests that zooplankton occur in patches, much like fish occur in schools. This greatly compounds the problems of assessment of standing stocks of these organisms. The nature of this patchiness is, at this time, unknown for the region. The diurnal vertical migration of zooplankton patches, feeding on phytoplankton at night time, may result in local patchiness of phytoplankton as well, compounding the problems associated with assessment of phytoplankton concentrations. Large-scale phytoplankton patchiness over the shelf is usually associated with nutrient availability. Concentrations of phytoplankton (and thus areas of high productivity) are found where upwelling is locally intense and also off the mouths of the major estuaries of the region.

#12. Harvest. There is no harvesting by man of producers or decomposers in the Euphotic Pelagic Zone of the ocean, and the harvest of the consumers is limited to organisms of the upper trophic levels in this region by commercial and sport fishermen. Some organic wastes from fish processing are returned to the habitat, but generally the fish products are removed from the system completely. This harvesting is regulated to some extent under federal and state fish and game management, which may become more effective with the recent increase of U.S. jurisdiction over these resources to 200 miles offshore (Fishery Conservation Act of 1976 - P.L. 94-265). Commercial fisheries information in terms of fish harvested is presented in Section 3.4.1.2 and sport fisheries information in terms of fish harvested in Section 3.4.2.3. Additional information on commercial and sport fisheries in terms of socioeconomics is presented in Section 4.3.

Important species that are taken from the Euphotic Pelagic habitat in the region include salmon (mainly chinook and coho), albacore (tuna), hake, and anchovy. Landings data supplied in Section 3.4.1.2 provide summaries of the amount of biomass being removed from the habitat on a yearly basis. Refer to the Annotated Species List in Volume 5 for further information on the species of commercial value and their range, trophic levels, etc.

#13. Waste Discharge. Wastes and spills that are generated in the ecosystem are slight, consisting of fish wastes, bilge and ballast tank wash-out, and potential spills of fuels from ships and boats. These wastes are insignificant in this region, although the potential of an oil spill from Alaskan oil shipping exists. A significant data gap exists in the lack of understanding of these pathways that any given pollutant might take once released to the Euphotic Pelagic ecosystem.

An oil spill in the region would behave with some predictability. Efforts are being made to model oil spill movements. The floating oil would probably effect air/water gaseous equilibrium processes near the surface, greatly affecting those members of the planktonic community close to the surface and the sea birds and marine mammals that interact across this air/water interface. The oil would be driven ashore if winds were from the south, west, or northwest. The most significant impact of such a spill would be to the intertidal areas: the Beach Surf Zone, the Rocky Surf Zone, and the various estuarine zones. For further discussion, refer to Note #11 in the Unprotected Beach Model (Section 3.2.1.4).

Direct dumping of municipal or industrial wastes into the Euphotic Pelagic Zone does not occur in this region. Municipal and industrial wastes are disposed of in estuaries and move through the estuarine ecosystem before reaching the ocean. The estuaries, through chemical, geological, and biological processes, effectively filter out much of this waste material before it reaches the ocean. Secondary effects of socioeconomic activities ashore are also presented as leading to an import of materials to the Euphotic Pelagic habitat. These materials include toxins and nutrients from agricultural practices, and increased suspended sediment from terrestrial activities which increase rates of erosion in the watersheds. Such materials would pass through the riverine and estuarine habitats first (see appropriate models). The sediment transport models for inland, estuarine, and coastal and oceanic areas are also relevant (Volume 1, Sections 2.5.4, 2.6.3.1, and 2.7.4). No thermal discharges to the Euphotic Pelagic Zone occur within this region.

#14. Dredge Spoil Disposal. Extraction industry activities, as modeled in Volume 1 (Section 4.6) include mining and dredging operations. Sea disposal of dredge spoils from navigation channels in the coastal estuaries currently affects suspended sediment loads in disposal areas on the shelf, although this effect is thought to be temporary. As the spoils settle, they alter the local bottom sediment and affect benthic organisms. This effect on benthic organisms is not clear from this model (Figure 3-51), as the spoil sediments merely pass through the Euphotic Pelagic water column. Sea disposal of dredge spoils is shown in the model as going to the suspended detritus and sediment storage component. From there it moves by deposition directly to the Vegetated Benthic Zone, or to the Non-vegetated Benthic Zone via the Disphotic Pelagic Zone. Dredge spoils may also be disposed of in landfills in or near the estuaries, or on beach and dune areas.

3.2.2 Food Webs. As discussed in the Model (Volume 1), food web models are attempts to "map" who eats whom in a given habitat. These models of community interaction have been developed for a number of the habitats identified in the region, as indicated in Table 2-1 of Volume 3, and are located in the habitat descriptions in Volume 3.

The previous discussions in Sections 3.2 and 3.2.1, as well as the habitat description pages in Volume 3, identify two major types of food webs found in the communities of the region: detrital, if the vast majority of the net primary production flows from the producers through decomposers and detritivores, and grazing if more than a very low percentage flows through primary and higher consumers.

Most of the terrestrial habitats of the region support detrital food webs, such as the old growth forest (described in detail in Section 3.2.1.1) with a consumer to producer biomass ratio of around 0.001:1. Terrestrial grasslands (Early Seral Grassland/Pasture), on the other hand, often have grazing food webs with ratios as high as 0.5:1. Freshwater aquatic systems also tend to have grazing food webs, with a relatively small producer biomass supporting a large biomass of insects, fish, and birds.

Most estuarine food webs are detrital, although they often support a higher relative consumer biomass because the turnover rates of their producers is greater (see Sections 3.2.1.2 and 3.2.1.3). Nevertheless, most of the food energy of estuarine organisms passes through detrital and seston stages rather than through direct grazing. The other coastal habitats (surf zones, dunes, headlands) are also primarily detrital.

In the ocean, both detrital and grazing food webs are evident. The Euphotic and Disphotic Pelagic Zones are grazing systems that support elaborate and interweaving consumer relationships. The consumer to producer biomass ratio in the pelagic systems is often 1:1 or even greater. The Benthic Zone food webs, on the other hand, are predominantly detrital. Many of the bottom fish in these habitats, however, migrate to the Pelagic Zones and join their grazing food webs. Also, a number of consumers in the Vegetated Benthic Zone graze the kelp, surfgrass, and epiphyton, although the majority of fixed energy from these habitats is consumed or exported as detritus.

Note that food webs are seldom completely detrital or completely grazing for any given habitat but, rather, proportions of energy and materials flow through both detrital and grazing components of the food webs. In many cases there is a seasonal shift in dominance of these food web components. During periods of peak primary predation, grazing becomes significant, but often wanes with the onset of senescence of phytoplankton. The canopy food web in an old growth forest is principally a grazing one, the forest floor web a detrital one, while the "bottom line" is a flow of less than 0.01% of the primary production through the consumers. The role of predators in food webs is also ambiguous, as they may prey upon secondary consumers from both grazing and detrital chains. For example, trout will take grazing mayflies or detritivore midges. Likewise the great horned owl will take a song bird which is dependent on the grazing food web or a shrew which is dependent on the forest floor detrital food web and also part of the "grazing" food web component as it also eats numerous conifer seeds. Similar dual roles often occur within marine and coastal communities.

The habitat description pages in Volume 3 give brief statements about the food webs of each community type.

3.2.3 Community Composition. The Community Composition Model for each habitat includes the major species that make up the community and the trophic level or general niche of each species (i.e. whether it is a producer, herbivore, parasite, etc.). These lists, for every habitat in the region except the Human Activity Zones, are printouts from the Annotated Species List and are found in Volume 3. All the species entered into the ASL, as described in Section 3.3 of this chapter and in Volume 5, are included in these lists. Range (Watershed Units 1-9), Abundance (Abundant, Common, Uncommon), and Status (Commercial, Rare, Endangered, etc.) are also given in these lists.

Data on biomass, productivity, and transfer rates within and between trophic levels for all of the habitats in the coastal region are not available. The very few data that do exist for the area are included in the five Ecosystem Model Notes sections in this Chapter. The rest form a significant data gap for the characterization of the region.

Some interesting generalizations are apparent from a review of these Community Composition lists. On a terrestrial to marine gradient, dominant producers change from vascular to non-vascular plants. Herbivores on this same gradient shift from largely insects on land to other invertebrates such as crustaceans in the sea. Omnivores are more common in terrestrial environments than in the complex food webs of the ocean. Dominant carnivores shift from mammals to fishes, and indiscriminate small particle eaters (filter feeders, etc.) gain in abundance and diversity, dominating the benthic environments. Knowledge of the scavengers and especially the decomposers is sparse throughout the habitats of the region.

Community Composition changes are great on an east-west transect through the region and minor on a north-south transect.

See Volume 3 for species lists, and Volume 5 for information on how they were compiled.

3.2.4 Succession. This section in Volume 1 presents some general comments about the phenomenon of biological succession, using a typical terrestrial succession model as an example. In the two sections which follow below (3.2.4.1 and 3.2.4.2), detailed accounts of terrestrial and estuarine succession are given for the region, with supporting data from in or near the study area.

3.2.4.1 Succession in Western Hemlock Zone. Succession in the Western Hemlock Zone is represented in a simplified way in Figure 3-53. As indicated in the figure, succession is initiated by logging activities or by some natural or man-induced catastrophe such as landslide, forest fire, windstorm, or vegetation changes. Figure 3-54 presents some indices which vary with this succession. The indices given in this figure are general; more specific information regarding change in function and structure of the community is discussed below.

Floral Changes. Although the succession model indicates a single path for succession and a single time scale, a more realistic presentation follows a number of possible changes based on site-specific conditions. Moisture is considered by some (Franklin and Dyrness, 1973) to be the most significant factor. Table 3-36 gives the patterns of succession which are predicted for different moisture conditions in Western Oregon. Other factors include soil type, aspect, seed source, and degree of disturbance.

Succession does not always follow a predictable pattern. Variable climate conditions, "natural" site preparation (e.g. nitrogen addition by alder, ceanothus, and Scotch broom; Trappe et al., 1967, and Gratowski, 1967), selective browsing, and the occurrence of pathogens or symbionts (e.g. mycorrhizae) also affect the rates and paths of succession, as reflected in the flora of the site. Brush fields (manzanita, ceanothus, chinquapin, vine maple, willows, salmonberry, thimbleberry) can become semi-permanent when overbrowsed by a combination of black-tailed deer, hare, and mountain beaver, although alone none of these species typically slows succession when present alone (Crouch, 1974). Often the establishment of permanent brush fields (especially in the Oregon and California portions of the study area) is related to burns or repeated burns (Gratowski, 1961).

Faunal Changes. The most readily observable faunal changes are those documented for avifauna. Table 3.37 shows the distribution of selected birds over seral stages. Obviously the avifaunal aspect of the community changes drastically with succession. Differences in density and biomass, with successional stage and season for Western Oregon, are given in Figure 3-55. (Note the successional pattern described is more closely associated with the pattern of succession typical of the slopes of the Willamette Valley than the coastal forests.) Other studies have reported greatest avian density and biomass in transitional stages (Weins and Nussbaum, 1975). Table 3-38 provides some site specific diversity, density, and biomass data for specific seral stages within the region. Additional work on the relationship between succession and avifauna are given by Balda (1975, S.H. Anderson (1970, 1972), and Weins (1975).

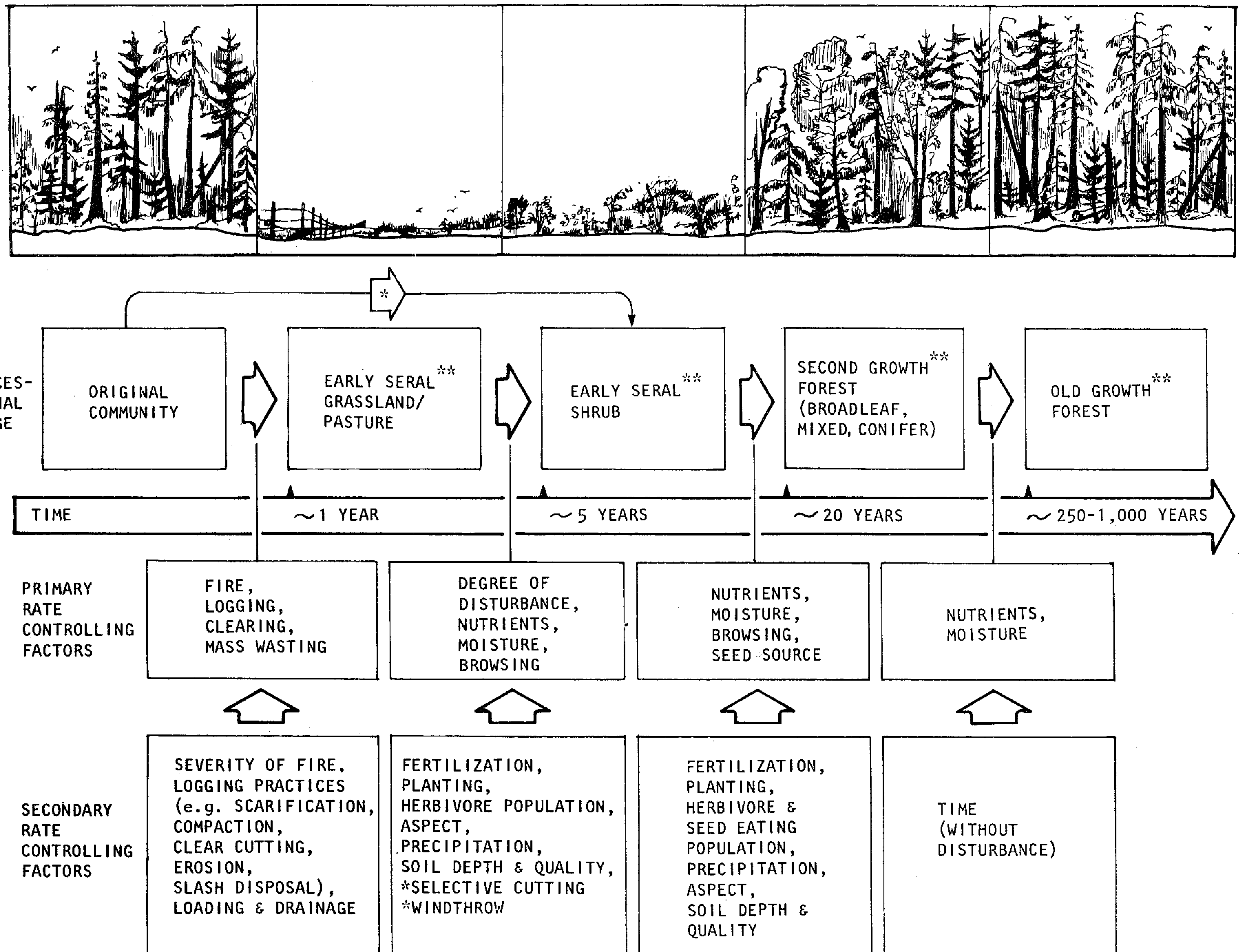


FIGURE 3-53.

SUCCESSION MODEL- WESTERN HEMLOCK ZONE

* SELECTIVE CUTTING & WINDTHROW REVERT ONLY AS FAR AS SHRUB STAGE.

** REFER TO APPROPRIATE HABITAT DESCRIPTION.

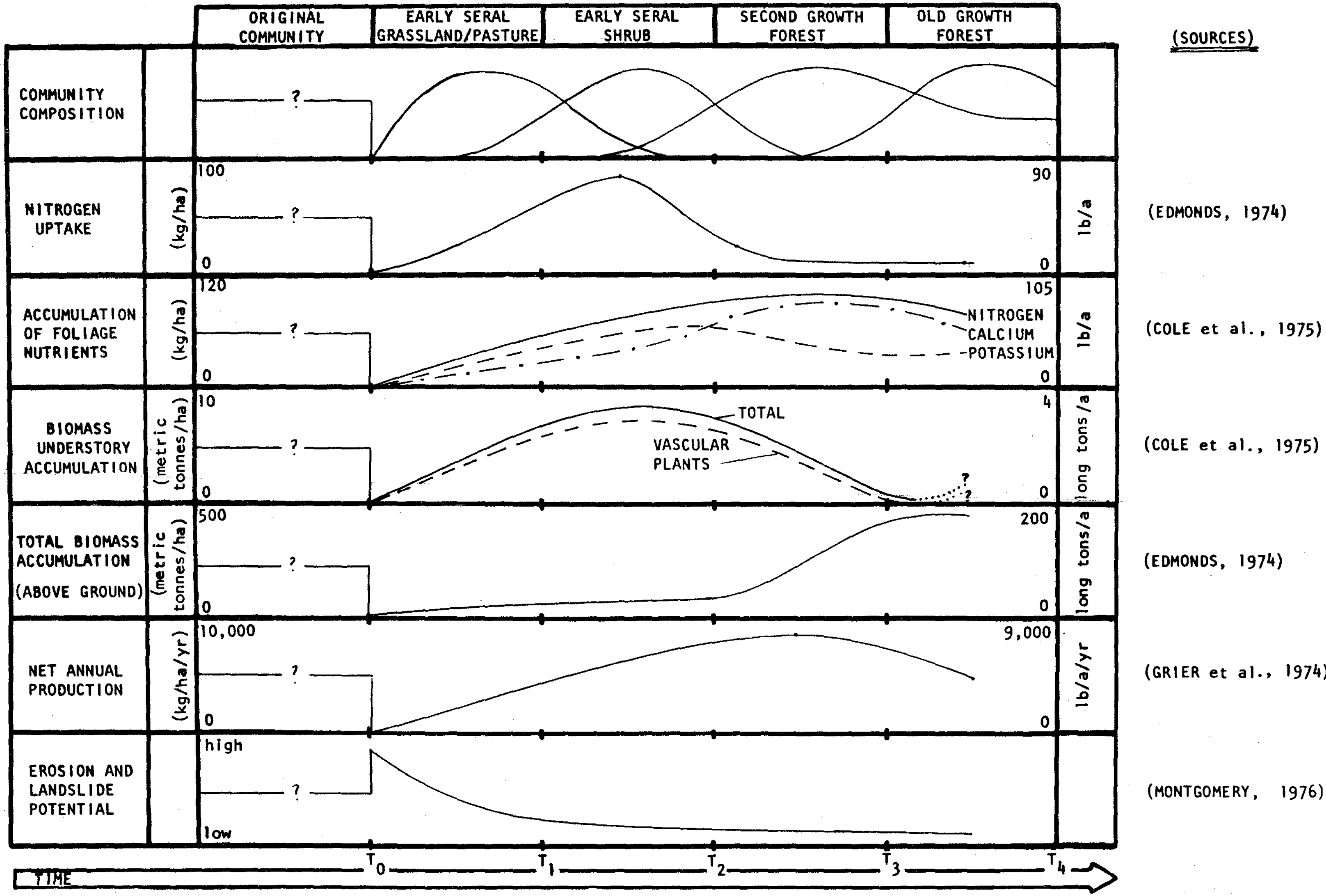


FIGURE 3-54. ***ENVIRONMENTAL INDICES ASSOCIATED WITH WESTERN HEMLOCK SUCCESSION***

TABLE 3-36. SERAL COMMUNITIES AND HYPOTHESIZED EQUIVALENT CLIMAX ASSOCIATIONS REPORTED FOR THE WESTERN HEMLOCK (*TSUGA HETEROPHYLLA*) ZONE IN WESTERN OREGON ARRANGED ALONG A MOISTURE GRADIENT FROM DRY (TOP) TO WET (BOTTOM). (From Franklin and Dyrness, 1973.)

DRY → WET

Early Seral Communities	Late Seral Communities	Climax association
Pteridium aquilinum-Gaultheria shallon (Corliss and Dyrness, 1965)		*Pseudotsuga menziesii/Holodiscus discolor/Gaultheria shallon*
Pteridium aquilinum-Gaultheria shallon (Corliss and Dyrness, 1965)	*Pseudotsuga menziesii/Gaultheria shallon* (Corliss and Dyrness, 1965)	*Tsuga heterophylla/Acer circinatum/Gaultheria shallon*
Vaccinium parvifolium/Gaultheria shallon, *Rubus parviflorus/Trientalis latifolia* (Bailey and Poulton, 1968; Bailey and Hines, 1971; Meurisse and Youngberg, 1971)		
	Pseudotsuga menziesii/Acer circinatum/Gaultheria shallon (Dyrness, Franklin, and Moir, unpublished)	*Tsuga heterophylla/Rhododendron macrophyllum/Gaultheria shallon*
	Pseudotsuga menziesii/Acer circinatum/Berberis nervosa (Dyrness, Franklin, and Moir, unpublished)	*Tsuga heterophylla/Rhododendron macrophyllum/Berberis nervosa*
Vaccinium ovatum-Rubus spectabilis, *Vaccinium parvifolium/Gaultheria shallon* (Meurisse and Youngberg, 1971)		*Tsuga heterophylla/Gaultheria shallon-Polystichum munitum*
Vaccinium parvifolium/Gaultheria shallon (Bailey and Poulton, 1968)		
Alnus rubra/Rubus spectabilis/Polystichum munitum (Corliss and Dyrness, 1965)	*Pseudotsuga menziesii/Acer circinatum/Polystichum munitum* (Corliss and Dyrness, 1965)	*Tsuga heterophylla/Polystichum munitum*
Acer circinatum/Polystichum munitum (Bailey and Hines, 1971)		
Alnus rubra/Acer circinatum, *Alnus rubra/Polystichum munitum* (Bailey and Poulton, 1968)		
Alnus rubra/Rubus spectabilis/Polystichum munitum (Corliss and Dyrness, 1965)		
Pteridium aquilinum-Lotus crassifolius, *Alnus rubra/Rubus spectabilis/Polystichum munitum* (Meurisse and Youngberg, 1971)		*Tsuga heterophylla/Polystichum munitum-Oxalis oregana*
Pteridium aquilinum-Lotus crassifolius, *Alnus rubra/Rubus parviflorus* (Bailey and Hines, 1971)		

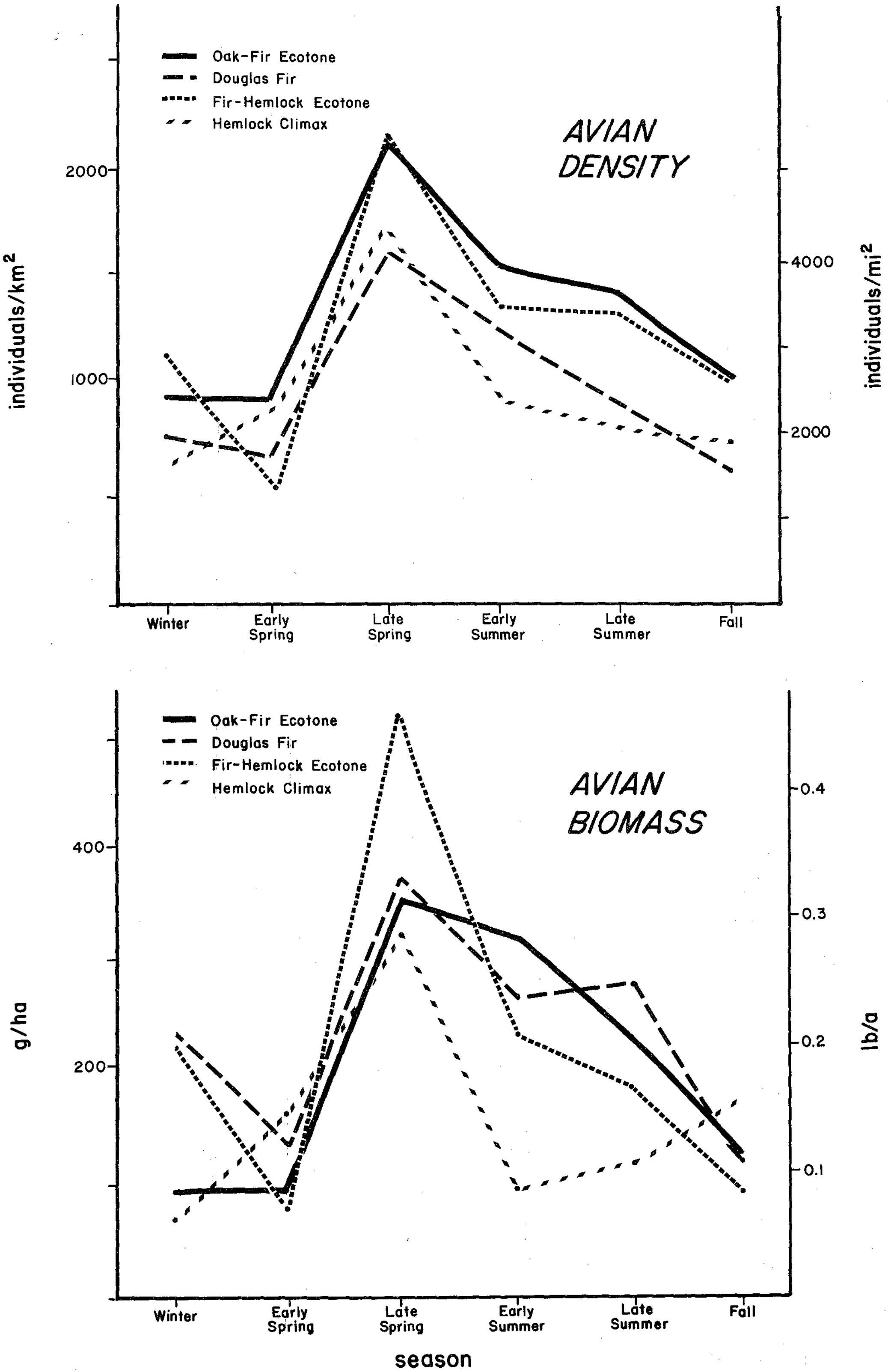


FIGURE 3-55. SEASONAL CHANGES IN AVIAN DENSITY AND BIOMASS FOR FOUR SERAL STAGES IN WESTERN OREGON. (After Anderson, 1970.)

TABLE 3-37. BIRD USE OF SERAL COMMUNITIES IN OREGON WEST OF THE CASCADE MOUNTAINS SUMMIT. Twenty species dependent on holes for nest sites are underlined. X = uses that seral stage, but not for nesting; XX = nests in that seral stage; XXX = nests primarily in that seral stage. (From Meslow and Wight, 1975.)

Bird Species (N = 84)	Seral Stage and Age in Years: Grass, Forbs 1-7	Shrub, Sapling 8-15	Second Growth 16-40	Older 2nd Growth 41-120	Mature Old Growth 120+
Savannah sparrow	XXX	X	-	-	-
Vesper sparrow	XXX	X	-	-	-
White-crowned sparrow	XX	XX	-	-	-
Song sparrow	XX	XX	-	-	-
Nighthawk	XX	XX	X	X	X
Oregon junco	XX	XX	XX	XX	XX
Fox sparrow	X	XXX	-	-	-
Chipping sparrow	X	XXX	-	-	-
Rufous-sided towhee	X	XXX	-	-	-
American goldfinch	X	XXX	-	-	-
Black-headed grosbeak	-	XX	XX	XX	XX
Bewick's wren	X	XXX	-	-	-
Lazuli bunting	X	XXX	-	-	-
Wilson's warbler	-	XXX	-	-	-
Yellow warbler	-	XXX	X	-	-
Nashville warbler	-	XX	XX	X	-
Orange-crowned warbler	-	XX	XX	-	-
Warbling vireo	-	XX	XX	X	X
Solitary vireo	-	XX	XX	XX	-
MacGillivray's warbler	-	XX	XX	XX	XX
Yellow-rumped warbler	-	XX	XX	X	X
Black-throated gray warbler	-	XX	X	XX	XX
Hutton's vireo	-	XX	X	XX	X
Swainson's thrush	X	XX	XX	X	X
Varied thrush	X	XX	XX	XX	XX
Robin	X	XX	XX	XX	X
Common bushtit	-	XXX	X	X	X
Scrub jay	X	XXX	-	-	-
Stellar's jay	X	XX	XX	XX	XX
Western wood pewee	-	XX	X	XX	XX
Western flycatcher	-	XX	XX	X	-
Traill's flycatcher	-	XX	X	-	-
Calliope hummingbird	X	XXX	-	-	-
Mourning dove	X	XX	XX	-	-
Mountain quail	X	XXX	X	X	X
Blue grouse	X	XX	-	XX	XX
Ruffed grouse	X	XX	XX	-	-
Sharp-shinned hawk	-	X	XX	XX	XX
<u>Saw-whet owl</u>	-	X	XX	XX	XX
Cooper's hawk	-	X	XX	XX	-
Pigeon hawk (Merlin)	-	X	XX	XX	-
<u>Pygmy owl</u>	-	X	XX	XX	XX
Long-eared owl	X	X	XX	XX	-
Rufous hummingbird	X	X	XX	XX	XX
<u>Tree swallow</u>	X	XX	XX	X	X
<u>Purple martin</u>	X	XX	XX	X	X
<u>Western bluebird</u>	X	XX	X	-	-
<u>Mountain bluebird</u>	X	XX	X	-	-
Great horned owl	X	X	XX	XX	X
Crow	X	X	XX	XX	XX
<u>Flicker</u>	X	X	X	XX	XX
Gray jay	-	X	X	XX	XX
<u>Yellow-bellied sapsucker</u>	-	X	XX	XX	XX
<u>Black-capped chickadee</u>	-	X	XX	XX	X
Winter wren	-	X	XX	XX	XX
Golden-crowned kinglet	-	X	XX	XX	XX
Ruby-crowned kinglet	-	X	XX	XX	XX
Red-tailed hawk	X	X	-	XX	XX

TABLE 3-37. BIRD USE OF SERAL COMMUNITIES (Continued).

Bird Species (N = 84)	Seral Stage and Age in Years				
	Grass, Forbs 1-7	Shrub, Sapling 8-15	Second Growth 16-40	Older 2nd Growth 41-120	Mature Old Growth 120+
Bald eagle	-	-	-	XX	XX
Osprey	-	-	-	XX	XX
Band-tailed pigeon	X	X	-	XX	XX
Screech owl	-	X	X	XX	XX
Pileated woodpecker	-	-	X	XX	XX
N. three-toed woodpecker	-	-	X	XX	XX
Hairy woodpecker	-	X	X	XX	XX
Downy woodpecker	X	X	-	XX	XX
Olive-sided flycatcher	X	X	-	XX	XX
Chestnut-backed chickadee	-	X	X	XX	XX
Red-breasted nuthatch	-	-	X	XX	XX
White-breasted nuthatch	-	-	X	XX	XX
Brown creeper	-	-	X	XX	XX
Townsend's solitaire	X	X	-	XX	XX
Hermit thrush	-	X	X	XX	XX
Townsend's warbler	-	-	-	XX	XX
Hermit warbler	-	-	X	XX	XX
Hammond's flycatcher	-	X	X	XX	XX
Western tanager	-	X	X	XX	XX
Evening grosbeak	-	X	X	XX	XX
Purple finch	-	X	X	XX	XX
Pine siskin	X	X	X	XX	XX
Red crossbill	-	-	-	XX	XX
Goshawk	-	-	-	X	XXX
Spotted owl	-	-	-	X	XXX
Vaux's swift	X	X	X	X	XXX
SUMMARY:					
Species occurring	38	72	59	64	58
% of total species occurring	45	84	70	76	69
Nesting primarily in that seral stage	2	12	0	0	3
Nesting species	6	39	31	51	46
% total species nesting within seral stage	7	46	37	61	55
Species nesting in holes	0	4	6	14	14

3.2.4.1 Succession in Western Hemlock Zone (continued)

Community composition changes in mammals are also apparent and are presented in Table 3-39. Additional work has been done in this area by Hooven and Black (1976), Black and Hooven (1974), Gashwiler (1959, 1970), Ahlgren (1966), and others.

Data for small mammals indicating relative densities for an area in Western Oregon in early stages of succession compared to a mature stand are given in Table 3-39 for burned and unburned sites. Black and Hooven (1974) and Gashwiler (1970) report that shrews are unfavorably affected by clearcutting, particularly with slash burning practices. Townsend chipmunks, snowshoe hares, red-backed voles, flying squirrels, and "pine" squirrels were also adversely affected by clearcutting. The Pacific water shrew also seems to be dependent on old growth habitats (Silovsky and Pinto, 1974). Deer mice and other voles (Oregon and long-tailed) become more common in clearcuts, although the voles do not respond well to slash burning. Gashwiler (1959) reports a two-to three-fold increase in deer mouse densities following clearcutting and burning. Red-backed vole populations are depressed after burning of the clearcut (Gashwiler, 1970). Gashwiler (1959) also reports depletion of chickaree, flying squirrel, and snowshoe hare populations following logging. Responses of selected small mammals to clearcutting and early stages of succession are indicated by Figure 3-56.

TABLE 3-38. DIVERSITY, DENSITY, AND BIOMASS OF AVIFAUNA (BIRDS) FOR VARIOUS SERAL STAGES OF SITES NEAR OR IN THE REGION. (After Weins, 1975.)

Location	Forest Type	No. Samples	No. Species	Density (indiv./km^2)	Standing Biomass (g/ha)	Reference
Oregon	Douglas Fir	1	12	1779.0	262.8	Weins & Nussbaum, 1975
	Hemlock-Douglas Fir	1	12	1380.0	275.8	"
	Hemlock-Maple	1	12	2619.0	424.3	"
	Hemlock-Silver Fir	1	15	2887.0	526.1	"
	Douglas Fir-Noble Fir	1	7	1910.0	223.3	"
	Mountain Hemlock	1	13	1229.0	361.9	"
	DF ecotone	1	16	1440.6	328.4	S.H. Anderson, 1970, 1972
	Douglas Fir	5	13	1071.9	227.9	"
	Hemlock ecotone	1	16	1250.3	238.1	"
	Hemlock	1	7	896.9	94.6	"
California	Cutover DF	3	9	647.4	365.6	Hagar, 1960
	Douglas Fir	2	13	588.1	148.1	"
	Bishop Pine	4	26	1770.0	323.1	Stewart & Higbee, 1973; Darling, 1971; Akers & Hansen, 1973
	Douglas Fir	3	21	1626.7	288.2	Darling, 1971; Milton & Murray, 1972; Akers & Hansen, 1973

TABLE 3-39. SMALL MAMMAL USE OF SERAL COMMUNITIES. Data are recorded on three study plots during 1968, 1969, and 1970. (From Hooven and Black, 1976.)

	CLEARCUT								OLD GROWTH			
	Unburned 10 acres (4.0 ha)				Burned 10 acres (4.0 ha)				5 acres (2.0 ha)[1]			
	1968	1969	1970	%	1968	1969	1970	%	1968	1969	1970	%
Years After Disturbance	1	2	3		5	6	7		Circa 125			
Sorex trowbridgii	67	97	50	19.8	28	68	34	10.1	88	124	108	25.0
Sorex vagrans	5	17	50	6.6	5	5	5	2.1	20	14	86	9.7
Sorex bendirii	--	1	--	--	2	0	1	0.2	--	--	--	--
Neurotrichus gibbsii	1	1	2	0.4	--	--	--	--	6	4	12	1.7
Scapanus orarius	2	0	0	--	0	1	0	--	1	0	0	--
Ochotoma princeps	--	--	--	--	--	--	--	--	1	0	0	--
Lepus americanus	0	0	1	--	--	--	--	--	16	12	10	3.0
Aplodontia rufa	0	0	1	--	--	--	--	--	--	--	--	--
Spermophilus beecheyi	--	--	--	--	8	0	0	0.6	--	--	--	--
Eutamias townsendii	30	99	34	15.0	99	146	37	21.8	156	114	38	24.1
Tamiasciurus douglasii	0	0	1	--	--	--	--	--	4	10	8	1.7
Glaucomys sabrinus	--	--	--	--	--	--	--	--	8	2	0	0.8
Peromyscus maniculatus	36	222	94	32.5	59	227	130	32.2	16	174	66	20.0
Neotoma cinerea	2	0	0	--	--	--	--	--	1	0	0	--
Clethrionomys californicus	3	0	0	--	--	--	--	--	74	8	8	7.0
Phenocomys albipes	0	0	2	--	--	--	--	--	1	0	0	--
Microtus oregoni	23	100	96	20.2	61	99	189	27.0	10	28	30	5.3
Microtus richardsoni	0	3	6	0.8	21	5	5	2.4	--	--	--	--
Zapus trinotatus	0	0	11	1.0	16	9	9	2.6	4	6	0	0.8
Erethizon dorsatum	0	0	0	--	--	--	--	--	1	0	0	--
Mustela erminea	2	1	3	0.5	3	4	2	0.7	4	2	4	0.8
Mustela frenata	--	--	--	--	1	0	0	--	--	--	--	--
Spilogale putorius	--	--	--	--	0	0	1	--	--	--	--	--
	171	541	351		303	564	425		411	498	370	
		1,063				1,292				1,279		

[1] The data from this 5-acre trapping grid have been adjusted (doubled) for comparison with the catches recorded on the larger 10-acre grids on the clearcut areas.

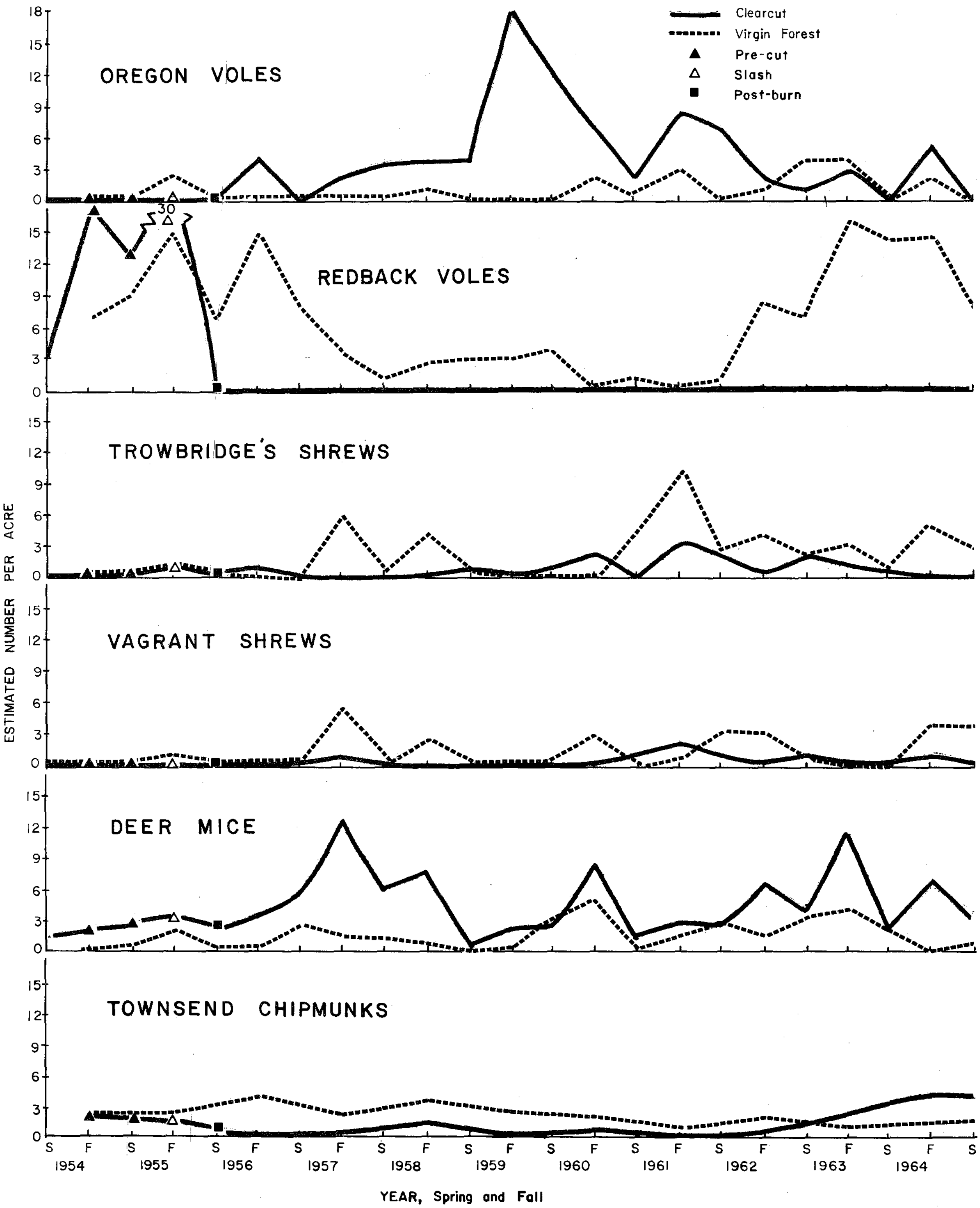


FIGURE 3-56. RESPONSES OF SMALL MAMMAL SPECIES TO CLEARCUTTING AND EARLY SERAL STAGES. Multiply by 2.5 for estimated number per hectare. (From Gashwiller, 1970.)

Elk and black-tailed deer also respond to clearcutting, with their preferred habitats being a mixture of forest/clearcut of an approximate 40/60 ratio. (See Species of Concern accounts in Part 2.) The black-tailed deer and Roosevelt elk both prefer the shrub stages for foraging but have cover requirements of taller vegetation. Black bear also respond in a similar fashion and are favorably affected by forestry management practices which place landscape into shrub stages. The bear's preferred habitat is the late shrub state when tree saplings become established, providing cover (Lindzey and Meslow, 1977).

Insect populations also respond to clearcutting and slash burning practices. Hooven and Black (1976) report that insects associated with dead or dying trees, particularly beetle species, e.g. bark beetles (Scolytidae), long-horned wood borers (Cerambycidae), metallic wood borers (Bubprestidae) and chick beetles (Elateridae), and some predators such as checkered beetles (Cleridae), are largely eliminated where slash is burned. Most butterflies (Lepidoptera), their larvae, bees, wasps, and other pollen-feeding insects are also eliminated by slash burning. Insect pests (those associated with dead or dying trees, e.g. the Douglas Fir beetle) are concentrated in areas where logs or damaged trees occur, such as extensive forest fire areas. Populations can increase to epidemic levels and attack adjacent healthy trees (Furniss, 1941).

Successional studies have not been completed for herpetofauna. Some species (e.g. tailed frog and Pacific giant salamander) are thought to be restricted to old growth (Silovsky and Pinto, 1974).

Functional Changes (Productivity, Biomass, etc.). Functional changes also occur concomitant with succession including changes in productivity, biomass, nutrient cycling, and forest structure. Net primary productivity is typically thought to be greater in mid-successional conditions than during climax conditions for terrestrial plant communities (E. P. Odum, 1971).

In the Western Hemlock Zone, the data presented in Table 3-40 provide some evidence for greater net primary productivity during the mid-successional stages.

TABLE 3-40. NET[a] ANNUAL ORGANIC MATTER AND NUTRIENT ACCUMULATION BY VEGETATION IN SECOND AND OLD GROWTH SITES. Data are from 43- and 450-year-old Douglas fir stands[b] on the Thompson site, Washington, and the H. J. Andrews Experimental Forest, Oregon, and are in kg/ha. (From Grier et al., 1974.)

Location	Organic Matter	N	P	K	Ca
Thompson site (43 years old)					
Total all vegetation	9988	23.6	6.6	14.4	8.7
Watershed 10 (450 years old)					
overstory	2362	5.0	1.1	4.4	4.3
understory[c]	1840	d	d	d	d
Total all vegetation	4202				

[a] Mortality not deducted from above figures.

[b] Does not include root production.

[c] From Russel, 1973.

[d] Not available at time of writing.

Unlike net primary productivity, an ecosystem's standing biomass is thought to be maximized under climax conditions (E. P. Odum, 1971). Table 3-41 provides some evidence to support this hypothesis. Figure 3-57 provides additional evidence on forest floor biomass, while Figures 3-58 and 3-59 give some additional evidence concerning foliage biomass. Although foliage biomass curves flatten or maximize at 40 to 60 years, bole and wood biomass continues to increase, as indicated in Figure 3-60. Resultant total biomass is greatest in an old growth forest.

TABLE 3-41. STANDING BIOMASS DATA FOR VARIOUS AGES AND TYPES OF FORESTS. (A) Biomass (metric tonnes/ha) of the above-ground and below-ground components. (B) Biomass (metric tonnes/ha) of the above-ground components. (From Edmonds, 1974.)

(A)

	Douglas Fir	
	Washington (35 yr)	Oregon (450 yr)
Overstory	171.1	530.0
Subordinate vegetation	1.0	8.8
Dead + litter	10.7	98.5
Above-ground	182.8	637.3
Roots	33.0	74.3
Soil	123.0	150.0
TOTAL	338.8	861.6

(B)

	Western Hemlock Oregon (26 yr)		Douglas Fir Washington (35 yr)		Douglas Fir Oregon (450 yr)	
Foliage	21.1	41.8	9.1	31.1	8.9	57.5
Branches	20.7		22.0		48.6	
Bole	150.9		140.0		472.5	
TOTAL	192.7		171.1		530.0	

Nutrient uptake and cycling also undergo change with succession. The role of nutrient cycling has been studied in the Western Hemlock Zone with some work on the True Fir and Sitka Spruce. Early stages of succession associated with red alder - and ceanothus species which fix nitrogen - add nitrogen and other nutrients to the nutrient capital of the site and in the case of red alder, rapidly cycle nutrients through the ecosystem, as indicated in Figure 3-61. In early successional stages, much of the nutrient cycling is done by the understory vegetation (Cole et al., 1975). Some evidence exists (Grier et al., 1974; Cole et al., 1975) which suggests nutrient requirements are decreased with succession, as the rate of nitrogen uptake decreases and more nutrients are cycled internally (see Table 3-42). The soil thus becomes less important as a supplier of nutrients (Edmonds, 1974). A young forest continues to accumulate nutrients in biomass, recycling these nutrients through litterfall by the overstory species. Old growth, with associated canopy openings, once again replaces nutrient cycling through understory vegetation, with epiphytic contributions to litterfall also being important (Grier et al., 1974). Some epiphytic lichens, e.g. Oregon lungwort (Lobaria oregana), contain nitrogen fixing blue-green algae and continue to contribute to the nitrogen capital of a site in many old growth forests (Denison et al., 1976).

Cole et al. (1975) provide evidence for canopy dominance beginning at around age 20 (Figure 3-62). However, Grier et al. (1974) indicate that in old growth forests (450 years old) understory again become an important component in the forest structure. This understory regeneration is concomitant with openings in the canopy caused by mortality in old stands. Forest structure in a successional sequence is thus typified by a dominance of understory for the first twenty or so years followed by a nearly complete dominance by the canopy species until the stand becomes decadent and the canopy begins to open, at which time understory species once again become significant. Also the occurrence of epiphytes increases which succession and maximizes in old growth in the Western Hemlock and True Fir Zones (Pike et al., 1977). However, in the Sitka Spruce Zone a community of epiphytes is associated with big-leaf maple and red alder, both second growth broadleaf trees (Franklin and Dyrness, 1973).

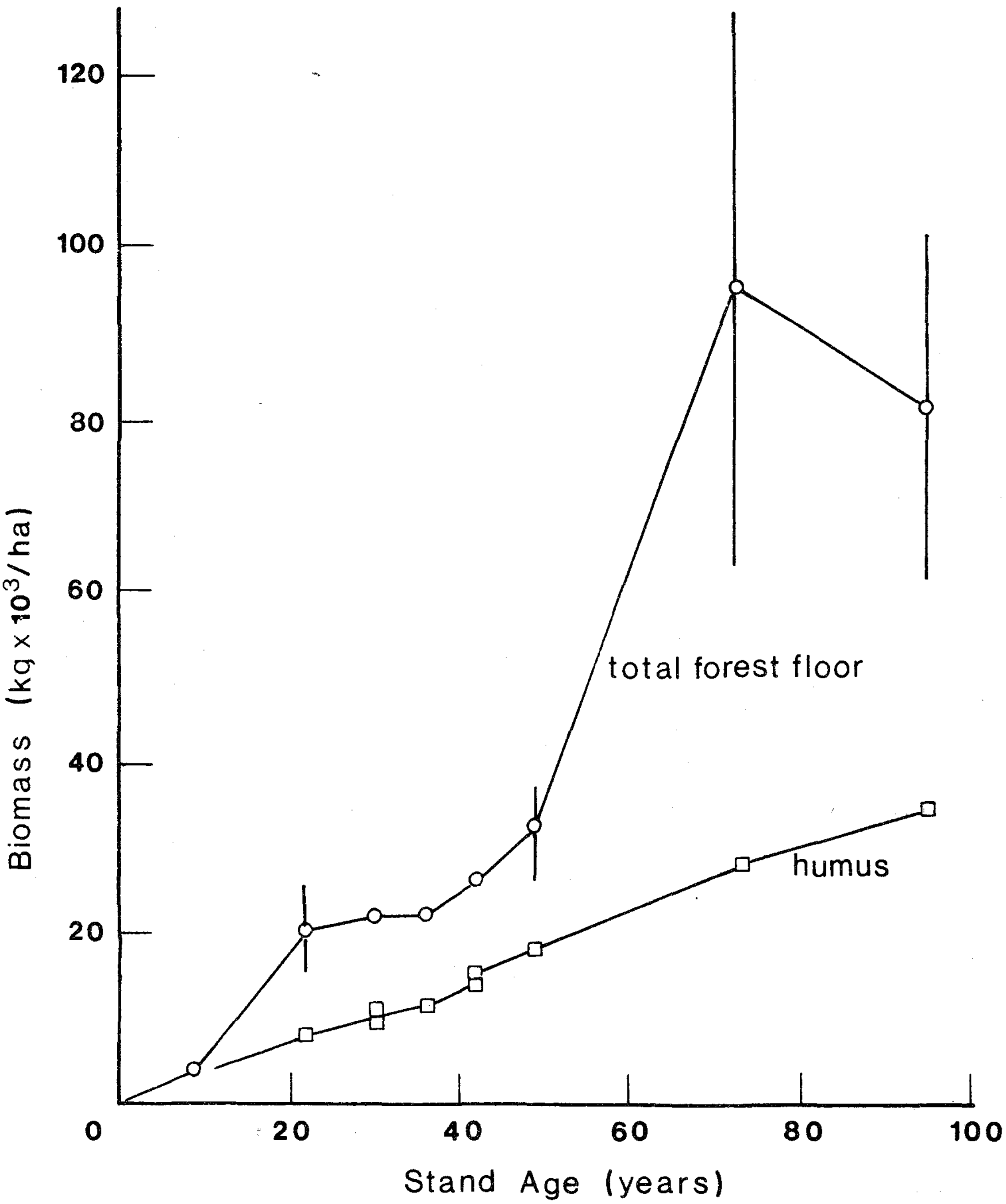


FIGURE 3-57. ACCUMULATION OF FOREST FLOOR BIOMASS UNDER VARIOUS AGED STANDS OF DOUGLAS FIR. (From Cole et al., 1975.)

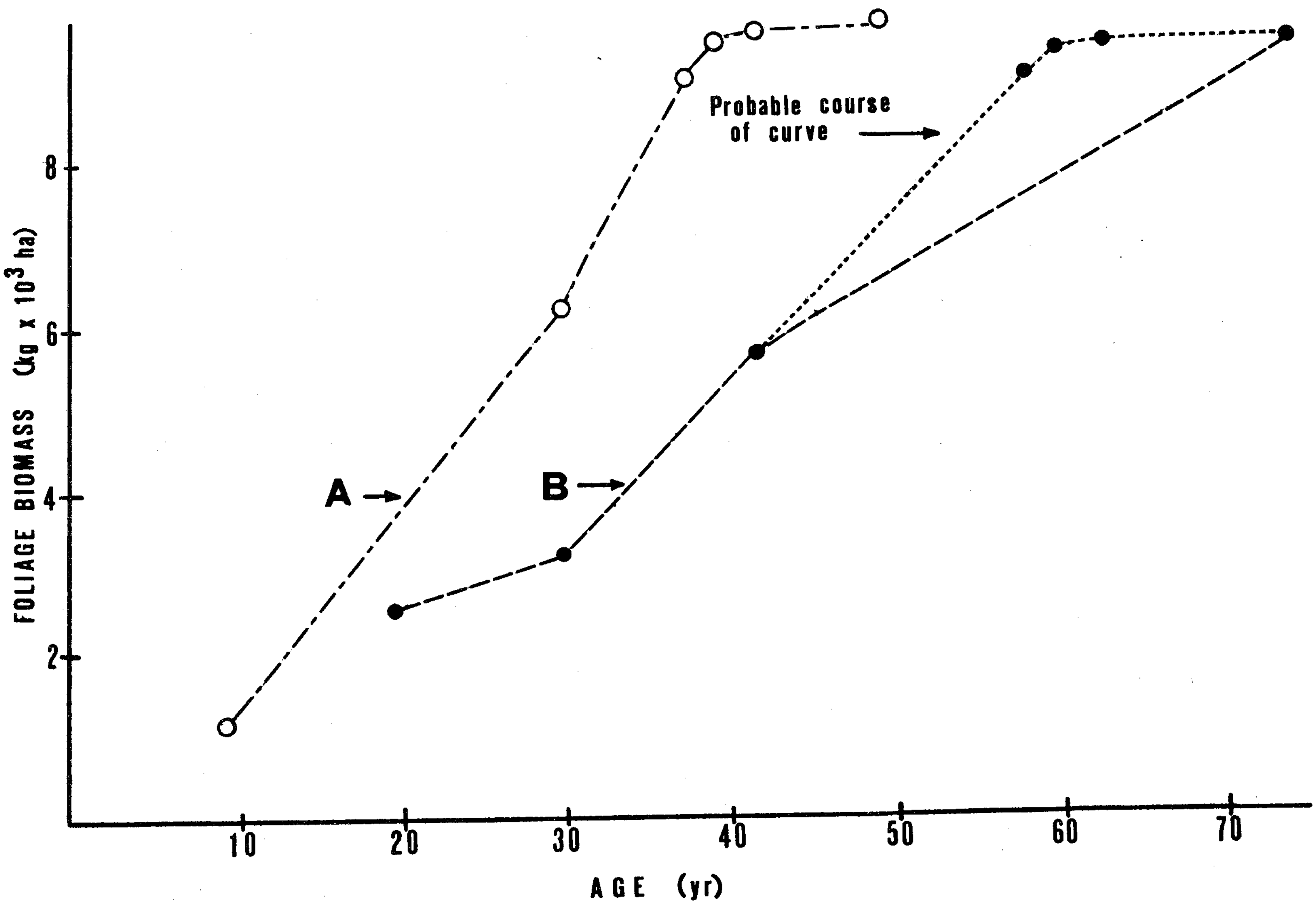


FIGURE 3-58. FOLIAGE BIOMASS AS A FUNCTION OF AGE AT THE THOMPSON SITE (WESTERN HEMLOCK ZONE) IN A PLANTATION (A) AND A NATURALLY REGENERATED STAND (B). (From Edmonds, 1974.)

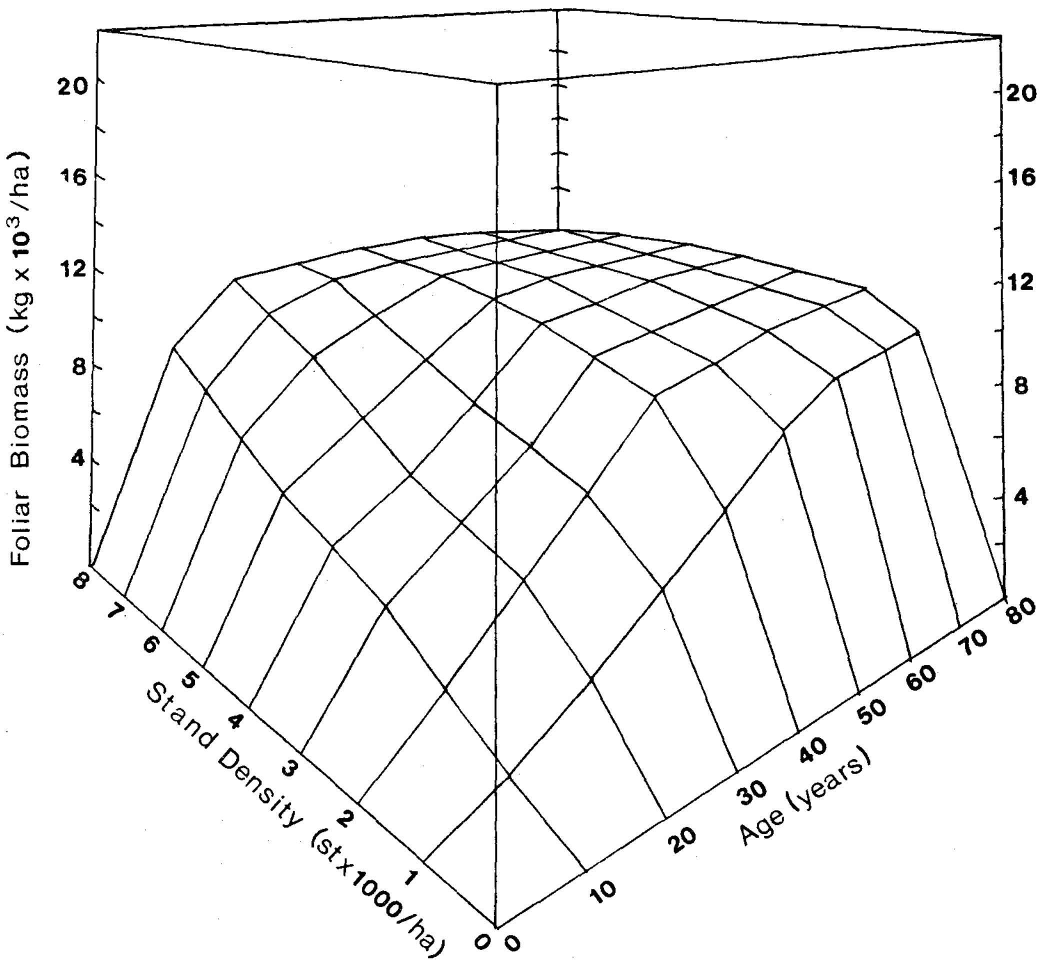


FIGURE 3-59. RELATIONSHIP BETWEEN FOLIAR BIOMASS, STAND AGE, AND STAND DENSITY (STEMS PER HECTARE) FOR DOUGLAS FIR STANDS OF LOW PRODUCTIVITY. (From Cole et al., 1975.) St represents stems.

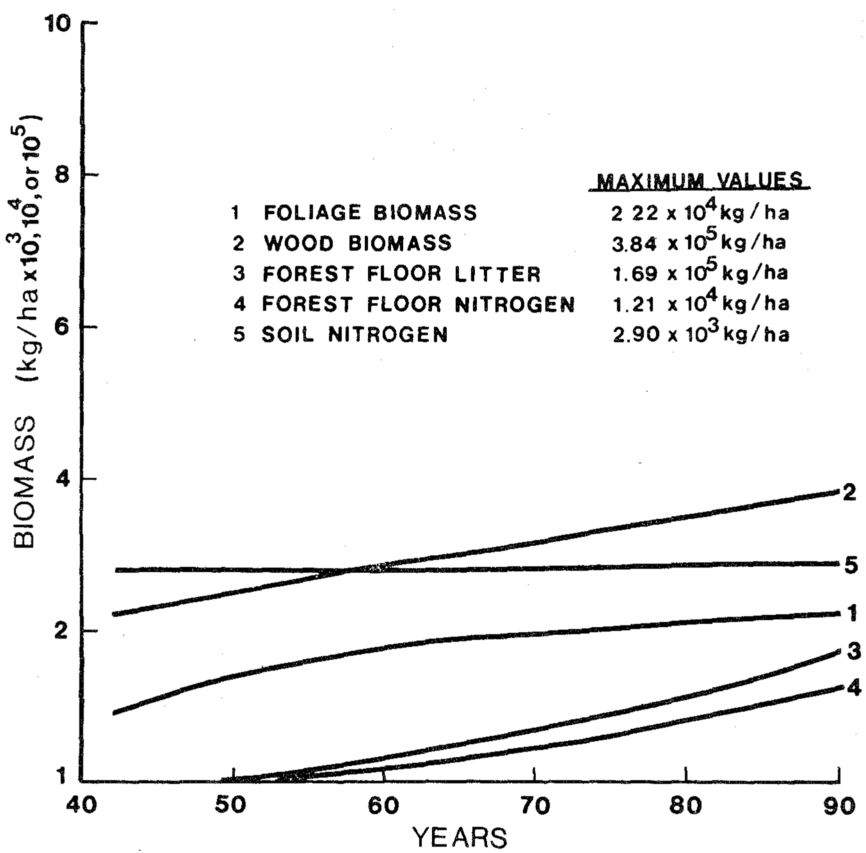


FIGURE 3-60. PREDICTED BIOMASS AND NITROGEN VALUES FROM INTERNATIONAL BIOLOGICAL PROGRAMME SIMULATION MODEL. (From Edmonds, 1975.)

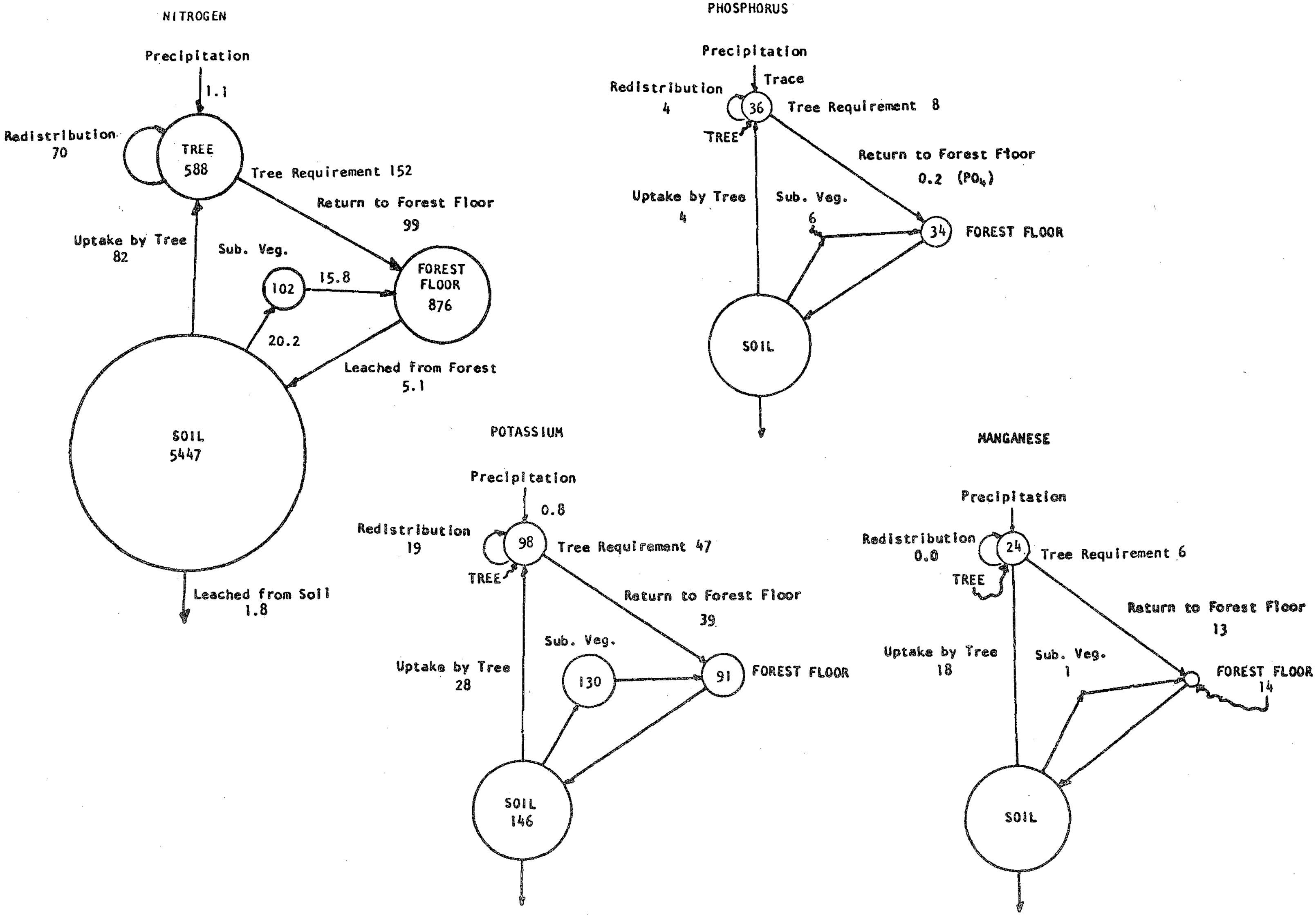


FIGURE 3-61. DISTRIBUTION AND CYCLING OF NITROGEN, PHOSPHORUS, POTASSIUM AND MANGANESE IN A 35 YEAR-OLD RED ALDER ECOSYSTEM. Nutrient capitals and flows are kg per ha and kg per ha per year, respectively. Compare this figure with Figure 3-10 in the Old Growth ecosystem model discussion for changes in nutrient cycling between seral stages. (From Edmonds, 1974.)

TABLE 3-42. CHANGES IN THE DYNAMICS OF NITROGEN UPTAKE, REQUIREMENTS, AND ACCUMULATION FOR A SERIES OF AGES OF DOUGLAS FIR. (From Cole et al., 1975.)

Age (yr)	Total tree accumulation (kg/ha)	Tree require-ments (kg/ha)	Tree uptake (kg/ha)	Requirements/ total tree (%)	Uptake/ total tree (%)	Uptake/ require-ments (%)
9	33	4	2	12	6	55
35	288	39	21	14	7	54
73	297	42	22	14	7	53
95	362	35	19	10	5	53

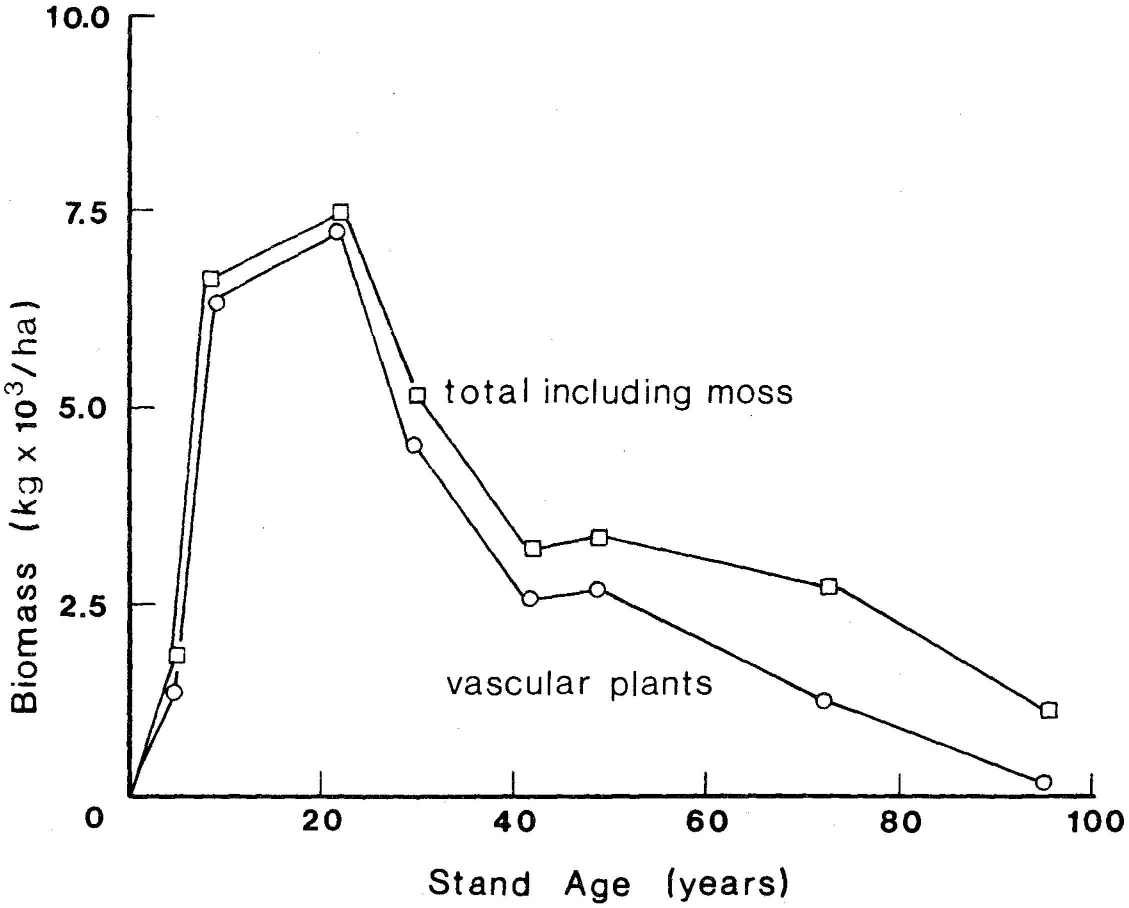


FIGURE 3-62. ACCUMULATION OF BIOMASS IN THE UNDERSTORY VEGETATION OF VARIOUS AGED STANDS OF DOUGLAS FIR. (From Cole et al., 1975.)

3.2.4.2 Estuarine Succession. The principal geomorphological estuary type in the region is the drowned river valley. As the name implies, these features were created by rising sea level or land subsidence which then flooded a former river valley. Typically, littoral transport begins to separate an estuary from the ocean by developing spits. The spits are generally kept from closing by the constant tidal currents of water moving in and out of the embayment and by runoff into the embayment. Section 2.6 of Volumes 1 and 2 presents information on these physical processes of estuary formation and function with general and regional-specific discussions.

Figure 3-63 presents a very general estuarine succession model for the region. As with any such model, it is a simplified representation, but shows some of the major processes and rate-controlling factors that act in estuarine habitat changes. The following brief discussion elaborates on this model.

As stated in Section 2.6 of Volume 1, the material budget of estuaries is almost always positive and has been documented as such within the region. For example, sediments are being deposited in Tillamook Bay at an estimated rate of 135,000 tons annually (Klingeman et al., 1969); the estuary is now only forty percent of its former size (James, 1970). Similar trends are documented for most of the low gradient estuaries in Oregon by Percy et al. (1974).

Low gradient estuaries act as sediment basins for materials from both upland and coastal origins. One suggested explanation for recent increases in sedimentation and filling of estuaries has been proposed as increased erosion resulting from extensive forest fires around the 1900's and subsequent poor logging practices (James, 1970; Coats, 1978). However, there is considerable debate concerning the likelihood of sedimentation originating from poor logging practices (Gibbons and Salo, 1973; Crow et al., 1976).

In any case, sedimentation is responsible for the constant dredging required in estuarine channels by the U.S. Army Corps of Engineers and is the source of sediments which, in conditions of low current and energy, establish mud and sand flats. Eelgrass helps to stabilize these sediment flats where conditions for its colonization and growth are present. This in turn often leads to further sedimentation in the eelgrass "trap," until the area rises in elevation to the intertidal zone, often reverting then to sand or mud flats with ephemeral algae coverings. Phillips (1978, pers. comm.) suggests caution, however, in assuming the predictability of such an eelgrass-induced succession.

Field data support the hypothesis of marsh succession from the intertidal mud and sand flats within the region (Johannesson, 1964). Soil cores in upper marshes show remains of plant species which are characteristic of lower marshes (Eilers, 1975; Jefferson, 1974). Also, expansion of salt marshes is well documented in the region (see Emergent Vegetation Ecosystem Model Notes, Section 3.2.1.2 of this volume, Note #6).

Salt marshes develop on mud and sand flats approximately 1.25 meters (4 ft) above MLLW. Once these have been established - probably by rhizome fragments - progradation is increased by the filtering action of the marsh plants. Some erosion occurs but progradation is likely as long as sediment supply is available. Under some conditions a dynamic equilibrium can be reached, which tends to fix the successional sequence, as materials are deposited and eroded at similar rates. Simultaneously, incipient marsh creeks become fixed in position although little hydraulic head is available for the formation of deep channels.

At lower elevations, long submergence periods allow only monospecific plant communities to develop, hence low diversity is characteristic of these areas.

Vertical accretion continues as vegetation binds surface sediments, adds root growth, and continues to reduce currents and increase sedimentation. At this point, detritus is not incorporated into the soil but is largely exported to adjacent estuarine environments (Eilers, 1975).

As the marsh height approaches MHHW, rates of accretion increase due to 1) increased deposition of plant detritus, 2) poor decomposition conditions established by anaerobic soils and the presence of _Juncus balticus_ and _Agrostis alba_, which are resistant to decay, and 3) decreased export of detritus due to less frequent inundation. A break in slope occurs between MHHW and approximately 0.5 meter (1.5 ft) above MHHW. At this point vertical accretion is again reduced (Eilers, 1975).

Several interrelated factors contribute to this developmental sequence. The soils above this break in slope are aerobic and therefore condusive to rapid decomposition. The species colonizing the high marsh are not as resistant to decay as the species of the transition area. The soil of the high marsh is host to numerous soil decomposers such as earthworms which increase decomposition rates. Consequently, once established, the high marsh remains largely level with some invasion of more terrestrial flora on logs which are deposited in high water at the fringe of the

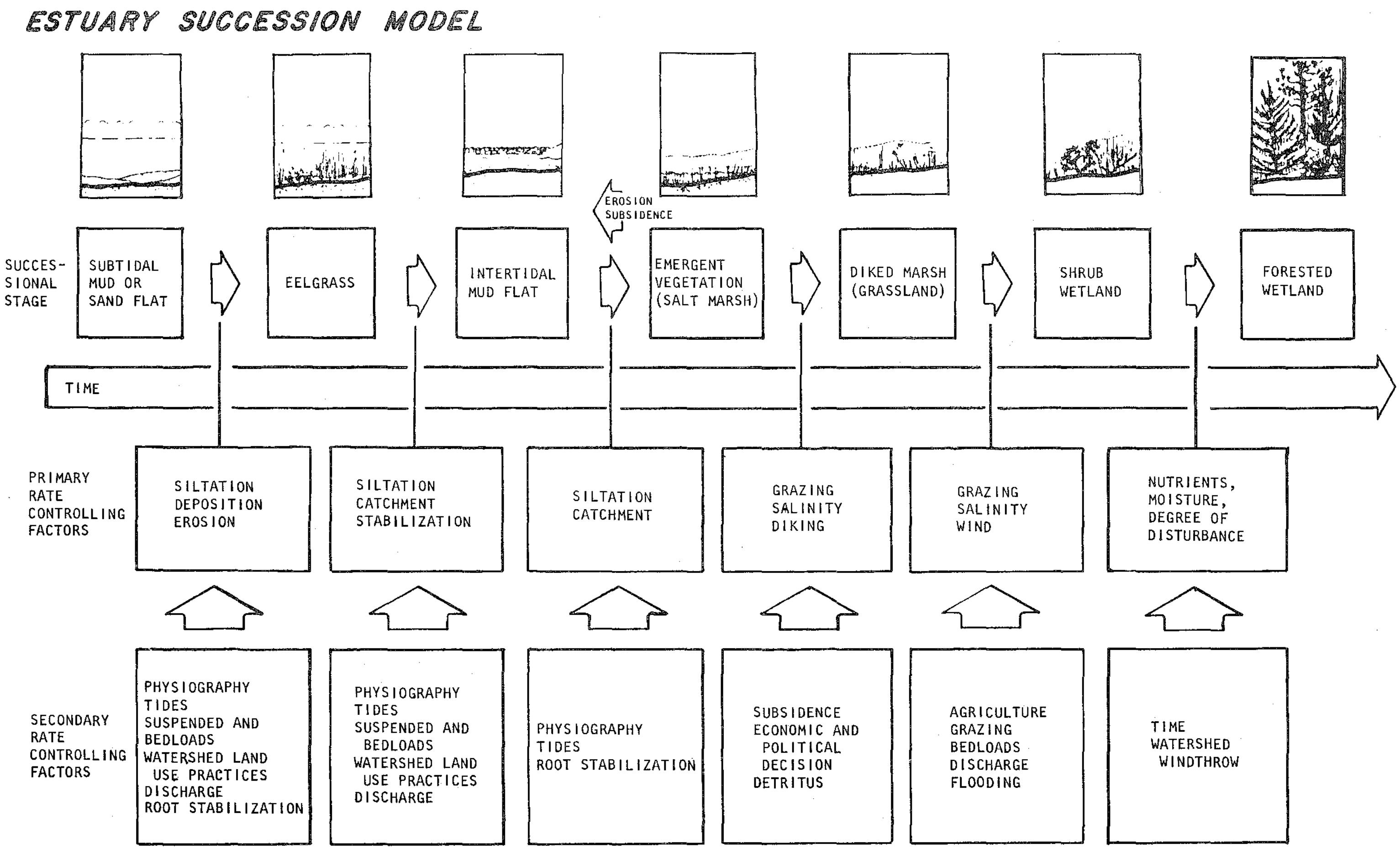


FIGURE 3-63. ESTUARY SUCCESSION MODEL.

marsh. Near stable conditions in high marshes have been documented in other areas (Ranwell, 1972), as have successional sequences into more upland conditions.

A stable high marsh presumes a condition of a static sea level. With a dropping sea level, the high marsh would succeed to upland communities. With a rising sea level, the community would revert to transitional or low marsh condition. If particular conditions in a high salt marsh are such that organic accumulation is greater than decomposition and subsidence, the community would succeed to upland brush and forest community.

As discussed in the ecosystem model notes (Section 3.2.1.2) under loss of habitat (Note #17), successional sequences in salt marshes have been truncated by diking and filling. Extensive areas of salt marsh have been transformed into upland habitats for various land uses, principally agriculture and urban or commercial development.

Figure 3-64 suggests a generalized successional sequence in an estuary and a beach, as well as a "reverse succession" in an eroding shore.

Although a single sequence is implied in the previous discussion, actual succession is more complex and dependent on sediment type, estuary type, and gradient. Figure 3-65 shows some hypothetical patterns of succession as proposed by Jefferson (1974). Additional species distribution information can be assessed from Figure 3-23, 3-24, and 3-25 given in Section 3.2.1.2. Species on the lower elevations indicated in these figures are early successional species, while those in the upper elevations are later successional species. (Not all species are necessarily part of successional process.)

Estuary succession of the region has been discussed by Eilers (1975), Jefferson (1974), Vanderzanden (1976), and others. Eelgrass, mud flat, and emergent vegetation succession have been reported in considerable detail. Additional information on succession is provided in the Emergent Vegetation Ecosystem Model Notes (Section 3.2.1.2).

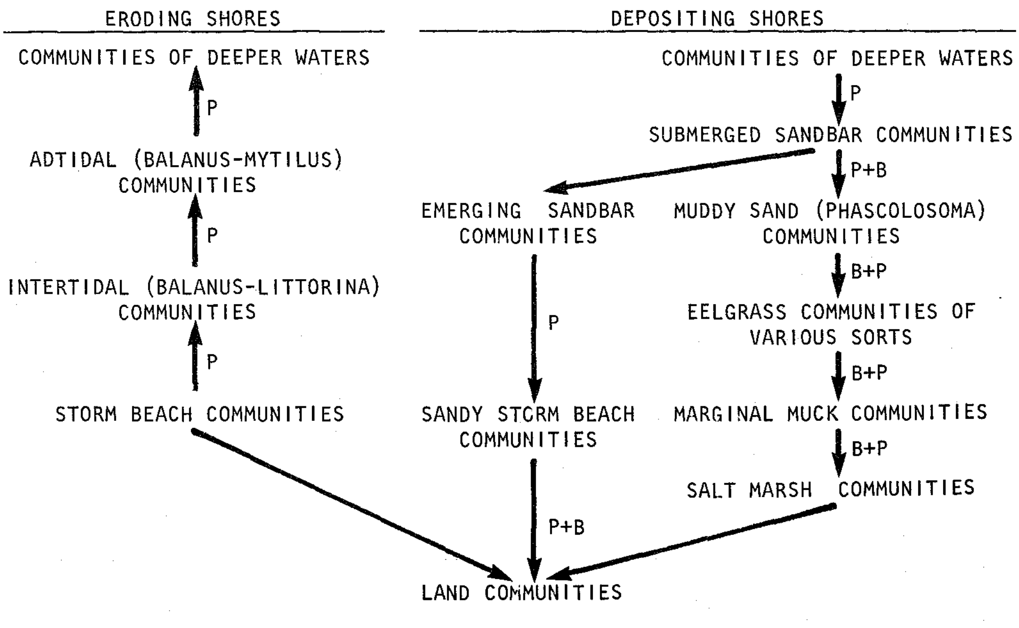


FIGURE 3-64. SCHEMATIC DIAGRAM OF COMMUNITY EVOLUTION IN ESTUARINE (RIGHT) AND OPEN BEACH (CENTER) DEPOSITING SHORES AND IN ERODING SHORES. Arrows show direction of succession. Letters show the principal forces acting: P = physiographic, B = biotic. (After Allee, 1934, in Phillips, 1974.)

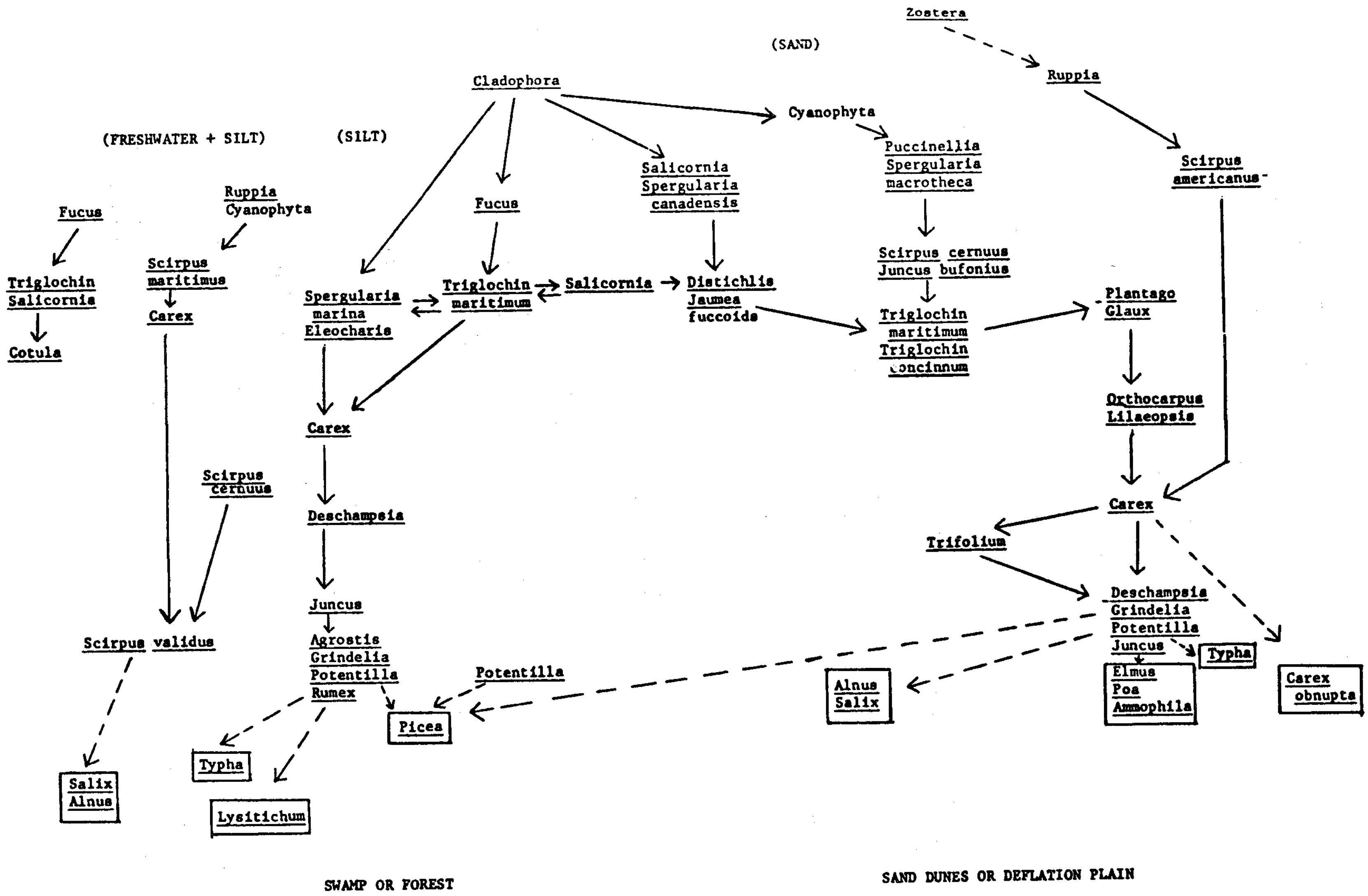


FIGURE 3-65. HYPOTHESIZED SPECIES SUCCESSION IN AN OREGON COASTAL SALT MARSH. Common names can be found in the ecosystem notes (Section 3.2.1.2), in the Annotated Species List, and in the Community Composition printout for Emergent Vegetation in Volume 3. (Solid lines indicate documented succession. Dashed lines indicate possible succession but no documentation exists at this time. Pers. comm. 30 January 1980, Carol A. Jefferson, State University at Wanona, Winona, Minnesota.) (From Jefferson, 1974.)

3.3 THE ANNOTATED SPECIES LIST

The computerized information system developed for the species found in the Pacific Northwest Coastal Region is described briefly in this section (3.3) of Volume 1 and presented in full in Part 2 of Volume 5.

The ASL, although general in its structure, is specific to this region in the zones and habitats included and in the ranges (by Watershed Units), abundances, seasonalities, and other species data entered. Only the most common, characteristic, or significant plants have been entered in the inland, estuarine, shoreline, and oceanic fields (vascular and non-vascular), due to the large numbers encountered; all the tree species and most major shrubs are included. Likewise, only a sampling of the major invertebrates was entered for these areas, again because of large numbers of species found in the region in this diverse animal category. (Insect species alone are estimated at over 5,000 in the region.) For the other major groups (fish, reptiles and amphibians, birds, and mammals), an effort was made to include all the species usually found in the coastal region. The major functional group of organisms not included in the ASL at this time is the decomposers, because of the numbers involved, the taxonomic problems encountered, the lack of regional-specific and species-specific data, and the "black box" treatment of the group in most environments by most authors.

See Volume 5 for more details.

3.4 SPECIES OF CONCERN

A number of species within the region are of significant interest or concern, either because of commercial value (e.g. Douglas fir, salmonids), recreational value (e.g. black-tailed deer, waterfowl, rainbow trout), rare, endangered, or threatened status (e.g. Columbian white-tailed deer), or community dominance (e.g. kelp, eelgrass). Many species fall into more than one of these categories, such as Douglas fir, which is a commercial species and a dominant species in many second growth forests, or salmon, which are of both recreational and commercial significance.

Species of Concern are treated in a number of places in this study. In this section (3.4) of Chapter 3, general data are presented for commercial species (3.4.1, forestry, fishery, and fur-bearing importance), recreational species (3.4.2, big-game, small-game, and sport fishery value), and "status" species (3.4.3, rare, threatened, endangered, or other significance). Community dominant species such as eelgrass are presented in the ecosystem model notes in Section 3.2.1 for five key habitats.

Selected species or groups of species, as indicated in Table 3-43, are discussed in detail in part 2 of this volume, following the population model format introduced in Section 3.4 of Volume 1. A brief discussion of mortality, reproductive rate, population size, interaction with man, etc., is provided for each species or group, with access to the pertinent literature on these topics indicated throughout.

Habitat use and additional information for any species can be gained from the Annotated Species List in the Data Source Appendix (Volume 5, Part 2). The Status field of the ASL includes the following categories: rare (R), endangered (E), threatened (T), peripheral (P), endemic (I), game (G), commercial or potentially commercial (C), and pest (X), any of which can be searched for a particular Watershed Unit, zone, habitat, or trophic level. All rare, endangered, or threatened animals (official) and plants (proposed) of the region are included in the ASL and printed out as special tables in Section 3.4.3 of this chapter.

One can review the ecosystem models, the community composition models, and the food web models of the habitats (Volume 3, Part 2) in which the species are found, to determine the role the species of interest plays in that given community and ecosystem. Species of Concern are keyed in the community composition lists to facilitate cross-reference.

Living resources are fundamental to the economy of the coastal region. Forestry and fisheries, two of the basic industries of the region and major sources of income and employment (see Chapter 4), are completely dependent upon native flora and fauna and a reasonably intact supporting ecosystem. Other organisms which are not commercially or recreationally exploited have real economic values as well (Ehrenfeld 1976).

TABLE 3-43. SELECTED SPECIES OF CONCERN. The following species or groups are discussed in detail in Part 2 of this volume. These species accounts, presented in order as below, are prepared as notes to the population model (Figure 3-12 in Volume 1 and Figure 1 of Part 2 of this volume).

PLANTS	
trees:	Douglas Fir (Pseudotsuga menziesii)
	Oregon Myrtle (Umbellularia californica)
	Port Orford Cedar (Chamaecyparis lawsoniana)
	Red Alder (Alnus rubra)
	Redwood (Sequoia sempervirens)
	Sitka Spruce (Picea sitchensis)
	Western Hemlock (Tsuga heterophylla)
	Western Red Cedar (Thuja plicata)
ANIMALS	
invertebrates:	Dungeness Crab (Cancer magister)
	Insects
fish:	Chinook (Oncorhynchus tshawytscha)
	Coho (Oncorhynchus kisutch)
birds:	Bald Eagle (Haliaeetus leucocephalus)
	Sea Birds (Alcids, Shearwaters, Petrels, Gulls, etc.)
	Snowy Plover (Chadaerius alexandrinus)
	Spotted Owl (Strix occidentalis caurina)
mammals:	Black-tailed Deer (Odocoileus hemionus columbianus)
	Columbian White-tailed Deer (Odocoileus virginianus leucurus)
	Marine Mammals (Cetaceans, Seals, Sea Otter)
	Roosevelt Elk (Cervus canadensis roosevelti)

3.4.1 Species of Commercial Value.

3.4.1.1 Forestry Species. Major forestry species and their proportional contribution to forest harvest of the region are provided in Tables 3-44, 3-45, and 3-46. As the data indicate, Douglas fir followed by western hemlock are the principal commercial tree species in Watershed Units 1-7 with redwood followed by Douglas fir as the principal tree species in Units 8 and 9. In recent years Douglas fir has made up more than 60% of the tree harvest in the study area.

The regional forests are among the most productive in the world, for volume of timber produced (about 36 metric tonnes/ha/year, or 14 long tons/a/year, on optimum sites) (Fujimori, 1971) and high standing biomass (2,300 and 1,600 metric tonnes/ha, or 920 and 640 long tons/a, for redwood and Douglas fir stands respectively) (Franklin and Dyrness, 1973). In fact, a review of the National Register of Big Trees (Pardo, 1978) indicates that of the 25 tree species which ranked over 500 points (a rating involving circumference, crown spread, and height) all but eight were found in the study area. Four out of the five largest trees listed, i.e. redwood, western red cedar, Sitka spruce, and Douglas fir, are located within the region, the exception - and largest tree - the giant sequoia of the California Sierras. Trees of the study area are fast growing, long-lived, and large.

As an indication, the coastal area (including forests to the crest of the Cascades) provides about 35-37% of the softwood production in the United States, approximately one quarter of which is derived from the study area (Western Wood Products Association, 1976). In 1966 through 1974 Oregon, California, and Washington, in that order, were the leading lumber producing states in the country (Western Wood Products Association, 1976).

As indicated in Tables 3-44 through 3-46, the major commercial tree species of the area are principally conifers, with Douglas fir being the most significant and redwood, western hemlock, western red cedar, Sitka spruce, and grand fir being locally abundant. The cause of coniferous dominance in the region is not well understood. Climatic conditions which include high total precipitation that is distributed principally during spring, fall, and mild winters is thought to be a key factor (Franklin and Dyrness, 1973). Such conditions give coniferous species a competitive advantage over hardwoods because of their ability to assimilate energy during fall, winter, and spring. The dry summer conditions limit photosynthesis during the periods when deciduous trees are typically most productive. The few hardwood species are predominantly seral species (e.g. red alder), although evergreen hardwoods (e.g. Oregon myrtle, Umbellulario californica) become more significant in the southerly portions of the region.

TABLE 3-44. LUMBER PRODUCTION IN WESTERN WASHINGTON AND WESTERN OREGON BY SPECIES, 1964-76[1] AND TOTAL LUMBER PRODUCTION FOR CALIFORNIA REDWOOD REGION, 1964-1975. Data are in million board feet. (From Ruderman, 1977A,B,C, and Western Wood Products Association, 1976.)

	Western Washington and Western Oregon[2]									California Redwood Region[3]
Year	All Species	Douglas Fir	Western Hemlock	Western Red Cedar	Sitka Spruce	Grand Fir	Pine	Other Softwoods	Hardwoods[4]	All Species
1964	8,578	5,346	2,239	300	70	310	184	49	80	2,263
1965	8,422	5,201	2,263	330	78	231	196	42	81	2,105
1966	8,012	5,003	2,051	321	57	215	221	50	94	2,022
1967	7,617	4,778	1,922	328	50	208	192	48	91	1,998
1968	8,130	5,190	1,909	363	45	245	222	52	104	2,385
1969	7,632	5,073	1,652	306	29	198	210	48	116	2,308
1970	7,475	4,907	1,697	300	17	227	195	26	106	2,238
1971	8,283	5,297	2,022	331	19	246	208	55	105	2,312
1972	8,983	5,711	2,244	348	41	251	241	37	110	2,515
1973	9,074	5,659	2,266	369	40	287	277	36	140	2,519
1974	7,777	5,074	1,719	358	32	177	250	33	134	2,390
1975	7,134	4,684	1,535	364	15	148	233	46	109	2,194
1976	8,322	5,363	1,967	368	30	171	231	64	128	

[1] Includes areas outside of study area to crest of Cascades.

[2] From Ruderman, 1977A,B,C.

[3] From Western Wood Products Association, 1976.

[4] Predominantly red alder.

TABLE 3-45. 1975 LUMBER PRODUCTION BY COUNTY AND SPECIES IN THE COAST REGION.[1] Data are in million board feet. (From Western Wood Products Association, 1976.)

STATE & COUNTY	Total Production	Douglas Fir	Western Hemlock	Western Red Cedar	Sitka Spruce	Grand Fir	Pines	All Others
OREGON								
Clatsop-Tillamook	159	46	104	1	2	--	--	5
Coos	427	407	19	1	*	--	--	*
Curry	90	88	1	*	*	*	--	1
Douglas	687	433	76	49	--	12	84	32
Lane	1,141	911	156	62	--	--	2	10
Lincoln	118	112	5	*	*	--	--	1
Total	2,622	1,997	361	113	2	12	86	49
WASHINGTON								
Clallam-Jefferson-Kitsap-Mason	327	169	139	12	1	--	*	6
Grays Harbor	114	47	57	4	--	--	--	5
Pacific-Skamania-Thurston	192	102	68	3	11	--	7	1
Total	633	318	264	19	12	--	7	12
TOTAL OREGON AND WASHINGTON REGION	3,255	2,315	625	132	14	12	93	61

[1] Whole county totals are given, including data from areas outside of the watershed boundaries of this study.

* Less than 500,000 board feet.

TABLE 3-46. 1972 LOG CONSUMPTION BY SPECIES FOR NORTH COAST[1] OF CALIFORNIA. Data are in million board feet, local scale. (From Howard, 1974.)

	All Species	Douglas Fir	Western Hemlock	True Firs	Redwood	Ponderosa and Sugar Pines	Incense Cedar	Other Softwoods	Hardwoods[2]
Total	1,711	585	14	58	950	60	3	41	2

[1] Includes all of Humbolt and Mendocino Counties, including areas outside of the watershed boundaries of this study. Note that ponderosa and sugar pines are not found in the study area.

[2] Primarily madrone and tanoak.

The use of fast growing trees (e.g. red alder) on marginal sites for the production of biologically derived fuel ("biomass conversion") has attained considerable public and private attention in recent years. Recent and ongoing studies will determine the economic and ecological feasibility of such production in the near future (Smith, 1973; Kimmins and Krumlik, 1976; Carlisle, 1976; Ince, 1977; and others).

Other commercial uses of forest species in the region are usually categorized as "special forest products" and include Christmas tree production, coniferous Christmas tree boughs, floral greenery, native transplants, edible products, crude drugs, forest seed cones, fuelwood, decorative wood, split cedar products, small roundwood products (e.g. poles), and others (Hirsch, 1970). Total value of special products production in Washington and Oregon for 1969 was 15.5 million dollars, with a substantial portion of the production developed in the study area.

Principal Christmas tree species are Douglas fir, true firs (noble, shasta, silver, alpine, grand, concolor), and pines (Scotch, shorepine). Species used for Christmas tree boughs include noble, shasta, silver, and alpine firs, Douglas fir, western red cedar, Port Orford cedar, and pines. Floral greenery species include swordfern, evergreen huckleberry, and salal; native transplants are principally rhododendron, salal, evergreen huckleberry, vine maple, and shorepine. Edible forest products are taken from huckleberry, trailing blackberry, Himalayan blackberry, evergreen blackberry, and wild plum. Species used for deriving crude drugs include cascara, quinine conks, Douglas fir pitch, prince's pine (pipsissewa), Oregon grape, and false hellebore. Oregon myrtle is the principal decorative wood species of the study area and western red cedar is the tree species most commonly used for shake production; alder is the principal wood fuel species, with madrone and tanoak more commonly used in the southerly Watershed Units. The preferred species for round wood poles is Douglas fir.

An extensive literature has been developed on silvics (life histories) of the commercial tree species. A useful synoptic silvics review by species is provided by Fowells (1965). Additional information on distribution is provided by Griffin and Critchfield (1972) for California, and Franklin and Dyrness (1973) for Oregon and Washington. The PACFORNET MASTER KEY WORD INDEX found at the Forest Resources Library at the University of Washington and at Pacific Southwest Science Literature Service, Berkeley, California, is another good source of species-specific information about the commercial forest trees found within the region.

<u>3.4.1.2 Fishery Species.</u> Fish and shellfish play an important role in the coastal economy as documented in Chapter 4 (Section 4.3). Commercial and sport fishing combined - it is often impossible to separate the two in fishery statistics - are a $100 million+ per year industry in the coastal region and account for three to eight percent of the region's payroll employment, as well as undocumented significance in the tourism/recreation economy of the area.

Fisheries species and their proportional contribution to catch are provided in Tables 3-47, 3-48, and 3-49 for Washington, Oregon, and California, respectively. As indicated, coho and chinook salmon, albacore tuna, Dungeness crab, flatfish, lingcod, rockfish, shrimp, and oysters are the important commercial groups. Catch of specific species varies considerably year to year, with composition of total catch being based on status of stocks in a given year as well as market demands. Some species, e.g. shark livers, are no longer taken due to lack of market demand, and others, such as sockeye, chum, and sardine catches, are no longer taken in large quantities because of reduced stocks (Pruter and Alverson, 1972; Washington State Department of Fisheries, 1976). An example of the variability which can be expected in species composition and catch is provided in Table 3-50.

Historically, foreign catches on the continental shelf have been taken by the Soviet trawler fleet in pursuit of hake and by Japanese trawlers in pursuit of Pacific Ocean perch. The Soviet trawlers caught 136,000 metric tons in 1966. They subsequently made an agreement to restrict fishing for ocean perch but continued to take hake, with the largest catch of 226,000 metric tons in 1972. The U.S. jurisdictional extension of fishing management areas (from 12 to 200 miles) may restrict Russian fishing activity on the coast.

In recent years, U.S. fishermen have complained that the foreign fishing of hake and sablefish has caused gear loss for U.S. fishermen (Oregon State Department of Fish and Wildlife, 1976B). As a consequence, many Oregon fishermen left the fisheries. There are also reports of catch of nonpermissible species (e.g. salmon) being taken (Oregon State Department of Fish and Wildlife, 1976A; Sanders, personal communication, 1978).

The Japanese fisheries reached a maximum catch in 1968 of 4,500 metric tons, but dwindled to 500 metric tons shortly thereafter (U.S. National Marine Fisheries Service, 1977B) and is now closely regulated through the Fishery Conservation and Management Act of 1976 (the "200-Mile Fisheries Act:" P.L. 94-265).

TABLE 3-47. WASHINGTON COASTAL COMMERCIAL LANDINGS OF FINFISH AND SHELLFISH 1974, 1975, AND TWO YEAR AVERAGE. All figures are in pounds. (From Washington State Department of Fisheries, 1976.)

WASHINGTON	1974	1975	AVERAGE
FINFISH			
Cod (true)	809,437	714,396	761,917
Flounders	141,507	35,830	88,668
Hake	2,440	--	1,220
Halibut	3,742	17,531	10,637
Lingcod	940,499	659,802	800,151
Pacific Ocean Perch		4,530	2,265
Rockfish	1,818,099	1,591,762	1,704,931
Sablefish/Black Cod	484,848	656,864	570,856
Salmon			
Chinook	5,407,838	5,810,388	5,609,113
Chum	775,163	429,688	602,426
Coho	7,133,423	4,904,534	6,018,979
Humpback/Pink	2,833	275,204	139,019
Sockeye	105,715	304,011	190,460
Shad	232,580	60,460	146,520
Smelt[1]	2,092,799	2,106,391	2,099,595
Anchovy	554,000	567,000	560,500
Turbot	185,843	42,558	114,201
Sole[2]	2,596,441	1,653,898	2,125,170
Sturgeon[3]	233,920	329,480	281,700
Albacore/Tuna	14,946,440	15,414,528	15,180,484
Other Fish	99,692	56,644	78,168
TOTAL FINFISH	38,567,259	35,635,499	37,086,980
SHELLFISH			
Clams			
Bay	12,177	938	6,558
Razor	170,763	219,769	195,266
Crabs/Dungeness	4,765,585	6,114,817	5,440,201
Shrimp[4]	9,262,345	10,000,690	9,631,518
Pacific Oyster	2,404,398	2,624,445	2,514,422
Octopus	1,661	1,771	1,716
Crawfish	353	161	257
TOTAL SHELLFISH	16,617,282	18,962,591	17,789,938
GRAND TOTAL	55,184,541	52,598,090	54,876,918

[1] All species of smelt including eulachon.

[2] All species of sole combined.

[3] Combined white and green sturgeon data.

[4] All species of shrimp, dominated by pink shrimp *Pandalus jordani*.

3.4.1.2 Fishery Species (continued)

Productivity of the continental shelf in the study area is high, with annual potential yield of demersal fish and shellfish estimated at 3 metric tonnes/km^2 dropping to 2 metric tonnes/km^2 for California waters (Rounsefell, 1975). Barss et al. (1977) report a potential yield of 0.39 metric tonnes/km^2 for six species of flatfish making up 46% of the standing biomass of demersal fish based on an averaged two year sample for the shelf waters off Washington. Total yield excluding foreign catch for the 1974-1975 average was 186,747,750 pounds or about 2.6 metric tonnes/km^2, approaching the potential yield estimated by Rounsefell (1975).

TABLE 3-48. OREGON COASTAL COMMERCIAL LANDINGS OF FINFISH AND SHELLFISH. All figures are in pounds. (From Oregon State Department of Fish and Wildlife, 1976B.)

OREGON	1974	1975	AVERAGE
FINFISH			
Cod (True)	700,607	588,029	644,318
Flounders	613,504	887,588	750,546
Hake	36,416	6,320	21,360
Halibut	67,630	57,616	62,623
Lingcod	2,167,563	1,664,442	1,916,003
Mink Food	724,342	432,367	578,355
Pacific Ocean Perch	887,044	921,419	904,232
Rockfish	4,021,492	3,256,707	3,639,100
Sablefish/Black Cod	601,181	728,981	665,081
Salmon and Steelhead			
Chinook	4,911,284	6,534,955	5,723,120
Chum	3,272	4,625	3,949
Coho	10,054,741	5,823,540	7,939,141
Humpback/Pink	81	1,041	561
Sockeye	21	7	14
Steelhead	129,414	26,529	77,972
Shad	264,505	456,758	350,631
Smelt	424,627	9,147	216,887
Sole			
Dover	5,714,525	4,886,918	5,300,722
English	1,786,406	2,173,321	1,979,864
Petrale	2,746,087	2,654,859	2,695,973
Other	1,665,878	1,677,052	1,671,465
Striped Bass	35,151	18,019	26,585
Sturgeon			
Green	85,771	32,974	59,373
White	271,203	301,284	296,244
Albacore/Tuna	33,039,926	23,584,409	28,455,289
Other Fish	395,770	1,137,350	766,560
TOTAL FINFISH	71,348,441	57,866,257	64,607,345
SHELLFISH			
Clams			
Bay	16,403	28,508	22,456
Razor	8,553	40,465	24,509
Crabs/Dungeness	3,917,625	4,126,937	3,972,281
Shrimp	20,313,760	24,083,568	22,198,664
TOTAL SHELLFISH	24,256,341	28,179,478	26,217,909
GRAND TOTAL	95,604,782	86,045,735	90,825,255

Hart (1973) gives a good review of the biology of marine fish species of the region as well as some information on harvest trends. Isakson (1976B) reviews literature specific to Washington State which includes many of the commercial species of the study area. Oregon State University (1971) provides good literature review on selected species of the continental shelf which includes commercial species. Information about the distribution, abundance, and seasonality of salmonids for Washington coastal waters is given by Washington State Department of Fisheries (1973). Oregon State Fish and Game Commission (Lauman et al, 1972A; Smith and Lauman, 1972; Lauman et al., 1972B; Lauman, 1972; Thompson et al., 1972) lists similar information for Oregon waters. The Pacific Marine Fisheries Commission (Portland, Oregon) is in the process of developing a "salmon plan" and has a number of resource reports summarizing the status of salmonids of the region. Oregon and Washington now jointly publish an annual report on the Columbia River anadromous fish status (Gunsolus, 1977). The International Pacific Halibut Commission maintains current data on halibut stocks and publishes annual reports on their status (International Pacific Halibut Commission, 1976; 1978).

TABLE 3-49. EUREKA DISTRICT COMMERCIAL LANDINGS OF FINFISH AND SHELLFISH. All figures are in pounds. (After California State Department of Fisheries, 1974, 1975.)

EUREKA DISTRICT CALIFORNIA NORTH COAST	1974	1975	AVERAGE
FINFISH			
Shark	7,769	5,200	6,485
Skate	33,503	38,988	36,245
Eel	45	0	23
Cod (True)	7	0	4
Flounders	387,149	199,451	293,300
Hake	14,669	50	7,360
Halibut	4,105	3,973	4,039
Lingcod	1,413,264	627,809	1,020,537
Perch	1,653	0	827
Rockfish	6,650,179	4,480,987	5,565,583
Cabezon	545	0	273
Sablefish	4,847,879	3,820,944	4,334,412
Grenadiers	43,436	80,534	61,985
Salmon	4,804,548	4,295,661	4,550,105
Shad	290	2,385	1,338
Herring	119,683	26,082	72,883
Smelt	661,473	543,734	602,604
Anchovy	940	0	470
Turbot	5,311	6,008	5,660
Sanddab	300,048	178,354	239,201
Sole			
Dover	15,119,494	10,454,058	12,786,776
English	1,620,120	1,087,673	1,353,897
Petrale	1,401,148	885,180	1,143,164
Rex	870,177	717,663	793,920
Sand	74,917	42,373	58,645
Other	2,955	97	1,526
Surfperch	31,912	22,558	27,235
Albacore/Tuna	3,134,721	2,318,991	2,726,856
Mackerel, Jack	2,623	8	1,316
Other Fish	5,556	176	2,417
TOTAL FINFISH	41,560,119	29,838,937	35,699,086
SHELLFISH			
Clams	104	144	124
Crab/Dungeness & Market	335,176	3,475,722	1,905,450
Shrimp	2,214,492	3,745,954	2,980,223
Pacific Oyster	478,633	396,429	437,531
Octopus	19,476	10,204	14,840
Squid, Market	0	891	446
Sea Urchin	15,759	0	7,880
TOTAL SHELLFISH	3,063,640	7,629,344	5,346,494
GRAND TOTAL	44,623,759	37,468,281	41,045,580

3.4.1.2 Fishery Species (continued)

The National Marine Fisheries Service (Seattle, Washington) keeps up-to-date records on stocks and catch of commercial species within the region. Washington State Department of Fisheries publishes an annual report on catch. The Oregon State Department of Fish and Wildlife Research Laboratory at Newport maintains up-to-date data on Oregon demersal stocks and trends. The International North Pacific Fisheries Commission publishes various technical reports on status of commercial species of the study area.

TABLE 3-50. COMPARATIVE ANNUAL LANDINGS OF FISH, SHELLFISH, AND SHARKS (LIVERS) FOR THE GRAYS HARBOR DISTRICT, WASHINGTON, IN NUMBER OF POUNDS.[1] (From Washington State Department of Fisheries, 1976.)

YEAR	Salmon	Bottom Fish	Other Food Fish	Shellfish	Shark Livers	Total Landings	YEAR
1935.....	5,544,587	....	101,465	1,145,716	.....	6,791,768	1935
1936.....	5,069,308	2,016	13,210,505	1,272,117	.....	19,553,946	1936
1937.....	3,895,270	34,702	34,727,537	1,273,523	.....	39,931,032	1937
1938.....	4,093,046	2,758	56,668,596	1,891,152	.....	62,655,552	1938
1939.....	4,027,032	35,858	37,459,182	1,624,956	.....	43,147,028	1939
1940.....	5,503,682	200,262	2,614,090	2,125,882	.....	10,443,916	1940
1941.....	8,308,135	968,776	35,279,806	2,217,908	34,248	46,808,873	1941
1942.....	4,985,018	843,439	2,590,325	2,491,457	39,272	10,949,511	1942
1943.....	3,968,827	2,840,055	26,114,568	2,971,423	200,333	36,095,206	1943
1944.....	3,891,296	6,583,603	10,011,335	3,178,463	204,664	23,869,361	1944
1945.....	6,303,804	7,393,591	10,090,251	3.243,988	120,040	27,151,674	1945
1946.....	5,610,053	4,504,934	14,168,226	4,766,852	100,206	29,150,271	1946
1947.....	5,639,836	1,433,057	6,565,549	7,902,401	9,077	21,549,920	1947
1948.....	6,304,947	1,828,541	4,437,142	10,145,169	6,607	22,722,406	1948
1949.....	5,667,279	375,836	4,240,371	8,920,811	4,912	19,209,209	1949
1950.....	6,828,337	711,721	3,650,585	3,448,834	758	14,640,235	1950
1951.....	7,909,320	1,013,631	797,435	2,529,713	10,052	12,260,151	1951
1952.....	9,714,586	2,089,729	585,884	2,504,288	18,688	14,913,175	1952
1953.....	7,537,352	792,102	492,455	3,842,519	52,403	12,716,831	1953
1954.....	6,674,163	617,996	621,550	4,515,690	96	12,429,495	1954
1955.....	6,899,157	606,581	588,574	5,125,973	177	13,220,462	1955
1956.....	5,992,036	603,677	695,703	5,543,918	.....	12,835,334	1956
1957.....	5,565,527	444,491	432,791	11,011,571	69	17,454,449	1957
1958.....	4,704,710	1,148,719	1,352,009	14,134,703	539	21,340,680	1958
1959.....	4,391,810	579,975	2,410,868	7,240,888	869	14,624,410	1959
1960.....	2,586,317	1,157,823	585,369	4,822,624	935	9,153,068	1960
1961.....	4,547,889	609,635	675,499	5,182,018	267	11,015,308	1961
1962.....	5,036,235	1,067,372	610,246	4,573,236	.....	11,287,089	1962
1963.....	5,579,791	984,907	363,940	4,064,003	.....	10,992,641	1963
1964.....	4,350,161	1,048,251	533,824	3,314,842	.....	9,247,078	1964
1965.....	5,361,253	1,492,902	898,295	5,697,445	.....	13,449,895	1965
1966.....	6,268,188	1,735,021	4,263,437	8,141,757	.....	20,408,403	1966
1967.....	6,814,942	933,358	19,708,462	6,760,606	.....	34,217,368	1967
1968.....	5,691,733	466,740	954,634	6,369,907	.....	13,483,014	1968
1969.....	5,086,720	521,692	1,534,424	14,310,669	.....	21,453,505	1969
1970.....	7,918,084	698,547	1,472,885	11,847,150	.....	21,936,666	1970
1971.....	7,651,758	935,674	6,105,843	8,498,122	.....	23,191,397	1971
1972.....	5,474,754	1,973,106	4,470,205	8,758,305	.....	20,676,370	1972
1973.....	8,211,140	3,623,631	3,312,015	4,325,670	.....	19,472,456	1973
1974.....	8,754,477	5,674,795	4,413,563	5,067,649	.....	23,910,484	1974
1975.....	6,517,905	4,262,746	6,834,757	6,801,810	.....	24,417,218	1975

[1]Table includes all fish landed in Grays Harbor and LaPush ports from inshore and offshore waters of Watershed Units 1 and 2. These were almost half of the total commercial landings for coastal Washington for the years 1974 and 1975 (see Table 3-47).

Salmonids. Chinook and coho are the major commercial and sport salmon species throughout the region, although sockeye, chum, and pink salmon are taken in northern portions of the study area.

Salmonid species are migratory with catch off any given portion of coast line of mixed origin. Conditions are further complicated as stocks and fishery fleets cross state and national boundaries. The generalized migration pattern of stocks is indicated in Figures 3-66 and 3-67 for coho and chinook respectively. The distribution of fishery fleets is presented in Figure 3-68 The Columbia River, Fraser River (in Canada), and Puget Sound rivers are major contributors to chinook stocks off Washington. Chinook stocks off California originate in California and Oregon. The Oregon fleet principally fishes Oregon coastal chinook stocks, California chinook stocks, and Columbia River chinook stocks. The Washington fleet's chinook catch is from Oregon coastal, Columbia River, Idaho, Washington coastal, and British Columbia stock (U.S. National Marine Fisheries Service, 1977B). Stocks of coho and chinook salmon are heavily utilized with catch to escapement ratios varying from 3:1 to 4.9:1 (Korn, 1977; Holland, 1977). Specific years and stocks may vary from these ratios.

The catch pattern for coho differs markedly from that of chinook. California coho catches are principally from Oregon coastal, Columbia River, and Washington coastal stocks. The Washington take is derived from Puget Sound, Washington and Oregon coastal, and Columbia River stocks (U.S. National Marine Fisheries Service, 1977B). There is a marked northerly migration of Washington chinook and coho stocks (Holland, 1977).

Recently, genetic selection for stocks which remain near the area of release, and timing of release of juveniles so that their normal migratory pattern is altered are modifying the migratory pattern of some local stocks.

The commercially important salmonid species of the study area are anadromous and ascend rivers and streams to spawn. Eggs are laid on gravel of freshwater streams and the hatched juveniles spend some portion of their early lives in those streams prior to migrating to the ocean. A two to six year period of feeding and rapid growth in the ocean is followed by return of sexually mature adults to the parent stream. Information on life cycle, biology, and related population topics for chinook and coho salmon is provided in the Species of Concern section in Part 2 of this volume.

Population fluctuations are typical for salmon species but causes of the variability are not clearly documented. Figure 3-69, which presents salmon catch for Washington State from 1935 to 1975, illustrates this year to year variability. Factors which are significant to the population status of salmon are complex, interractive, and cumulative. Environmental conditions in streams during spawning periods, destruction of spawning habitat, impediment of migration, mortality caused by nitrogen supersaturation and power generating turbines during the downriver migration of juveniles, and oceanic predation, all in combination with food supply and oceanic migration, establish the population level for a given area at a given time.

Excluding the Columbia River runs, little information is available on total strength of runs produced in waters of the study area. The only available data are an escapement, i.e. an estimate of the number of fish which return to spawn, but these numbers do not include fish which are taken by various fisheries. Estimated escapement for the region is presented in Table 3-51. The data may be misleading, as exploitation rates are as high as 85% for fall run of chinook of the Columbia River and approximately 0% for protected runs such as the summer chinook run of the Columbia. Even for a given run, escapement as a proportion of total run is not constant.

Natural production of salmon has been augmented by hatchery production. Summaries of hatchery production for Washington State coastal waters, Oregon, and California are presented in Tables 3-52, 3-53, and 3-54, respectively. Table 3-55 summarizes hatchery production on the Columbia River system which has many of its production areas outside of the coastal area. However, all of these anadromous fish from the Columbia enter the study area for a portion of their life cycle. Loss of natural production due to land use changes, water quality problems, etc., have, at least in part, been compensated by the hatchery production. Fulton (1968, 1970) reports serious depletion of Columbia River runs (steelhead trout, chum salmon, coho salmon, sockeye salmon, and king salmon) because of loss of suitable spawning areas through land use changes, water quality changes, or access problems caused by dams. Chum, sockeye, and the summer run (Columbia) chinook are the species most significantly affected in the Columbia runs (Korn, 1977). Most authorities agree that without the artificial propagation even the healthy chinook and coho runs would be very low (Holland, 1977; Korn, 1977). The trend in increased hatchery production is exemplified in Table 3-52. In addition several new hatcheries are under construction (Oregon State Department of Fish and Wildlife, 1976B).

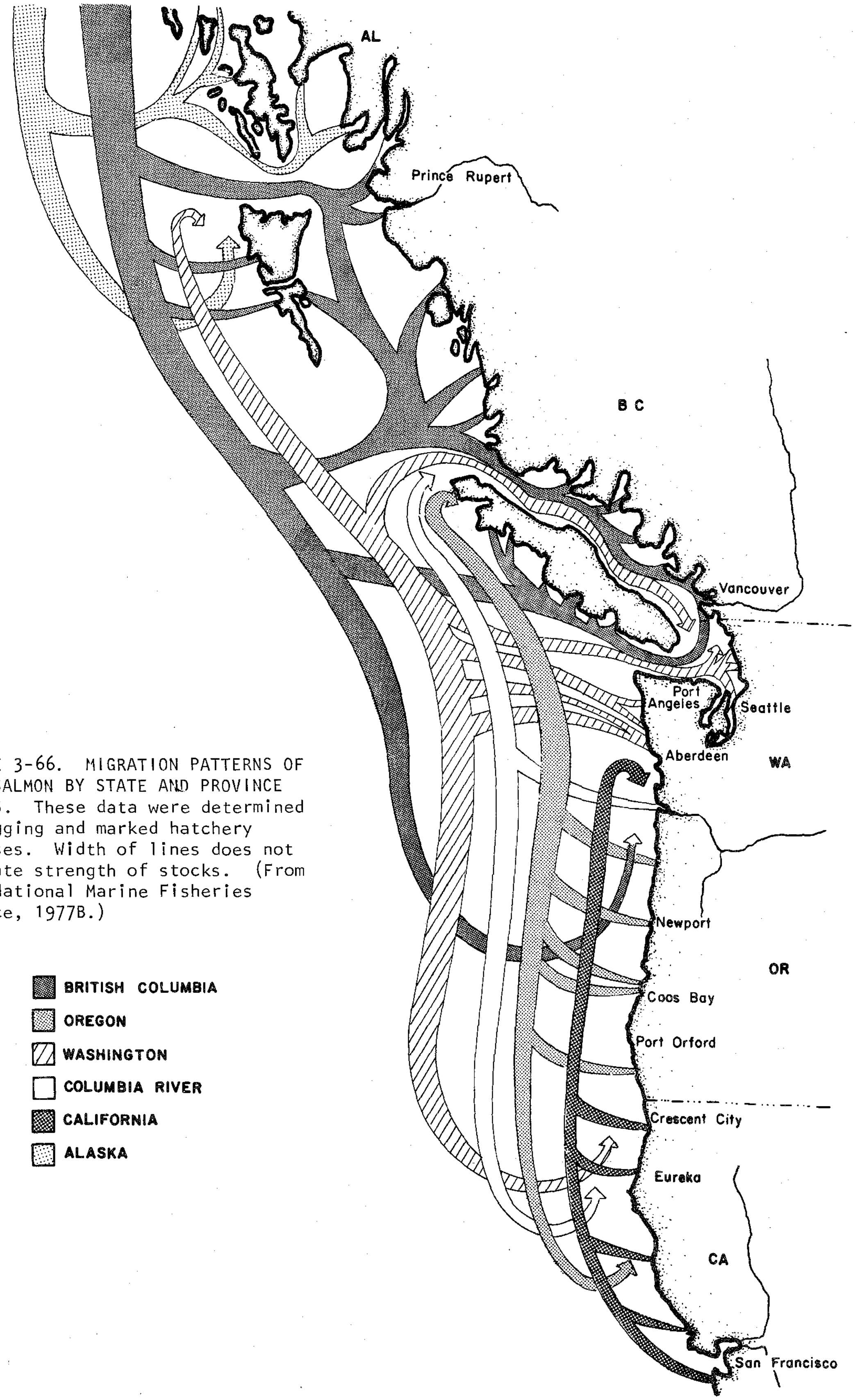


FIGURE 3-66. MIGRATION PATTERNS OF COHO SALMON BY STATE AND PROVINCE STOCKS. These data were determined by tagging and marked hatchery releases. Width of lines does not indicate strength of stocks. (From U.S. National Marine Fisheries Service, 1977B.)

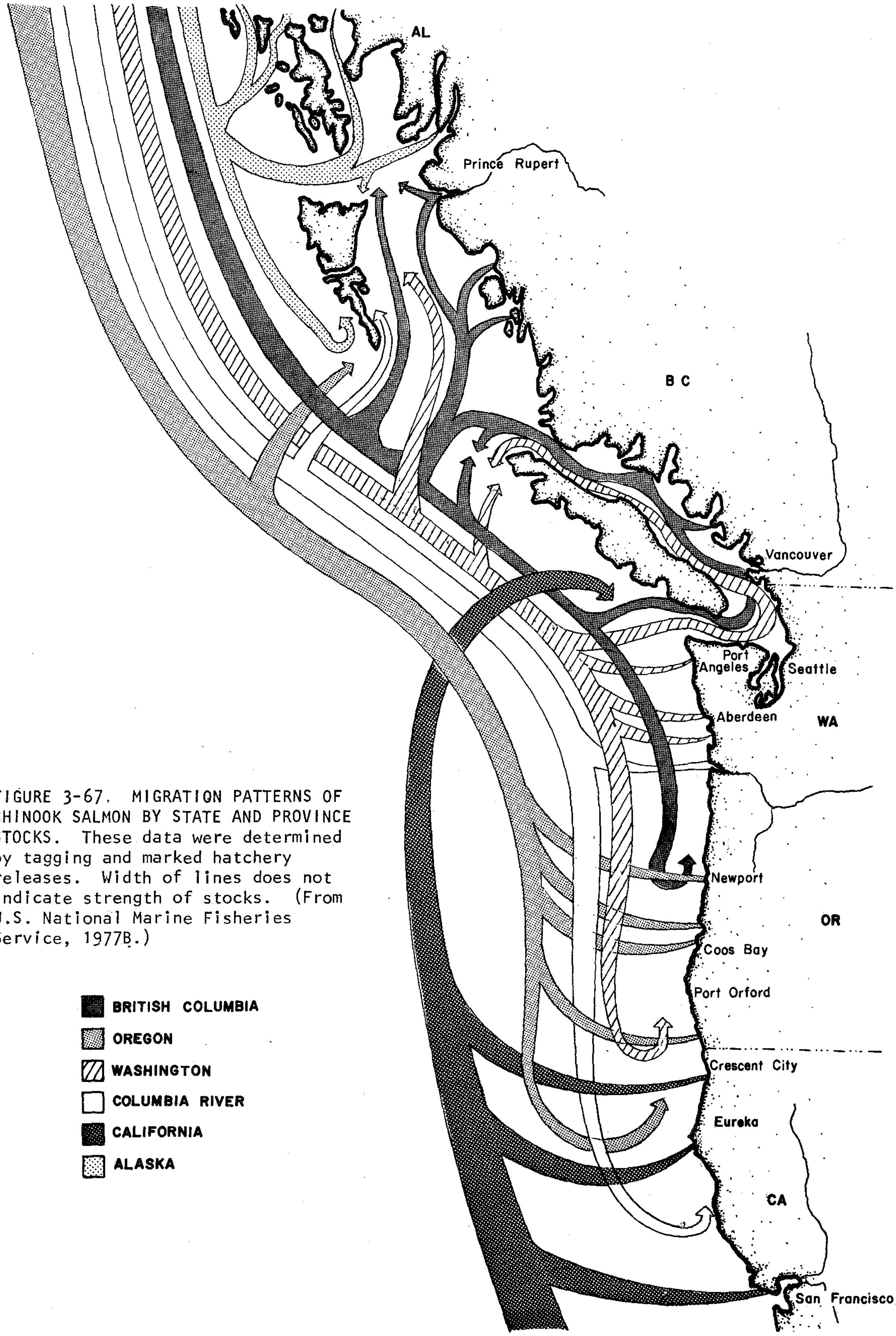


FIGURE 3-67. MIGRATION PATTERNS OF CHINOOK SALMON BY STATE AND PROVINCE STOCKS. These data were determined by tagging and marked hatchery releases. Width of lines does not indicate strength of stocks. (From U.S. National Marine Fisheries Service, 1977B.)

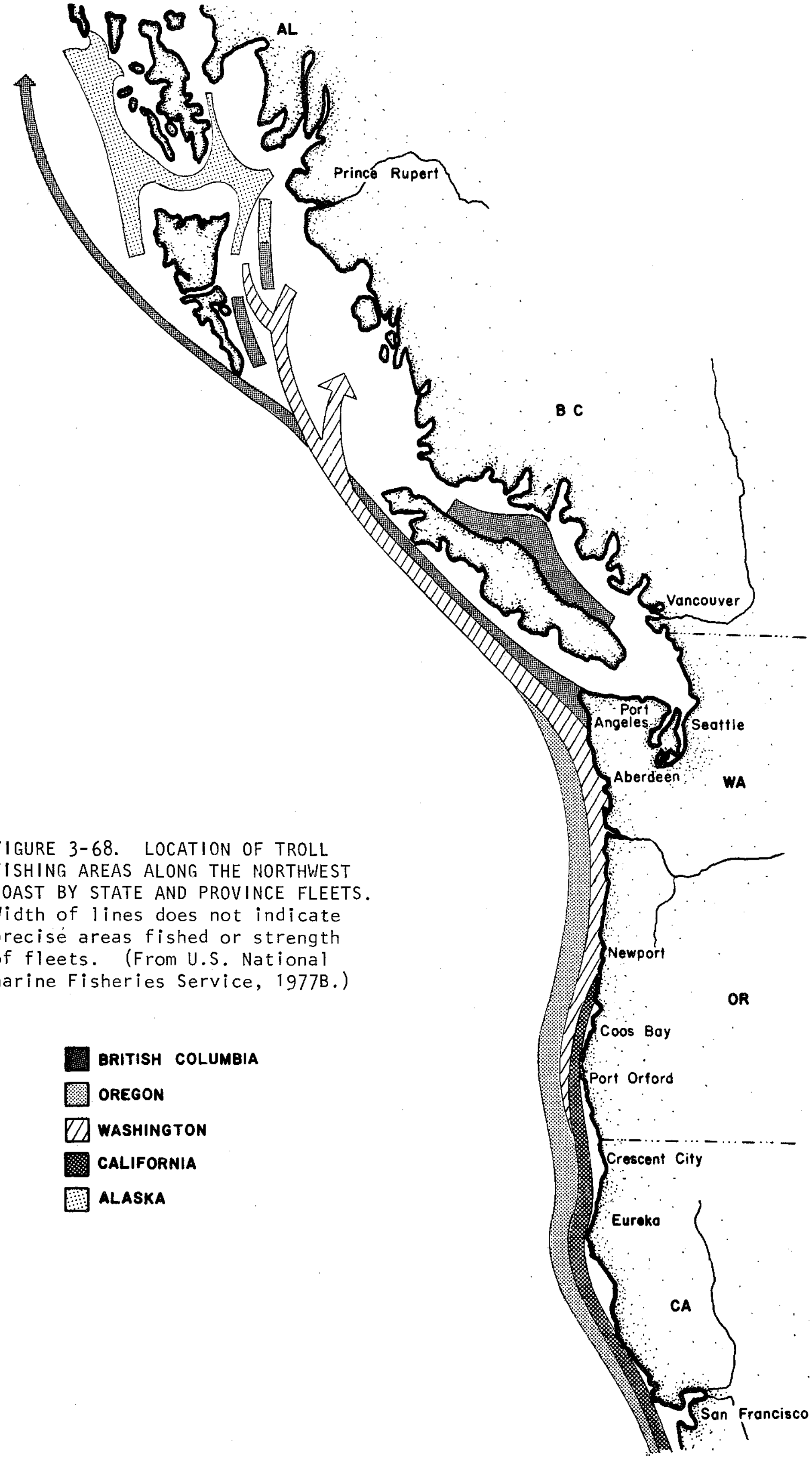


FIGURE 3-68. LOCATION OF TROLL FISHING AREAS ALONG THE NORTHWEST COAST BY STATE AND PROVINCE FLEETS. Width of lines does not indicate precise areas fished or strength of fleets. (From U.S. National Marine Fisheries Service, 1977B.)

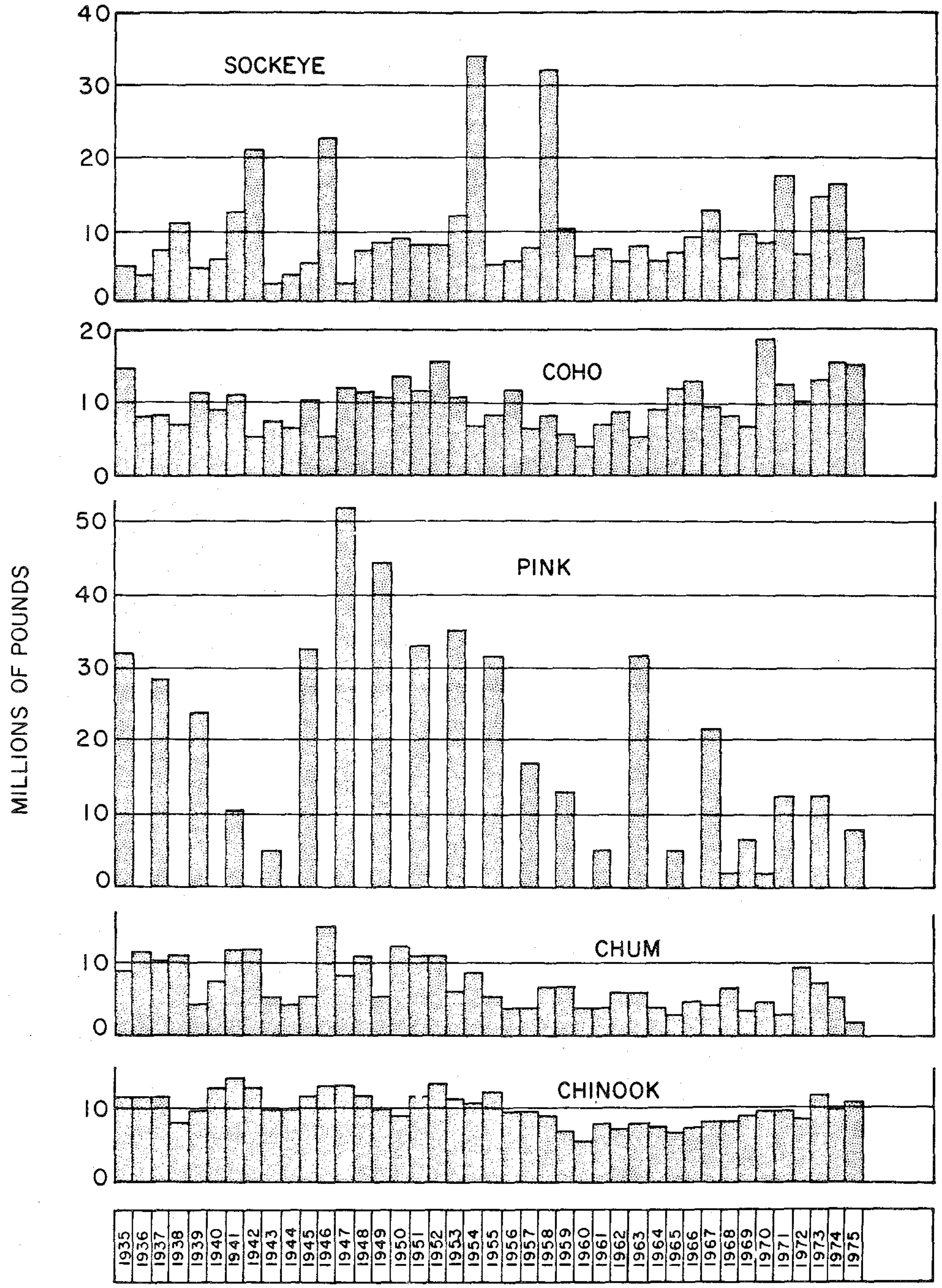


FIGURE 3-69. TOTAL SALMON PRODUCTION FOR WASHINGTON STATE OVER 40 YEARS. (From Washington State Dept. of Fisheries, 1976.)

TABLE 3-51. ESTIMATED ESCAPEMENT OF SALMON IN STUDY AREA.

WATERSHED UNIT	CHINOOK[1]	COHO	CHUM	SOCKEYE
1[2]	33,000	70,000	8,000	115,000
2[3]	33,400	165,400	20,000	--
3[4]	406,800[5]	252,050[6]	--[7]	52,100[8]
4[9]	80,860	118,705	14,750	--
5[10]	44,580	139,980	--	--
6N[11]	17,600	25,000	--	--
6S[12]	111,500	5,000	--	--
7 & 8[13]	19,030	51,700	--	--
9[14]	27,140	5,680[15]	--	--

1 Combines spring, fall, and summer runs.

2 Source: Washington State Department of Fisheries, 1973; nearly all natural production.

3 Source: Washington State Department of Fisheries, 1973; includes hatchery production.

4 Source: Korn, 1977, averaged for 1971-1974. Data includes all Columbia basin production.

5 Spring and fall runs are largely maintained by hatchery production. Summer runs are being depleted due to passage conditions and no attempt has been made at hatchery production.

6 Approximately 1/2 of production is through hatchery production (Korn, 1977).

7 Chum production in Columbia has been reduced from a peak of 850,000 fish in 1928 to practically no production in recent years. In fact, no chum were recorded passing Bonneville Dam in 1975 and 1976 (U.S. Army Corp of Engineers, 1976J).

8 Populations fluctuate widely, but have been low in recent years. Majority of production occurs in Lake Wenatchee and Lake Osoyoos in Central Washington.

9 Estimates based on Lauman et al., 1972A.

10 Estimate based on Smith and Lauman, 1972.

11 Estimate based on Lauman et al., 1972B.

12 Estimate based on Lauman, 1972.

13 Estimate based on Thompson et al., 1972.

14 Source: Fry, 1977; includes production in all of Klamath, Trinity, and S. Fork of Eel River Basins, averaged for 1971-1973.

15 Incomplete count; total California escapement estimated at 100,000 (Fry, 1977).

TABLE 3-52. ANNUAL PLANTINGS OF COHO AND FALL CHINOOK SMOLTS (1,000 POUNDS) FROM WASHINGTON STATE COASTAL HATCHERIES, 1953-74. Figures are in 1,000 pounds. (From Holland, 1977.)

Year	Coho	Chinook
1953	27	21
1954	38	13
1955	37	19
1956	40	16
1957	32	29
1958	53	17
1959	23	20
1960	33	18
1961	36	8
1962	48	4
1963	14	6
1964	72	15
1965	86	24
1966	111	26
1967	137	41
1968	149	35
1969	177	42
1970	191	54
1971	236	33
1972	244	47
1973	219	76
1974	257	47

TABLE 3-53. FISH RELEASED IN OREGON COASTAL WATERS FOR RECENT TWO YEAR SAMPLES. Upper figure is number of individuals, lower figure is pounds of fish. (From Oregon State Department of Fish and Wildlife, 1976B)

	Chinook			Steelhead	
Hatchery	Spring	Fall	Coho	Summer	Winter
**Alsea Salmon		290,697 27,755	2,039,025 129,022		
*Bandon				385,279 50,900	176,472 17,547
**Big Creek		12,641,932 159,070	1,461,763 114,959		111,331 17,765
*Cedar Creek	106,998 19,286	133,673 15,067		115,758 2,840	1,228,451 166,674
**Elk River		2,195,458 167,434			
*Gnat Creek	28,685 5,870			573,992 76,676	703,676 89,955
**Klaskanine		4,657,527 66,997	2,884,568 203,295		84,409 13,838
**Nehalem		110,451 3,347	2,791,873 176,707		120,114 18,678
**Siletz			969,816 71,927		
**Trask	1,343,940 48,456	664,220 38,784	804,565 51,742		
TOTAL	1,553,235	21,172,412	2,039,025	1,205,445	2,748,910

* Releases for calendar years 1974 and 1975.
** Releases for fiscal years 1975 and 1976.

TABLE 3-54. SALMON HATCHERIES CAPACITY IN NORTHERN CALIFORNIA. (From Fry, 1977.)

Name	River	Operated by	Capacity (thousands)			
			Chinook			Coho
			Eggs	90/pound	Yearlings	Yearlings
Iron Gate Salmon and Steelhead Hatchery	Klamath	Calif.	12,000	10,000	50	20
Prairie Creek Hatchery	Prairie Cr.	Humboldt Co.	500			350
Mad River Hatchery	Mad	Calif.	10,000	5,000		300
Trinity R. Salmon and Steelhead Hatchery	Trinity	Calif.	25,000	10,000		500

TABLE 3-55. COLUMBIA RIVER SALMON HATCHERIES PRODUCTION. (From Korn, 1977.)

State Hatcheries	Year of Construction	Smolts Produced[1]		
		Spring Chinook	Fall Chinook	Coho
Idaho				
Rapid River	1964	600,000	--	--
Oregon				
Big Creek	1938	--	6,000,000	800,000
Bonneville	1909	--	10,000,000	2,000,000
Cascade	1961	--	--	2,000,000
Klaskanine	1911	--	--	1,200,000
Marion Forks	1950	1,000,000	--	--
McKenzie	1902	300,000	--	--
Oxbow	1937	--	3,000,000	--
Sandy	1948	--	--	1,000,000
S. Santiam	1923	300,000	--	--
Willamette	1911	2,000,000	--	--
Washington				
Cowlitz	1967	3,500,00	5,000,000	3,000,000
Elokomin	1954	--	3,000,000	2,250,000
Grays River	1961	--	2,400,000	1,500,000
Kalama Falls	1959	100,000	4,000,000	1,500,000
Klickitat	1950	600,000	3,000,000	1,500,000
Lewis River	1909	--	--	400,000
Speelyai	1958	--	--	1,200,000
Toutle River	1952	--	3,000,000	2,000,000
Washougal	1958	--	2,000,000	3,000,000
Federal Hatcheries				
Carson	1937	1,250,000	--	--
Eagle Creek	1957	675,000	--	1,175,000
Leavenworth	1938	--	--	3,139,000
Little White Salmon	1898	456,000	6,360,000	--
Spring Creek	1901	--	12,074,000	--
Willard	1951	--	--	2,552,000
TOTAL		10,781,000	59,834,000	30,216,000

[1] Number of smolts released varies annually at most hatcheries; figures listed indicate general magnitude of releases in recent years. Additional to the smolts produced, millions of fry and fingerling salmon are released from the hatcheries. Annual releases of fry and fingerlings vary widely and are not shown.

Demersal Fish. Demory et al. (1976) and Barss et al. (1977) have recently reviewed the status of demersal fish populations on the shelf waters of Oregon and Washington.

Demersal fish biomass estimates for the continental shelf are summarized in Table 3-56. Hake is the most abundant species from the shelf and is probably underutilized. Barss et al. (1977) report that, with the exception of petrale sole, most of the flatfish stocks are underutilized. Distribution and relative density for the area between Cape Flattery and Cape Blanco have been established for the species indicated in Table 3-56. Figures 3-70 and 3-71 are provided as examples of the mapping and density data available for important demersal fish on the continental shelf from Cape Flattery to Cape Blanco.

Association of bottom type with particular species is provided in the Annotated Species List. There is a seasonal onshore/offshore migration pattern (Figure 3-72) which places many of the demersal species in shallower water during the summer months. Some authorities believe the migration is linked to the intrusion of upwelled waters into shallow nearshore areas (Alverson et al., 1964). Migration is also linked to winter spawning. Dense migrating schools are susceptible to commercial fishing efforts.

Geographic patterns of migration are not well documented for most demersal species. Most bottom species have relatively sedentary habits and are thought to be distributed in discreet and localized stocks with varying but limiting amounts of exchange between them (U.S. National Marine Fisheries Service, 1977A). Individual species of sedentary stocks have traveled great distances, however, with sablefish and Englis sole traveling as far as 1600 km (1000 mi) or more along the coast (Alverson et al., 1964; U.S. National Marine Fisheries Service, 1977A).

3.4.1.3 Furbearing Species. In recent years there has been an increased interest in furbearers due to increased market demand as indicated in Table 3-57. Pelt prices have more than doubled in the last ten years with a subsequent increased interest by trappers. This increase is documented by Table 3-58 in Washington, with similar conclusions drawn by Oregon State Department of Fish and Wildlife (1976B). Total value of trapping in Oregon State in the 1975-1976 period was estimated at $1,138,000. Value of trapping in Washington for the 1976-77 period was estimated to be $1,625,400.

Species composition of furbearer harvest for the coastal counties of Oregon and Washington is shown in Table 3-59. As these data indicate, beaver, muskrat, coyote, and raccoon are the principal species taken. Interestingly enough, the introduced opossum and nutria are also taken as furbearers in some counties. Recently, concern about the status of the bobcat as a threatened species has been raised (Oregon State Department of Fish and Wildlife, 1976A) and some protective measures may be needed if fur prices remain high. Similar problems can be expected with other furbearers unless protective measures and census techniques are developed.

A review of the Annotated Species List and other sources (Thomas et al., 1976; Forbes et al., 1976) indicates that riparian habitat is of critical importance to most furbearers, with palustrine, riverine, and lacustrine habitats also important. Species-specific accounts of furbearing species of the coastal area are provided by Maser et al. (1977). However, information is generally lacking on the status of furbearers. Population status is generally determined by harvest and population estimates tend to differ widely.

The California State Fish and Game Commission (1965A) projected the 1980 status of California furbearers as follows:

Common to abundant (more than adequate stocks will be present to meet anticipated use):

opossum	spotted skunk
raccoon	gray fox
ring-tailed cat	coyote
weasels	bobcat
striped skunk	muskrat

Locally common (use will have to be carefully regulated to maintain stocks):
- marten (presently totally protected)
- mink
- badger
- river otter (presently totally protected)
- mountain lion
- beaver

Rare or endangered:
- fisher
- wolverine (probably extinct in study area)

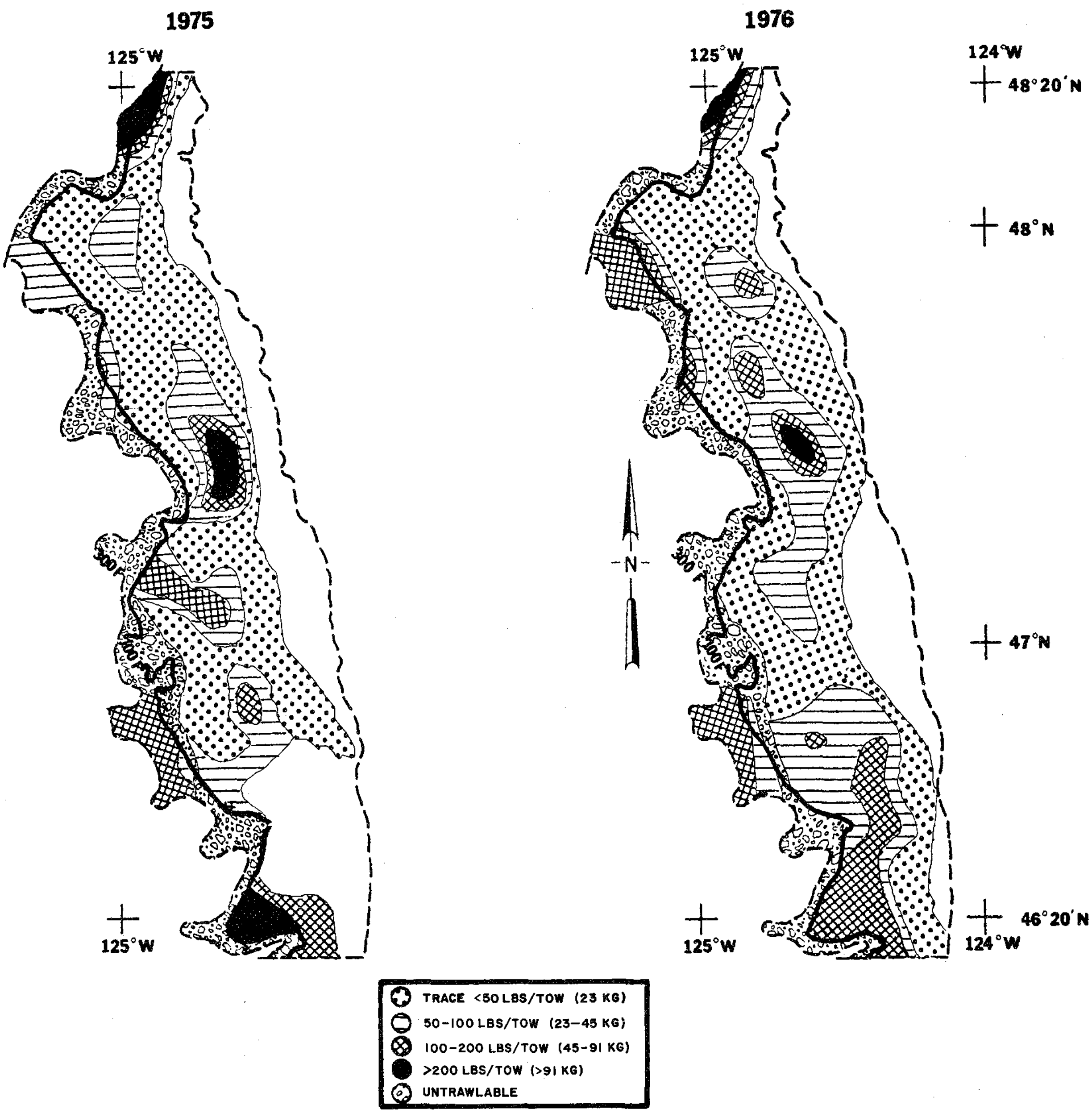


FIGURE 3-70. DISTRIBUTION AND RELATIVE ABUNDANCE OF DOVER SOLE FOR TWO ONE-YEAR SAMPLING PERIODS ON THE CONTINENTAL SHELF OF WASHINGTON, AS DEVELOPED BY BARSS ET AL. (1977). The heavy broken lines define survey limits.

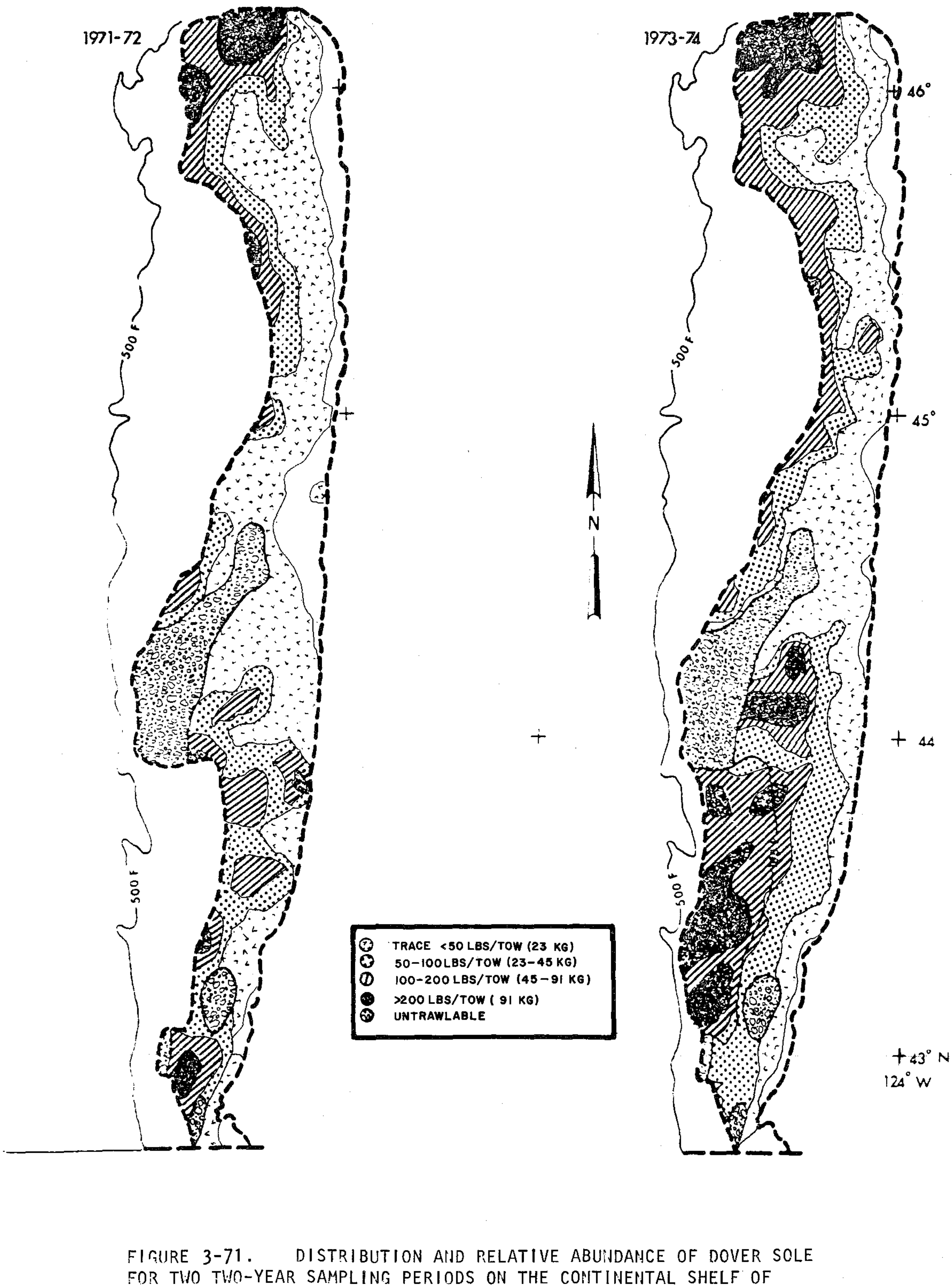


FIGURE 3-71. DISTRIBUTION AND RELATIVE ABUNDANCE OF DOVER SOLE FOR TWO TWO-YEAR SAMPLING PERIODS ON THE CONTINENTAL SHELF OF OREGON, AS DEVELOPED BY DEMORY ET AL. (1976). The heavy broken lines define survey limits.

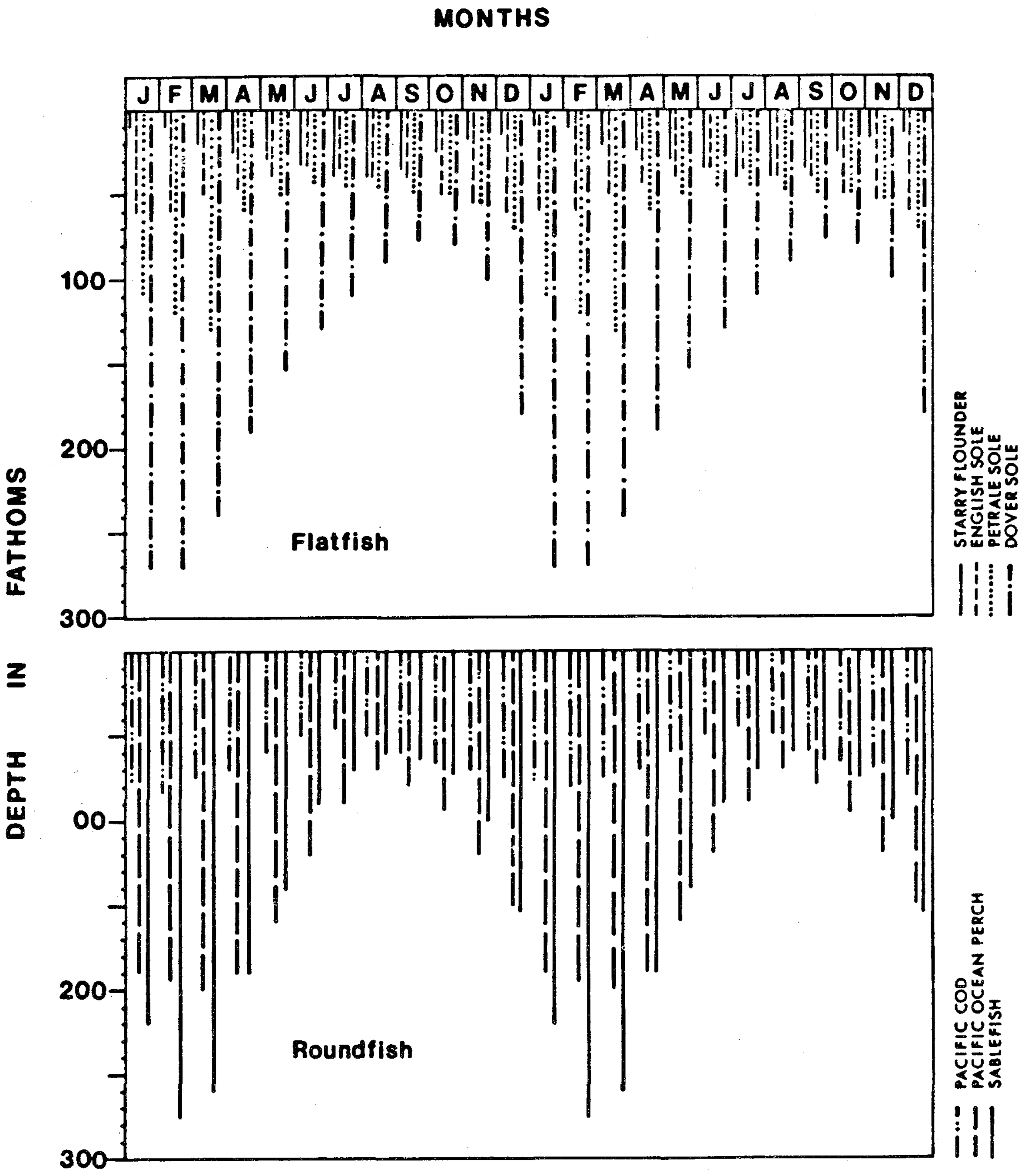


FIGURE 3-72. SEASONAL SHELF MIGRATION FOR FLATFISH AND ROUNDFISH. Vertical distribution corresponds to seasonal onshore/offshore migrations. Note: 1 fathom = 1.83 meters = 6 feet. (From Alverson et al., 1964.)

TABLE 3-56. ESTIMATES OF BIOMASS OF PRINCIPAL FISH SPECIES ON THE CONTINENTAL SHELF AND UPPER SLOPE BETWEEN CAPE FLATTERY, WASHINGTON, AND CAPE BLANCO, OREGON. Confidence Limits (95%) are expressed as ±%. (From Barss et al., 1977, and Demory et al., 1976.)

	Cape Flattery to Columbia River[1]					Columbia River to Cape Blanco[2]				
	Biomass (metric tons)				% Change from	Biomass (metric tons)				% Change from 1971-72
Species	1975	±%	1976	±%	1975-76	1971-72	±%	1973-74	±%	Shelf Only
**Spiny dogfish	7,791	62	11,225	31	+44	3,655	55	12,687	36	+247
**Skates	12,991	44	13,343	26	+03	16,925	20	17,019	12	+1
**Ratfish	1,780	44	1,534	37	-14	12,883	27	12,396	27	-4
American shad	709	55	534	76	-25	-	-	-	-	-
Pacific cod	1,977	81	1,491	93	-25	747	99	807	65	+8
**Pacific hake	11,400	79	35,662	52	+213	132,626	34	68,177	30	-49
Walleye pollock	-	-	29	179	-	-	-	-	-	-
Rockfish										
Bocaccio	93	140	81	154	-13	1,172	82	897	97	-23
Widow rockfish	2	200	1	200	-50	167	147	113	122	-32
Black rockfish	50	142	75	200	+50	290	107	471	77	+62
Yellowtail rockfish	2,616	127	611	74	-77	2,152	95	2,055	78	-5
Canary rockfish	1,976	91	825	62	-58	2,727	57	16,969	177	+522
Blackmouth rockfish	-	-	-	-	-	592	66	895	58	+51
Redstripe rockfish	16	200	19	195	+19	-	-	151	141	-
Pacific ocean perch	2,724	68	2,421	99	-11	397	126	738	36	+86
Stripetail rockfish	19	166	5	159	-74	462	98	729	98	+58
Splitnose rockfish	1,909	186	798	155	-58	114	161	154	117	+35
Flag rockfish	-	-	-	-	-	845	139	170	68	-80
Sharpchin rockfish	48	114	183	168	+281	332	98	70	114	-80
Greenstriped rockfish	553	51	503	75	-9	5,284	46	3,610	53	-32
Rosethorn rockfish	107	43	108	110	+1	32	113	383	157	+1,097
Yellowmouth rockfish	-	-	-	-	-	152	107	14	170	-91
Longjaw rockfish	-	-	-	-	-	497	128	74	200	-85
Rougheye rockfish	66	75	36	168	-45	3	200	2	127	-33
Aurora rockfish	4	200	-	-	-	35	200	25	116	-29
Turkey-red rockfish	-	-	-	-	-	-	-	119	97	-
Shortspine thornyhead	504	112	329	67	-35	1,298	46	2,509	35	+93
Darkblotched rockfish	549	54	181	58	-67	-	-	-	-	-
Redbanded rockfish	374	87	79	76	-79	-	-	-	-	-
Yelloweye rockfish	279	104	169	109	-39	-	-	-	-	-
Silvergray rockfish	12	166	18	126	+50	-	-	-	-	-
Quillback rockfish	10	200	-	-	-	-	-	-	-	-
**Sablefish	5,515	54	3,982	200	-28	11,351	63	9,763	33	-14
**Lingcod	4,717	37	2,498	33	-47	4,400	26	4,097	40	-7

TABLE 3-56. ESTIMATES OF FISH BIOMASS (continued).

Species	Cape Flattery to Columbia River[1] Biomass (metric tons) 1975	±%	1976	±%	% Change from 1975-76	Columbia River to Cape Blanco[2] Biomass (metric tons) 1971-72	±%	1973-74	±%	% Change from 1971-72 Shelf Only
Flatfish										
** Pacific sanddab	8,442	69	8,276	26	-2	10,894	56	11,988	36	+10
** Arrowtooth flounder	15,070	42	10,558	37	-30	7,759	24	7,187	19	-7
Slender sole	2,345	47	2,091	31	-11	481	34	555	26	+15
** Petrale sole	1,650	33	1,043	25	-37	5,804	40	3,980	27	-31
Flathead sole	1,018	108	1,067	43	+5	389	59	262	48	-33
Sand sole	435	85	930	87	+114	1,235	100	536	50	-57
Butter sole	8,021	105	3,962	52	-51	457	39	776	53	+70
** English sole	18,443	60	16,141	55	-12	17,936	25	19,713	41	+10
Rock sole	78	78	8	114	-90	330	96	326	75	-1
** Dover sole	14,501	31	11,218	23	-23	26,128	20	22,835	17	-13
** Rex sole	13,511	31	13,938	24	+3	12,130	20	10,843	22	-11
Starry flounder	1,011	144	1,359	55	+34	471	90	408	77	-13
Curlfin sole	47	146	26	189	-45	111	111	109	73	-2
Pacific halibut	84	147	-	-	-	487	71	505	81	+4
Total	143,447		147,303		+3	283,750	--	235,117	--	-17
**Rockfish	11,911		6,442		-46	16,551	--	30,148	--	+82
Flatfish	84,656		70,617		-17	84,612	--	80,023	--	-5

[1] Data are for 1975 and 1976, from Barss et al., 1977.

[2] Data are for 1971-1974, from Demory et al., 1976.

** Distribution and relative density are mapped by Barss et al., 1977, and Demory et al., 1976.

TABLE 3-57. AVERAGE PELT PRICES IN WASHINGTON AND OREGON. (From Oregon State Wildlife Commission, 1973; Washington State Game Department, 1977.)

Species	1968-69[1]	1969-70[1]	1970-71[1]	1971-72[1]	1972-73[1]	1976-77[2]
Mink	$ 8.28	$ 5.31	$ 3.29	$ 4.96	$ 9.08	$15.33
Muskrat	.91	1.01	.91	1.27	2.04	5.04
Marten	8.33	6.61	5.77	5.08	7.93	25.53
Otter	25.21	26.17	23.60	31.84	46.80	79.09
Beaver	15.11	11.59	9.52	13.90	16.67	21.77
Wildcat	17.21	14.75	13.66	20.96	39.43	64.43[3]
Coyote	6.82	7.24	6.93	8.69	13.33	23.16[4]
Badger	4.17	2.90	3.25	4.35	5.81	19.10
Raccoon	3.91	3.06	1.98	3.77	6.85	20.98
Gray Fox	2.27	2.88	2.45	3.26	6.80	42.55[5]
Red Fox	4.63	6.44	5.33	7.72	18.55	
Skunk	.91	1.09	1.24	1.12	1.49	3.75[6]
Civet Cat	1.42	1.15	.91	1.59	2.26	
Weasel	.41	.42	.32	.19	.44	.79
Opossum	.76	.32	.61	.49	.50	--
Ring-tailed Cat	1.25	--	--	--	--	--
Nutria	1.63	1.51	1.50	2.07	2.75	5.29

1 Source: Oregon State Game Division, 1973.
2 Source: Washington State Game Department, 1977.
3 Price for eastern species was $126.96.
4 Price for eastern species was $53.02.
5 Did not differentiate between fox species.
6 Did not differentiate between civet cat and skunk.

TABLE 3-58. FURBEARER HARVEST IN THE STATE OF WASHINGTON. (From Washington State Game Department, 1977.)

SPECIES	1969 1970	1970 1971	1971 1972	1972 1973	1973 1974	1974 1975	1975 1976	1976 1977
Beaver	10,340	8,460	8,350	7,380	12,370	11,300	7,240	15,410
Muskrat	26,340	27,390	30,660	21,450	32,560	41,320	50,100	82,550
Otter	400	490	600	560	640	690	660	1,290
Mink	1,890	1,180	1,130	930	1,370	1,610	1,360	2,010
Coyote	1,090	1,020	1,480	1,870	5,120	6,420	6,480	13,570
Raccoon	2,360	1,810	1,630	1,730	3,790	3,690	3,720	6,090
Bobcat	670	570	840	510	1,090	820	1,035	1,650
Skunk	380	340	330	40	690	460	550	900
Nutria	--	--	--	60	570	1,010	820	1,610
Weasel	240	190	100	120	130	130	180	310
Badger	20	10	10	30	150	90	50	220
Canada Lynx	30	20	10	10	10	40	40	90
Marten	100	60	20	20	20	40	150	250
Fox	250	120	110	90	230	210	180	360

TABLE 3-59. FURBEARER CATCH FOR COASTAL COUNTIES OF OREGON AND WASHINGTON.[1] (From Washington State Game Department, 1977; Oregon State Wildlife Commission, 1973.)

Watershed Unit	County	Beaver	Muskrat	Otter	Mink	Coyote	Raccoon	Bobcat	Skunk	Nutria	Weasel	Opossum	Gray Fox	Red Fox
1	Clallam[2]	170	147	37	2	90	97	60	42	--	1	--	-- 17[3]	--
1	Jefferson[2]	44	81	28	2	88	100	15	--	--	1	--	-- 10[3]	--
2	Gr. Harbor	711	600	127	49	123	224	85	15	70	1	--	-- 3[3]	--
2	Pacific	515	711	45	23	123	143	82	9	17	7	--	-- --	--
3	Wahkiakum	99	246	3	14	15	79	7	2	176	2	--	-- --	--
3 & 4	Clatsop	693	502	7	54	3	128	23	5	403	7	7	--	--
4	Tillamook	635	404	51	22	14	170	117	13	17	1	63	--	1
5	Lane[2]	1,618	539	67	77	86	386	206	10	867	1	30	18	69
5	Lincoln	439	224	18	9	23	252	82	36	142	4	41	1	--
6N	Douglas[2]	1,227	249	36	18	30	146	40	3	12	--	--	4	4
7	Coos	750	196	30	13	1	78	28	11	--	--	4	--	--
6S, 8	Curry	154	82	10	2	--	20	10	9	--	--	--	--	--

[1] 1972-1973 data for Oregon
1976-1977 data for Washington.

[2] Includes large portion of county outside study area.

[3] Data for Washington is combined for Gray and Red Fox.

3.4.1.3 Furbearing Species (continued)

The grizzly bear and the timber wolf are no longer found in the study area. Cougar (mountain lion) populations are concentrated in the Olympic Peninsula as are black bear populations (Nowak, 1976; Poelker and Hartwell, 1973).

3.4.2 Species of Recreational Value. This section concerns itself with species which are harvested for recreational purposes, including big game animals such as deer and elk, small game species such as bobcat and gamebirds, and fish caught for sport such as trout, salmon, and bass.

Many species within the region are utilized in a non-consumptive way for aesthetic purposes. Usually this form of use is in conjunction with the physical attributes and beauty of the location and is thus not species-specific. California State Fish and Game Commission (1965C) reports deer as an important species for recreational observation and photography. Information on the amount of such non-consumptive utilization of wildlife is sparse within the study area. Washington State Game Department (1977) reports that 61% of the use (man days) for all of Washington State Wildlife Recreation Areas for 1975 and 1976 was non-consumptive. A similar ratio is reported by the Oregon State Wildlife Commission (1973) for recreational use of Oregon State Wildlife Management Areas in 1972. One can expect at least as high a ratio for the study area. The Forest Service (USDA, 1977A) briefly summarizes a trend of increased non-consumptive wildlife use nationwide.

3.4.2.1 Big Game Species. The major big game species of the region are Roosevelt elk, black-tailed deer, black bear, and mountain lion. Although mountain lions are completely protected in California and elk are in low numbers and lightly hunted in California, substantial populations of all these species occur within the study area. The largest concentrations of mountain lion, black bear, and Roosevelt elk in the study area occur on the Olympic Peninsula (Nowack, 1976); black bear are considered forest pests in this area (Watershed Units 1 and 2). Elk are concentrated in Watershed Units 5 and 7. Black-tailed deer are common throughout the region. Data on harvest for major portions of the region are given in Tables 3-60 and 3-61.

TABLE 3-60. 1976 HARVEST OF BIG GAME IN WASHINGTON COASTAL COUNTIES. (From Washington State Game Department, 1977.)

COUNTY	DEER	ELK	BEAR	COUGAR
Clallam	1,150	480	180	12
Grays Harbor	1,650	500	220	20
Jefferson	920	440	140	1
Pacific	1,670	740	80	--
Skamania	1,430	360	170	--
TOTAL	6,820	2,520	790	33

TABLE 3-61. OREGON BIG GAME HARVEST FOR COASTAL AREAS.

DEER[1]	ELK[1]	BEAR[2]	COUGAR[3]
26,040 + 16,200	1,506 + 867	1,770	16

[1] Northwest and southwest region data are for 1972 (Oregon State Wildlife Commission, 1973).

[2] Statewide total for 1975 (Oregon State Department of Fish and Wildlife, 1976B).

[3] Statewide total for 1975 (Oregon State Department of Fish and Wildlife, 1976B). Nowak (1976) reports only scattered population of cougar in Oregon Coastal Range.

Trends in harvest are exemplified by Tables 3-62, 3-63, and 3-64. Note that the trends and percentage of hunter success are summarized for the entire state of Washington on Table 3-62 and for all or most of Western Oregon in Tables 3-63 and 3-64. Nationwide, the Forest Service (USDA, 1977A) reports an 80% increase of big game hunters between 1955 and 1970.

TABLE 3-62. BIG GAME HARVEST TRENDS IN WASHINGTON STATE.[1] (From Washington State Game Department, 1977.)

YEAR	DEER	ELK	BEAR	COUGAR
1971	52,800	8,520	4,100	250
1972	40,000	8,600	3,400	200
1973	58,320	14,140	2,830	200
1974	50,600	10,060	3,910	210
1975	58,700	12,730	3,760	230
1976	48,810	10,030	3,150	190

[1] Data are statewide totals.

TABLE 3-63. OREGON STATE DEER HUNTING TRENDS.[1] (From Oregon State Wildlife Commission, 1973.)

	BLACK-TAILED DEER		
YEAR	GENERAL SEASON HUNTERS	NUMBER HARVESTED	PERCENT HUNTER SUCCESS
1952	61,531	24,867	40
1953	83,552	40,668	49
1954	80,430	35,745	44
1955	81,919	43,708	53
1956	87,274	40,277	46
1957	81,333	34,626	43
1958	94,702	45,001	47
1959	104,750	56,670	54
1960	110,725	61,382	55
1961	101,971	65,988	65
1962	108,343	62,936	58
1963	105,603	52,941	50
1964	110,555	58,358	53
1965	108,281	47,732	44
1966	110,384	59,459	52
1967	109,250	54,820	50
1968	111,940	62,360	56
1969	88,850	32,640	37
1970	92,050	29,400	32
1971	109,120	40,560	37
1972	127,200	44,020	35

[1] Data are principally for western portions of state.

California State Fish and Game Commission (1965C) reported black-tailed deer and black bear (in that order) were the two most common big game animals in the state. They estimated 395,000 hunters went after all species of deer in California in 1963, taking 60,450 deer, and projected an increase to 525,000 hunters for 1980.

Black bear take varied from 600 to 1,000 per year for all of California in the early 1960's (California State Fish and Game Commission, 1965C).

Roosevelt elk population in California is small in numbers (more or less 2,000). Annual harvest is less than 100 elk with some years closed to hunting altogether (California State Fish and Game Commission, 1965C).

TABLE 3-64. OREGON STATE ELK HUNTING TRENDS.[1]
(From Oregon State Wildlife Commission, 1973.)

	ROOSEVELT ELK		
YEAR	HUNTERS	NUMBER HARVESTED	PERCENT HUNTER SUCCESS
1940	1,343	198	15
1945	1,327	222	17
1950	6,076	1,947	32
1955	6,205	973	16
1961	14,835	3,130	21
1962	13,559	1,791	13
1963	13,508	3,123	23
1964	21,888	4,702	21
1965	19,736	2,904	15
1966	18,674	2,684	14
1967	18,100	2,620	14
1968	20,300	3,260	16
1969	19,700	2,038	10
1970	21,370	3,340	16
1971	22,910	2,680	12
1972	25,400	2,380	9

[1] Data are principally for western portions of state.

<u>3.4.2.2 Small Game Species.</u> The regional fauna includes numerous small game species, such as waterfowl, upland game, and rabbits. Recent harvest data for small game are provided in Tables 3-65, 3-66, and 3-67. Important species include band-tailed pigeon, ruffed grouse, ring-necked pheasant, quail, American widgeon, pintail, mallard, and Canada goose.

Trends in utilization of small game species nationwide indicate a 20% increase in the number of small game hunters between 1955 and 1970 (U.S.D.A., Forest Service, 1977A). The statewide trend in hunters and harvest (1971 to 1975) for Washington is indicated in Table 3-68. Similarly, statewide trends for small game for Oregon are given in Table 3-69 for the period of 1954 to 1972. The population status of small game in the region is fairly stable. The predominant land use of forestry in the region leaves much of the landscape in early successional stages which are favored by most upland small game species as well as big game (Maser et al., 1977; Brown, 1961). Blue grouse and band-tailed pigeon are not as dependent on early seral stages, but neither do they appear to require old growth within the region.

Since little of the land within the region is in agricultural use, small game species commonly associated with agricultural land (e.g. ring-necked pheasant and eastern cottontail rabbit) are uncommon and do not play a significant role in the recreational harvest.

Waterfowl productivity (breeding) within the region is modest (five or less individuals per square mile), but use by wintering-populations and fall and spring migrant populations is substantial. The region is within the Pacific flyway with coastal estuaries, lakes, and wetlands playing an important role as feeding, wintering, and resting areas. Waterfowl concentration areas for the region are indicated in Figure 3-73. Major concentration areas are Grays Harbor, Willapa Bay, Columbia River, Coos Bay, and Humboldt Bay. Important hunted waterfowl include American widgeon, mallard, pintail, canvasback, Canada goose, and black brant.

TABLE 3-65. 1976 SMALL GAME HARVEST DATA FOR WASHINGTON STATE COASTAL COUNTIES. (From Washington State Game Department, 1977.)

County	Bobcat	Raccoon	Coyote	Rabbits	Dove	Pigeon	Snipe	Pheasant	Grouse	Ducks	Geese	Quail
Clallam[1]	800	330	660	2,320	310	1,200	450	1,260	11,190	21,600	640	1,250
Grays Harbor	510	620	940	940	0	5,850	1,330	4,050	12,620	38,010	1,230	0
Jefferson[1]	100	780	360	920	0	3,260	350	310	3,480	10,240	0	90
Pacific	70	220	870	1,320	0	5,520	1,520	920	11,170	30,790	1,780	0
Skamania	240	990	280	400	570	1,090	0	40	5,800	780	120	470
TOTAL	1,720	2,940	3,110	5,900	880	16,920	3,650	6,580	44,260	101,420	3,770	1,810

[1] Includes portions outside of study area.

TABLE 3-68. SMALL GAME HUNTER AND HARVEST TRENDS FOR WASHINGTON STATE, 1971-1976. (From Washington State Game Department, 1977.) (Figures in thousands.)

	Bobcat		Raccoon		Coyote		Rabbits		Pheasant		Grouse		Waterfowl[1]		Dove		Pigeon[2]		Snipe		Quail	
Year	Hunters	Kill	Hunters	Kill	Hunters	Kill	Hunters	Kill	Hunters	Kill	Hunters	Kill	Hunters	Kill	Hunters	Kill	Hunters	Kill	Hunters	Kill	Hunters	Kill
1971	5	5	4	11	22	33	23	136	93	419	102	331	90	945	28	318	20	130	7	35	32	149
1972	4	4	4	10	22	38	24	130	99	469	105	361	86	1008	27	280	19	101	7	35	35	155
1973	5	6	4	15	26	41	26	183	99	480	106	362	88	1059	29	317	19	99	6	35	35	166
1974	4	7	5	15	35	47	27	154	102	437	112	306	91	950	28	263	19	91	7	31	39	181
1975	4	3	4	12	37	55	30	162	97	461	114	369	90	1042	26	275	17	81	8	40	42	247
1976	5	4	5	17	38	51	30	184	99	404	114	336	88	1023	24	212	18	76	8	37	47	285

[1] Includes both geese and ducks.

[2] Band-tailed pigeons.

TABLE 3-66. 1972 HARVEST OF SMALL GAME IN OREGON STATE COASTAL AREAS. (From Oregon State Wildlife Commission, 1973.)

Habitat Area	Squirrel	Pheasant	Grouse	Quail	Pigeon
North Coast	--	--	6,730	970	19,210
South Coast	1,210	--	1,540	2,050	18,890
Umpqua	3,420	1,330	3,040	8,510	7,650
Rogue	5,310	11,990	1,460	12,980	7,230

TABLE 3-67. 1972 WATERFOWL HARVEST IN OREGON COASTAL COUNTIES. (From Oregon State Wildlife Commission, 1973.)

County	Harvest		
	Duck	Goose	Snipe
Lane	35,320	940	1,850
Clatsop	25,910	330	110
Lincoln	5,410	0	30
Tillamook	13,640	330	910
Coos	25,600	110	1,160
Curry	1,440	660	0
Douglas	14,250	80	300

3.4.2.2 Small Game Species (continued)

An estimated 50,000 ducks and 6,000 geese utilize Grays Harbor estuary during winter months (OIW, 1974). Over 200,000 waterfowl are thought to inhabit Willapa Bay during peak periods, including 50,000 black brant and 1,400 to 1,600 canvasback ducks. The Bay is also an important wintering area for the dusky Canada goose, which breeds in the Copper River area in Alaska.

Waterfowl use in the Columbia River estuary is shown in Figure 3-74 and summarized in Tables 3-70 and 3-71 for lower and upper Columbia estuary respectively. Little specific data are available for Oregon estuaries. Thompson and Snow (1974) report 124,000 waterfowl use the Oregon coastal zone annually. However, summarized data reported by Akins and Jefferson (1973) indicate an estimate of only 42,000.

Humboldt Bay is the most important wintering site for waterfowl in California north of San Francisco Bay, and is extremely important to maintenance of the Pacific flyway. Wintering populations of ducks in the 1960's were estimated at 124,000 with an additional 35,000 black brant (California State Fish and Game Commission, 1965A).

An estimated 100 million ducks, 5 to 6 million geese, and 100 to 150 thousand swans utilize all flyways of the United States. Approximately 20% of these waterfowl, excluding swans, utilize the Pacific flyway; a larger proportion of the swans use the Pacific flyway (USDA, Forest Service, 1977A).

Willapa Bay and Humboldt Bay are becoming increasingly important wintering areas for canvasback ducks as San Francisco Bay and other south coast wintering areas are deleteriously affected by development, concomitant land use changes, and pollutants.

Wintering waterfowl are dependent on unimpacted wetlands, estuaries, embayments, lakes, salt marshes, and intertidal flats of the region. Yocum (1951) reports the plant species listed in Table 3-72 as the major food sources for ducks in the Pacific coastal area. Black brant are dependent on eelgrass for food source. Snails, bi-valves, insects, and crustaceans are also important duck food, accounting for about 30% of the animal material occurring in study samples (Yocum, 1951).

TABLE 3-69. SMALL GAME HUNTER AND HARVEST TRENDS FOR OREGON STATE, 1954-1972. Figures given in thousands. (From Oregon State Wildlife Commission, 1973.)

Year	Pheasants		Quail		Grouse		Pigeons[1]	
	Hunters	Kill	Hunters	Kill	Hunters	Kill	Hunters	Kill
1954	95	293	30	149	19	33	--	--
1955	93	278	26	150	20	32	--	--
1956	83	226	25	116	22	37	--	--
1957	89	310	22	124	19	39	15	94
1958	103	477	38	280	27	74	20	122
1959	97	376	33	224	15	33	13	86
1960	95	352	31	191	17	37	13	87
1961	91	376	35	242	18	45	15	121
1962	82	329	29	130	14	29	14	121
1963	84	374	31	265	14	35	12	91
1964	82	337	31	231	12	27	12	104
1965	75	255	26	168	--	--	13	105
1966	72	243	26	159	8	17	12	121
1967	72	263	35	251	13	37	10	82
1968	68	217	31	217	13	35	12	95
1969	72	224	29	174	15	41	11	85
1970	73	232	31	236	17	49	13	99
1971	54	168	27	179	16	43	11	84
1972	58	179	30	192	18	58	12	87

[1] Band-tailed pigeons.

TABLE 3-70. MIGRANT WATERFLOW CONCENTRATIONS IN THE LOWER (RIVER MILE 1-12) COLUMBIA RIVER ESTUARY. (From Oregon Cooperative Wildlife Research Unit, 1976.)

Species	Concentration	Geographical Location	Vegetation Habitat	Seasonal Occurrence
American widgeon	High	Baker Bay	Tidal Marsh/ Open Water	Fall
Coot	Low	Baker Bay	Tidal Marsh/ Open Water	Fall
Canvasback duck	Moderate	Baker Bay	Tidal Marsh/ Open Water	Winter
Surf & White-winged scoters	Low	Baker Bay	Tidal Marsh/ Open Water	Winter
Western grebe	Moderate	Baker Bay	Tidal Marsh/ Open Water	Winter
Pintail	High	Baker Bay	Tidal Marsh/ Open Water	Fall

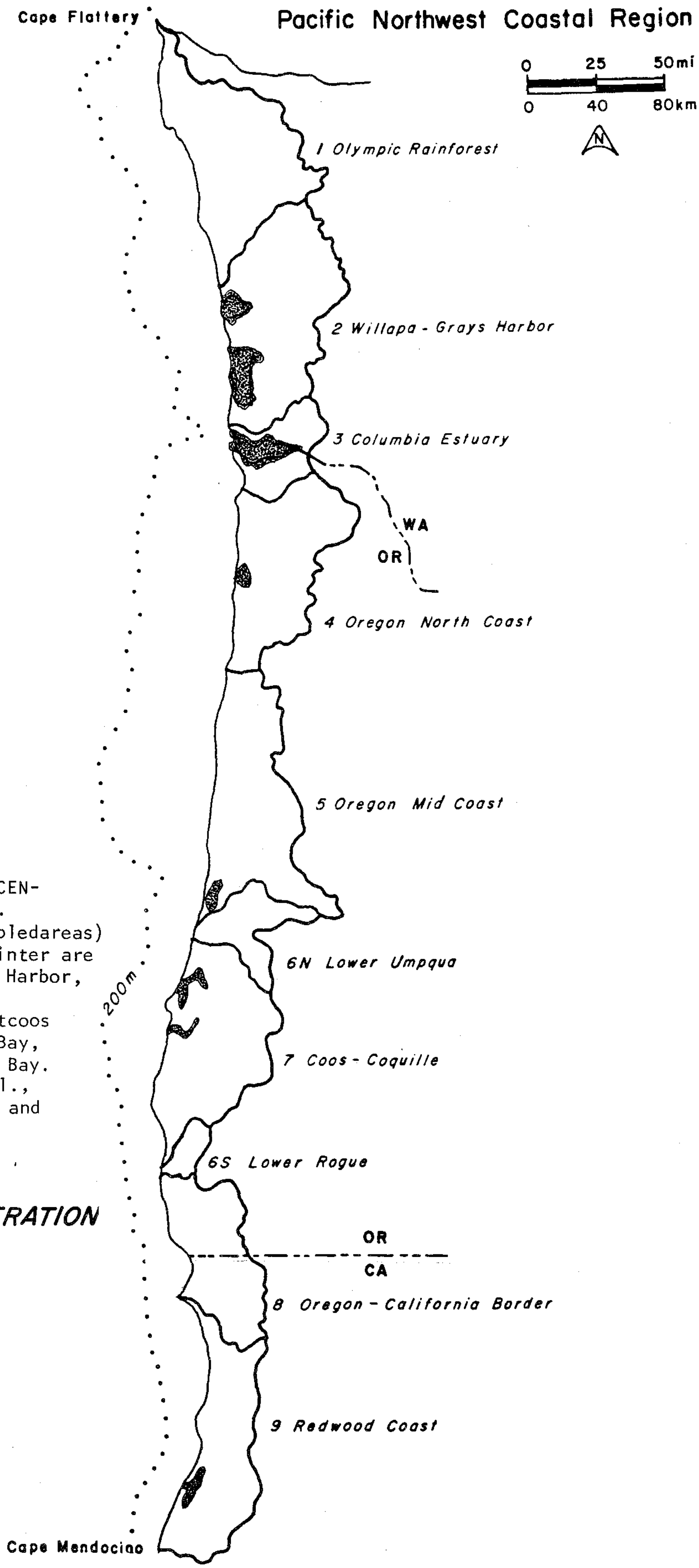


FIGURE 3-73. WATERFOWL CONCENTRATION AREAS IN THE REGION. These major locations (stippledareas) where ducks and geese overwinter are (from north to south) Grays Harbor, Willapa Bay, Columbia River estuary, Tillamook Bay, Siltcoos and Tahkenitch Lakes, Coos Bay, Coquille River, and Humboldt Bay. (From ACOE, 1975F; Loy et al., 1976; California State Fish and Game Commission, 1965A.)

WATERFOWL CONCENTRATION AREAS

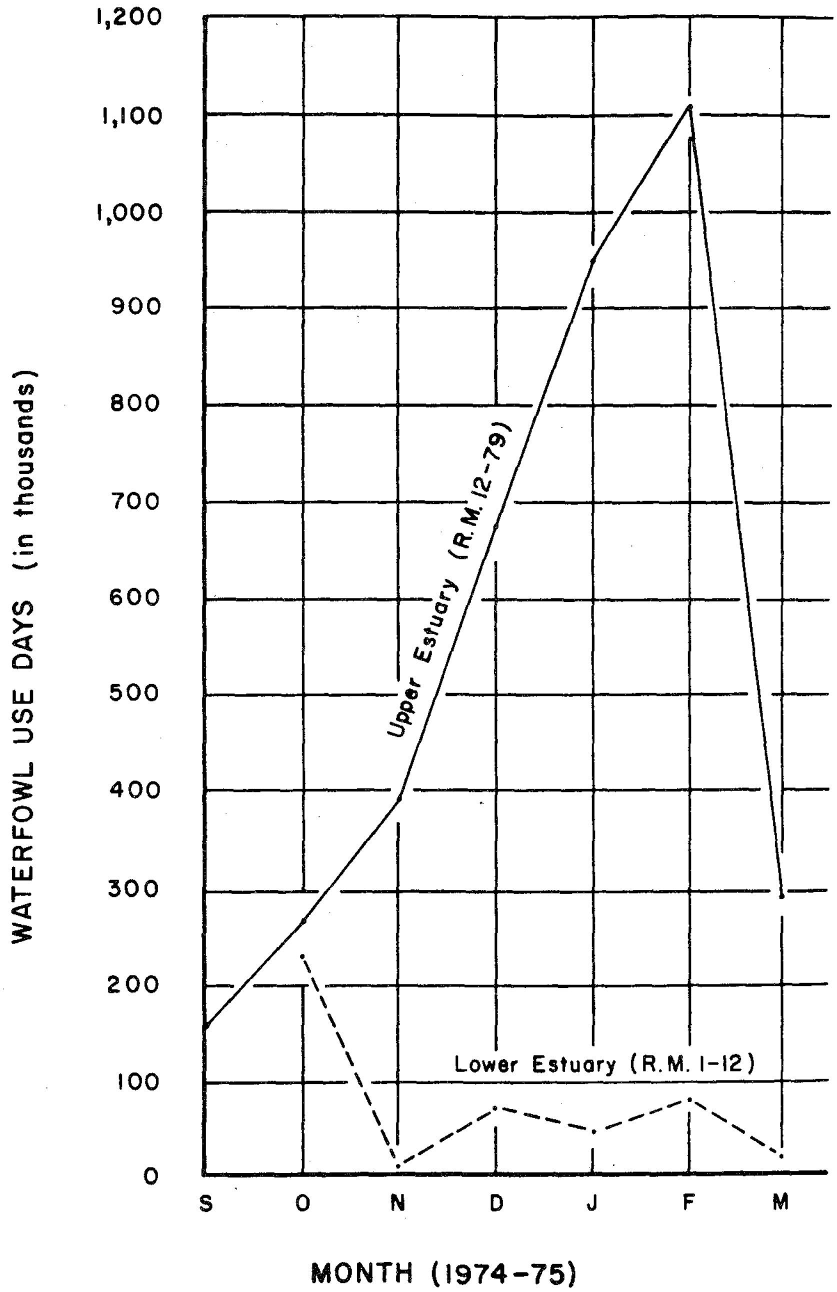


FIGURE 3-74. ESTIMATED WATERFOWL USE OF THE UPPER AND LOWER COLUMBIA RIVER ESTUARY DURING FALL AND WINTER, 1974-75. R.M. = river mile (from mouth). (From Oregon Cooperative Wildlife Research Unit, 1976.)

TABLE 3-71. MIGRANT WATERFOWL CONCENTRATION IN THE UPPER (RIVER MILE 12-50) COLUMBIA RIVER ESTUARY. (From Oregon Cooperative Wildlife Research Unit, 1976.)

Species	Concentration	Geographical Location	Vegetation Habitat	Seasonal Occurrence
Canada goose	Moderate	National Wildlife Refuge RM 18-38	Tidal Marsh and Islands	Winter
White-fronted goose	Low	National Wildlife Refuge RM 18-38	Tidal Marsh and Islands	Fall/ spring
Mallard	High	National Wildlife Refuge RM 18-38	Tidal Marsh and Islands	Winter
Widgeon	High	National Wildlife Refuge RM 18-38	Tidal Marsh and Islands	Winter
Pintail	High	National Wildlife Refuge RM 18-38	Tidal Marsh and Islands	Winter
Whistling swan	High	Grassy, Russian & Seal Islands	Intertidal Marsh and Flats	Winter

TABLE 3-72. DUCK FOOD ITEMS OF THE PACIFIC COAST. (From Yocum, 1951.)

Species	Occurrence	Volumetric Percentage
Potamogeton spp. (Pondweed)	149	12.1
Scirpus spp. (Bulrush)[1]	155	4.8
Cyperus spp. (Cyperus)	8	4.4
Zannichellia palustris (Horned Pondweed)	9	3.1
Zostera marina (Eelgrass)	3	3.0
Eleocharis spp. (Spike Rush)	50	2.9
Triglochin maritima (Arrowgrass)	89	2.6
Distichlis spp. (Salt Grasses)	18	2.2
Ruppia maritima (Widgeon Grass)	19	2.2
Polygonum spp. (Smartweeds)	60	1.8

[1] Three-square bulrush (Scirpus americanus) is the preferred species in salt marsh areas.

3.4.2.2 Small Game Species (continued)

Access to the literature for small game is listed in the Annotated Species List under the notes column. Additional information can be found in Salo (1975), Bent (1919-1968), and Yocum (1951) for waterfowl; Ingles (1965) and Maser et al. (1977) for mammals; Wahl and Paulson (1971) and Jackman and Scott (1975) for selected birds. Alcorn (1972) provides a bibliography for the gamebirds found in the region. The WESTFORNET Annotated Computer System (with access at Berkeley, California, and University of Washington, Seattle) includes species-specific access to recent West Coast publications. Wildlife Review also allows species-specific access to the literature for a number of years.

3.4.2.3 Recreational Fishery Species. Oceanic, coastal, and inland fish species contribute to an intensive recreational fishery in the region. Nationwide, fishing was the preferred outdoor activity for a third of all Americans in 1960, second only to swimming. Principal sport species are coho and chinook salmon (primarily taken at sea although some are taken in estuaries and lower rivers), cutthroat trout (taken in estuaries, streams, and some lakes and beaver ponds), rainbow trout (taken in larger rivers and lakes), steelhead trout (taken in major rivers), striped bass (taken in southerly estuaries and rivers), marine perch (taken off jetties, docks, and beaches), lingcod and rockfish (taken near rocky areas in coastal and marine waters), large mouth bass (taken in lowland lakes), and miscellaneous spiny ray fish (also taken in lowland lakes).

Razor clams are an important recreational species of the coastal beaches in the more northerly watershed units. The significance of the effort and harvest are shown in Table 3-73.

Hard shelled clams are important recreational species in estuaries throughout the region. Principal species are gapper clam, bent-nose clam, Manila clam, and soft shell clam. The Oregon State Fish Commission (1973-1974) has summarized catch and effort for Oregon estuaries for a one year sample.

Trends in recreational fisheries indicate an increased demand, with the number of fishermen having increased 60% from 1955 to 1970 nationwide (U.S.D.A., Forest Service, 1977A). The number of recreational salt water fishermen more than doubled between 1955 and 1970 with effort or fishing days showing a parallel trend. Recreational fishing was the fastest increasing consumptive use of fish and wildlife in the 1955 to 1970 period (U.S.D.A., Forest Service, 1974B).

Fishing for anadromous species is the most significant sport fishing activity of the region. Table 3-74 indicates the importance of the fishery, and of particular anadromous fish species. Washington State (including Puget Sound waters) has the largest recreational catch of salmon in the U.S., followed by Oregon, California, and Alaska (Salo, 1974).

Catch data and trends for Washington State coastal waters are summarized in Tables 3-75 and 3-76 for both saltwater and freshwater takes. As indicated, sport catch has been steadily increasing in the offshore fishery.

Oregon's recreational harvest for 1974 and 1975 is summarized in Table 3-77 showing a substantial catch.

Natural production of salmon has decreased in recent years. There is little agreement on the cause of the decline, but it is probably due to a combination of factors including dams and their impedence to anadromous migration, loss of spawning habitat through land use changes, inundation, and commercial overfishing of stocks through the 1950's (foreign take of salmon is still poorly regulated) (Korn, 1977; Fulton, 1968 and 1970). The losses to a large extent have been compensated by hatchery production (see commercial fishery section). The long term genetic effects of loss of the wild stock (genetic variability, etc.) is unknown.

Literature on the ecology of recreational fish species of the study area has been reviewed by Moyle (1976B), Hart (1973), Scott and Crossman (1973), and Wydowski and Whitney (in press). A few additional references are provided in the Annotated Species List.

TABLE 3-73. SUMMARY OF YEARLY DIGGING EFFORT AND CATCH FOR ALL RAZOR CLAM FISHERIES AT THE WASHINGTON STATE OCEAN BEACHES, 1946 THROUGH 1970. Catch limits for the years were: 36 clams for 1946 and 1947, 24 clams for 1948 through 1959 (except 18 in 1950), and 18 clams for 1960 through 1970. (From Tegelberg et al., 1971.)

Year	Thousands of Sport Diggers						Catch in Millions of Clams		
	Long B.	Twin H.B.	Copalis	Mocrocks	Kalaloch	Total	Sport	Comm.	Total
1946	134	28	46			208	7.4	7.6	15.0
1947	167	35	59			261	9.4	7.1	16.5
1948	79	39	69			187	5.2	6.8	11.0
1949	84	62	87			233	5.5	4.0	9.5
1950	86	63	88			237	4.6	1.4	6.0
1951	161	110	151			422	10.0	2.8	12.8
1952	154	90	122			366	8.1	2.6	10.7
1953	163	144	161			468	11.8	2.8	14.6
1954	186	171	165			522	12.5	2.3	14.8
1955	158	151	165			474	11.3	2.5	13.8
1956	150	154	155			459	10.1	1.7	11.8
1957	172	186	188			546	11.6	2.1	13.7
1958	174	247	263			684	14.9	3.0	17.9
1959	197	162	166	14	7	546	9.8	2.3	12.1
1960	149	128	205	17	11	510	6.8	0.9	7.7
1961	157	100	278	26	14	575	8.2	1.2	9.4
1962	183	172	272	45	11	683	11.2	0.7	11.9
1963	192	213	293	52	15	765	13.1	1.0	14.1
1964	120	208	261	41	13	643	10.8	0.0[a]	10.8
1965	127	154	252	50	--	582	9.2	0.6	9.8
1966	185	159	288	50	--	682	11.5	1.0	12.5
1967	215	173	275	86	--	749	11.5	0.6	12.1
1968	159	120	240	115	--	634	9.4	--	9.4
1969	104	100	248	103	--	554	8.4	--	8.4
1970	120	87	274	142	--	622	6.8	--	6.8

[a] Season was closed after two days because of oil spillage.

TABLE 3-74. RECREATIONAL SALTWATER FISHING FOR THE ANADROMOUS SPECIES OF THE PACIFIC COAST[1] BY PRINCIPAL SPECIES, 1970.[2] (From Deuel, 1973.)

Species	Number of Fishermen	Number of Fish Caught	Proportion Taken in Bays, Sounds, and Tidal Portions of Rivers
	(Thousands)	(Thousands)	(Percent[3])
Salmon, chinook	218	912	47
Salmon, coho	321	1,447	34
Salmon, pink	54	162	57
Shad, American	3	69	95
Smelts	104	4,812	94
Steelhead	116	724	90
Striped bass	153	2,031	88
Trout, cutthroat	48	1,100	99
Trout, Dolly Varden	27	199	100

[1] Northern California to Washington plus Alaska, except 10 percent of smelt taken in Southern California.

[2] Excludes fish caught in freshwater portions of river systems.

[3] Based on data from both Atlantic and Pacific Coasts.

TABLE 3-75. SALT WATER SPORT CATCH AND TREND OF COHO AND CHINOOK SALMON[1,2] FOR WASHINGTON[3] 1946-1975. (From Washington State Department of Fisheries, 1976.)

	Coho	Chinook		Coho	Chinook
1946[4]	2,600	23,400	1961	149,100	66,700
1947	3,200	12,800	1962	271,300	82,400
1948	2,800	--	1963[5]	246,500	88,100
1949	--	11,200	1964	216,100	98,400
1950	2,300	16,600	1965	451,300	123,100
1951	1,900	7,200	1966	276,200	131,300
1952	20,000	65,000	1967	413,400	154,300
1953	21,600	18,200	1968	382,400	136,100
1954	44,600	39,100	1969	345,700	141,900
1955	51,200	64,900	1970	455,400	153,400
1956	136,000	110,400	1971	675,600	151,100
1957	151,700	79,900	1972	494,800	197,600
1958	97,000	65,000	1973	440,500	188,800
1959	119,400	66,200	1974	529,800	197,700
1960	69,500	84,100	1975	442,300	247,800

[1] Based on salmon punch card figures.

[2] A few pink salmon are taken in odd years but in small numbers, less than 20,000 for the coast.

[3] Columbia River catch (lower river) and ocean fishery only.

[4] 1946-1964 Columbia, Washington, and Oregon are combined for Columbia River area and are included.

[5] Salt water areas only after 1963.

TABLE 3-76. FRESHWATER SALMON SPORT FISHERY CATCHES IN WASHINGTON COASTAL STREAMS, 1973-1975[1]. (From Washington State Department of Fisheries, 1976.)

	1973	1974	1975
COASTAL			
Queets River..............	261	272	372
Clearwater River[2]..........	6	25	12
Chehalis River............	3,359	4,963	2,033
Satsop River[3].............	951	613	699
Wynooche River[3]...........	751	186	246
Willapa River[2]............	232	318	360
Nemah River[2].............	2,145	2,084	1,043
Quinault River............	30	53	89
Lake Quinault.............	5	--	4
Hoh River.................	861	736	1,079
Quillayute River..........	2,145	425	473
Bogachiel River...........	173	97	275
Calawah River.............	32	--	85
Soleduck River............	2,469	769	2,065
Copalis River.............	60	31	8
Humptulips River[2]..........	5,140	2,357	1,871
Naselle River.............	314	206	246
North River...............	51	46	141
John River[2]...............	13	33	8
Elk River[2]................	--	33	12
Smith Creek[2]..............	3	5	--
Wishkah River.............	113	153	263
Hoquiam River[2]............	26	5	36
Other Streams.............	19	49	100
COLUMBIA RIVER			
Main Stem.................	34,278	14,619	14,079
Grays River[2]..............	401	227	129

[1] Data are from salmon punch cards.

[2] Open to jack salmon only.

[3] Certain areas open to jack salmon only.

TABLE 3-77. SPORT HARVEST OF SALMON AND STEELHEAD OF WATERS OFF THE COAST OF OREGON. (From Oregon State Department of Fish and Wildlife, 1976A.)

		CHINOOK		COHO	STEELHEAD
OCEAN					
	1974	33,000		318,000	
	1975	72,000		228,000	
COASTAL RIVERS					
	1974	--	111,700	--	160,200
	1975	--	75,300	--	179,600

3.4.3 Rare, Endangered, Threatened, or Otherwise Significant Species. Since the region covers a three state area, the various rare, endangered, threatened, and similar classifications for the species within the region are overlapping and lengthy. Many lists have been generated regarding the status of species in the region. A summary is provided in Tables 3-78 and 3-79 for animals and plants, respectively, in matrix form. These tables identify the designator of the status, as well as the Watershed Units in which each species occurs, and selected references. Information on which habitat the species occurs in, along with some data on specific location, is provided in the Annotated Species List.

The definitions of status, e.g. endangered, threatened, rare, endemic, etc., as we have used them, are provided in the glossary. However, as each listing party has a slightly different definition of these terms, the reader should check or refer to the definitions as used by the listing party. Eaton et al. (1975) and Dyrness et al. (1975) give useful reviews of status terminology.

The causes for the endangered or threatened status of species within the region are varied, and in some cases controversial. Generally species have become threatened, endangered, or extinct throughout the world due to loss of suitable habitat (Taber, 1970). Examples from the study area include the Columbian white-tailed deer, the snowy plover, and the spotted owl. Species which are endemic or have limited ranges (e.g. Columbian white-tailed deer, Olympic mudminnow, and numerous plants) are particularly sensitive to this type of disturbance. Habitat protection is paramount to their survival and establishes a criterion for critical areas (see Section 3.5).

More typical causes of endangerment in the region have been over-harvesting (e.g. Pacific sea otter) and toxic pollutant effects (e.g. peregrine falcon, southern bald eagle, and brown pelican). The reduction of these latter species which occupy niches near the apex of food webs is generally attributed to the effects of the organochlorine DDT and its derivatives, which accumulate in fatty tissue and cause eggshell thinning and subsequent reproductive failure (Simmons, 1974; Wurster, 1971).

In other regions the introduction of exotic species has caused or nearly caused the extinction of species or subspecies (e.g. the decline of the Aleutian Canada Goose), particularly in island ecosystems (Holdgate and Wace, 1971). Closer to the study area, Moyle (1976) indicates that introduced exotic competitors are the cause of population declines of several fish species in California.

The result of these pressures is a decline in species diversity (Taber, 1970) as well as genetic diversity for the remaining species (Vida, 1977). The potential problems of monocrop systems with little genetic variability have been raised by E. P. Odum (1971), among others, and more recently by Silen and Doig (1976) for forestry species of the area. Their argument states that genetic variability discourages epidemics of pests or disease. Also, the natural genetic pool of a species, having evolved over a long period of time with many changes in environmental conditions, provides greater resiliency to disturbances as well as better adaptation to edephic or otherwise site-specific conditions than the small gene pool which a monoculture could provide.

Three species lists within the region have official and legal significance: the federal, Oregon State, and California State lists. The national and international list is published by the U.S. Department of Interior, Fish and Wildlife Service, through the Federal Register as prescribed by the Endangered Species Act of 1973 (16 U.S.C. 1531-1543). The State of Oregon list is published by the Oregon State Department of Fish and Wildlife as prescribed by Oregon Administrative Rule 630-25-243. The California list is published by the California Fish and Game Commission as required by the California Endangered Species Act of 1970 (Sections 2050 and 2055 of the California Fish and Game Code). Species listed by these three agencies have been designated in the preceeding Table 3-78.

There are no officially designated endangered or threatened plants within the study area, although, as Table 3-79 indicates, numerous non-official or proposed listings exist (Denton et al., 1977; Siddall, 1977A and 1977B; Powell, 1974; Smithsonian Institution, 1975; FWS, 1976C).

Washington State has a list of "protected" wildlife (i.e. protected from hunting) which includes most non-game bird and mammal species. However, no special legal status is designated for this list.

TABLE 3-78. RARE, ENDANGERED, OR THREATENED[a] FAUNA OF THE PACIFIC NORTHWEST COASTAL AREA.

	Range[b]	Oregon[c]	California[d]	National	Species List
INVERTEBRATES					
Cape Mendocino Snail Helminthoglypta arrosa mattolensis	8,9			PT[e]	Inland
Newcomb's Littorine Algamorda newcombiana	2,7,9[f]			PT[e]	Estuary
Karok Indian Snail Vespericola karokorum	9			PE[8]	Inland
Rocky Coast Snail Monadenia fidelis pronotis	8,9			PE[8]	Coastal
FISH					
NONE					
REPTILES AND AMPHIBIANS					
Siskiyou Mountain Salamander Plethodon stormi	8,9[g]		R	Q[h]	Inland
BIRDS					
California Brown Pelican Pelecanus occidentalis californicus	2-9	E	E	E[i]	Oceanic, Estuary, & Coastal
Bald Eagle Haliaeetus leucocephalus	1-9	T	E	E/T[a]	Estuary, Coastal, & Inland
American Peregrine Falcon Falco peregrinus anatum	1-9	E	E	E[i]	Estuary, Coastal, & Inland
Arctic Peregrine Falcon Falco peregrinus tundrius		E		E[j*]	Coastal, Estuary, & Inland
Northern Spotted Owl Strix occidentalis caurina	1-9	T			Inland
Western Snowy Plover Chadaerius alexandrinus nivosus	1-9	T			Coastal
California Clapper Rail Rallus longirostris obsoletus	8-9		E	E[i]	Estuary
Aleutian Canada Goose Brantá canadensis leucopareia	1-9	E		E[i]	Estuary, Coastal, & Inland
MAMMALS					
Sea Otter Enhydra lutris	1,7	T			Oceanic, Coastal
Bobcat Lynx rufus	1-9			Q	Inland, Coastal
River Otter Lutra canadensis	1-9			Q	Inland, Estuary, & Coastal

TABLE 3-78. RARE, ENDANGERED, OR THREATENED[a] FAUNA OF THE PACIFIC NORTHWEST COASTAL AREA, continued.

	Range[b]	Oregon[c]	California[d]	National	Species List
MAMMALS, continued					
Wolverine *Gulo gulo*	9	T	R		Inland
Columbian White-tailed Deer *Odocoileus virginianus leucurus*	3	E		E[i]	Inland
Blue Whale *Balaenoptera musculus*	10 (1-9)			E[j]	Oceanic
Pacific Right Whale *Balaena glacialis*	10 (1-9)			E[j]	Oceanic
Sei Whale *Balaenoptera borealis*	10 (1-9)			E[j]	Oceanic
Fin Whale *Balaenoptera physalus*	10 (1-9)			E[j]	Oceanic
Humpback Whale *Megaptera noveangliae*	10 (1-9)			E[j]	Oceanic
Gray Whale *Eschrichtius robustus*	10 (1-9)			E[j]	Oceanic
Sperm Whale *Physeter catodon*	10 (1-9)			E[j]	Oceanic

[a] Sayre, 1978.

[b] Refer to Figure 1 in Introduction for Watershed Units.

[c] Oregon State Department of Fish and Wildlife, 1977.

[d] California State Fish and Game Commission, 1973.

[e] U.S. Fish and Wildlife Service, 1977A.

[f] Newcomb's Littorine may be found in more estuaries than documented to date.

[g] Range is probably inland of study area.

[h] U.S. Fish and Wildlife Service, 1977B.

[i] U.S. Fish and Wildlife Service, 1978.

[j] U.S. Fish and Wildlife Service, 1976C.

KEY

E = Endangered
T = Threatened
PT = Proposed Threatened
PE = Proposed Endangered
Q = Status under Review
R = Rare
* Not listed in 1978 checklist (Note #8).

TABLE 3-79. FLORA OF THE PACIFIC NORTHWEST COASTAL REGION PROPOSED FOR RARE, ENDANGERED, OR THREATENED STATUS. All of the vascular plants of the study area that are proposed in the Washington (Denton et al., 1977), Oregon (Siddall, 1977A & 1977B), California (Powell, 1974; listed here as CNPS, 1974), or national (Smithsonian Institution, 1975; U.S. Fish & Wildlife Service, 1976C) lists for rare (R), endangered (E), or threatened (T) status have been entered in the Annotated Species List and are printed out below in three groups: Inland, Estuary, and Shoreline. Range (Watershed Units 1-9), Status (R=rare; I=endemic), and Notes on listing authority (above references plus Dyrness et al., 1975), name synonyms, etc., are given. Since none of these lists is official, all status entries are R or, where appropriate, I. Full names -- (the computer format unfortunately cut off names at 30 characters for this table) -- and zone and habitat information can be found in the Annotated Species List.

SCIENTIFIC NAME COMMON NAME	RANGE	STATUS	NOTES
INLAND			
ALLIUM AMPLECTENS SLIM-LEAVED ONION	128	R	R,E,T STATUS IN OR (SIDDALL, 1977A). LILIACEAE.
ALLIUM BOLANDERI BOLANDER'S ONION	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). LILIACEAE.
ALLIUM CERNUUM NODDING ONION	12345678	R	R,E,T STATUS IN OR (SIDDALL, 1977B). LILIACEAE.
ALLIUM CRENULATUM SCALLOPED ONION	123456789	R	R,E,T STATUS IN OR (SIDDALL, 1977A). GRAVELLY SOILS. LILIACEAE.
ALLIUM HOFFMANII BEEGUM ONOIN	9	I	OUTCROPS NEAR MT. LASSIC. R,E,T STATUS IN CA (CNPS, 1974). LILIACEAE.
ANDROMEDA POLIFOLIA BOG-ROSEMARY	12	R	BOGS. REPORTED IN WA, NOT CONFIRMED. R,E,T STATUS IN WA (DENTON ET AL., 1977). ERICACEAE.
ANEMONE OREGANA VAR. FELIX OREGON ANEMONE	25	R	SPHAGNUM BOGS. R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). AND OREGON SIDDALL, 1977A, AND 1977B:
ARABIS ACULEOLATA PRICKLY ROCKCRESS	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975). CRUCIFERAE.
ARABIS MCDONALDIANA MCDONALD'S ROCKCRESS	8	I	R,E,T STATUS IN CA (CNPS, 1974). CRUCIFERAE.
ARCTOSTAPHYLOS HISPIDULA HAIRY MANZANITA	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). ROCKY SUMMITS. ERICACEAE.
ARCTOSTAPHYLOS STANFORDIANA STANFORD'S MANZANITA	9	I	R,E,T STATUS IN CA (CNPS, 1974). ERICACEAE.
ARENARIA HOWELLII HOWELL'S SANDWORT	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975) AND CA (CNPS, 1974). CARYOPHYLLACEAE.
ARENARIA PALUDICOLA SWAMP SANDWORT	23456789	R	COASTAL SWAMPS. R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL 1975. SIDDAL 1977A AND 1977B. CARYOPHYLLACEAE.
ASARUM CAUDATUM VAR. VIRIDIFLO GREEN-FLOWERED WILD GINGER	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A). ARISTOLOCHIACEAE.
ASTER BRICKELLIOIDES BRICKELL'S ASTER	3	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975). COMPOSITAE.
ASTER HALLI HALL'S ASTER	123456789	R	FORMERLY A CHILENSIS SSP. HALLII. R,E,T STATUS IN WA (DENTON ET AL., 1977) AND OR (SIDDALL, 1977A; SMITHSONIAN INST., 1975). COMPOSITAE:
ASTER PAUCICAPITATUS OLYMPIC MOUNTAIN ASTER	1	I	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). COMPOSITAE.
ASTRAGALUS AGNICIDUS HUMBOLDT LOCOWEED	9	I	R,E,T STATUS IN CA (CNPS, 1974). LEGUMINOSAE.

TABLE 3-79. RARE, ENDANGERED, OR THREATENED FLORA (continued)

SCIENTIFIC NAME COMMON NAME	RANGE	STATUS	NOTES
ASTRAGALUS COTTONII COTTON'S MILK-VETCH	1	I	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS E T AL., 1975). LEGUMINOSAE.
BENSONIELLA OREGANA BENSONIELLA	89	R	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL. , 1975; SMITHSONIAN INST., 1975; FWS, 1976C) AND C A (CNPS, 1974). MOUNTAIN BOGS.
BOTRYCHIUM LANCEOLATUM LANCE-LEAVED GRAPE-FERN	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS E T AL., 1975) AND OR (SIDDALL, 1977A). OPHIOGLOSSA CEAE.
BOTRYCHIUM VIRGINIANUM VIRGINIA GRAPE-FERN	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS E T AL., 1975) AND OR (SIDDALL, 1977A). MOIST WOODS . OPHIOGLOSSACEAE.
CALAMAGROSTIS CRASSIGLUMIS THURBER'S REEDGRASS	123456789	R	FRESHWATER MARSHES AND WETLANDS. R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975) AND CA (CNPS, 1974). GRAMINEAE.
CALAMAGROSTIS FOLIOSA LEAFY REEDGRASS	89	R	R,E,T STATUS IN CA (CNPS, 1974). GRAMINEAE.
CALYPSO BULBOSA FAIRY-SLIPPER	123456789	R	R,E,T STATUS IN WA (DENTON ET AL., 1977) AND OR (S IDDALL, 1977A). ORCHIDACEAE.
CAMPANULA PIPERI OLYMPIC HAREBELL	12	R	BOGS. R,E,T STATUS IN WA (DENTON ET AL., 1977; DY RNESS ET AL., 1975). CAMPANULACEAE.
CARDAMINE PATTERSONII SADDLE BITTERCRESS	34	R	OPEN SLOPES ON SADDLE AND SUGARLOAF MTNS. AND ONIO N PEAK, CLATSOP CO. E STATUS IN OR (SIDDAL, 1977A AND C(CNPS,1974). 976C; DYRN ESS ET AL., 1975). CRUCIFERAE.
CAREX LIVIDA PALE SEDGE	123456789	R	BOGS AND SWAMPS. R,E,T STATUS IN WA (DENTON ET AL ., 1977). CYPERACEAE.
CAREX PLURIFLORA SEVERAL-FLOWERED SEDGE	12	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS E T AL., 1975). CYPERACEAE.
CASTILLEJA BREVILOBATA SHORT-LOBED RED INDIAN PAINTBR	3	R	DRY, OPEN, STONY SLOPES. R,E,T STATUS IN OR (SIDD ALL, 1977A; SMITHSONIAN INST., 1975) AND CA (CNPS, 1974). SCROPHULARIACEAE.
CASTILLEJA ELATA UPLIFTED PAINTBRUSH	3	I	FORMERLY C. MINIATA SSP. ELATA. R,E,T STATUS IN O R (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONI AN INST., 1975). SCROPHULARIACEAE.
CASTILLEJA PARVIFLORA VAR. OLY OLYMPIC MOUNTAIN PAINTBRUSH	1	R	R,E,T, STATUS WA, (DENTON ET AL. 1977, DYRNESS ET AL. 1975, SMITHSONIA1975. SCROPHULARIACEAE.
CHEILANTHES LANOSA LANATE LIP-FERN	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS E T AL, 1975). ROCK CREVICES IN OLYMPIC MTNS. POLY PODIACEAE.
CIMICIFUGA ELATA TALL BUGBANE	1234	R	R, E, T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). MOIST WOODS. RANUNCULACEAE.
CLADOTHAMNUS PYROLAEFLORUS COPPER BUSH	134	R	OLYMPIC MTNS., WA, AND SADDLE MTN ^ ONION PK, OR. R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL. , 1975).
CLINTONIA ANDREWSIANA ANDREW'S BEADLILY	89	R	R,E,T STATUS IN OR (SIDDALL, 1977A ^ 1977B; DYRNES S ET AL., 1975). LILIACEAE.
CYPRIPEDIUM CALIFORNICUM CALIFORNIA LADY-SLIPPER	8	R	BOGS AND SPRINGS. R,E,T STATUS IN OR (SIDDALL, 19 77A; DYRNESS ET AL.,1975; SMITHSONIAN INST., 1975) . ORCHIDACEAE.
DARLINGTONIA CALIFORNICA CALIFORNIA PITCHER - PLANT	56789	R	BOGS. R,E,T STATUS IN OR (SIDDALL, 1977A ^ 1977B; SMITHSONIAN INST., 1975; DYRNESS ET AL., 1975). SARRACENIACEAE.
DELPHINIUM NUTTALLII NUTTALL'S DELPHINIUM	23	R	R,E,T STATUS IN WA (DENTON ET AL., 1975) AND OR (S IDDALL, 1977A). FORMERLY D. OREGANUM. RANUNCULAC EAE.

TABLE 3-79. RARE, ENDANGERED, OR THREATENED FLORA (continued)

SCIENTIFIC NAME COMMON NAME	RANGE	STATUS	NOTES
DICENTRA CUCULLARIA DUTCHMAN'S BREECHES	3	R	R,E,T STATUS IN WA (DENTON ET AL., 1977) AND OR (SIDDALL, 1977A). ALONG COLUMBIA R. FUMARIACEAE.
DICENTRA FORMOSA VAR. OREGANA OREGON BLEEDINGHEART	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975; FWS, 1976C) AND CA (CNPS, 1974). FUMARIACEAE.
DICHELOSTEMMA VENUSTUM ROSE FIRE-CRACKER-FLOWER	8	R	OPEN SLOPES. R,E,T STATUS IN CA (CNPS, 1974). LILIACEAE.
DOUGLASII LAEVIGATA VAR. CILIO SMOOTH DOUGASIA	134	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975) AND OR (SIDDALL, 1977A). PRIMULACEAE.
DRABA INCERTA YELLOWSTONE DRABA	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). CRUCIFERAE.
DROSERA ROTUNDIFOLIA ROUND-LEAVED SUNDEW	123456789	R	BOGS. R,E,T STATUS IN CA (CNPS, 1974). MORE COMMON NORTH. DROSERACEAE.
EBUROPHYTON AUSTINIAE PHANTOM-ORCHID	12	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975) AND OR (SIDDALL, 1977A). ORCHIDACEAE.
ELMERA RACEMOSA VAR. PUBERULEN HAIRY ELMERA	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975) AND OR (SIDDALL, 1977A). SAXIFRAGACEAE.
ELMERA RACEMOSA VAR. RACEMOSA RACEMED ELMERA	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). SAXIFRAGACEAE.
EMPETRUM NIGRUM CROWBERRY	123456789	R	BOGS AND HEADLANDS. R,E,T STATUS IN OR (SIDDALL, 1977A ^ 1977B; DYRNESS ET AL., 1975). MORE COMMON IN WA ^ CA. EMPETRACEAE.
ERIGERON ALICEAE ALICE FLEABANE	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). COMPOSITAE.
ERIGERON CERVINUS DAISY	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975) AND CA (CNPS, 1974). COMPOSITAE.
ERIGERON DELICATUS DEL NORTE DAISY	8	R	R,E,T STATUS IN OR (SIDDAL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975; FWS, 1976C) AND CA (CNPS, 1974). COMPOSITAE.
ERIGERON FLETTII OLYMPIC MOUNTAIN DAISY	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). COMPOSITAE.
ERIGERON PEREGRINUS SSP. PEREG SUBALPINE DAISY	34	R	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). SADDLE MTN. AND ONION PK., CLATSOP CO., OR. COMPOSITAE.
ERIOGONUM HIRTELLUM KLAMATH MT. ERIOGONUM	8	R	R,E,T STATUS IN CA (CNPS, 1974). POLYGONACEAE.
ERIOGONUM PENDULUM WALDO BUCKWHEAT	8	I	DRY, OPEN SLOPES. R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975) AND CA (CNPS, 1974). POLYGONACEAE.
ERYSIMUM ARENICOLA VAR. ARENIC SAND-DWELLING WALLFLOWER	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). CRUCIFERAE.
ERYTHRONIUM HENDERSONII HENDERSON'S FAWN-LILY	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A). LILIACEAE.
ERYTHRONIUM REVOLUTUM GLACIER-LILY	123478	R	COASTAL FAWN - LILY. R,E,T STATUS IN WA (DYRNESS ET AL., 1975) AND OR (SIDDALL, 1977A^ 1977B; DYRNESS ET AL., 197?; .,). LILIACEAE.
FILIPENDULA OCCIDENTALIS FILIPENDULA	345	R	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975). ROSACEAE.
FRITILLARIA GLAUCA WHITE FRITILLARY	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., U975) AND CA (CNPS, 1974). LILIACEAE.

TABLE 3-79. RARE, ENDANGERED. OR THREATENED FLORA (continued)

SCIENTIFIC NAME COMMON NAME	RANGE	STATUS	NOTES
GENTIANA BISETAEA TWO-BRISTLED GENTIANA	8	I	SEEPAGE SLOPES. R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975; FWS, 1976C). GENTIANACEAE.
GENTIANA DOUGLASIANA SWAMP GENTIAN	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). LAKE OZETTE, WA. GENTIANACEAE.
GEUM TRIFLORUM VAR. CAMPANULAT BELL-SHAPED PURPLE AVENS	134	R	OLYMPIC MTNS., WA, AND SADDLE MTN. AND ONION PEAK, R,E,T STATUS WA (DETON ET EL., 1977. DRYNESS ET AL., 1975) OR ISIDDAL ET AL., 1977A.
HEMITOMES CONGESTUM GNOME-PLANT	123456789	R	R,E,T STATUS IN WA (DENTON ET AL., 1977), OR (SIDDALL, 1977A ^ 1977B), AND CA (CNPS, 1974). ERICACEAE.
HIERACIUM BOLANDERI BOLANDER'S HAWKWEED	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). COMPOSITAE.
HORKELIA SERICATA SERRATED HORKELIA	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). ROSACEAE.
HOWELLIA AQUATILIS AQUATIC LOBELIA	123456789	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975), OR (SIDDAL, 1977A), AND CA (CNPS, 1974), CAMPANULACEAE.
HYDROCOTYL VERTICILLATA WATER-PENNYWORT	8	R	R,E,T STATUS IN OR (SIDDALL, 1977A ^ 1977B; DYRNESS ET AL., 1975). GARRISON LAKE, CURRY CO. UMBELLIFERAE.
HYPOPITYS MONOTROPA PINESAP	123456789	R	R,E,T STATUS IN OR (SIDDALL, 1977A). SAPROPHYTE. ERICACEAE.
IRIS BRACTEATA BRACTEAL IRIS	78	I	R,E,T STATUS IN OR (SIDDAL, 1977A; DYRNESS ET AL., 1975) AND CA (CNPS, 1974). IRIDACEAE.
IRIS TENAX SSP. KLAMATHENSIS KLAMATH IRIS	9	R	WOODED HILLSIDES ABOVE WEITCHPEC, HUMBOLDT CO. R,E,T STATUS IN CA (CNPS, 1974). IRIDACEAE.
ISOETES NUTTALLII NUTTALL'S QUILLWORT	123456789	R	,T STATUS IN OR (SIDDALL, 1977A). ISOETACEAE.
JUNCUS SUPINIFORMIS SPREADING RUSH	123456789	R	R,E,T STATUS IN OR (SIDDALL, 1977B). JUNCACEAE.
JUNIPERUS COMMUNIS VAR. JACKII JACK'S JUNIPER	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). CUPRESSACEAE.
LEDUM GROENLANDICUM LABRADOR TEA	12345	R	BOGS. R,E,T STATUS IN OR (SIDDALL, 1977A ^ 1977B; DYRNESS ET AL., 1975). ERICACEAE.
LEUCOTHOE DAVISIAE SIERRA LAUREL	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). HILLSIDE BOGS. ERICACEAE.
LEWISIA COLUMBIANA VAR. RUPICO COLUMBIA LEWISIA	134	R	OLYMPICS AND SADDDLE MTN. AND ONION PEAK, CLATSOP CO., OR. R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975) AND OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975). PORTULACACEAE.
LEWISIA COTYLEDON CUP-SHAPED LEWISIA	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975). PORTULACACEAE.
LEWISIA OPPOSITIFOLIA OPPOSITE-LEAVED LEWISIA	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975) AND CA (CNPS, 1974).
LILIUM BOLANDERI BOLANDER LILY	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). OPEN HILLSIDES. LILIACEAE.
LILIUM OCCIDENTALE WESTERN LILY	89	R	R,E,T STATUS IN OR (SIDDALL, 1977A ^ 1977B; FWS, 1976C; SMITHSONIAN INSTITUTE, 1975) AND CA (CNPS, 1974). COASTAL SHRUB AND BOGS. LILIACEAE.
LILIUM PARDALINUM LILY	678	R	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). BOGS AND SPRINGS. LILIACEAE.

TABLE 3-79. RARE, ENDANGERED, OR THREATENED FLORA (continued)

SCIENTIFIC NAME COMMON NAME	RANGE	STATUS	NOTES
LILIUM VOLLMERI VOLLMER LILY	89	I	R,E,T STATUS IN OR (SIDDALL, U977A, SMITHSONIAN INST., 1975; DYRNESS ET AL., 1975) AND CA (CNPS, 1974). HILLSIDE BOGS. LILIACEAE.
LILIUM WIGGINSII WIGGINS LILY	9	R	R,E,T STATUS IN OR (SIDDALL, 1977A; SMITHSONIAN INST., 1975) AND CA (CNPS, 1974).
LOMATIUM HOWELLII HOWELL'S LOMATIUM	8	I	ROCKY SERPENTINE SLOPES. R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975) AND CA (CNPS, 1974). UMBELLIFERAE.
LOMATIUM MARTINDALEI VAR. FLAV MARTINDALE'S YELLOW LOMATIUM	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). UMBELLIFERAE.
LUPINUS TRACYI TRACY'S LUPINE	9	R	R,E,T STATUS IN CA (CNPS, 1974). LEGUMINOSAE.
LYCOPODIUM CLAVATUM GROUNDPINE CLUBMOSS	123456789	R	R,E,T STATUS IN CA (CNPS, 1974). MORE COMMON NORTH. LYCOPODIACEAE.
LYCOPODIUM INUNDATUM BOG CLUBMOSS	123456789	R	COASTAL BOGS. R,E,T STATUS IN OR (SIDDALL, 1977A) AND CA (CNPS, 1974). LYCOPODIACEAE.
MONARDELLA PURPUREA PURPLE MONARDELLA	78	I	R,E,T STATUS IN OR (SIDDALL, 1977A; SMITHSONIAN INST., 1975; DYRNESS ET AL., 1975) AND CA (CNPS, 1974). LABIATAE.
MONOTROPA UNIFLORA INDIAN-PIPE	123456789	R	SAPROPHYTE. R,E,T STATUS IN CA (CNPS, 1974). ERICACEAE.
PEDICULARIS BRACTEOSA VAR. ATR DARK-RED BRACTED LOUSEWORT	1	R	R,E,T STATUS IN WA (DENTON ET AL., U977; DYRNESS ET AL., 1975). SCROPHULARIACEAE.
PERIDERIDIA ERYTHRORHIZA RED-ROOTED PERIDERIDIA	8	I	R,E,T STATUS IN OR (SIDDALL, 977AN SMITHSONIAN INST., U975). UMBELLIFERAE.
PETROPHYTUM HENDERSONII OLYMPIC MOUNTAIN ROCKMAT	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). ROCKY CLIFFS. ROSACEAE.
PHACELIA BOLANDER BOLANDER'S PHACELIA	3	R	R,E,T STATUS IN WA (DENTON ET AL.. 1977; DYRNESS ET AL., 1975). WAHKIAKUM CO., WA. HYDROPHYLLACEAE.
PHACELIA CAPITATA CAPPED PHACELIA	7	I	ALONG COQUILLE. R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975; FWS, 1976*). HYDROPHYLLACEAE.
PHLOX PECKII SPREADING PHLOX	123456789	R	FORMERLY PHLOX DIFFUSA. R,E,T STATUS IN OR (SIDDALL, 1977A; SMITHSONIINST., 1975). POLEMONIACEAE.
PITYOPUS CALIFORNICUS PINE-FOOT	39	R	SAPROPHYTE. R,E,T STATUS IN OR (SIDDAL, 1977A; SMITHSONIAN INST., 1975) AND CA (CNPS, 1974). ERICACEAE.
PLANTAGO MACROCARPA ALASKAN PLAINTAIN	12345	R	R,E,T STATUS IN WA (DENTON ET AL, 1977) AND OR (SIDDALL, 1977A ^ 1977B; DYRNESS ET AL., 1975). PLANTAGINACEAE.
PLATANTHERA UNALASCENSIS SSP. GREEN'S BOG-ORCHID	456789	R	FORMERLY HABENARIA GREENEI. R,E,T STATUS IN OR (SIDDALL, 1977A ^ 1977B; FWS, 1976C; SMITHSONIAN INST., 1975). CLIFFS AND DRY HILLS. ORCHIDACEAE.
PLEURICOSPORA FIMBRIOLATA FIRNGED PINESAP	123456789	R	SAPROPHYTE. R,E,T STATUS IN WA (DENTON ET AL., 1977) OR (SIDDALL, 1977A ^ 1977B). ERICACEAE.
PLEUROPOGON REFRACTUS NODDING SEMAPHORE GRASS	123456789	R	R,E,T STATUS IN CA (CNPS, 1974). GRAMINEAE.
POLEMONIUM CARNEUM SALMON POLEMONIUM	123456789	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). POLEMONIACEAE.
POLEMONIUM ELEGANS ELEGANT SKY-PILOT	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977). POLEMONIACEAE.
POLYSTICHUM CALIFORNICUM CALIFORNIA SWORD-FERN	6789	R	R,E,T STATUS IN WA (DENTON ET AL., 1977) AND OR (SIDDALL, 1977A). POLYPODIACEAE.

TABLE 3-79. RARE, ENDANGERED, OR THREATENED FLORA (continued)

SCIENTIFIC NAME COMMON NAME	RANGE	STATUS	NOTES
QUERCUS SADLERIANA SADLER OAK	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). FRAGACEAE.
RANUNCULUS LOBBII LOBB'S WATER-BUTTERCUP	123456789	R	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). VERNAL POOLS. RANUNCULACEAE.
RHINANTHUS CRISTA-GALLI YELLOW RATTLE	34	R	SADDLE MTN., CLATSOP CO., AND TILLAMOOK PRAIRIE. R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). SCROPHULARIACEAE.
SALIX FLUVIATILIS COLUMBIA RIVER WILLOW	3	R	R,E,T STATUS IN WA (DENTON ET AL., 1977) AND OR (SIDDALL, 1977A; SMITHSONIAN INST., 1975). ALONG COLUMBIA R. SALICACEAE.
SANGUISORBA MENZIESII MENZIES BURNET	12	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). COASTAL BOGS AND MARSHES. ROSACEAE.
SANICULA PECKIANA PECK'S SANICLE	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST. 1975) AND CA (CNPS, 1974). UMBELLIFERAE.
SANICULA TRACYI TRACY'S SANICLE	89	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; FWS, 1976C) AND CA (CNPS, 1974). UMBELLIFERAE.
SARCODES SANGUINEA SNOW PLANT	8	R	SAPROPHYTE. R,E,T STATUS IN OR (SIDDALL, 1977A). ORCHIDACEAE.
SAXIFRAGA BRONCHIALIS VAR. VES MATTED SAXIFRAGE	134	R	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). OLYMPIC MTNS., WA, AND SADDLE AND SUGARLOAF MTNS, AND ONION PEAK, CLATSOP CO., OR. SAXIFRAGACEAE.
SAXIFRAGA CAESPITOSA VAR. EMAR TUFTED SAXIFRAGE	134	R	OLYMPIC MTNS., WA, AND SADDLE MTN. AND ONION PEAK, CLATSOP CO., OR. R,E,T STATUS IN OR (SIDDALL, 1977A). SAXIFRAGACEAE.
SAXIFRAGA FRAGARIOIDES FRAGILE SAXIFRAGE	3	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). MOUNTAIN CLIFFS. SAXIFRAGACEAE.
SAXIFRAGA OCCIDENTALIS VAR. LA WESTERN SAXIFRAGE	34	R	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975). SADDLE MTN. AND ONION PK., CLATSOP CO., OR. SAXIFRAGACEAE.
SAXIFRAGA OPPOSITIFOLIA PURPLE SAXIFRAGE	1	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975) AND OR (SIDDALL, 1977A). SAXIFRAGACEAE.
SCHOENOLIRION BRACTEOSUM BRACTED SCHOENOLIRION	8	I	R,E,T STATUS IN OR (DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975) AND CA (CNPS, 1974). MOUNTAIN MEADOWS.
SCOLIOPUS HALLII FETID ADDER'S-TONGUE	45678	R	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). LILIACEAE.
SEDUM LAXUM SSP. HECKNERI HECKNER'S LAX TONECROP	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; SMITHSONIAN INST., 1975; DYRNESS ET AL., 1975). DRY CLIFFS. CRASSULACEAE.
SENECIO FLETTII FLETT'S GROUNDSEL	123	R	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975) AND OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). OLUMPICS, WA., TO ONION PK., CLATSOP CO., OR. COMPOSITAE.
SENECIO NEOWEBSTERI OLYMPIC MOUNTAIN BUTTERWEED	1	I	FORMERLY S. WEBSTERI. R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975). COMPOSITAE.
SIDALCEA HIRTIPES HAIRY-STEMMED CHECKER-MALLOW	45	R	R,E,T STATUS IN WA (DENTON ET AL., 1977) AND OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). ALSO ON HEADLANDS. MALVACEAE.
SISYRINCHIUM CALIFORNICUM GOLDEN-EYED GRASS	123456789	R	R,E,T STATUS IN WA (DETNON ET AL, 1977; DYRNESS ET AL., 1975) AND OR (SIDDALL, 1977A AND 1977B; DYRNESS ET AL., 1975). BOGS AND WET GROUND ALONG IMMEDIATE COAST. ORCHIDACEAE.

TABLE 3-79. RARE, ENDANGERED, OR THREATENED FLORA (continued)

SCIENTIFIC NAME COMMON NAME	RANGE	STATUS	NOTES
SYNTHYRIS PINNATIFIDA VAR. LAN WOLLY FEATHERLEAF KITTENTAILS	1	I	R,E,T STATUS IN WA (DENTON ET AL., 1977; DYRNESS ET AL., 1975). SCROPHULARIACEAE.
SYNTHYRIS RENIFORMIS VAR. CORD CORDED SNOWQUEEN	3	I	R,E,T STATUS IN OR (SIDDALL, 1977A). SCROPHULARIACEAE.
SYNTHYRIS SCHIZANTHA FIRNGED SYNTHYRIS	134	R	R,E,T STATUS IN WA (DETNON ET AL., 1977; DYRNESS ET AL., 1975) AND OR (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975). MOIST CLIFFS AND LEDGES; NEAR LK. QUINAULT, OLYMPIC MTNS., WA., AND SADDLE MTN. AND ONION PEAK, CLATSOP CO., OR.
TAUSCHIA GLAUCA WHITE TAUSCHIA	68	I	R,E,T STAUS IN OR (SIDDAL, 1977A; DYRNESS ET AL., 1975) AND CA (CNPS, 1974). UNBELLIFERAE.
TAUSCHIA HOWELLII HOWELL'S TAUSCHIA	8	I	R,E,T STATUS IN OR (SIDDAL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975) AND CA (CNPS, 1974). DRY SLOPES. UMBELLIFERAE.
THELYPODIUM HOWELLII HOWELL'S THELYPODIUM	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A). FORMERLY STREPIANTHUS HOWELLII. CRUCIFERAE.
TRILLIUM KURABAYASHII KURABAYASHI'S TRILLIUM	678	I	R,E,T STATUS IN OR (SIDDALL, 1977A ^ 1977B). LILIACEAE.
TRILLIUM RIVALE RIVER TRILLIUM	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975) AND CA (CNPS, 1974). LILIACEAE.
VACCINIUM OXYCOCCUS VAR. INTER LARGE-LEAVED WILD CRANBERRY	12345	R	SPHAGNUM BOGS. R,E,T STATUS IN OR (SIDDALL, 1977A AND 977B; DYRNESS ET AL., 1975). MORE COMMON IN WA. ERICACEAE.
VANCOUVERIA CHRYSANTHA GOLDEN INSIDE-OUT-FLOWER	8	I	R,E,T STATUS IN OR (SIDDALL, 977A; DYRNESS ET AL., 1975; SMITHSONIAN INST., 1975) AND CA (CNPS, 1974). BERBERIDACEAE.
VANCOUVERIA PLANIPETALA FLAT-PETALED INSIDE-OUT-FLOWER	8	I	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). DRY WOODS. BERBERIDACEAE.
VIOLA ADUNCA VAR. UNCINULATA HOOK VIOLET	9	R	R,E,T STATUS IN OR (SIDDALL,1977A). VIOLACEAE.
WOODWARDIA FIMBRIATA CHAIN FERN	123456789	R	R,E,T STATUS IN WA (DENTON ET AL., 1977 AND OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). POLYPODACEAE.
ZAUSCHNERIA LATIFOLIA	5	R	R,E,T STATUS IN OR (SIDDALL, 1977A; DYRNESS ET AL., 1975). ALONG LOWER ROGUE RIVER. ONAGRACEAE.

ESTUARY

SCIENTIFIC NAME COMMON NAME	RANGE	STATUS	NOTES
CORDYLANTHUS MARITIMUS SSP. PA MARSH BIRD'S BEAK	6789	R	R, E, T STATUS IN OREGON (SIDDALL, 1977A AND 1977B; DYRNESS ET AL., 1975; SMITHSONIAN INSTITUTION, 1975) AND CALIFORNIA (CNPS, 1974). SCROPHULARIACEAE.
CORDYLANTHUS MARITIMUS VAR. MA SEASIDE BIRD'S BEAK	6789	R	LOW SAND MARSH. R, E, T STATUS IN OREGON (SIDDALL, 1977A; DYRNESS ET AL., 1975; SMITHSONIAN INSTITUTION, 1975; FWS, 1976C) AND CALIFORNIA (CNPS, 1974). SCROPHULARIACEAE.
JUNCUS GERARDII MUD RUSH	123456789	R	R, E, T STATUS IN OREGON (SIDDALL, 1977B). JUNCACEAE.
ORTHOCARPUS CASTILLEJOIDES VAR HUMBOLDT ORTHOCARPUS	9	R	R, E, T STATUS IN CALIFORNIA (CNPS, 1974). SCROPHULARIACEAE.
SALIX HOOKERIANA COAST WILLOW	123456789	R	ON LOGS, AT MARSH MARGIN. PIONEER. R, E, T STATUS IN OREGON (SIDDALL, 1977A AND 1977B; DYRNESS ET AL., 1975). SALICACEAE.
STELLARIA HUMIFUSA SPREADING STARWORT	12345	R	R, E, T STATUS IN WASHINGTON (DENTON ET AL., 1977) AND OREGON (SIDDALL, 1977A AND 1977B; DYRNESS ET AL., 1975). CARYOPHYLLACEAE.

TABLE 3-79. RARE, ENDANGERED, OR THREATENED FLORA (continued)

SCIENTIFIC NAME COMMON NAME	RANGE	STATUS	NOTES
SHORELINE			
ABRONIA UMBELLATA PINK SAND-VERBENA	123456789	R	R, E, T STATUS IN OREGON (SIDDALL, 1977B). NYCTAG INACEAE.
CAREX LIVIDA PALE SEDGE	123456789	R	R, E, T STATUS IN WASHINGTON (DENTON ET AL., 1977) ; COMMON TO SOUTH. CYPERACEAE.
CIRSIUM ACANTHODONTUM SPINEY-TOOTHED THISTLE	3	I	STATUS IN OREGON (SIDDALL, 1977A AND 1977B). COMP OSITAE.
CLARKIA AMOENA VAR. PACIFICA PACIFIC FAREWELL-TO-SPRING	58	I	STATUS IN OREGON (SIDDALL, 1977A AND 1977B). ONAGR ACEAE.
CORDYLANTHUS MARITIMUS SSP. PA MARSH BIRDSBEAK	6789	R	R, E, T ATATUS IN OREGON (SIDDALL, 1977A AND 1977B ; DYRNESS ET AL., 1975; SMITHSONIAN INSTITUTION, 1 975) AND CALIFORNIA (CNPS, 1974). SCROPHULARIACEA E.
DARLINGTONIA CALIFORNICA PITCHER PLANT	56789	R	IN BOGS. R, E, T STATUS IN OREGON (SIDDALL, 1977A AND 1977B; SMITHSONIAN INSTITUTION, 1975; DYRNESS ET AL., 1975). SARRACENIACEAE.
DROSERA ROTUNDIFOLIA ROUND-LEAVED SUNDEW	123456789	R	IN BOGS AND COLD SWAMPS. R, E, T STATUS IN CALIFO RNIA (CNPS, 1974); MORE COMMON NORTH. DROSERACEAE .
EMPETRUM NIGRUM CROWBERRY	123456789	R	R, E, T STATUS IN OREGON (SIDDALL,1 977A AND 1977B ; DYRNESS ET AL., 1975). MORE COMMON IN WASHINGTO N AND CALIFORNIA. ALSO IN BOGS. EMPETRACEAE.
LASTHENIA MACRANTHA GOLD LASTHENIA	7	R	R, E, T STATUS IN OREGON (SIDDALL, 1977A AND 1977B ; SMITHSONIAN INSTITUTION, 1975). BLUFFS NORTH OF GOLD BEACH. COMPOSITAE.
LASTHENIA MINOR VAR. MARITIMA HAIRY LASTHENIA	12589	R	R, E, T STATUS IN WASHINGTON (DENTON ET AL., 1977) , OR (SIDDALL, 1977AR, E, T STATUS IN WASHINGTON (DENTON ET AL., 1977), OREGON (SIDDALL, 1977A AND 1 977B; SMITHSONIAN INSTITUTION, 1975; DYRNESS ET AL ., 1975), AND CALIFORNIA (CNPS, 1974). COMPOSITAE
LEDUM GROENLANDICUM BOG LABRADOR TEA	12345	R	R, E, T STATUS IN OREGON (SIDDALL, 1977A AND 1977B ; DYRNESS ET AL., 1975); MORE COMMON NORTH. ERICA CEAE.
LYCOPODIUM INUNDATUM BOG CLUB-MOSS	123456789	R	R, E, T STATUS IN OREGON (SIDDALL, 1977A) AND CALI FORNIA (CNPS, 1974). MORE COMMON NORTH. LYCOPOIA CEAE.
MICROSERIS BIGELOVII COAST MICROSERIS	123456789	R	R, E, T STATUS IN OREGON (SIDDALL, 1977A AND 1977B ; DYRNESS ET AL., 1975). COMPOSITAE.
PHACELIA ARGENTEA SILVER PHACELIA	6789	R	R, E, T STATUS IN OREGON (SIDDALL, 1977A AND 1977B ; DYRNESS ET AL., 1975) AND CALIFORNIA (CNPS, 1974). HYDROPHYLLACEAE.
POA PACHYPHOLIS SEACLIFF BLUEGRASS	3	I	R, E, T STATUS IN WASHINGTON (DENTON ET AL., 1977; DYRNESS ET AL., 1975; SMITHSONIAN INSTITUTION, 19 75). ILWACO PACIFIC COUNTY , OCEAN CLIFFS. GRAMI NEAE.
ROMANZOFFIA TRACYI TRACY'S MISTMAIDEN	123456789	R	R, E, T STATUS IN WASHINGTON (DENTON ET AL., 1977) AND OREGON (SIDDALL, 1977A AND 1977B; DYRNESS ET AL., 1975). BORAGINACEAE.
SALIX HOOKERIANA COAST WILLOW	123456789	R	R, E, T STATUS IN OREGON (SIDDALL, 1977A AND 1977B ; DYRNESS ET AL., 1975). SALICACEAE.
SEDUM LANCEOLATUM VAR. NESIOTI LANCE-LEAVED STONECROP	12	R	R, E, T STATUS IN WASHINGTON (DENTON ET AL., 1977) . CRASSULACEAE.
SEDUM LAXUM PERPLEXUM BLACK STONECROP	3	R	R, E, T STATUS IN OREGON (SIDDALL, 1977A AND 1977B ; DYRNESS ET AL., 1975). CRASSULACEAE.

TABLE 3-79. RARE, ENDANGERED, OR THREATENED FLORA (continued)

SCIENTIFIC NAME COMMON NAME	RANGE	STATUS	NOTES
SIDALCEA HIRTIPES HAIRY-STEMMED CHECKER-MALLOW	345	R	R, E, T STATUS IN WASHINGTON (DENTON ET AL., 1977) AND OREGON (SIDDALL, 1977A; DYRNESS ET AL., 1975) . ALSO IN MOUNTAINS. MALVACEAE.
SILENE DOUGLASII VAR. ORARIA DOUGLAS SILENE	4	I	R, E, T STATUS IN OREGON (SIDDALL, 1977A AND 1977B ; DYRNESS ET AL., 1975; FWS, 1976C; SMITHSONIAN INSTITU RGN, 1975). TILLAMOOK HEAD. CARYOPHYLACEAE .
SISYRINCHIUM CALIFORNICUM GOLDEN-EYED GRASS	23456789	R	R, E, T STATUS IN WASHINGTON (DENTON ET AL., 1977; DYRNESS ET AL., 1975) AND OREGON (SIDDALL, 1977A AND 1977B; DYRNESS ET AL., 1975). ORCHIDACEAE.

3.5 AREAS OF ECOLOGICAL CONCERN

The concept of "critical areas" has come to prominance in recent years and has been the subject of considerable study (Council of State Governments, 1974, 1975). Recently the definition of an "endangered habitat" or critical ecological area has been expanded (Dyrness et al., 1975; Garcia, 1974; Johnson and Jones, 1977; Pickett and Thompson, 1978; and others). In response, research natural area preserves of various types are being proposed and steps taken for their protection (Dyrness et al., 1975; The Nature Conservancy, 1977).

A definition of areas of ecological concern has been proposed by the Senate Committee on Interior and Insular Affairs (1973) as follows:

> Natural areas containing rare, remnant, unique, or otherwise significant ecological communities, such as virgin forests, vegetation types rare or unusual in an area, endangered botanical species, and others.
>
> Natural wildlife habitats of rare and endangered species, and other significant migratory routes, breeding, nesting, and feeding and resting areas of terrestrial, ornithological, and aquatic animals.

The following definition of critical wildlife habitats is given by the California State Office of Planning and Research (1973):

> Wildlife habitats considered as areas of potential Critical Concern are those which:
>
> 1. support breeding grounds and/or principal concentrations of species declared to be rare and endangered and/or species of economic value either commercially or as game species. Rare and endangered species are those designated by the Department of Fish and Game and reported to the Governor and the Legislature under the provisions of the Fish and Game Code, Article 1, Section 903
> 2. provide areas of seasonal concentrations of wildlife species, e.g., winter deer range
> 3. are riparian habitats in valley and foothill areas
> 4. are wetlands, inland and coastal, supporting concentrations of waterfowl
> 5. are bays and estuaries providing important breeding and nursery habitat for marine species and birdlife
> 6. are streams which provide salmon and steelhead nursery and spawning habitat of economic significance and
> 7. are areas having present or potential human uses including scientific and educational uses.

Similarly, Garcia (1974) identified critical habitats as follows:

1. Habitats having seasonally high concentrations of wildlife (e.g. wintering areas, waterfowl concentration areas)
2. Habitats receiving significant use by rare, threatened, or endangered wildlife
3. Habitats (communities) which are rare or scarce - having limited areal distribution within the region under consideration
4. Migration routes.

The research natural areas programs are oriented towards identifying characteristic and unique habitats and collecting samples of the identified habitat or community types for preservation as well as educational and scientific uses. The rationale for establishment of such areas includes preservation of environemntal and genetic diversity, and provision of a baseline of natural conditions from which changes in human-affected environments can be measured.

Existing federal research natural areas of the region are described by Franklin et al. (1972), Dyrness et al. (1973), and Hood (1977).

Research natural area needs for Washington and Oregon have been reviewed by Dyrness et al. (1975). State and private natural areas and critical habitats are catalogued for Oregon by The Nature Conservancy (1977). Thompson and Snow (1974) and Battelle Pacific Northwest Laboratories (1973) have also listed information on areas of ecological concern for Oregon. Research natural areas are in the process of being catalogued for Washington (Matai, 1977, pers. comm.). The U.S. Army Corps of Engineers (1975F) has developed a preliminary atlas of potentially critical areas. Isakson and Reichard (1976B) have developed an atlas of critical areas for coastal species in Washington State.

Hood (1977) has published a list of existing and proposed research natural areas for California along with their description and characteristic species. The California Coastal Zone Conservation Commission (1975) maps areas of ecological concern in Northern California including eelgrass beds, waterfowl nesting sites, waterfowl concentration areas, clam preserves, oyster beds, and rookeries.

Recently the Department of Interior, Fish and Wildlife Service, under the Land Heritage Act of 1977, has established a program for identifying and acquiring critical wildlife areas called The Unique Wildlife Ecosystem Program. Under the program some $80 million per year nationwide will be earmarked for acquisition of areas identified as critical to endangered, threatened, or otherwise significant species (Paulen, 1978, personal communication). The program is more oriented to nongame species than the previous wetlands acquisition programs funded through the Pittman-Robertson Wildlife Restoration Act.

In addition, two national parks - Olympic National Park and Redwood National Park - also provide for the protection and preservation of selected inland ecosystems in the study area, including portions of the Redwood Zone, Sitka Spruce Zone, True Fir Zone, and Arctic Alpine Zone.

Some portions of the study area have been classified as wilderness areas, e.g. portions of the Olympic National Park, Flattery Rocks, Quillayute Needles, Copalis, Three Arch Rocks, and Oregon Islands National Wildlife Refuges. Several areas within the region are roadless areas and some are proposed as wilderness areas under the Rare II program. Existing and proposed areas are documented by the U.S. Department of Agriculture in their Rare II, Roadless Area Review and Evaluation statements nationwide and appendices for Washington, Oregon, and California (USDA, 1978A, -B, -C, and -D). (Status of the proposed areas will not be resolved until after this study goes to press.) In addition, Brown (1977) has recently reviewed the proposals and status for such areas in Oregon.

Several national wildlife refuges which offer protection to particular species (e.g. the Columbian White-tailed Deer NWR) or groups of species (e.g. the Oregon Islands NWR) exist in the study area. Flattery Rocks, Quillayute Needles, Copalis, Cape Meares, Three Arch Rocks, and Oregon Islands National Wildlife Refuges were established principally for the protection of breeding marine birds, although marine mammals also derive considerable benefits. Willapa, Lewis and Clark, and Humboldt Bay National Wildlife Refuges were for the protection of migratory waterfowl. The Columbian White-tailed Deer National Wildlife Refuge was established for the protection of the endangered Columbian white-tailed deer (see Species of Concern in Part 2 of this volume).

The South Slough of Coos Bay has been given a protected status as an estuarine sanctuary under the Coastal Zone Management Act of 1972 (16 U.S.C. Section 1461), the first such sanctuary nationwide (Oregon State Department of Land Conservation and Development, 1974). South Slough is a relatively pristine estuary with extensive eelgrass beds.

Figure 3-75 summarizes the national wildlife refuges, the Coos Bay estuarine sanctuary, and the national parks of the region, as well as other public lands of interest. Existing and proposed research natural areas and other critical areas are given in Volume 4 in the respective Watershed Units.

The special use of specific areas by Species of Concern also establishes areas of ecological concern e.g. waterfowl concentration areas. These areas are presented in Section 3.4 of this chapter and in the individual species accounts in Part 2.

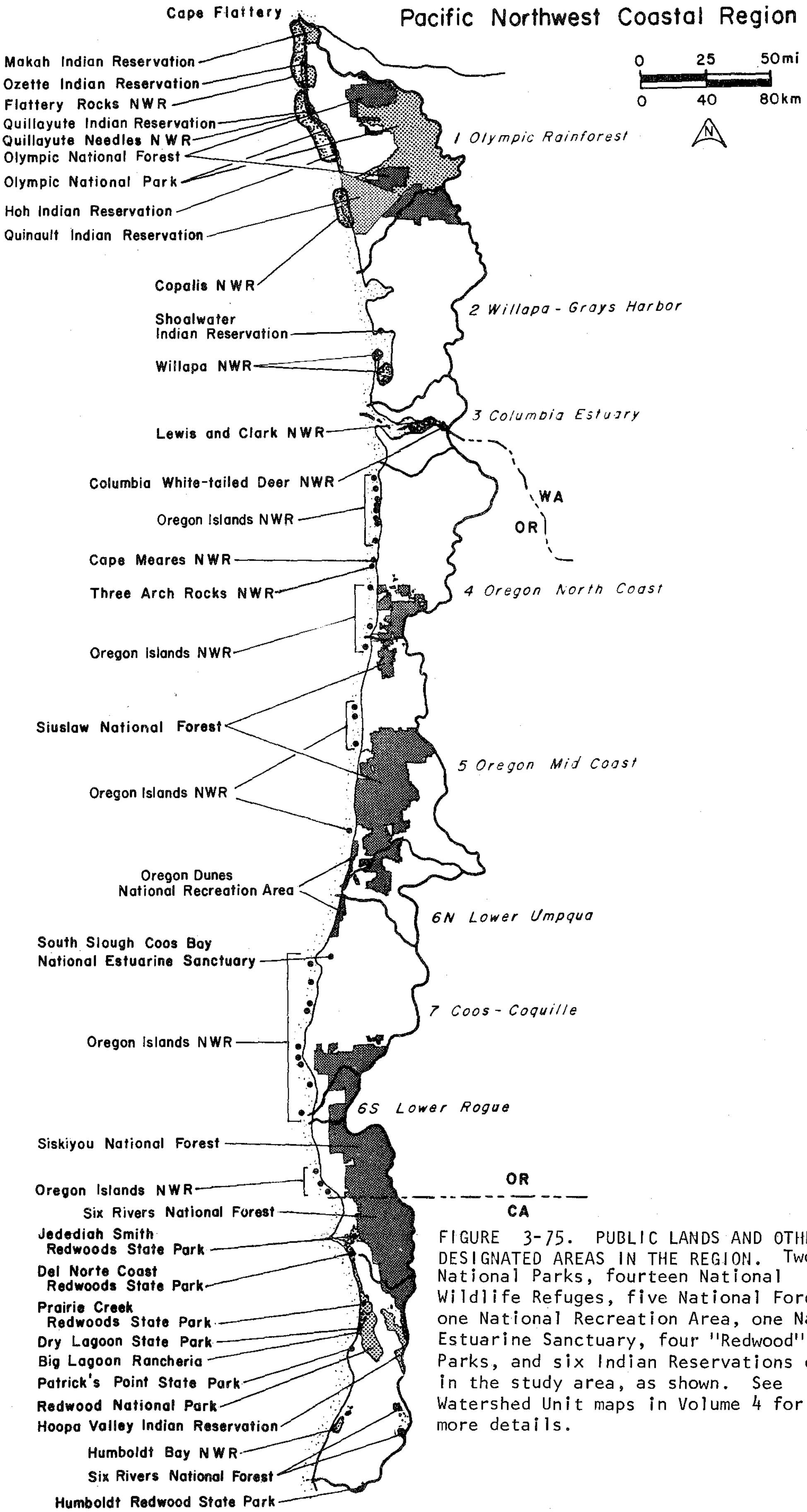


FIGURE 3-75. PUBLIC LANDS AND OTHER DESIGNATED AREAS IN THE REGION. Two National Parks, fourteen National Wildlife Refuges, five National Forests, one National Recreation Area, one National Estuarine Sanctuary, four "Redwood" State Parks, and six Indian Reservations exist in the study area, as shown. See Watershed Unit maps in Volume 4 for more details.

Chapter Four – SOCIOECONOMIC ENVIRONMENT

4.1 THE SOCIOECONOMIC ENVIRONMENT

The socioeconomic environment of the Pacific Northwest Coastal Region is strongly influenced by the fluctuating, declining, or expanding levels of its natural resource based export (basic) industries. To date, relatively little employment or income is derived from activities not directly linked to local natural resources. Other major sources of income are indirectly resource-related. They include growing in-migration of retirees and seasonal residents and intervention of the federal government in the form of unemployment compensation, training, economic development programs, and regulation of land and ocean use. Population densities throughout the region are low compared with those of the highly developed Puget Sound and Willamette Valley regions. Unemployment and seasonal employment are more widespread than in those major urban areas, and income levels are generally lower.

4.1.1 Principal Natural Resources. The economically valuable natural resources of the region include: extensive forests, estuarine and marine fish and shellfish, small areas of productive agricultural land, limited mineral deposits, and a shoreline suitable at several points for port development. The largely unspoiled natural recreation attractions of both coastal and inland areas, historic sites, and fish and wildlife constitute valuable resources, including, in particular, the estuarine habitats, dunes, and beaches. The overwhelming predominance of the forest resource is diminishing as old growth on private lands is harvested. This fact and a reassessment of the value of the forest resource for other uses are contributing to a shift in the way the region's natural resources are valued.

4.1.2 Supply and Demand. Demand for all of the region's natural resources is increasing. At the same time, because of growing understanding both of the effects of over-exploitation and of conflicts between uses, limitations are being placed on resource extraction. Such limitations, and changes in policy regarding the manner in which resources should be used, lead to economic dislocations. Adjustment to such dislocations tends to be difficult and costly due to the region's lack of diversification and its population's traditional ties with a few basic industries. For the same reason, the region is also strongly affected by fluctuations, both cyclic and seasonal, in demand for its resources and products based on them.

4.1.3 Capital, Labor, and Facilities. The region is relatively isolated from major population and industrial centers. Transportation routes are limited; fuel and power are mainly imported from outside the region, and the population density is low. Major sources of capital have tended to be national forest industry firms or local processors strongly dependent on them. Much of the region's economic activity is carried out by self-employed individuals in the agriculture, fisheries, and recreation industries who lack extensive capital resources. Participation in the labor force tends to be lower in the region than in the more urbanized areas of each state. This reflects the limited industrial employment opportunities but also represents a potentially valuable human resource.

4.1.4 Major Basic Industries. With the exception of sand, gravel, and other minerals, each of the economically and culturally valuable resources is in demand by markets outside the study area. The traditionally dominant industry throughout the region has been the forestry and forest products industry. The relative ranking of this industry and of fisheries, agriculture, recreation, mineral industries, and transportation involving external markets varies between the watersheds. The overall ranking throughout the region is discussed in Section 4.9, following discussion of each activity individually.

The forestry and forest products, agriculture, and fisheries industries have been declining for a number of years and are expected to continue to decline in terms of employment as productivity increases. The long-term outlook for forestry is the subject of debate depending upon assumptions regarding management of the industry. The economic effect of efforts to diversify industrial activity through increasing emphasis on recreation, aquaculture, and crop growing does not yet appear to be significant.

4.1.5 Service Activities. The basic industrial activity of the region supports a relatively well developed service sector. The relationship between the basic and service sectors in terms of employment and income (the multiplier) is difficult to determine because employment in agriculture, fisheries, and recreation, for several reasons discussed in later sections, can only be estimated. In addition, some trade and service activities serve both the local population and tourists and so are partially basic. It would appear, however, that the regional employment multiplier is on the order of 2.3 (also see Section 4.8 Service Activities).

4.1.6 Population, Employment, and Income. The Pacific Northwest Coastal Region is relatively sparsely populated, with a concentration of urban centers along the coastal strip. The population is made up of a relatively high proportion of elderly people. For this reason, and also due to limited employment opportunities, participation in the labor force tends to be lower than the average in each of the three states. Low labor force participation rates, high unemployment, and severe seasonal fluctuations in employment contribute to median family and per capita personal income levels significantly below state averages.

4.1.7 Data Availability and Presentation. Socioeconomic data specific to the Pacific Northwest Coastal Region as defined for this study are typically not available. In most cases the data units are the twelve counties which comprise the region. The term Coastal Region is used in this chapter to refer to these twelve counties: Clallam, Jefferson, Grays Harbor, Pacific, and Wahkiakum in Washington; Clatsop, Tillamook, Lincoln, Coos, and Curry in Oregon; and Del Norte and Humboldt in California (see Figure 1-2 in Chapter 1 for county location). Data are usually presented for each county rather than aggregated by state or the coastal region as a whole. There are two reasons for using this approach. First, while the coastal region is relatively homogenous, there are differences between counties which are significant in terms of vulnerability to change and need or suitability for certain types of economic development. Secondly, consistent and comprehensive data are frequently lacking for all parts of the region, necessitating use of those individual counties for which data are available as examples. Where comprehensive data do exist, they may require careful interpretation. For example, County Business Patterns (U.S. Department of Commerce, 1977D), while more detailed than other sources of employment data, seriously understates employment in industries with strong seasonal patterns since data were collected only on a single occasion in the low season.

4.2 FORESTRY AND FOREST PRODUCTS

The forest and forest products industry is the dominant basic industry in terms of both employment and value throughout the Pacific Northwest Coastal Region.

4.2.1 Forest Resources. The forest resources of the Pacific Northwest Coast are vast. Forestland covers almost 90% of total land area. Of that amount, approximately 89% is classified as commercial forests.

4.2.1.1 Species Range. The principal commercial species of the study area include Douglas fir, western hemlock, Sitka spruce, and redwood. Very generalized maps showing species range may be found in U.S. Army Corps of Engineers (1975F), Loy et al. (1976), and Plank (1975). The Douglas fir is found all along the coast and is the dominant tree in the study area in terms of volume, acreage, and commercial exploitation (see Species of Concern in Part 2 of this volume for a more thorough discussion). The western hemlock, another important commercial conifer, populates the coastal areas of Oregon and Washington. It is the most common species found in the Washington coastal counties of Grays Harbor, Pacific, Clallam, and Jefferson counties (U.S. Army Corps of Engineers, 1976C, 1976H; Washington DCED, 1977A,B). The Sitka spruce, also common along the Washington and Oregon coast, becomes most populous in the northern part of the study area. A number of other commercially less significant conifers can be found throughout the study area, including the western red cedar in parts of the Oregon and Washington coast, the Ponderosa pine and Port Orford cedar (in Curry County, Oregon), the lodgepole pine, and the grand fir. Redwoods are the second most populous species (after Douglas fir) of Humboldt and Del Norte Counties, California. Commercial exploitation of redwoods is being limited, however, by national park expansion (QRC Research Corporation, 1978; Broida et al., 1975).

Hardwood species in the study area include the tanoak, madrone, red alder, and true oak. Hardwoods cover approximately 15% of forest area along the coast; however, they account for only about 5% of sawtimber volume (Schmisseur and Boodt, 1975; QRC Research Corporation, 1978; Washington DCED, 1977A,B,C). Where hardwoods are present in coniferous stands, they frequently become the dominant stand component when the conifers are removed by cutting or fire. Inventory data related to cutting history indicate that cutting has been a major factor affecting type succession; where cutting is not followed by prompt restocking of conifers, hardwoods are the most likely successors. In Humboldt County, for example, hardwood forest types occupy 53 percent of the cutover commercial forest area, but only 28 percent of area where no previous cutting has occurred (Oswald, 1968). Most of the hardwood type area is inherently capable of supporting softwood types. Over 90 percent of the area now in hardwood type is classified as capable of growing merchantable stands of coniferous timber. There is little present demand for hardwoods and the value of hardwoods will probably always be less than for softwoods. Hardwood stands are characterized by low volumes per acre (Oswald, 1968).

For a discussion of forest species, listed by biological zones (inland, coast, etc.) and habitat type (early seral shrub, second growth forest, old growth forest, etc.) see Volume Three Zone and Habitat Descriptions. For additional discussion of commercial forest species, including harvest data, see Section 3.4.1.1 in Chapter 3 and individual species of concern accounts in Part 2 of this volume.

4.2.1.2 Productivity. The Douglas fir is the most abundant and widespread of all study area conifers. For these reasons, it is used as the index species for the potential productivity of forest land. Table 4-1 outlines the classification. The system uses the size of 100-year-old trees to distinguish five productivity classes which are measures of climate and soil favorability in a given spot. In an area of dry, shallow soils, Douglas fir may grow only 30 meters or less in a century; in a good site, it may double that growth (Loy et al., 1976).

TABLE 4-1. FOREST SITE CLASS (PRODUCTIVITY) CHARACTERISTICS.
(From Loy et al., 1976.)

Height of Trees When 100 Years Old		Site Class	Wood Growth Per Year	
Meters (approx.)	Feet		m^3/hectare	ft^3/acre
Under 30	Under 100	V	Under 75	Under 5.2
30 - 40	100 - 130	IV	75 - 120	5.2 - 8.4
40 - 50	130 - 160	III	120 - 156	8.4 - 10.9
50 - 60	160 - 190	II	156 - 184	10.9 - 12.9
Over 60	Over 190	I	Over 184	Over 12.9

Table 4-2 shows the distribution of land for counties in the study area by U.S. Forest Service land classification: productive-reserved, unproductive, and commercial forest lands, and non-forest lands.

The Forest Service defines these classifications as follows:

> Forest Land - land at least 10% stocked by forest trees of any size or formerly having had such tree cover and not currently developed for nonforest;
>
> Commercial Timberland - forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation;
>
> Productive-reserved Forest Land - productive public forest and withdrawn from timber utilization through statute or administrative regulation;
>
> Unproductive Forest Land - forest land incapable of yielding crops of industrial wood because of adverse site conditions. Includes sterile or poorly drained forest land, subalpine forests, and steep rocky areas where topographic conditions are likely to prevent management for timber production (Bassett and Choate, 1974A.)

The fifth classification of forest land, Deferred Forest land, refers to National Forest lands that meet productivity standards for commercial timberland, but are under study for possible inclusion in the Wilderness System (see p. 4-3). At the time of the inventories shown in Table 4-2, no land in the study area was classified as Deferred Forest land.

Study area totals in Table 4-2 reflect inventories of forest land from differing years (1973 for coastal Oregon and Washington, 1965 and 1967 for northern coastal California). These totals should be treated as approximations. U. S. totals are included for comparative purposes.

Forest lands cover 88.7% of the Pacific Northwest Coastal Region compared to only 33.2% of the U. S. as a whole. Of this forest land, 81.6% is classified as productive (both commercial and productive-reserved). For the U. S. as a whole, only 33.2% of the forest land is productive. Of productive land, 5.6% is listed as productive-reserved in the study area and 0.9% for the U. S. In sum, these figures indicate that the Pacific Northwest Coast is a very heavily forested area, with highly productive forest land, a relatively large portion of which is protected from commercial harvest.

TABLE 4-2. FOREST LANDS IN THE PACIFIC NORTHWEST COASTAL STUDY AREA. Data, in thousands of acres, are from U.S. Forest Service Timber Resource Statistics for Oregon and Washington, 1973, Humboldt County, California, 1967, and Del Norte County, 1965. (From Bassett and Choate, 1974A and 1974B; Oswald, 1968; Oswald and Walton, 1966; and Kuhn et al., 1974.)

Region or County	Total Land Area	Forest Land Total	Forest Land Commercial	Forest Land Productive Reserved	Forest Land Unproductive	Non-Forest Land
Clallam	1122	971 (86.5%)	684	168	119	151 (13.5%)
Jefferson	1155	1031 (89.3%)	528	318	119	151 (13.1%)
Grays Harbor	1222	1107 (90.6%)	1076	10	21	115 (9.4%)
Pacific	581	535 (92.1%)	518	2	15	46 (7.9%)
Wahkiakum	167	149 (89.2%)	140	-	9	18 (10.8%)
Washington Coast	4247	3793 (89.3%)	2946(69.4%)	498(11.7%)	349 (8.2%)	454 (10.7%)
Clatsop	515	487 (94.6%)	462	5	20	28 (5.4%)
Tillamook	714	644 (90.2%)	637	6	1	70 (9.8%)
Lincoln	631	574 (91.0%)	572	1	1	57 (9.0%)
Coos	1028	891 (86.7%)	874	3	15	136 (13.2%)
Curry	1041	1005 (96.5%)	760	50	195	36 (3.5%)
Oregon Coast	3929	3602 (91.7%)	3305(84.1%)	65 (1.7%)	232 (5.9%)	327 (8.3%)
Del Norte	642	607 (94.5%)	487	13	107	35 (5.5%)
Humboldt	2287	1850 (80.9%)	1701	47	102	437 (19.1%)
California Coast	2929	2457 (83.9%)	2188(74.7%)	60 (2.0%)	209 (7.1%)	472 (16.1%)
Study Area Total	11105	9852 (88.7%)	8439(76.0%)	623 (5.6%)	790 (7.1%)	1253 (11.3%)
U. S. Total	2270.1M	753.5M (33.2%)	449.7M(22%)	19.9M(0.9%)	233.9M(10.3%)	1516.6M(66.8%)

M = 1 million

Among the factors which influence the commercial availability of the forestry resource, apart from productivity variations, are competing uses, such as high value agricultural land, mineral extraction, high-use recreation, and special ecological concerns. For example, the large difference in percentage of forest land that is commercially productive on the Washington coast (77.7%) as compared to the Oregon coast (91.8%) is in part due to the Olympic National Park in Clallam and Jefferson Counties, Washington. All of the Park's forestland is classified as productive-reserved or unproductive, thereby reducing coastal Washington's commercial timberland resources.

4.2.1.3 Ownership. Ownership of timber resources is a particularly important characteristic of the industry. Ownership patterns influence the utilization of the resource as policies and management techniques vary by owner. As a result, the volume of harvest for a given area will depend heavily on the patterns of ownership of commercial forestland.

Data on forestry resource ownership patterns for the Pacific Northwest Coast are plentiful, although the data's recency varies. The varying dates must be borne in mind in the following discussion and accompanying tables. U.S. Forest Service surveys are available for all of coastal Oregon and Washington as of January, 1973 (Bassett and Choate, 1974A and 1974B). One regional study, Timber Resources of Southwest Oregon, 1975 (Bassett, 1977), is also available. Unfortunately the most up-to-date and complete Forest Service inventories for coastal California, (Humboldt and Del Norte Counties) occurred in 1965 and 1967 (Oswald and Walton, 1966; and Oswald, 1968). These data should be evaluated with caution, as considerable change has taken place in the resource situation in Humboldt and Del Norte Counties since 1968. New inventories have not been produced in comparable form (see Oswald, 1978). Oswald estimates, however, that privately-owned acreage in sawtimber on the Californian north coast declined 15 percent from 1967 to 1975.

A Humboldt County forest resource inventory based on aerial photographs is available for 1975 (QRC Research Corporation, 1978). This survey, unfortunately, uses a different data presentation, making comparisons over time with Forest Service data valueless.

Table 4-3 lists areas of commercial timberland in coastal Oregon and Washington by ownership class for 1973. Included in this table is a listing of commercial timberland by ownership class for the California counties from the inventories taken in 1965 and 1967.

TABLE 4-3. AREA OF COMMERCIAL FOREST LAND BY OWNERSHIP CLASS IN THE PACIFIC NORTHWEST COASTAL REGION. Data are in thousands of acres. From U.S. Forest Service Timber Statistics for Oregon and Washington, 1973; and California, Del Norte County, 1965, and Humboldt County, 1967. (From Bassett and Choate, 1974A and 1974B; Oswald and Walton, 1966; and Oswald, 1968; 1970 figures for U.S. appear in Kuhn et al., 1974.)

Region or County	All Ownership	National Forest	Other Public	Forest Industry	Other Private
Clallam	684	178	183	217	106
Jefferson	528	122	201	115	90
Grays Harbor	1076	130	263	484	199
Pacific	518	-	67	385	66
Wahkiakum	140	-	29	90	21
Washington Coast	2946 100%	430 14.6%	743 25.2%	1291 43.8%	482 16.4%
Clatsop	462	-	142	225	95
Tillamook	637	89	347	128	73
Lincoln	572	165	41	259	107
Coos	873	54	219	300	300
Curry	760	397	51	167	145
Oregon Coast	3304 100%	705 21.3%	800 24.2%	1079 32.7%	720 23.7%
Del Norte	487	334	-	130	24
Humboldt	1701	292	126	531	752
California Coast	2188 100%	626 28.6%	126 5.8%	661 30.2%	776 35.3%
Study Area Total	8438 100%	1761 20.9%	1669 19.8%	3031 35.9%	1978 23.4%
U. S. Total	499697 100%	91924 18.0%	37365 8.0%	67341 14.0%	296236 59.0%

A comparison of study area totals and U. S. totals in Table 4-3 indicates that a much higher percentage of commercial forest land is owned by the forest industry on the Pacific Northwest Coast than for the country as a whole (very approximately, 36% for the study area; 14% for the U.S.). Commercial timberland owned by the industry comprises approximately 27% of total land area along the coast. Public agencies also own a large part of commercial timberland in the study area. National Forests contain 21% of commercial timberland and 19.8% is other public lands including Bureau of Land Management lands, Indian lands, and state, county, and municipal land. In short, the unusual nature of the Pacific Northwest coast's commercial timber resources is its large concentration in the hands of public agencies and the forest industry. Other private owners (mainly farmers who possess 59% of commercial forest land nationwide, own only 23% on the coast.

Much of the public commercial timber land is land which was never taken into private ownership, or which was abandoned, often in mountainous and less accessible areas, with incomplete road systems. Much is therefore inherently less productive. In addition, lack of funds for forest management, and the claims of non-timber uses (such as watershed or fish spawning grounds, recreation, and wilderness, as mentioned above), as well as aesthetic concerns, discourage intensive timber management.

4.2.1.4 Use of the Resource. Timber is the major product of commercial forestland along the Pacific Northwest Coast. Other services and products provided by forest lands are relatively insignificant in terms of employment and income. Forestry and other uses of timberland are generally incompatible, although a few recreational activities can coexist with forestry activity (see Section 4.4.1) and to a very limited degree forests also provide grazing in California (U. S. Department of Agriculture, 1978A).

Ownership has a significant effect on type and intensity of timberland use. The forestry industry has the basic goal of harvesting a profitable volume of timber. Public timberland owners such as the U. S. Forest Service and the Bureau of Land Management (BLM) are primarily concerned with the maintenance of existing forest resources. The National Forest Management Act of 1976 states:

> "The annual allowable harvest from each National Forest will generally be limited to a quantity equal to or less than a quantity which can be removed annually on a sustained yield basis."

The Bureau of Land Management follows the same management principle.

Statistically, it is difficult to demonstrate the deficiencies of publicly-owned commercial timberland relative to industry-owned. Site class data are too generalized to allow for detailed analysis. Forest Service classifications (productive or non-productive) tell nothing about the gradients of productivity. Available sources agree with this general conclusion (Loy et al., 1976; Schmisseur and Boodt, 1975).

Annual "allowable cuts" have been established by government and industry to insure sustained yield of wood from coastal timberlands. Allowable harvests are established for conifers only. Coastal area forest industries receive much of the harvests from public lands (Schmisseur and Boodt, 1975).

Timber harvests on private lands are not constrained by allowable cut calculations. Private cuts are determined by market conditions, harvestable supplies, and individual management plans. The long-term trend in private timber harvest is exhibiting a decline because old-growth stands are no longer abundant; however, private timber holdings have often been able to supply necessary roundwood to meet short-term surges in market demand (Schmisseur and Boodt, 1975).

Table 4-4 lists volume of sawtimber on commercial timberland by ownership class in the twelve counties of the Pacific Northwest Coast. A comparison with Table 4-3, which lists area of commercial timberland by ownership class, indicates the relative effects of private and public timberland management policies. Private commercial timberlands, both "forest industry" and "other private" in Table 4-3, cover a larger area than public lands, "National Forest" and "Other Public" -- mainly BLM lands. However, in terms of sawtimber volume, public lands are better stocked than private lands in the study area. The volume of standing sawtimber, according to the inventories for the study area (excluding Del Norte County) in the late 1960s and early 1970s, averaged 28,000 mbf/acre on public lands and only 18,000 mbf on private lands. Trends in volume per acre statistics along the coast (Table 4-5) indicate differing management practices. Forest industry and other privately-owned lands have shown large declines in volume per acre values. National Forest and other public lands (much of which are BLM lands) have demonstrated only small increases or declines in sawtimber volume per acre, showing management policies have been successful.

TABLE 4-4. VOLUME OF STANDING SAWTIMBER ON COMMERCIAL TIMBERLAND BY OWNERSHIP CLASS. Data are in million board feet, International 1/4 inch rule, from U.S. Forest Service Timber Statistics for Oregon and Washington, 1973, Del Norte County, 1965, and Humboldt County, 1967. (From Bassett and Choate, 1974A and 1974B; Oswald and Walton, 1966; and Oswald, 1968; 1970 figures for U.S. appear in Kuhn et al., 1974.)

Region or County	All Ownership		National Forest		Other Public		Forest Industry		Other Private	
Clallam	21,155		6377		5597		5853		3328	
Jefferson	21,437		5449		11,983		3129		876	
Grays Harbor	22,530		6461		3830		8468		3771	
Pacific	11,814		-		1553		8902		1359	
Wahkiakum	2990		-		553		2380		57	
Washington Coast	79,926	100%	18,287	22.9%	23,516	29.9%	28,732	35.9%	9391	11.7%
Clatsop	9014		-		2256		4431		2327	
Tillamook	11,669		4095		3865		1332		2377	
Lincoln	15,846		8348		2238		4602		658	
Coos	20,296		2202		8489		4944		4661	
Curry	16,383		10,571		1300		3106		1406	
Oregon Coast	73,208	100%	25,216	34.4%	18,148	24.8%	18,415	25.2%	11,429	15.6%
Del Norte	12,836		n/a		-		n/a		n/a	
Humboldt	32,561	100%	8499	26.1%	2696	8.3%	14,117	43.4%	7249	22.3%
California Coast	58,233									
Study Area Total	211,367		52,002[1]		44,360		61,264[1]		28,069[1]	

[1]Excludes Del Norte County. n/a = Not available.

TABLE 4-5. LIVE SAWTIMBER VOLUME/ACRE BY OWNERSHIP FOR PACIFIC NORTHWEST COASTAL COUNTIES. U.S. Forest Service data are board feet/acre-International 1/4 inch rule. (From Bassett and Choate, 1974 and Bassett, 1977.)

COUNTY	NATIONAL FOREST	OTHER PUBLIC	FOREST INDUSTRY	OTHER PRIVATE
Coos				
1973	40,778	38,762	16,480	15,336
1975	80,297	29,554	15,408	4,397
% Change	97%	-24%	-7%	-71%
Curry				
1973	26,627	25,490	18,599	13,390
1975	25,512	23,458	3,092	1,481
% Change	-4%	-8%	-83%	-89%

4.2.1.5 Outlook and Effects. Future supply of timber resources along the Pacific Northwest Coast will depend on the regenerative ability of forests, and on technological improvements and management practices exercised by owners of present resources. In addition to biological volume growth, factors affecting productivity include improvements in timber utilization and accessibility plus changes in scaling standards (QRC Research Corporation, 1978). Management practices are closely tied to ownership type. The extent to which growing timber stock will be harvested after old growth timber is exhausted in the study area is a major factor affecting future timber stock. Timber supply will also be strongly affected by environmental constraints placed on public and private commercial timberlands. The 1978 expansion of the Redwood National Park is estimated to reduce the current inventory of private commercial timberland in Humboldt County by 11% (QRC Research Corporation, 1978). Park expansion is expected to remove 42% of potentially harvestable public land from commercial exploitation. Additions to wilderness areas or maintenance of roadless areas through implementation of the RARE II (Roadless Area Review) evaluation of National Forest lands could further deplete the future supply of timber along the coast (see U.S. Department of Agriculture, 1978A-1978D).

Projections of future timber supplies and harvests for the coastal region take into account many of these factors. A 1975 U. S. Forest Service study made two projections of timber resource supplies along the West Coast. The first, assuming no change in management practices, predicts a continuous decline in Western Washington and California softwood sawtimber and roundwood supply of approximately 6.1% and 4.0% per decade, respectively. Softwood timber supplies are also expected to decline in Western Oregon until the year 2000 and then to level off. The second projection by the Forest Service, assuming intensified management practices for one decade, estimates an increase in timber harvest for Western Washington and Oregon of almost 16 billion board-feet over the next seven decades (see Gedney et al., 1975, for further discussion). Both projections assume that regeneration efforts will be successful.

A recent report by Beuter et al. (1976) has estimated the magnitude of harvest decline for various timbersheds within the State of Oregon. Based on continuation of present policies and actions, they conclude that the current total harvest for Douglas County could be maintained through 1995, after which a decline of 22% would occur. For the south coast timbershed of Coos and Curry Counties, they estimate that the total harvest could be maintained through 1995 after which a decline of 35% could be expected. According to these authors, the timing of the decline in harvest is impossible to predict because the decrease is anticipated in the private forest industry sector and it is the industry's market decisions that will determine the rate of harvest.

A 1978 study of Humboldt County timber resources has calculated annual cuts for the next thirty years based on three sets of assumptions: inventory replacements will continue at the present rate; all old growth timber will be used up before second growth; and harvesting will occur simultaneously in stands for all trees above 60 years old. Annual cuts for these assumptions range from approximately 1,200 million board feet in the first case to 700 million board feet in the third (see QRC Research Corporation, 1978). These projections appear to be unrealistic. Annual cuts in both Humboldt and Del Norte Counties combined between 1967 and 1974 averaged only 1,000 million board feet. Oswald (1978) estimates that output of softwood sawtimber from private timber lands in California's North Coast Region is likely to decline substantially in the next 10 to 15 years because there are not sufficient sawtimber stocks with associated growth to maintain output. The major portion of the decline will occur in Humboldt and Del Norte Counties and affect both Douglas fir and redwood output. Oswald states that no reordering of cutting priorities among different types of stands will have a significant impact on the prospective decline. He estimates that while output of sawtimber from public lands within and adjoining the region will increase. This is unlikely to offset the private sector decline. He estimates the combined sawtimber output from Humboldt, Del Norte, and neighboring Mendocino and Sonoma Counties to drop from 1,500 million board feet (the 1967-1974 average) to 354 million board feet by 2000.

The socioeconomic consequences of lost timber resources and the resulting reduced harvest can be measured in terms of employment and income losses. A number of studies have calculated expected reductions in employment and income associated with resource decline. Wall (1973) estimated employment changes in the industry from 1970 to 2000, based on various assumptions concerning labor productivity, log exports, and an employment-wood consumption ratio in Western Washington and Western Oregon. Estimates have varied widely according to the assumptions employed. Darr and Fight (1974) estimated employment, income, and multiplier effects of reductions in timber harvests for Douglas County, Oregon. Wall and Oswald (1975) used a different technique (employees per million board feet) to relate timber harvest and total employment. Oswald (1978) has examined the effect of declining sawtimber output on processing centers in northern California. Schallou et al. (1969) calculated employment multipliers for forestry in the Pacific Northwest Coast in their economic impact projections for alternative levels of timber production.

4.2.2 Forestry and Log Production.

4.2.2.1 Timber Harvest Volume. As indicated above, the volume of timber harvest varies according to productivity, ownership, and management practices. Table 4-6 lists harvest volumes by county for the Pacific Northwest Coast broken down by ownership class; Tables 3-44, 3-45, and 3-46 in Section 3.4.1.1 give harvest data for the region by tree species.

TABLE 4-6. TIMBER HARVEST VOLUMES BY COUNTY AND OWNERSHIP CLASS. Data are in thousands of board feet. (Washington data are for 1976 from U.S. Forest Service, 1978 A-D; Oregon data are 1975 figures from USDA Forest Service, 1977; Humboldt and Del Norte County figures are for 1976 from California State Department of Forestry).

AREA	FOREST INDUSTRY	OTHER PRIVATE	TOTAL PRIVATE	BLM	NATIONAL FOREST	OTHER FEDERAL	STATE	OTHER PUBLIC	TOTAL
Clallam	176,143	37,428	213,571	-	78,681	18,423[1]	75,558	600	386,833
Jefferson	99,737	48,156	147,893	-	19,579	7,417	206,108	629	381,626
Grays Harbor	242,058	50,513	292,571	-	70,067	120,283	7,208	468	490,597
Harbor Pacific	387,290	8,665	395,955	-	-	-	10,281	586	406,822
Wahkiakum	53,609	3,969	57,578	-	-	-	5,540	1,666	64,784
Washington Total									1,730,662
Clatsop	202,887	6,646	209,533	-	-	179	69,272	57	279,061
Tillamook	134,860	6,323	141,183	49,211	47,768	-	24,459	160	262,781
Lincoln	147,264	7,634	154,898	9,467	117,977	-	11,559	961	294,862
Coos	266,556	19,178	285,734	145,545	39,612	1,316	23,835	5,023	501,065
Curry	46,862	22,789	69,651	10,468	75,510	-	330	1,019	156,978
Oregon Total									1,494,747
Del Norte	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	242,548
Humboldt	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	957,154
California Total									1,199,702

[1]Mainly Indian lands.

Data for selected counties between 1973 and 1975 in Table 4-5 indicate two trends. Overall volume of timber harvest appears to be declining along the coast. The decline may be the result of exhaustion of old growth timber along the coast or may result from more intensive forestry management practices implemented over the last decade.

From Table 4-5, it can also be seen that the percentage of timber harvests on private land has declined. Exhaustion of old growth timber on forestry industry lands has increased the dependence of the forest industry on timber resources of National Forest, BLM, and other public lands. In the past, the public agencies have increased their allowable cut to respond to market demands.

With the advent of the "Multiple Use" and "Non-declining Even-Flow Sustained Yield" concepts of the U.S. Forest Service, it is apparent that the current level of the allowable cut is not likely to increase further without more intensive management of the forests. Public lands have reached the level of cut that will maintain a perpetual, sustained yield of timber with current investment funding levels. In addition, public concern over the environment and increasing recreational activity in the public forest could have the effect of reducing the timber land base and reducing the allowable cut further, or increasing the costs of harvesting public timber (Coos, Curry, Douglas EIA, 1977).

Possibly one of the most important factors which affects the volume of timber harvested along the Pacific Northwest Coast is the national demand for wood products, primarily by the home construction industry. Harvesting on forest industry lands is especially influenced by demand fluctuations. Sustained yield practices on federally controlled lands tend to stabilize harvest volumes. A private firm that is a successful bidder at a public timber auction may postpone cutting up to three years, however, in anticipation of better market conditions for wood products (Coos, Curry, Douglas EIA, 1977).

Competition from other timber producing regions also affects timber harvest in the study area. Producers in the Southern states are increasing production and capturing a larger share of national lumber and plywood markets each year. In 1975, Southern states accounted for 35.4% of total softwood plywood production in the United States, up from 32.2% of the market in 1970, 3.2% in 1965, and 0% in 1960. This trend is expected to continue in the future because of the South's proximity to large Eastern markets, the region's labor cost advantage, and its increasing raw material supply (Coos, Curry, Douglas EIA, 1977).

The other major factor affecting harvest volumes has been foreign demand for logs. Log export volume from the U. S. West Coast increased steadily through the 1960's into the 1970's. Washington and Oregon accounted for over 85% of annual softwood log exports from the West Coast from 1962 through 1973. Increasing exports combined with high domestic demand put pressure on the Pacific Northwest timber resources. In 1968, legislation limiting levels of exports was enacted. Logs are now harvested for export markets almost exclusively from private lands (Darr, 1975). Nevertheless, softwood exports from the states of Washington and Oregon to all countries have increased steadily from 335,675 thousand board feet (Scribner Scale) in 1961 to 2,737,074 thousand board feet in 1976 (Ruderman, 1977A). Softwood log exports have increased from approximately 3% of lumber harvest in 1963 to approximately 15% in 1973 (Ruderman, 1977A). Export volumes are affected by a variety of factors including foreign housing demand and U. S. dollar value relative to foreign currency and tend to fluctuate cyclically in a manner unrelated to domestic cycles (Darr, 1975).

4.2.2.2 Production Value. Few data sources exist for the value of log production for the Pacific Northwest Coast. Value added data for the industry as a whole (log production and processing) are given for twelve counties of the study area in Table 4-7 (for a discussion of the value-added concept, see Volume 1, Section 4.1.3.2 and Samuelson, 1961). The lumber and wood products sector (Standard Industrial Classification (S.I.C.) Code 24), includes the following subsectors: logging camps and contractors (S.I.C. 241), sawmills and planing mills (S.I.C. 242), millwork, plywood and structural members (S.I.C. 243), and wood containers (S.I.C. 244). Value added data for logging camps and contractors are only available for a few counties with high levels of logging employment.

The lumber and wood products sector represented over 72% of value added by manufacturing in the coastal study area (except Wahkiakum County). Logging camps and contractors sector employment contributed approximately 30% of value added in lumber and wood products (see Table 4-8) in the five counties of the study area where these data were available. Logging camps and contractors contributed approximately 22% of value added by all manufacturing in the listed counties.

4.2.2.3 Forestry and Logging Employment. Employment in forestry and log production for Pacific Northwest Coastal counties in 1975 is given in Table 4-9. Figures are taken from County Business Patterns (U. S. Department of Commerce, Bureau of Census, 1977D). Data for County Business Patterns were gathered during March, 1975. Due to the seasonality of forestry employment, these figures are probably below the annual average for forestry and log production.

Forestry and log production employment includes S.I.C. sectors forestry (S.I.C. Code 08) and logging camps and contractors (S.I.C. Code 241). Where figures were not available estimates based on regional averages are listed. As expected, forestry and log production employment correlate fairly well with logging harvests by county. Grays Harbor County, Washington, and Coos County, Oregon, are the largest logging employers and harvesters in the study area. Most forest industry employment is in forest products processing. Less than 30% of the industry's employees work in logging and forestry (see Table 4-10).

TABLE 4-7. VALUE ADDED BY MANUFACTURING IN LUMBER AND WOOD PRODUCTS SECTOR FOR PACIFIC NORTHWEST COAST - 1972. Data are in millions of dollars. (From 1972 Census of Manufacturers, Volume 4, U.S. Department of Commerce, Bureau of Census, 1974C.)

County	Total Value Added All Manufacturing Sectors	Value Added By Lumber & Wood Products	% Lumber And Wood Products
Clallam	66.3	39.2	59.1%
Jefferson	21.9	14.1 (e)	64.4%
Grays Harbor	157.6	101.2	64.2%
Pacific	22.1	18.5	83.7%
Wahkiakum	n/a	n/a	n/a
Washington Coast Totals	267.9	173.0	64.6%
Clatsop	41.0	22.6	55.1%
Tillamook	30.2	27.0	89.4%
Lincoln	39.7	17.9	45.1%
Coos	113.2	99.8	88.2%
Curry	25.4	24.7	97.2%
Oregon Coast Totals	249.5	192.0	77.0%
Del Norte	31.8	31.4	98.7%
Humboldt	220.7	180.3	81.7%
California Coast Totals	252.5	211.7	83.8%
Study Area Totals	769.9	576.7	74.9%

n/a = Not Available (e) = Estimate

TABLE 4-8. VALUE ADDED BY LOGGING CAMPS AND LOG CONTRACTORS - SELECTED COUNTIES, 1972. Data are in millions of dollars. (From 1972 Census of Manufacturers, Volume 4, U.S. Dept. of Commerce, Bureau of Census, 1974C.)

County	Value Added By Logging Camps/ Log Contractors	% of Wood Wood Products	% of All Manufacturing
Clallam	19.1	48.7%	28.8%
Grays Harbor	48.6	48.0%	30.8%
Clatsop	7.9	35.0%	19.3%
Coos	14.7	14.7%	13.0%
Humboldt	42.6	23.6%	19.3%

TABLE 4-9. LOGGING AND FORESTRY EMPLOYMENT IN THE PACIFIC NORTHWEST COAST - 1975. (From U.S. Department of Commerce, Bureau of the Census, 1977D.)

County	Forestry (SIC 08)	Logging Camps and Contractors (SIC 241)	Total
Clallam	54 (e)	947	1001
Jefferson	5 (e)	202	207
Gray Harbor	28 (e)	2482	2510
Pacific	40 (e)	130	170
Wahkiakum	3 (e)	407	410
Clatsop	25 (e)	474	499
Tillamook	6 (e)	273	279
Lincoln	12 (e)	209	221
Coos	110 (e)	1176	1286
Curry	8 (e)	170	178
Del Norte	10 (e)	422	432
Humboldt	33	581	614
STUDY AREA TOTAL	334	7473	7807

(e) = estimates

TABLE 4-10. FORESTRY INDUSTRY EMPLOYMENT IN THE PACIFIC NORTHWEST COAST REGION, 1975. (From U.S. Department of Commerce, Bureau of the Census, 1977D.)

	Forestry and Log Production	Forest Products Processing[1]	Paper and Allied Products Employment	Forest Industry Total	% All Employment
Clallam	1001	922	920 (e)	2843	34.1%
Jefferson	207	95	375 (e)	677	34.4%
Grays Harbor	2510	2218	1261	5989	38.4%
Pacific	170	585	-	755	27.5%
Wahkiakum	410	13	-	423	62.9%
Clatsop	499	424	35 (e)	958	15.2%
Tillamook	279	478	-	757	25.1%
Lincoln	221	471	670 (e)	1362	25.1%
Coos	1286	2977	175 (e)	4438	35.5%
Curry	178	821	-	999	41.9%
Del Norte	432	1284	20 (e)	1736	52.6%
Humboldt	614	5107	750 (e)	6471	29.7%
STUDY AREA TOTAL	7807	15395	4206 (e)	27408	32.6%

[1]These figures are derived from lumber and wood products (SIC 24) minus logging (SIC 241).

(e) = Estimated. SIC = Standard Industrial Classification

Time series data for lumber and wood products manufacturing employment in the study area indicate some recent trends in the industry. Between 1958 and 1972, logging employment in the five Oregon coastal counties declined steadily from 3,327 to 2,663, a decrease of 17% (summarized from data in Kuhn et al., 1974). Log production between 1958 and 1972 for the Oregon coast was more erratic showing approximately the same percentage decline, (Kuhn et al., 1974). Humboldt County, California, employment and production data for the period 1950 to 1976 indicate a similar decline (QRC Research Corporation, 1978). Data for Washington coastal forestry employment were not readily available.

Total employment levels in forestry depend on many factors, including demand for the industry's products, changing product mix, increased utilization of forest products, availability of raw material, level of capital expenditure, and skill and performance levels of labor (Wall and Oswald, 1975). The last factor, also known as productivity, can be measured by computing a ratio of raw materials (in thousands of board-feet of lumber or logs) to labor (number of employees). The productivity factor has two important uses: as an indicator of trends in productivity in the industry; and in predicting future levels of employment based on the predicted production and consumption of raw materials. In the Pacific Northwest, this measure can be particularly valuable when dealing with the question of employment impacts of declining timber resources. This subject has been examined by Wall and Oswald (1975).

Trends in labor-to-raw-materials ratio are presented in Figure 4-1 which plots average annual employment in logging per million board-feet for Western Washington, Western Oregon, and Coastal California for the period 1950 to 1970. These regions contain counties outside the study area, however. Other sources indicate that these figures represent general trends within the study area (Schmisseur and Boodt, 1975; Kuhn et al., 1974). Productivity declines in logging are apparent in all three areas for the specified period. For a discussion of employment projections based on productivity trends and timber resources for the Pacific Northwest Coast, see Wall (1973).

Seasonality is another important characteristic of the logging industry along the coast. Figure 4-2 presents monthly deviations from average annual employment in logging for Washington, Oregon, and California for 1969-1971. May-October appears to be the peak period for logging employment along the coast.

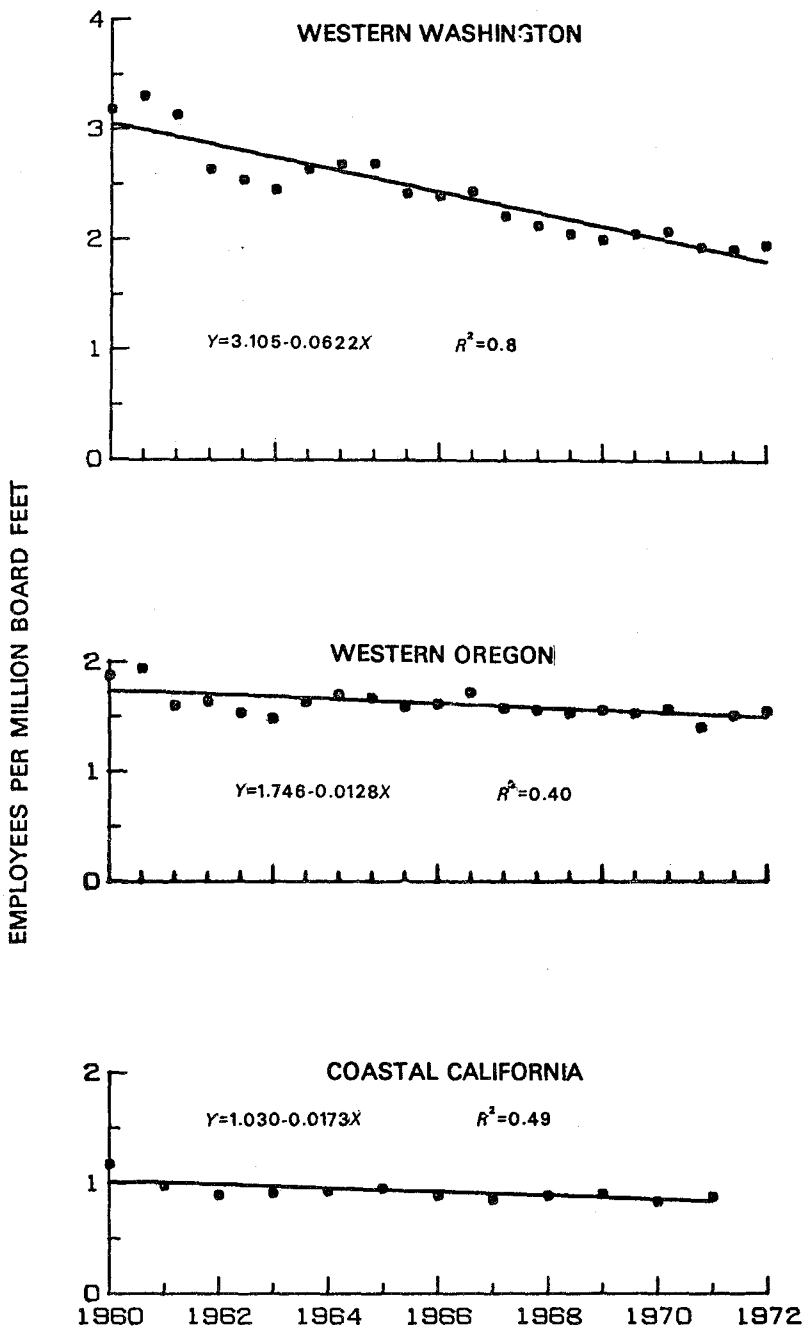


FIGURE 4-1. AVERAGE ANNUAL EMPLOYMENT TRENDS IN LOGGING FOR WESTERN WASHINGTON, WESTERN OREGON, AND COASTAL CALIFORNIA FOR THE PERIOD 1950 to 1970. (From Wall and Oswald, 1975.)

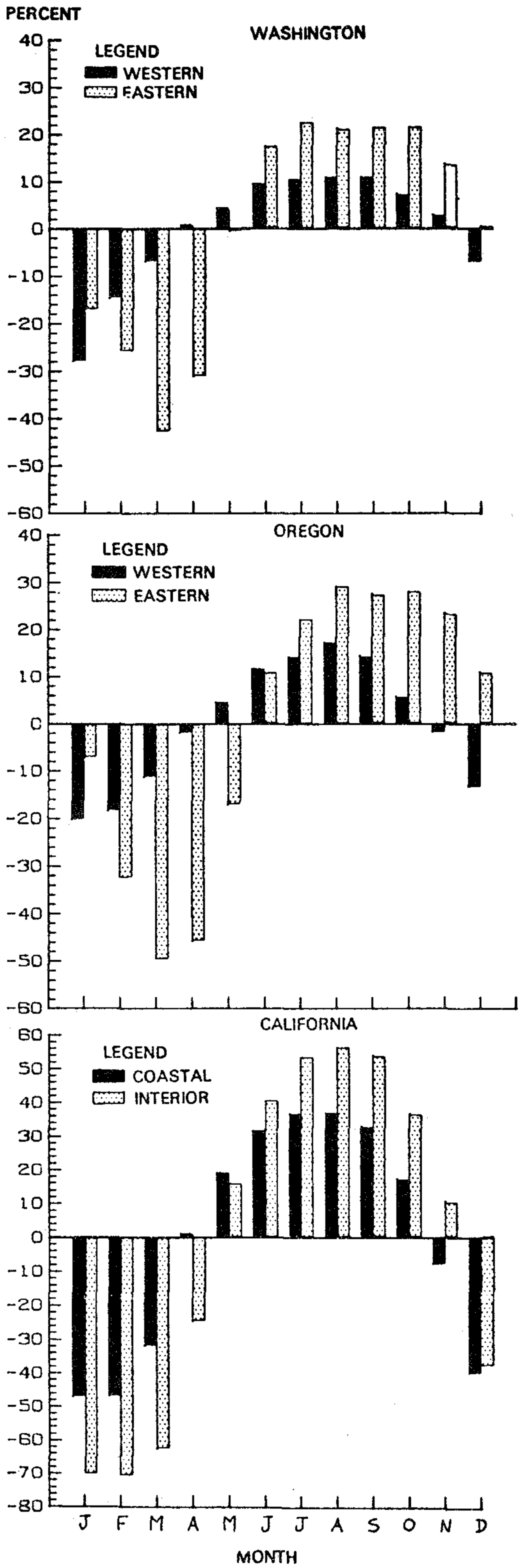


FIGURE 4-2. MONTHLY DEVIATIONS FROM AVERAGE EMPLOYMENT. (From Wall and Oswald, 1975.)

4.2.3 Forest Products Processing.

4.2.3.1 Processing Activities. Logs removed from Pacific Northwest coastal forests are either processed within the study area or exported from coastal ports to other locales for processing. Processing activities are categorized as follows: lumber (saw mills); veneer and plywood; pulp and board; log export; shake and shingle; pole, post and piling.

Tables 4-11 and 4-12 list the number of mills by county and by type for the study area. Mills are especially numerous around Grays Harbor, Washington, Coos Bay, Oregon, and Eureka, California.

TABLE 4-11. NUMBER AND TYPE OF MILL BY COUNTY, WASHINGTON COAST, 1976. (From Bergvall et al., 1977.)

County	Sawmills	Veneer and Plywood	Pulp and Board	Shake and Shingle	Pole, Post and Piling	Export Operations	TOTAL
Clallam	8	1	2	46	1	9[1]	67
Jefferson	4	1	1	6	-	-	12
Grays Harbor	8	5	2	88	-	17	120
Pacific	2	-	-	8	-	-	10
Wahkiakum	2	-	-	5	-	-	7
Washington Coast Total	24	7	5	153	1	26	216

[1]All 9 are in Port Angeles in Clallam County, however, outside the study area.

TABLE 4-12. NUMBER AND TYPE OF MILL BY COUNTY, CALIFORNIA AND OREGON COAST, 1972. (From Schuldt and Howard, 1974, and Howard, 1974.)

County	Sawmills	Veneer and Plywood	Pulp and Board	Shake and Shingle	Pole, Post and Piling	Export Operations	TOTAL
Clatsop	3	1	2	-	-	13	19
Tillamook	8	2	-	8	-	-	18
Lincoln	6	2	1	2	-	2	13
Coos	11	8	3	2	-	11	35
Curry	5	5	-	-	-	-	10
Oregon Coast Total	33	18	6	12	-	26	95
Del Norte	7	4	1	1	-	-	13
Humboldt	37	9	3	5	-	4	58
North California Coast Total	44	13	4	6	-	4	71

Data on the flow of logs from forests of origin to individual mills are not readily accessible. Mill surveys are conducted by the Washington State Department of Natural Resources, the Oregon State University Extension Service (Forestry Extension) and the USDA Forest Service Pacific Northwest Forest and Range Experiment Station for Washington, Oregon, and California, respectively. Questionnaires request information concerning the origin of logs processed by each mill. Figure 4-3 presents a section of the 1976 Washington Mill Survey. It is apparent that even if information were compiled and available for log flows to individual mills, more specific infomration than county and national forest origins could not be readily obtained.

6. **Origin of Logs Consumed During 1976**

a. **State or Province of Origin**

	Sound logs	Utility logs
Washington	____%	____%
Oregon	____%	____%
Idaho	____%	____%
British Columbia	____%	____%
Other	____%	____%
	100 %	100 %

b. **County of Origin (Wash.)**

	Sound logs	Utility logs
____________	____%	____%
____________	____%	____%
____________	____%	____%
____________	____%	____%
____________	____%	____%
____________	____%	____%
____________	____%	____%
From outside Washington	____%	____%
	100 %	100 %

c. **Age group**

	Sound logs	Utility logs
Old growth (100 + yrs.)	____%	____%
Young growth	____%	____%
	100 %	100 %

d. **Ownership Origin**

	Sound logs	Utility logs
State	____%	____%
US Forest Service	____%	____%
BLM	____%	____%
Other Public(Indian, etc.)	____%	____%
Forest Industry — Own Supply	____%	____%
Forest Industry — Other Supply	____%	____%
Farmer & Misc. Private	____%	____%
	100 %	100 %

*Name of National Forest ____________ ____%: ____________ ____%:
____________ ____%: ____________ ____%

7. **1976 Lumber Production:**

Produced__________,000 bf lumber tally

Green	____%	Rough	____%
Kiln-dried	____%	Surfaced	____%
Air-dried	____%		
	100 %		100 %

FIGURE 4-3. EXCERPT FROM WASHINGTON MILL SURVEY FORM. Washington State Department of Natural Resources. (From Bergvall et al., 1977.)

Log flow data for individual mills would be valuable for assessing the local economic and environmental impact of changes in the forestry resource situation. For example, an evaluation could be made of a change in status of timber resources from a commercial timberland to productive-reserved forestland (e.g. a wilderness area). Localized log flow data would reveal which mills (and mill-dependent economies) would be affected. The status of log flow data for coastal counties is summarized in Table 4-13. Available data on mill flows are presented in Tables 4-14 through 4-19. Table 4-14, mill flows for coastal Washington, indicates that logs in the northern part of the coast generally are sent to processors in the vicinity of Port Angeles which is outside the study area. Harvested logs in the southern part of the Washington coast are processed in Grays Harbor mills. Table 4-16 indicates that Grays Harbor and Port Angeles are also the most likely destination of logs harvested in coastal Washington that are intended for export.

For coastal Oregon (see Table 4-15), logs tend to be processed in the county of harvest. Tillamook and Lincoln Counties are exceptions. These counties send a large percentage of their logs out of the study area for processing.

Del Norte and Humboldt Counties process nearly all locally harvested logs.

By the use of mill flow data, a ratio of logs consumed to logs produced can be calculated for each county. The following figures represent comsumption as a percentage of total production in the county: Clallam - 123.3%, Jefferson - 6.5%, Pacific and Grays Harbor - 119.0%, Clatsop - 146.9%, Tillamook - 64.9%, Lincoln - 39.0%, Coos - 125.1%, Curry - 68.9%, Del Norte - 84.9%, and Humboldt - 113.2% Data for Washington counties are from 1976. Data for Oregon and California are for 1972. Pacific and Grays Harbor data have been combined by the Washington Department of Natural Resources to avoid disclosure of mill log flow data. Other sources indicate that the Grays Harbor consumption-production ratio is likely to be more than 100% and the Pacific County ratio under 100% (U. S. Army Corps of Engineers, 1976C and 1976H).

National Forest data are listed in Tables 4-18 and 4-19 for Oregon and California.

TABLE 4-13. SUMMARY OF DATA AVAILABILITY FOR LOG FLOWS IN PACIFIC NORTHWEST COASTAL AREA. (From Bergvall et al., 1977; Schuldt and Howard, 1974; and Howard, 1074.)

AREA OF ORIGIN	AREA OF USE		DATA AVAILABLE?
COUNTY	COUNTY:		
	Washington Coast	-	Yes, presented in Table 4-14
	Oregon Coast	-	Yes, presented in Table 4-15
	California Coast	-	Yes, presented in Table 4-17
SUB-COUNTY, SUB-NATIONAL	COUNTY, SUB-COUNTY OR INDIVIDUAL MILL:		
	Washington Coast	-	No, would require alteration
	Oregon Coast	-	of agency questionnaires.
	California Coast	-	(Table 4-16 gives Washington Coastal County flows to ports
NATIONAL FOREST	COUNTY:		
	Washington Coast	-	Yes, but not published[1]
	Oregon Coast	-	Yes, summarized in Table 4-19
	California Coast	-	Yes, summarized in Table 4-18
NATIONAL FOREST	SUB-COUNTY OR INDIVIDUAL MILL:		
	Washington Coast	-	Yes, but requires security clearance from agencies to obtain questionnaire response forms from individual mills and data tabulation not previously performed.
	Oregon Coast	-	
	California Coast	-	

[1]This information is published by resource areas (supra-county level) only. The table would be of no value for the study area and is not presented.

TABLE 4-14. LOG FLOW TO MILLS BY COUNTY OF ORIGIN AND USE, WASHINGTON COAST, 1976. Data are in thousand board feet, Scribner Log Rule. (From Bergvall et al., 1977.)

		County of Origin						
County Of Use	Total	Clallam	Grays Harbor	Jefferson	Pacific	Wahkiakum	Other Washington	Out-of-State
Clallam	565,707	363,976	1,371	195,882	-	-	-	4,478
Grays Harbor Pacific[1]	1,291,355	9,599	549,664	288,175	396,186	5,394	42,337	-
Jefferson	37,099	8,086	1,157	27,856	-	-	-	-
Cowlitz and Wahkiakum[1]	858,966	-	3,657	-	9,916	6,460	789,640	49,291
Puget Sound Counties[2]	2,123,848	73,024	35,485	57,075	46,778	-	1,867,022	44,464
Other Washington Counties	-	3,960	30,941	192	9,555	22,250	-	-
TOTAL, STATE	-	458,695	622,277	569,170	462,435	34,104	-	-

[1] Combined to avoid disclosure of mill log flow data.

[2] Includes San Juan Island, King, Kitsap, Pierce, Skagit, Snohomish, and Whatcom Counties, Washington.

TABLE 4-15. LOG FLOWS TO MILLS BY COUNTY OF ORIGIN AND USE - OREGON COAST, 1972. Data are in thousand board feet, Scribner Log Rule. (From Schuldt and Howard, 1974.)

		County of Origin								
County of Use	Total	Clatsop	Tillamook	Lincoln	Lane	Douglas	Coos	Curry	Other Oregon	Out-of-State
Clatsop	437,859	207,614	39,422	12,117	-	-	-	-	178,706	135,081
Tillamook	169,292	10,247	142,964	-	-	-	-	-	15,858	225
Lincoln	128,653	62	1,574	112,590	11,047	-	-	-	3,380	-
Lane	1,907,333	-	-	12,950	1,492,930	224,490	5,969	-	170,994	-
Douglas	1,202,527	-	-	-	3,579	1,062,550	67,422	21,659	47,317	-
Coos	857,584	-	-	-	23,680	166,615	586,235	65,434	13,942	1,678
Curry	202,924	-	-	-	4,097	5,600	25,898	165,097	2,232	-
Other Oregon	-	80,051	76,690	192,202	121,858	49,906	-	42,212	-	-
TOTAL	-	297,974	260,650	329,859	1,657,191	1,509,161	685,524	294,402	-	-

TABLE 4-16. LOG FLOWS TO PORTS BY COUNTY - WASHINGTON, 1976. Data are in thousand board feet, Scribner Log Rule. (From Bergvall et al., 1977.)

County of Origin	PORT AND COUNTY OF EXPORT: Grays Harbor[1]	Port Angeles[2]	Other Ports[3]
Clallam	8,660	132,077	12,656
Jefferson	261,053	135,119	4,292
Grays Harbor	283,076	-	-
Pacific	245,204	-	3,345
Wahkiakum	-	-	-
Other Washington Counties	4,168	-	-
Outside Washington	-	-	-
TOTAL	802,161	267,196	-

[1] In Grays Harbor County.

[2] In Clallam County, but out of study area.

[3] Out of study area.

TABLE 4-17. LOG FLOWS TO MILLS BY COUNTY OF ORIGIN AND USE, CALIFORNIA COAST, 1972. Data are in thousand board feet, Scribner Log Rule. (From Howard, 1974.)

		AREA OF ORIGIN			
County of Use	Total	Del Norte	Humboldt	Other California	Out-of-State
Del Norte	300,914	252,704	36,986	-	11,224
Humboldt	1,221,654	101,842	1,003,036	116,776	-
Other California	-	-	38,978	-	-
TOTAL		354,546	1,079,000		

TABLE 4-18. LOG FLOWS FROM NATIONAL FORESTS TO CALIFORNIA NORTH COAST COUNTIES, 1977. Data are in thousand board feet, local scale. (From Howard, 1974.)

		National Forest of Origin			
County of Use	All National Forests	Klamath	Shasta-Trinity	Six Rivers	Out-of-State National Forests
Del Norte	61,081	-	-	61,081	-
Humboldt	172,945	34,420	37,745	99,566	1,214

TABLE 4-19. LOG FLOWS FROM NATIONAL FORESTS TO OREGON COASTAL COUNTIES, 1972. Data are in thousand board feet, Scribner Scale. (From Schuldt and Howard, 1974.)

County of Use	All National Forests	NATIONAL FOREST OF ORIGIN						
		Mt. Hood	Rogue River	Siskiyou	Siuslaw	Umpqua	Willamette	Out-of-State National Forests
Clatsop	30,357	15,315	-	-	-	-	7,530	7,512
Tillamook	12,231	-	-	-	12,231	-	-	-
Lincoln	54,893	-	-	-	54,893	-	-	-
Coos	89,661	-	554	49,797	37,096	2,214	-	-
Curry	148,390	-	-	148,390	-	-	-	-

4.2.3.2 Volume Produced. The volume of wood products produced in the study area is heavily dependent on local log production. From log flow data (Tables 4-13 through 4-16) extent of this dependency can be calculated by dividing total log consumption in the study area by logs originating and consumed in the study area. Of all logs consumed by Washington coastal wood processors, 97.2% were produced by Washington coastal forests in 1976. For the Oregon and Northern California coast, in 1972, the figures are 76.2% and 91.6%, respectively (calculated from flow data). Fluctuation in study area timber resource supply would therefore have an effect on coastal wood processing.

A comparison of Oregon coastal log harvests and lumber production between 1962 and 1972 illustrates their relationship (see Figure 4-4). A regression coefficient calculated for log and lumber production along the Oregon coast showed a substantial correlation between the two ($r^2 = .4133$) (Kuhn et al., 1974).

Other factors that contribute to variation in wood products processing volumes include demand factors related to housing construction, substitutes for wood products, alternative sources of lumber supply, and foreign demand.

Residues from wood (wood chips) play an important part in the production of pulp and board along the coast. Lumber production (sawmill residues) is the largest source of wood residues used by the pulp and paper industries. Veneer and plywood production and shake and shingle production also produce wood residues (Bergvall et al., 1977).

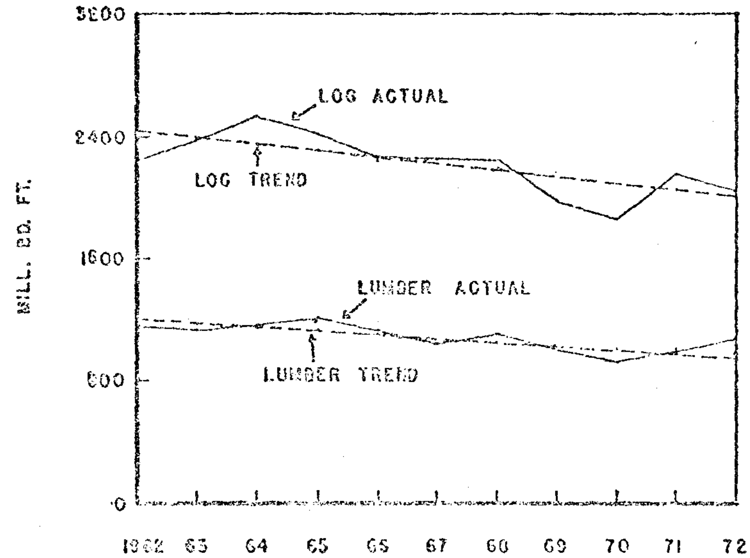


FIGURE 4-4. LOG HARVEST AND LUMBER PRODUCTION IN OREGON COASTAL COUNTIES, 1962 - 1972. Data are in millions of board feet. (From Kuhn et al., 1974.)

4.2.3.3 Value of Production. Data are not readily available for the value of wood products. Section 4.2.2.2 discusses value added for the lumber and wood products industry as a whole. Census of Manufacturing data indicate that the lumber and wood processing industry accounted for 72.4% of total value added by manufacturing in the study area (See Table 4-7 and Section 4.2.2.2 for discussion).

4.2.3.4 Employment. Employment in forestry products processing for 1975 in the study area is presented in Table 4-20. Processing employment (including paper and allied products employment) represents approximately 71.5% of total employment in the industry.

Included in forest products processing employment are sawmills and planing mills employment (SIC 242), millwork plywood and structural members employment (SIC 243), wood containers employment (SIC 244), and paper and allied products employment (SIC 25).

Trends in coastal Oregon forest products processing, shown in Table 4-20, indicate a general decline in wood products processing employment from 1958 to 1973, but a strong increase in paper and allied products employment during this period. Paper and allied products employment increased by 34+% during this period. The rapid increase is related to increased use of wood chips for paper production and increased national demand for paper products (discussed in Section 4.2.3.2). Data for western Washington and coastal California indicate declines in sawmill and planing mills employment between 1950 and 1971.

Productivity is measured by trends in a ratio of employees per million board feet of wood consumption. Declines in this ratio from 1950 to 1970 indicate an increase in productivity in the wood products industry between 1950 and 1970 for western Oregon, western Washington and coastal California (see Figure 4-5, below, and Wall and Oswald, 1975, for a full discussion of productivity in wood products processing).

Decreases in available timber resources in the study area affect processing employment in addition to logging employment. As discussed in Section 4.2.3.2, study area mills are heavily dependent on local resources for timber.

Seasonality in forestry products processing employment follows the same general trend as seasonality in logging for the coast. The peak period of processing employment is June to November. Deviations from annual averages are not as severe, however, monthly deviations in processing rarely exceed 10% (Wall and Oswald, 1975).

TABLE 4-20. WOOD PRODUCT PROCESSING AND PAPER PROCESSING EMPLOYMENT IN COASTAL REGION[1] OF OREGON, 1958 - 1972. Figures are number of employees. (From Kuhn et al., 1974; Oregon State Employment Division, various dates.)

Year	Wood Products	Paper Products
1958	13104	348
1959	13490	397
1960	13371	427
1961	12151	446
1962	11856	610
1963	11425	634
1964	12174	617
1965	12057	734
1966	11601	904
1967	11232	1196
1968	11083	1359
1969	10702	1467
1970	9966	1440
1971	9831	1542
1972	9875	1507
1973	10303	1538

[1]Data include Clatsop, Tillamook, Lincoln, Coos, and Curry Counties, but not coastal parts of Lane and Douglas Counties.

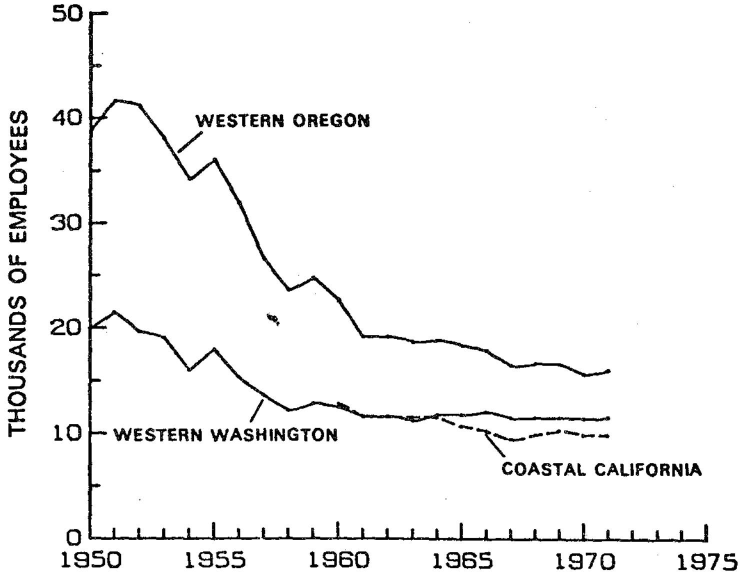


FIGURE 4-5. AVERAGE ANNUAL EMPLOYMENT IN SAWMILLS AND PLANING MILLS IN WESTERN WASHINGTON, WESTERN OREGON, AND COASTAL CALIFORNIA, 1950-71. (From Wall and Oswald, 1975.)

4.2.4 Distribution and Secondary Activities. The forestry, logging, lumber, and wood products sectors of the industry all require additional supporting economic activities to market and transport logs and finished products. Supporting activities are also needed for the manufacturing and marketing of equipment and machinery required by each sector of the economy.

Distribution of wood products and logs occurs by water, land, and sea routes. Logs are exported to Japan, South Korea, and Canada through coastal ports (Ruderman, 1977A). Wood and paper products are exported to all ports of the nation. A Tillamook County study estimated that 99.7% of sawmill products and 99.86% of other wood products are sold outside the county (Youmans et al., 1977). For a further discussion of distribution of wood products, see Section 4.7 (Transportation).

4.2.5 Summary and Effects

4.2.5.1 Summary of Employment and Value Added. Employment in forestry and forest products in the Pacific Northwest Coastal Region amounts to approximately 1/3 of all employment in the study area. Value added by the industry as a percentage of total value added by manufacturing is about 70%.

Declining trends in forestry and forest products employment over the last two decades are probably related to decreasing timber resources and increasing labor productivity. Timber resource management practices and environmental interests are likely to play a large role in determining future levels of employment. Management practices that emphasize sustainable yields will conserve timber resources and may stabilize forestry and forest products employment in the long term. However, continued removal of timberland from commercial exploitation for environmental and resource protection reasons and for recreation will have the opposite effect on timber-related employment. National Forest lands are being currently evaluated under the Roadless Area Review (RARE II) program to determine the suitability for and impacts of assigning wilderness or continued roadless status to certain areas. (For maps and discussion, see U.S. Department of Agriculture, 1978 A-D.) Such withdrawals are not all likely to be from productive timberland. Some, however, may be and, together with the Redwood National Park expansion, will tend to reduce timber availability and related employment.

To offset both short- and long-term forest industry employment and losses and long-trem output losses, labor-intensive restoration of watersheds affected by clearcutting has been proposed. The recently implemented California Forest Practices Act requires many new pre- and post-harvesting activities in conjunction with logging. Rehabilitation and reforestation of privately-owned commercial timberlands which are unstocked, poorly stocked, or stocked with hardwoods is proposed by the USDA Forestry Incentives Program. The National Park Service has also suggested such a program for Humboldt County, California, to help offset impacts of Redwood National Park expansion.

4.2.5.2 Multiplier Effects The total impact of decline in timber resources must take into account community employment lost due to multiplier effects as well as forest industry employment declines. The general formula for computing the total employment impact of a decline in timber resources on forest products processing employment is as follows:

(Employment/Wood Consumption Ratio) X (Change in Quantity of Logs Supplied) X (Employment Multiplier) = Total Employment Change.

Data are not available for forestry and forest products employment in the study area. However, there are data for general basic employment multipliers for coastal counties for 1970. These multipliers, calculated from a U. S. Department of Commerce Bureau of Economic Analysis publication by Ashley and Cartwright, are found in Bell (1977) and are presented in Table 4-49, Section 4.8. Forest industry income multipliers calculated for Lincoln, Clatsop and Douglas Counties for 1970 were very low compared to other industries (Schmisseur and Boodt, 1975). The Tillamook County study also indicates relatively low income multipliers in all but the logging and log-hauling sectors of the industry (Youmans et al., 1977).

4.2.5.3 Ecosystem Effects.

Atmosphere. Recently the issue of forest slash burning as a major source of particulate pollution has been raised. In Oregon and Washington forestry slash burnings are considered a major source of total air suspended particulates, hydrocarbons, and carbon monoxide and a minor source of nitrogen oxides (GEOMET, 1978). The generation of pollutants per site is highly variable and dependent on such factors as fuel, topography, weather, and season. Estimates of fuel burned at 39.8 tons in Oregon and 31.9 tons in Washington have been suggested (GEOMET, 1978). However, actual fuel residues are highly variable and specific to site and logging practices. The problem of forest harvesting residues, slash burning, and associated air pollution problems are explored in some detail by GEOMET (1978), Cramer (1974), Brown et al. (1973), Fredriksen (1974), and EPA (1976A).

Hydrosphere. The effects of forest practices on basin hydrology are somewhat controversial and must be considered on a site-specific basis. Increases in water yield have been recorded following clearcutting by various studies (Rothacher, 1970A, 1970B; Hibbert, 1967). The increases in yield are typically measurable in fall and spring. The effect is most often short lived, lasting only four to five years after harvest (Crow et al., 1976) but may last longer if revegetation is inhibited. The amount of increased yield is typically proportional to the percent of the watershed cut.

There is litte agreement on the effect of forestry peak flows (floods). In studies outside of the region, increased peak flows have been documented and modeled (Swanson and Hillman, 1977). Within the region many authorities do not believe forest clearcutting increases peak flows, as most floods are "wetmantle" floods and occur after the soil is thoroughly saturated. Typically within the region soils become so saturated in early fall. However other authorities believe this explanation is an oversimplification and that increased peak flows are measurable, particularly when a watershed has extensive logging road systems and associated impervious surfaces and ditchlines. The effects of forestry practices on hydrology are discussed in detail by Crow et al. (1976), Gibbons and Salo (1973), and Fredriksen et al. (1973).

The effect of forest practices on water quality can be separated into three topics: temperature effects, chemical effects, and increased sediment loads. Temperature increases due to removal of riparian vegetation along small streams have been well documented (G.W. Brown, 1970; Brown and Krygieir, 1970; Brown et al., 1971). The temperature response of a small watershed is shown in Figure 4-6. However this effect must be viewed within a specific setting, as other studies have found decreased temperatures following clearcutting due to increased ground water flow. Such temperature impacts are reviewed by Moring (1975), Crow et al. (1976), Gibbons and Salo (1973), and Montgomery (1976). Temperature effects can usually be easily eliminated by streamside buffers.

The potential effects of forest practices on water chemistry are reviewed in some detail by Newton and Norgren (1977) as well as Montgomery (1976), Fredriksen (1971 and 1972), Fredriksen et al. (1973) and Brown et al. (1973). Effects include increased nutrient levels and pesticide and herbicide residues. Water quality impacts of associated pulp and paper wastes are reviewed by Gehm (1973).

Sediment increases following forest harvest have been measured in many cases but not all cases (Gibbons and Salo, 1973; Crow et al., 1976). The principal source of sediment in watersheds under forest management appears to be roads.

The problems of forestry-generated sediments within the region are discussed in considerable detail by Gibbons and Salo (1973), Crow et al. (1976), EPA (1975A), Anderson (1972), Moring (1975), and Coats (1978). Increases in fines and loss of suitable salmonid spawning gravel have been documented, but such effects are highly variable.

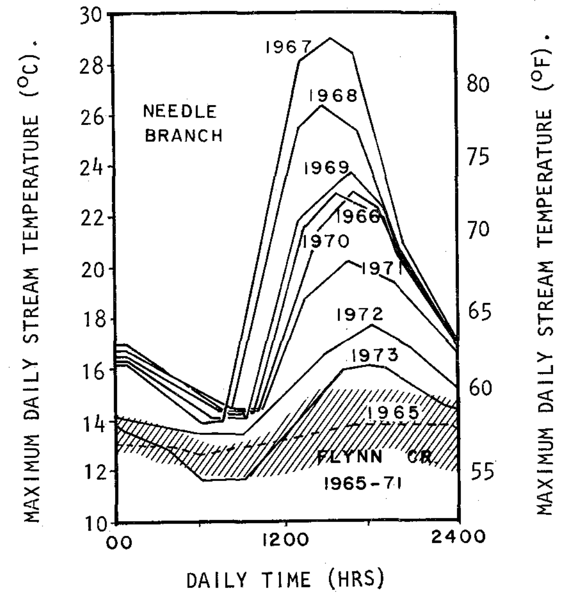


FIGURE 4-6. EFFECT OF CLEARCUTTING ON STREAM TEMPERATURE. The temperature pattern on the days of the annual maximum, as recorded on Needle Branch (clearcut) and Flynn Creek (uncut control) in the Alsea watershed of Unit 5, are shown before (1965), during (1966), and after (1967-1973) logging. (From Moring, 1975.)

Lithosphere. The major and most obvious effect of forestry on the lithosphere is increased erosion as demonstrated by increased sediment loads in water courses (see previous sections above). The majority of the increased erosion is associated with road construction. Increased mass wasting on sensitive sites following clearcutting has also been well documented (Swanson and Dyrness, 1975; Fiksdal, 1974). The issue is discussed by Montgomery (1976). Burroughs et al. (1976) and the Washington Forest Practice Board (1976) provide mitigating techniques.

Biosphere. Biological effects of forest practices are treated to some degree in the Old Growth Ecosystem Model Notes presented in Section 3.2.1.1 of this volume and in the Western Hemlock Succession Model Notes (Section 3.2.4.1). Effects are site-specific and management-specific. Review of this topic is provided by Black (1974) and Gibbons and Salo (1973) with more specific treatment given by such studies as Black and Hooven (1974), Hooven and Black (1976), E.R. Brown (1961), Garcia et al. (1976), Moring (1975), Wight (1974), Taber (1973), and numerous others. Historical consequences have included reduced fauna associated with old growth (e.g. spotted owl), increased edge and brush dependent species (e.g. black-tailed deer), and controversial deleterious effects on salmonid reproduction.

4.2.5.4 Future Economic Importance of the Industry. The forest industry is the major employer and income producer in the study area. Additionally, the industry is the major non-public landowner. Forestry will probably remain the Pacific Northwest Coast's major industry in the near future. The relative importance of the industry in the longer term is dependent on a complex set of factors. These include continued productivity increases and related empolyment declines, withdrawal of timberland from commercial use, changes in the overall price of wood products, and management practices. Management decisions could determine whether output over the next 25 years declines steeply or gradually early in the period to reach relative stability or remains high until about 1990, dropping abruptly thereafter.

A major factor affecting the success of the forestry and processing industry in specific communities will be relative costs of materials. Large differences in material costs can occur in adjoining counties. For example, in 1972 the ratio of material cost to total shipment value of lumber was 64% in Del Norte County, and only 50% in Humboldt County. This differential has increased since 1967. A Del Norte County study lists three reasons for this cost differential:

1) increasing difficulty of access to timber stands in Del Norte; much of the remaining merchantable timberland is found in areas characterized by steep terrain and few roads;

2) environmental controls placed on lands adjacent to the Redwood National Park;

3) the high percentage of timber harvest from National Forest land which must be purchased by competitive bidding (Broida et al., 1975).

4.2.5.5 External Factors Affecting the Industry. The most significant external factors that may influence future as well as current levels of economic activity in the industry include: national monetary policy, national housing goals, international trade policy, technology, competition from non-wood products, and competition from other wood-producing regions. One factor hindering Northwest lumber producers from effectively competing in the Eastern market is the Jones Act. This federal law stipulates that all interstate shipping of domestic commerce is to utilize U.S. flagships. The U. S. merchant marine currently has a limited number of ships to transport lumber products and many of these are older, less efficient ships with smaller tonnage capacity. The larger, more efficient foreign flagships which have been designed specifically for shipping lumber commodities are limited to serving only the foreign export market and for use by foreign competitors in serving the Eastern U. S. market. Therefore, the Jones Act places West Coast producers at a further disadvantage in serving eastern markets and gives foreign (especially Western Canadian) producers a competitive advantage in serving this same market (Coos, Curry, Douglas EIA, 1977).

Another group of factors relates to the capability of coastal area timber lands to supply commodities in the future. These factors will be very important in determining the future levels of economic activity in the area's forest industries. They include: national and state environmental policies and laws, state regulation of forestry practices to insure maintenance of productivity, the impacts of demand for non-commodity use of forest lands, and trends in ownership.

Tax structures and industry and government sponsored forestry programs that affect the level of investment in coastal timberlands will also be very important in determining future levels of output. The impact of technology on utilization and the competitiveness of forest products in various markets is another important factor. Technology, through improved production techniques, the opening of new markets and uses, and relative cost reductions, can lead to a change in wood and paper products' competitive position in the market place. Wood fiber prices are generally highly competitive with substitute materials. This position is expected to remain favorable, as evidenced by recent developments in petroleum supplies and other finite resources. Technology, however, can lead to the development of new building materials which would reduce the demand for wood products; conversely, it can lead to the development of new applications of forest products which would expand the demand for wood, board, and pulp and paper products (Schmisseur and Boodt, 1975).

4.3 FISHERIES

This section discusses both commercial and sports fisheries even though sport fishing can be considered a recreational activity. The two activities are difficult to separate in many cases, being dependent on many of the same resources often using the same facilities. See Sections 3.4.1.2 and 3.4.2.3 on commercial and recreational fishery species, respectively, in Chapter 3 of this volume for more resource information.

4.3.1 Resources. Water resources in the Pacific Northwest Coastal Region are extensive. The Pacific Ocean, which forms the entire western border of the study area is abundantly populated with important commercial species. Inland are numerous fresh water streams, creeks, rivers and small lakes which contain many species of game fish and provide the spawning areas for salmon and other anadromous species.

4.3.1.1 Species and Range. The principal fishes harvested in the Pacific Northwest Coastal Region are tuna, salmon, groundfish (or bottom fish) such as perch, sole, and cod, and shellfish such as oysters, clams, crabs, and shrimp. For listing and discussion of species by habitat type, see Volume 3. For discussion of fishery species in general, including catch data, see Sections 3.4.1.2 and 3.4.2.3 of Chapter 3 of this volume. For further discussion of fish species, conditions, and range, see Squire and Smith (1977) and Frey (1971).

The albacore tuna is a migratory pelagic species found in temperate zones worldwide. Its range extends on the U.S. West Coast from the Gulf of California to the Gulf of Mexico. Fish population and fisheries vary with ocean currents and water temperatures. Over the decades, productive fishing areas have shifted up and down the coast. In the 1960's, for example, many tuna were landed off the Washington and Oregon coast but more recently a southward shift has been detected (Loy et al., 1976). The albacore tuna is usually harvested within 200 miles of the coast, although, being a deep sea fish, it is not normally associated with the continental shelf. Local trawlers travel great distances to fishing areas, up to 1000 miles from port (Kuhn et al., 1974).

Salmon spawn in freshwater streams of the coastal zone. Chinook and coho are common to the entire study area; chum are infrequent over the whole region, while pink and sockeye are limited to small numbers in the northern portion of the study area (Squire and Smith, 1977). Salmon harvesting is a significant part of the local commercial and sports fishing industry from Eureka to the Makah Indian Reservation at the tip of Cape Flattery. For more information on Chinook and coho salmon, see accounts in species of concern, Part 2 of this volume.

Another major fishery species is the Dungeness crab. The crab is found along the continental shelf at depths of 50 fathoms or less (U.S. Army Corps of Engineers, 1975A). Although crabs are not plentiful in some areas and their numbers follow cyclic variations, fishermen all along the coast can reach productive grounds (U.S. Army Corps of Engineers, 1975D and 1976H). See the Dungeness crab account in Part 2 for more information.

The Coos Bay and Humboldt Bay shrimp fisheries are among the most productive in the coastal region. Shrimp fisheries are not as productive off the Washington coast, although the southern grounds are accessible to Washington trawlers (U.S. Army Corps of Engineers, 1975C).

Oysters are grown and harvested in tidelands of certain estuaries along the coast. The single most significant producer of oysters is Willapa Bay in Washington (U.S. Corps of Engineers, 1976H). Oysters are also harvested in Tillamook, Coos, and Lincoln County estuaries in Oregon, and in Humboldt Bay, California (Schmisseur and Boodt, 1975; QRC Research Corporation, 1978). Oyster seed, until recently available only from Japan, is necessary for cultivation. Tidelands are leased commercially for oyster harvesting. There are 30 licensed oyster farmers in the Willapa Bay area; however, three firms own 90% of the productive areas.

Bottomfish including rockfish, lingcod, greenlings, cabezon, Pacific halibut, flounder, and surfperch are taken in well-defined areas throughout the region.

Perch was the most important commercial bottomfish along the coast in the 1960's; however, unregulated fishing by local and foreign (Polish, Japanese, and Russian) trawlers drastically reduced their numbers (Kuhn et al., 1974).

Hake now represents the most valuable untapped fishery resource in the region. Hake, a bottomfish, has been harvested from Pacific Northwest coastal waters by foreign trawlers for decades, but only in limited quantities. A 1971 Oregon Fish Commission biomass survey estimated that hake comprises 40-45% of bottomfish on the continental shelf between the Columbia River and Port Orford, Oregon (Kuhn et al., 1974, from Demory and Robinson, 1973). Similar concentrations of hake are believed to exist off the Northern California coast (QRC Research Corporation, 1978). Little effort has been made to exploit this potentially valuable resource (Coos, Curry, Douglas EIA, 1977).

Sole, sanddabs, black cod, and anchovies are other potentially exploitable resources along the coast (Kuhn et al., 1974; U.S. Army Corps of Engineers, 1975B). Scallops are believed to be plentiful off the coast and may also prove to be exploitable (U.S. Army Corps of Engineers, 1975B).

Steelhead, rainbow, and cutthroat trout are particularly important sport and commercial fish throughout the region. Steelhead are nurtured in the tributaries of the major estuaries before they begin their migration seaward, while the sea-run cutthroats grow in the estuaries before migrating to sea to mature. The non-anadromous cutthroats and the rainbow trout remain on freshwater habitats throughout their life cycles.

Razor, hardshell, and softshell clams are found in the region and are dug for sport. They are not a significant commercial resource (Schmisseur and Boodt, 1975; U.S. Army Corps of Engineers, 1976A), but razor clamming is a major recreational fishery activity in Southwestern Washington. Cultivation and harvest of mussels have been discussed for the Humboldt Bay area, but no action has yet been undertaken (QRC Research Corporation, 1978).

The location of sport shore fishing, bottom fishing, and salmon trolling areas and the general range of party boat fleet fishing along the Pacific Northwest Coast are mapped in Squire and Smith (1977). The location of clam and oyster beds on the Oregon coast are mapped in Oregon State Fish Commission publications.

4.3.1.2 Supply and Demand Factors. Estimates of the supply of fish are often expressed as fisheries biomass. Biomass depends on ocean currents, long-term population fluctuations, over-fishing, human alteration of habitats, and other factors (Loy et al., 1976; Kuhn et al., 1974). Fisheries biomass directly affects the price and quantity of fish taken by coastal fishermen. The effectiveness of a given level of fishing effort will, in part, be determined by available supply. Biomass and productivity are further discussed in Section 3.4.1.2 of Chapter 3.

The demand for fish depends on consumer tastes, the demand for protein-rich foods, and the price of other protein-rich foods (especially meats). Demand also affects quantity, price, and effort. The increased demand for shrimp in the late 60's illustrates the mechanism for changes in price, quantity, and effort. As consumer interest in shrimp increased in the late 60's, prices of shrimp increased in response. Increased return on shrimp sales induce fishermen to concentrate more on shrimp landings, resulting in a greater volume of shrimp taken (Kuhn et al., 1974).

The demand and supply of hake provide another example. Overfishing of perch by American and foreign trawlers caused a decrease in perch biomass (Kuhn et al., 1974). It is believed that hake would provide an excellent substitute for perch, considering its large biomass (QRC Research Corporation, 1978). However, the American consumer has yet to develop a taste for hake and is not willing to pay sufficiently high prices to make hake harvesting worthwhile to coastal fishermen.

The overall demand for fish in the U.S. is strong. From 1970 through 1974, average per capita consumption increased from 11.8 to 12.2 pounds (Wise and Thompson, n.d.). The figure for 1973 (12.9 pounds was an all time high. Worldwide demand for protein also appears to have kept demand for fish high (Kuhn et al., 1974). The market for Pacific Northwest Coastal fishery resources is principally on the West Coast. Canned salmon, however, is shipped to all parts of the U.S.

4.3.1.3 Seasonality, Control, and Competition. The fishing industry has a number of unusual economic characteristics. Its resources are essentially renewable and, under optimal conditions, can be harvested on a sustained yield basis (Kuhn et al., 1974). However, both these resources are unique with respect to their "common-property" attributes. Fish population resources are not owned to any significant extent. This means that any individual, in an unregulated situation, can harvest the resource as he pleases. A potentially harmful result of the common-property characteristic is over-fishing. An over-harvest of a species of fish or a fishing ground could affect the ability of the population to reproduce and result in a reduction or elimination of the resource. Despite this potentially adverse result, it serves the short-term economic interest of the individual fisherman to land as many fish as possible. In a situation where over-fishing is a danger, only government-imposed regulation can result in an optimal ecological and economic harvest. With the exception of salmon hatcheries and oyster culture, human intervention to increase productivity through culture of fish and shellfish species is not yet practiced on a large-scale throughout the region (for further discussion, see Section 4.3.5.5.)

Another unusual characteristic of the fishing industry is the high degree of physical mobility of its capital and labor resources. Fishing grounds are unstable, responding to ocean currents, bottom conditions, natural population cycles, and human-initiated environmental alterations (Loy et al., 1976). The albacore tuna population, for example, has periodically migrated up and down the Pacific West Coast. Fishermen are also very mobile. Trawlers and trollers can travel long distances from the coast to reach productive fishing grounds (see, for example, Figure 3-68 in Chapter 3). Consequently, the fishing industry is not entirely dependent on local conditions for economic success as are other resource industries. Physical mobility also allows direct competition for resources to occur between fishermen who dock at different ports. For example, Willapa Bay trawlers can sail to productive fisheries a few miles from Coos Bay.

Competition with fishermen from outside the region also occurs, although recent enactment of the Fishery Conservation and Management Act (P.L. 94-265) in March, 1977, extending national jurisdiction to 200 miles, has lessened competition with foreign trawlers. This is probably the most important regulation decision of the recent past. Effective enforcement of the limit has drastically reduced foreign fishing harvest along the Pacific Northwest coast.

Previously, Russian, Japanese, and Polish trawlers captured large volumes of hake, tuna, perch, and salmon from coastal fisheries. The reduction of foreign competition should spur a recovery in local fish populations.

In addition to competing directly with foreign trawlers for catch, local fishermen must also compete indirectly with fishermen abroad. Over 70% of seafood consumed in this country is purchased from abroad, especially from Japan, Iceland, and Canada (U.S. Army Corps of Engineers, 1975C). Available supplies of foreign fish help to drive down the price of seafood in the U.S., making it more difficult for American fishermen to earn a living.

Technology further influences the region's competitive position in the fishing industry. Harvesting and fish processing methods used in the U.S. have not changed greatly in recent years. Foreign competitors, such as the Russians, use more modern fish finding equipment, larger ships, and processing vessels. There is also a lack of research being conducted on the resource, production, and economic problems that are hindering the industry, as well as a general lack of incentive to seek new markets. These factors all play a role in whether future expansion of the fishing industry will occur at the region's ports. Present trends indicate that such an expansion within the region is not likely (U.S. Army Corps of Engineers, 1975D).

Regulation of fish harvesting also varies by species. The delicate ecological character of salmon spawning grounds and the threat of overfishing of salmon requires strict regulation of salmon harvesting and spawning ground conditions. In addition to regulation of catch, all three states in the region operate salmon hatcheries to maintain populations (Kuhn et al., 1974; U.S. Army Corps of Engineers, 1976C; QRC Research Corporation, 1978). Indications are that the hatchery programs are very successful. In Oregon, it has been estimated that over 50% of coho salmon caught along the coast were products of state hatcheries (Kuhn et al., 1974).

The danger of severe over-fishing of Dungeness crab has required strict regulation of that species. During an average season, over 90% of legal-sized males are usually taken (Loy et al., 1976). Tuna is also regulated by size.

Most fish harvesting is highly seasonal. Figure 4-7 indicates approximate annual seasons by species for Oregon. Calendars for Washington and California are not readily available but are likely to be similar. Implications of seasonal patterns are discussed in Section 4.3.2.3.

4.3.2 Commercial Fish and Shellfish Harvesting

4.3.2.1 Volume of Landings. Table 4-21 gives coastal region commercial landings by state of principal species or groups of species in 1974. Coastal Oregon and Washington catch was dominated by salmon, shrimp, and bottomfish. Tuna (except in Oregon), crabs, oysters, and clams constituted a relatively small share of total landings. The pattern in Northern California was very different, bottomfish comprising about two-thirds of the catch, followed by salmon, tuna, and shrimp (Wise and Thompson, n.d.).

In an analysis of the socioeconomic repercussions of environment-affecting policies, the volume of fish harvested can be a particularly valuable indicator. Caution is necessary, however, in ascribing fluctuations in landings to particular causes. Trends in harvest size may be related to a variety of occurrences, such as migration, weather conditions, hatchery activity, fishing effort, and natural population cycles. Explanations of fluctuations must attempt to keep all relevant causes in perspective.

Volume data are spotty for individual watersheds in the coastal study region. While catch data are important to understanding resource conditions, they are not of great value in a discussion of the relative importance of various species to the coastal economy. The dollar value of landings (discussed in the following section) will serve that purpose much better. Available volume data can, however, be valuable in a discussion of fluctuations in harvest of an individual species over time.

Shrimp catch for Oregon, which had not been high during the late 1950's and early 1960's, experienced a great increase in volume beginning in 1967. Landings remained at a high level and by 1973 shrimp was the largest catch by volume for Oregon coastal fishermen (Kuhn et al., 1974).

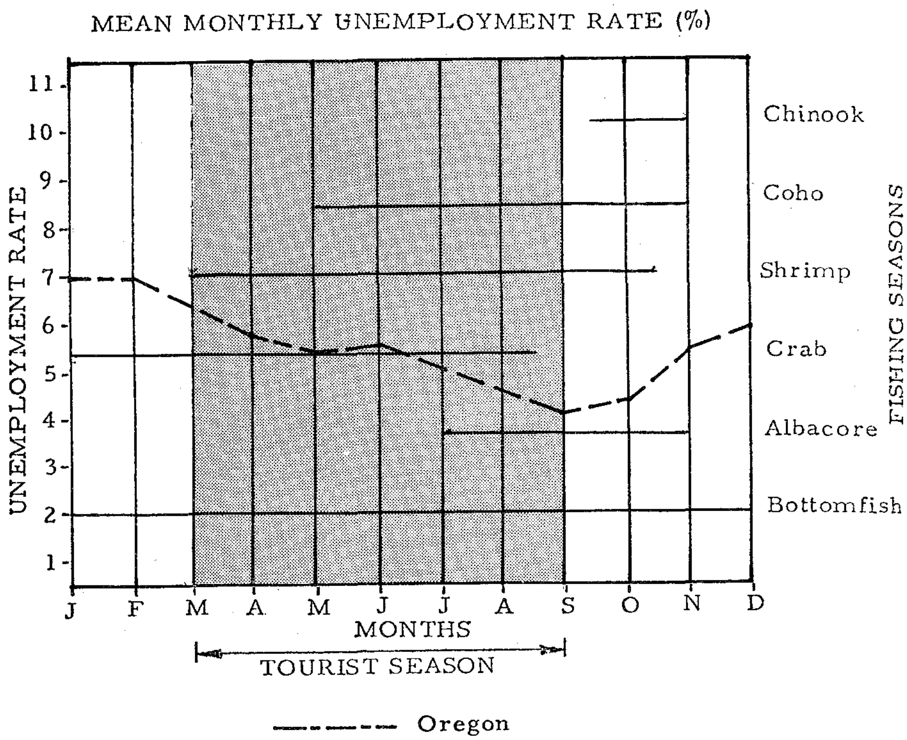


FIGURE 4-7. FISHING SEASONS AND AVERAGE UNEMPLOYMENT PATTERNS, OREGON COAST, 1960-1970. (From Kuhn et al., 1974 and Loy et al., 1976.)

TABLE 4-21. COMMERCIAL FISH LANDINGS ON THE PACIFIC NORTHWEST COAST, 1974. Data are in thousands of pounds. (From Wise and Thompson, 1977.)

	Northern[1] California	Coastal[2] Oregon	Columbia River-Oregon	Columbia River-Washington	Coastal Washington	Total
Salmon	5,126	10,614	4,583	3,847	9,581	33,751
Shrimp	2,216	13,605	6,709	536	8,726	31,792
Crab	355	2,539	1,398	1,146	3,620	9,058
Tuna	3,179	6,316	26,724	11,361	3,586	51,166
Bottomfish	33,394	10,940	7,674	714	5,000	57,722
Oysters	479	234	-	-	2,404	3,117
Clams	-	8	-	-	75	83
Other	4,489	1,582	3,434	2,490	1,832	13,827
TOTAL	49,238	45,838	50,522	20,094	34,824	200,516

[1]Data include Mendocino County, California.

[2]Data include Lane and Douglas Counties, Oregon.

Shrimp harvests also increased enormously along the Washington coast from 1970 to 1974, from 800 thousand pounds (Oceanographic Institute of Washington, 1977) to over 9 million pounds (Wise and Thompson, 1977). The rapid increase in volume has generally been related to increases in market demand for shrimp and technological improvements in shrimp processing, which could increase sales through lower prices (Loy et al., 1976). One source (Kuhn et al., 1974) also relates the increase to the discovery of new fishing grounds off the Oregon coast.

A general increase in the volume of salmon landings has also occurred along the Oregon coast since 1958. Lately, however, yearly volume of salmon caught has been inconsistent (Kuhn et al., 1976H.) Part of the earlier increase in salmon landings was undoubtedly associated with development of hatcheries and harvest management. Washington coast salmon landings have also been inconsistent in recent years (U.S. Army Corps of Engineers, 1976C and 1976H).

The volume of bottomfish caught in Oregon has been relatively consistent. The catch ranged between 20 million and 36 million pounds during the period from 1958 to 1974 (Kuhn et al., 1974), varying by no more than 2 million pounds between 1969 and 1975. Long-term data for bottomfish are not available for the study area in Washington and California. Grays Harbor fishing fleets have shown growth in bottomfish catch since 1970, increasing landings by over 600% during this period. Individual species in the bottomfish category showed even greater changes. The catch of flounder and sole grew by 1,000% on the Washington coast between 1970 and 1974 (U.S. Army Corps of Engineers, 1976C).

Volume of Dungeness crab landings have been particularly erratic, as recorded since 1958 in Oregon and since 1935 in Willapa Bay, Washington (Kuhn et al., 1974; U.S. Army Corps of Engineers, 1976H). An apparently cyclical, but unexplained trend was noted in the Willapa Bay EIS (U.S. Army Corps of Engineers, 1976H). A particularly sharp decline in crab landings occurred in all areas where data were available between 1970 and 1974. During this period, landings dropped 85% along the Oregon coast and 75% along the Washington coast. Individual harbors also recorded enormous declines (Kuhn et al., 1974; U.S. Army Corps of Engineers, 1976C; Oceanographic Institute of Washington, 1977). Some processors contend that the sharp reduction was due to excessive harvest of the crab resources in 1970 and 1971 (Kuhn et al., 1974). Research at Oregon State University relates fluctuations in crab landings to rainfall, which affects the salinity of marshes where crab larvae mature (Lough, 1974).

Increases in tuna landings occurred in 1967, at about the same time as shrimp harvest increases. Between 1967 and 1974 both the Washington and Oregon coastal study area showed large increases (over 200%) (Kuhn et al., 1974; Oceanographic Institute of Washington, 1977). Ocean current fluctuations, resulting in a northward move of albacore tuna in the late 1960's, has been an explanation for this trend (Loy et al., 1976).

Oyster harvests have shown a continuous decline in volume since the 1940's. Willapa Bay's oyster production, which accounts for more than 80% of oyster production in the entire coastal study area in 1970 (Oceanographic Institute of Washington, 1977; U.S. Army Corps of Engineers, 1976H), produced a peak harvest of over 10 million pounds in 1946 and has declined steadily ever since. Production in the 70's ranges between 3 and 4 million pounds at Willapa Bay. One factor contributing to the decline has been widespread oyster mortalities in the bay, a problem which affects both juvenile and adult oysters. Adult oyster mortalities were reported in 1962 and 1963. Before that time, the adult mortalities were approximately 5 percent of the total population. By 1964, they exceeded 50 percent. The mortalities were most noticeable near the influence of the Willapa River, giving rise to the hypothesis that the cause involved nutrients brought down by the river which initiated phytoplankton blooms. Related factors include tannin and lignin from log handling and processing operations, which make iron, a frequently limiting nutrient for these organisms, more available in the water. It is also possible that mortalities are related to spawning since they often occur immediately after the spawning season. Research into this problem is underway, but no conclusive findings are available as yet (U.S. Army Corps of Engineers, 1976H). A 50% decline in Humboldt Bay oyster harvest has also occurred in recent years (QRC Research Corporation, 1978).

Small volumes of halibut, sea herring, cod, and clams are also harvested along the coast. Hake harvest has been insignificant until very recently (Oceanographic Institute of Washington (OIW), 1977; QRC Research Corporation, 1978).

Despite enormous fluctuations among individual species, the overall volume of fish harvested has shown a consistently upward trend since 1958 for the Oregon coast (Kuhn et al., 1974). Long-term data for Washington and California coastal areas are not available. In terms of weight, the percentage of total fish catch for the coastal study area (excluding California counties) in 1974 by species were shrimp (28%), salmon (25%), bottomfish (21%), tuna (12%), Dungeness crab (8%), and oysters (4%). Rankings and percentages can change greatly from year to year. In 1970 Dungeness crabs were first in volume for the coastal area with 33% of the total catch (calculated from U.S. National Marine Fisheries Service data, 1976, found in OIW, 1977).

4.3.2.2 Value of Landings. Value of landings is the best indicator of the relative economic importance of the species of fish harvested. Total value is the product of volume and unit price. The price of fish depends on a large number of supply and demand factors previously discussed (Section 4.3.1.2). Volume, as discussed above, can fluctuate enormously from year to year. Since value is a function of both volume and price, yearly fluctuations in value can also be large.

Table 4-22 lists value, volume, and average ex-vessel price of major species of fish harvested for the coastal region for 1974. Although third in volume landed, salmon was the species most valuable to coastal fishermen due to its higher market price. Figures for 1970 (not listed) indicate that although a greater volume of crabs than salmon were landed, in that year in coastal Oregon and Washington, salmon still led as the largest income producer because of its much higher market price at the time (OIW, 1977).

TABLE 4-22. VALUE OF PACIFIC NORTHWEST COASTAL REGION FISH LANDINGS, 1974. Note: Data includes Lane and Douglas Counties, Oregon, and Mendocino County, California. Figures are rounded, may not sum to total. (From Wise and Thompson, 1977.)

	Weight (In Thousands of Pounds)	Average Ex-vessel Price/Pound (In Dollars)	Total Value (In Thousands of Dollars)
Salmon	33,750	.78	26,266
Shrimp	31,792	.21	6,636
Dungeness Crab	9,058	.71	6,473
Tuna	51,166	.38	19,201
Oysters	3,117	1.15	3,600
Bottomfish	57,722	.14	7,991
Other	13,910	.13	1,743
TOTAL	200,515	.36	71,910

Table 4-23 further illustrates the relationship between price, volume, and value. Data for salmon and crab harvest for coastal Oregon between 1967 and 1973 show that the volume of salmon landings was basically unrelated to the price of salmon over this period. Crabs, on the other hand, show a definite correlation between price and volume. After 1971, a sharp decrease in volume landed is associated with a sharp increase in price to bring crabs close to the price of salmon. The decrease in total value of crab landings was due to a reduction in available supply. The increase in value of salmon landings, however, is probably related to demand conditions.

TABLE 4-23. OREGON COAST[1] SALMON AND CRAB FISHING HARVEST. (From Fish Commission of Oregon data in Kuhn et al., 1974.)

Year	Salmon			Crab		
	Price[2] (per lb)	Weight (1000 lbs)	Value (100 $)	Price[2] (per lb)	Weight (1000 lbs)	Value (1000 $)
1967	.53	10,399	5,511	.17	9,620	1,635
1968	.58	6,205	3,599	.22	11,352	2,497
1969	.62	5,327	3,303	.29	9,784	2,837
1970	.77	10,585	8,150	.26	14,929	3,882
1971	.59	11,241	6,632	.29	14,856	4,308
1972	.75	7,084	5,313	.57	6,762	3,854
1973	.90	9,876	8,888	.80	2,349	1,879

[1] Includes Lane, Douglas Counties in addition to Clatsop, Tillamook, Lincoln, Coos, and Curry Counties.

[2] Real price, using consumer price index deflater, 1967 = 100.

4.3.2.3 Employment. Usual employment data sources are not valid for the calculation of the number of persons employed in fishing. Each source has a number of basic flaws. In the employment by industry section of publicly accessible editions of the 1970 United States Census, fishing employment is grouped with forestry and agriculture employment. More up-to-date data collected by state employment agencies for unemployment insurance purposes also cannot be considered to provide accurate counts of fishing employment. Partnerships, family businesses, and self-employed persons are not required to contribute to state unemployment funds, and as a result, many fishing businesses are exempt. Additionally, a number of fishing captains illegally list their crew members as partners or family members to avoid unemployment contributions (Kuhn et al., 1974).

Many studies, such as Kuhn et al. (1974), and U.S. Army Corps of Engineers (1975C), use the number of commercial fishing licenses issued to estimate fishing employment. Since separate licenses are issued for sport and commercial fishing in California, Oregon, and Washington, this would appear to be an excellent method of estimating fishing employment. Unfortunately this method also raises major questions of validity. First, both part-time and full-time fishermen can receive licenses. From licensing data alone it is therefore impossible to determine how many of the licensees are primarily fishermen or use fishing as a supplement to income derived from another source. Some surveys have been taken to separate full-time and part-time fishermen. Defining a full-time fisherman has been a problem. One study called any licensee earning over 50% of his income from fishing a full-timer (Oregon State University Extension Marine Advisory Program Survey, 1970, cited in Kuhn et al., 1974). Another used a minimum annual income figure of $5,000 as a requirement for full-time status (Fish Commission of Oregon, 1973, cited in Kuhn et al., 1974).

Both methods of defining "full-time" have problems. Many crew members of trawlers do not record any catch on their required personal licenses. While they may show an income of zero according to licensing records, they should be considered full-time fishermen. Other fishermen who record no catch, however, may simply be dormant license holders. There is no data base for determining the real percentages (Kuhn et al., 1974),

Another problem concerns the residence of fishermen. Many licensees who fish along the coast do not live in the coastal study area year round. In fact, the OSU Extension Survey found that 29% of Oregon's licensees lived out-of-state in 1970 (from Kuhn et al., 1974). A decision on these part-time residents must be made in counting coastal fishing employment. Finally, license survey data are collected by state; county data are not available.

The present analysis will use 1975 County Business Patterns data (U.S. Department of Commerce, 1977D), licensing data, and Oregon licensing surveys to estimate employment in the coastal study area. Licensing surveys are not available for Washington and California counties.

The County Business Patterns data on employment are compiled from payroll data submitted by employers in conjunction with payroll tax payments to the Internal Revenue Service. Used alone, the data have a number of shortcomings for determining fishing employment. Since self-employed persons, partnerships, and family businesses are not required to make payroll tax deposits, their numbers are not included. Also, the week of March 12 is the only period used for counting employees. Therefore, the data has built-in seasonality shortcomings. This should not be a problem for fishing, however. Various measures of seasonality indicate that March fishing employment is very close to the yearly average.

Table 4-24 lists the County Business Patterns payroll employment in the fishing industry for 1975. Data are actually for "fishing, hunting and trapping" (S.I.C. Code 09). However, it can be reasonably expected that all payroll employment is in fishing for this area. For some counties, such as Clallam and Jefferson, with totals less than 50, employment and payroll data are estimated.

Fishery employees (not including self-employed, partnership, and family fishermen) in the twelve coastal counties of the study area totalled approximately 722 in 1975. Annual payroll totalled some $9,036,000. For the entire coastal area, according to County Business Patterns data, fishing has less than 1% of total payroll employment in 1975; Pacific County, WA (3.2%), Lincoln County, OR (2.1%), and Del Norte County, CA (2.2%) have the largest concentrations of payroll fishery employment.

Multiplying the number of state licenses issued in each state in 1975 by the ratio of fishing industry payroll employment in the coastal area to total fishing employment in each state, an estimate of 9,584 licenses is derived (see Table 4-25). This is, of course, a highly conjectural method and probably produces an overstatement since many licensees live outside the region and some live in other states (Kuhn et al., 1974). Applying findings on Oregon place of residence surveys quoted in Kuhn et al. (1974), only 2,966 of the estimated 4,847 Oregon coastal licenseholders would probably live in the coastal region. The remainder typically would moor their boats in coastal harbors during the peak summer salmon season. The choice between the two figures (2,966 or 4,847) is important because the contribution to the local economy of licensees who fish only in the summer is probably similar to that of sports fishermen. They do not generate year-round needs for other services and employment and probably spend the bulk of the income derived from fishing in their home communities (Kuhn et al., 1974).

TABLE 4-24. PAYROLL EMPLOYMENT FOR THE FISHING INDUSTRY[1] IN COASTAL COUNTIES, 1975. (From U.S. Department of Commerce, County Business Patterns, 1977D.)

County	# Of Employees	Total Annual Payroll (in thousands of dollars)	Average Annual Salary
Clallam	45 (est.)	563 (est.)	-
Jefferson	12 (est.)	150 (est.)	-
Grays Harbor	87	1,402	16,115
Pacific	87	616	7,080
Wahkiakum	7 (est.)	88 (est.)	-
Clatsop	73	1,418	19,424
Coos	64	703	10,984
Curry	19 (est.)	238 (est.)	-
Lincoln	114	1,707	14,974
Tillamook	57	293	5,140
Del Norte	73	650	8,904
Humboldt	84	1,208	14,381
TOTAL	722	9,036	12,515 (overall average)

[1] Data are for S.I.C. Code 09, Fishing, Hunting, and Trapping but the latter two are not considered significant payroll classes in this region.

TABLE 4-25. ESTIMATION OF COASTAL COMMERCIAL FISHING LICENSES, 1975. Note: California coast includes Del Norte and Humboldt counties only; Oregon coast includes Lane and Douglas Counties. (From U.S. Department of Commerce, 1977D, Washington State Department of Fisheries, 1978, personal communication; California State Department of Fish and Game, 1978, personal communication.)

State	FISHING INDUSTRY PAYROLL EMPLOYMENT			COMMERCIAL FISHING LICENSES	
	Coast	State	% Coast	State	Coast (Est.)
Washington	238	1,127	21.1%	8,603	1,817
Oregon	327	367	89.1%	5,440	4,847
California	157	1,751	9.0%	13,968	2,920
TOTAL	722	-	-	38,011	9,584

It cannot be assumed, however, that the estimated 2,966 coastal fishermen in Oregon are full-time. The 1970 OSU Extension Survey determined that 46% of Oregon's commercially licensed fishermen (in-state and out-of-state) earned all of their annual income from fishing (from Kuhn et al., 1974). The 1971 Fish Commission Study calculated that only 10.9% of Oregon fishermen earned more than $5,000 from fishing (that study's benchmark for full-time status). The latter figure may be low because inactive licenses are included. The figures are for the state as a whole. No definite conclusion can be drawn about numbers of coastal fishermen.

Some other data from the 1971 Fish Commission study may shed further light on the situation. Table 4-26 shows that the great majority of all licensed fishermen fished for salmon. Of the full-time licensees (as defined by the study), most fished for tuna and crab. In a 1975 Oregon State University Sea Grant study (cited in Coos, Curry, Douglas EIA, 1977), all licensees specializing in salmon were assumed to be part-timers.

TABLE 4-26. SPECIALIZATION OF FISHERMEN BY SPECIES, OREGON COAST, 1971. (Data from Oregon State Fish Commission, 1971, in Kuhn et al., 1974.)

Species	All License Holders	License Holders With $5,000 Or More Income From Fishing
Troll Salmon	70%	22%
Albacore Tuna	15%	33%
Dungeness Crab	11%	28%
Groundfish	2%	9%
Shrimp	2%	8%

Taking various data sources and employment calculation methods into consideration, a picture of fishing employment on the coast begins to emerge. In 1975, there were nearly 5,500 fishermen who held Oregon commercial fishing licenses. Of these, approximately 15% (800) could be considered full-time commercial fishermen who specialized in tuna, crab, salmon, groundfish, or shrimp landing. Nearly all of these full-timers lived in the study area. This is borne out by the 1975 payroll employment data which shows that 89.1% of fishing industry employees lived on the coast in March, which is out of season for salmon fishers. Most of the remaining 4,600 licenseholders were part-time (weekend or summer) troll salmon fishermen who generally travel to the coast to fish. Of these part-timers, approximately 1,100 lived out-of-state and approximately 1,400 were inland Oregoners. This would leave approximately 2,100 part-time fishermen living on the coast.

Of the part-timers, many may rely on the income received from salmon fishing as a major supplement to their income, particularly if they are underemployed or retired (Coos, Curry, Douglas (CCD) EIA, 1977). The size of this group should be ascertained to gain a better understanding of the economic importance of fishing employment.

No surveys were available to determine what percentage of California and Washington employment occurs in the coastal study area. In the absence of better survey data, the calculations from payroll employment in Table 4-24 should suffice.

An unusual aspect of fishing employment in the study area is local dependence on this resource as a supplemental food supply. No data are available to estimate the degree to which local residents rely on fish or shellfish for food supply. Observations from one study indicate that this activity is a key element in local lifestyle and an important factor in reducing the impact of seasonal incomes (U.S. Army Corps of Engineers, 1976).

Salmon fishing also appears to be a significant source of income and food supply for Indians living on the Makah, Quillayute, and Quinault Reservations of coastal Washington. An Indian gill-net fishery is operated on the Chehalis River by the Chehalis Indians, whose reservation is inland of the Watershed Unit 2 boundary. It has captured an average of 4,050 salmon annually during recent years (U.S. Army Corps of Engineers, 1976C). Salmon fishing forms the base of the Quillayute, Hoh, Quinault, and Makah Indian Nation economies in Washington (Washington DCED, 1977A) as well as of the Hoopa Indians in Northern California.

4.3.3 Sports Fishing. Sports fishing incorporates elements of both commercial fishing and recreation. Often the only distinction between commercial and sports fishermen is statistical. The states of Washington, Oregon, and California issue separate licenses for sports and commercial fishing. Many sports salmon fishermen, however, acquire commercial licenses to retain a higher catch limit than permitted under the sport fishing license (Kuhn et al., 1974).

Sports fishing generally has an effect on the coastal economy similar to other recreational activities. Unlike commercial fishermen, the most significant expenditures of sports fishermen are indirect: lodging, food, drink, and gasoline. With the exception of chartered boat services, major expenditures tend to be purchased in the area of residence of the sports fishermen (Schmisseur and Boodt, 1975). In Washington, less than 8% of over 456,000 sports fishing licensees lived in the coastal area of that state in 1976, and 27% lived outside the state (Washington State Department of Fisheries, 1978, personal communication). Washington State Department of Fisheries indicate that as much as half of the sports fishing in the state takes place in the coastal area. Most sports fishermen probably visit the study area during vacations or on weekends, bring their own equipment and purchase services (lodging, food, and fuel) not directly connected with the fishing industry.

4.3.3.1 Species and Volume of Catch. As with commercial fisheries, reliable data throughout the region are lacking. Although the Washington Department of Fisheries and the Fish Commission of Oregon prepare a salmon sport catch report, sport and commercial landings of other species are not differentiated. Sports fishing activity involving other species is reported in terms of numbers of angler-days rather than pounds caught. It is therefore not possible to either examine the sport catch by species or to compare the total catch with commercial landings.

The principal game fish sought by sports fishermen in the coastal area are salmon and trout (Schmisseur and Boodt, 1975). In Lincoln County, Oregon, out of the 9.7 million dollars spent annually on sports fishing, 83% was spent on salmon fishing (mainly ocean), and nearly all the remainder on steelhead and cutthroat angling (U. S. Army Corps of Engineers, 1976G and I). All available studies of the coastal area refer to salmon fishing as the most important sports fishing activity (U. S. Army Corps of Engineers, 1976C and H; Coos, Curry, Douglas EIA, 1977; QRC Research Corporation, 1978; etc.). Trout are also mentioned frequently as important game fish. Steelhead and cutthroat appear to be present throughout the study area. Rainbow trout angling is significant in Pacific and Grays Harbor Counties in Washington (Washington Department of Commerce and Economic Development, 1977B). Less important game fish in the region include mountain whitefish, Kokanee, bass, blue gill, crappie, catfish, and perch. Razor clamming is also mentioned as an important recreational activity on the Washington south coastal beaches (U.S. Army Corps of Engineers, 1976C and H). Clamming is also important in other estuaries such as Coos Bay (Oregon Fish Commission, 1973-1974).

4.3.3.2 Value and Employment. Measuring the economic impact of sports fishing is difficult because of incomplete data and the variety of units used. For Oregon, estimates of gross annual sports fishing expenditures range from 50 million dollars for the state as a whole to the same amount for Oregon's coastal area alone (Schmisseur and Boodt, 1975). A Humboldt County estimate placed the annual value of sports fishing at $5-10 million compared to $35 million for commercial fishing (QRC Research Corporation, 1978). Some data are collected by "angler days"; however, converting these units to dollars requires estimates of per day expenditures which vary widely (Schmisseur and Boodt, 1975; U. S. Army Corps of Engineers, 1976C; Stoevener et al., 1972).

Many studies assert that sports fishing is the primary recreational activity that attracts tourists to the parts of the study area (U. S. Army Corps of Engineers, 1976I; Coos, Curry, Douglas EIA, 1977). A 1972 Oregon State Game Commission study states that "the bulk of the recreation spending in Lincoln County is in all likelihood related to the area's excellent sports fishing" (U. S. Army Corps of Engineers, 1976G). All agree that sports fishing has been growing in recent years. Data for Washington state sports fishing licenses bear this out. Washington State Department of Fisheries data indicate (1978, pers. comm.) that between 1972 and 1976 the number of sports licenses issued by the state increased each year.

Sports fishing-related employment is also very difficult to measure. Directly related employment (boat/yacht rental, bait and ice stores, lauching facilities) account for a very small portion of local employment (U. S. Army Corps of Engineers, 1976G). Employment in more widely dispersed activities related to sports fishing, such as lodging, food, and fuel, is difficult to measure (Schmisseur and Boodt, 1975).

Sports fishing is a major and growing recreational activity with an important economic impact on tourist-related businesses. Sports fishing is second to commercial fishing in overall importance, mainly because sports fishing does not produce a saleable product even though important indirect expenditures are generated in the service and trade sectors. Comparison of available angler expenditure data for areas with and without access to the ocean indicates that the economic value of ocean salmon fishing far surpasses that of other forms of sport fishing. Total annual expenditure for salmon, steelhead, and cutthroat angling in the major Lincoln County fishing areas was estimated at $9.7 million in the early 1970's (Oregon State Game Commission data for 1972 in U.S. Army Corps of Engineers, 1976I). Of this total, $3.3 million was spent in the Yaquina Bay area. The same data showed that only $207,000 was spent by estuary and river anglers for food, fuel, lodging, marinas, supplies, and other goods. The moorage, boat and tackle rentals, bait and ice, parking and small boat launching facilities, and smokehouses account for the additional expenditures attributable to marine fisheries.

With the value of the Lincoln County forest products production set at $40 million in 1972 (Kuhn et al., 1974), the sport fishing industry, with expenditures of $10 million, is clearly highly significant. Areas which can offer only river angling or estuarine angling, clamming, and crabbing, but have limited marina and boat rental facilities appear to benefit to a much smaller extent, however, an input-output study of the Yaquina Bay area in (Stoevener et al., 1972) shows that marine angling transactions are roughly 7 percent of total area transactions. (Adjusting 1963 data for inflation, river and estuarine expenditures, on the same basis, would account for only about 0.1 percent of total expenditures.)

A further discussion of all types of angling is found in a study of the economic impact of small boat facility development of the Umpqua River estuary in Douglas County, Oregon (Schmisseur et al., 1975B). This study indicates that the average expenditure-per-visitor day by anglers totals almost twice that of non-fishing visitors. The implications of these studies are further examined in the following Section 4.4 on recreation.

4.3.4 Fish Processing.

4.3.4.1 Volume Produced. The fish processing industry in the coastal area is dependent on the local commercial catch (Kuhn et al., 1974). However, it is difficult to estimate what percentage of local catch is processed locally and what percentage is shipped elsewhere for processing. A study of Coos, Curry, and Douglas Counties indicated that although these counties accounted for 30% of Oregon's total fish catch by weight, only 16.7% of the state's seafood processing employment was located there (Coos, Curry, Douglas EIA, 1977). The study goes on to say "a large amount of the total catch had only minimal processing before being shipped to other areas for further processing." There is no mention of where this "further processing" occurs.

Data on the number of processing plants indicate that there were 19 canneries and 19 packaging plants along the Oregon coast in 1972 (Kuhn et al., 1974). 1975 data indicate that there were at least 14 plants along the Washington coast and 6 in the California portion of the study area (U. S. Department of Commerce, Bureau of the Census, 1977D). Most plants are located in coastal ports (Kuhn et al., 1974).

4.3.4.2 Value. Data on the value of fish processed are spotty. A Tillamook County study found that local seafood processors exported 1,274,000 pounds of processed fish, 1% of the county's total exports in 1973 (Youmans et al., 1977). Willapa Bay's seafood processors accounted for 10% of exports in 1971 (U. S. Army Corps of Engineers, 1976H). The total value of seafood processing for the Oregon coast in 1971 was estimated at $50 million (Schmisseur and Boodt, 1975).

4.3.4.3 Employment. Employment in seafood processing is highly seasonal, and tends to follow the seasonality of fish landings. The peak period of processing employment is April to October. Peak employment in August, 1973 on the Oregon coast was 53% above the average for the year (Oregon State Employment Division, 1974).

Table 4-27 gives a rough estimate of seafood processing on the coast. The only region-wide employment data are found in County Business Patterns, 1975 (U.S. Department of Commerce, Bureau of Census, 1977D).. The survey period for these data is the second week of March. It should be kept in mind that March is a period of low employment in the seafood processing industry, so annual average employment has been estimated based on a low figure. Average annual income figures are also included for seafood processing employment where available.

County Business Patterns data for 1975 show no processing employment for Tillamook, Lincoln, or Curry Counties. Oregon State Employment Division data, however, indicate that processing plants in these counties employed some 347 workers in 1973. These data are, therefore, used for Oregon. Comparing Table 4-27 with Table 4-24 suggests that, on the coast as a whole, payroll fishing employment is approximately 27% of seafood processing employment. Over two-thirds of all Oregon processing employment was located in Clatsop County, while fishing was spread more evenly among Clatsop, Lincoln, and Coos Counties.

TABLE 4-27. EMPLOYMENT IN SEAFOOD PROCESSING IN PACIFIC NORTHWEST COASTAL COUNTIES, 1973 AND 1975. Figures for Washington and California are estimates based on County Business Patterns data for 1975. Figures for Oregon are from Oregon State Employment Division for 1973. (From U.S. Department of Commerce, 1977D; Kuhn et al., 1974.)

County	Employees	Estimated Average Annual Salary
Clallam	-	-
Jefferson	-	-
Grays Harbor	132 (e)	6,850
Pacific	328 (e)	4,030
Wahkiakum	-	-
Clatsop	1,229	5,870
Tillamook	57	n/a
Lincoln	199	n/a
Coos	337	6,670
Curry	91	n/a
Del Norte	-	-
Humboldt	295 (e)	n/a

(e) = Estimate.
n/a = Not available.

Data for coastal Oregon seafood processing employment from 1958 to 1973 indicate a gradual but uneven increase with approximately parallels the increase in the volume of fish landings for the same area (see Figure 4-8). Not unexpectedly, processing employment appears to depend on local volume of fish catch. The decline in employment during 1970-1972 is related to mechanization of the shrimp processing process (Kuhn et al., 1974).

4.3.4.4 Volume and Destination. Very little data are available on the desination and volume of fish products. A Tillamook County study indicates that 99.1% of seafood processing plant output is exported out of the county. It is not clear, however, what percent of that output leaves the coast (Youmans et al., 1977).

Except for some processed fish, such as canned salmon, fish products of the coastal area are consumed primarily in markets of the western United States. A portion is also sold locally. Of the products sold within the region, a large percentage is sold to tourists (U.S. Army Corps of Engineers, 1975C).

FIGURE 4-8. VOLUME OF FISH LANDINGS (A) AND FISH PROCESSING EMPLOYMENT (B), OREGON COASTAL COUNTIES, 1958 - 1973. Employment data are for Clatsop, Tillamook, Lincoln, Coos, and Curry Counties only. Fish landing data also include Lane and Douglas Counties. In A the solid line indicates millions of pounds and the dashed line indicates millions of dollars. (From Kuhn et al., 1974.)

4.3.5 Summary and Effects.

4.3.5.1 Summary of Employment and Value Added. Employment in fisheries and seafood processing on the Pacific Northwest Coast accounts for an estimated three percent of payroll employment. If estimated part-time and other non-covered fishery employment is included, the percentage may be as high as eight percent. This is insignificant compared with forest industry employment but relatively significant compared with agriculture and recreation. Both employment and output of the industry, nevertheless, are very important to certain counties and communities. On the Oregon coast in 1973, the value of the commercial fisheries output (ex-vessel) amounted to close to the total value of real gross farm sales. In some counties, such as Humboldt County, California, it is estimated that sport and commercial fisheries are second in value to the forest industry.

Only 1.2% of fresh and processed fish are estimated to be sold locally in Clatsop County, accounting for 26% of county exports (Collin et al., 1973). Processing employment is particularly important in Clatsop County and to a lesser degree also in Pacific and Humboldt Counties. Part-time fishing is also a source of employment, income, and food supply throughout much of the region.

Commercial fisheries provide a full-time living or a significant income or food supplement for many coastal area residents and others. Processing activities provide one of the few important employment opportunities for women in the region.

Sports fisheries are valuable to the region's economy as one of the principal attractions for recreational visitors (see Section 4.4.2.1).

4.3.5.2 Multiplier Effects. The Youmans et al. (1977) study of the Tillamook County economy shows relatively high income multipliers for commercial fisheries and seafood processing (2.7 and 3.0, compared with 1.8 and 2.25 for forestry and sawmills). In Clatsop County, where fisheries and fish processing are much more important, Collin et al. (1973), calculated multipliers of 2.76 and 1.75. (See adjusted figures in Schmisseur and Boodt, 1975.)

4.3.5.3 Natural System Effects. Commercial and sport fisheries have few direct natural system effects beyond the impacts of overfishing on some species populations. Depletion of stocks within the region are discussed by Pruter (1972). Localized pollution loads by fish processing plants may be a deleterious impact in some areas.

There are some long term food web and species interaction effects which are attributable to commercial fisheries. Removal of prey species (bait fish) will have potentially deleterious effects on dependent species, e.g. salmonids and sea birds, while removal of large numbers of predators can lead to increased populations of prey species. These types of interactions for the oceanic system are not well known, although some authorities suggest that the recent increased shirmp fishery is in part dependent on the increased foreign fleet harvest of hake, a major predator on shrimp.

Indirectly, the industry creates demands for marina development, dredging, and associated facilities. The effects of other activities in the region on aquatic habitats include increases in sediment, turbidity, toxic substances, changes in dissolved oxygen, disturbance of bottom materials, and blocking of fish runs. Some cause and effect relationships include the effects of dredging, effluent from industrial plants such as kraft mills and food processing plants, tannin and lignin from log handling and processing, and logs and debris from logging operations blocking streams. Maintenance and restoration of watershed quality, as well as controls on dredging and industrial waste discharge, are critical to the enhancement of fish populations.

Stoevener et al. (1972) have examined the economic effects on sports fisheries of kraft mill effluent degradation of water quality in Lincoln County, Oregon.

4.3.5.4 Outlook for the Industry. A complex set of environmental, economic, and political factors is influencing trends in the fishery industry. The natural environmental changes and harvesting pressures which have affected some species are being responded to through regulations which have varying impacts. Restriction of foreign ocean fishing activities should protect fish populations and permit larger harvests in the region. Moratoria on harvest of salmon on the Trinity and Klamath Rivers will, in the short-term, impact those dependent on salmon fishing; however, in the long-term, watershed restoration activities combined with hatcheries hopefully will assist in raising salmon population levels and thus salmon-related jobs.

An important potential for increasing the value of the industry lies in expanding aquaculture, mariculture,and hatchery activities. In Humboldt County, "it is believed that landings of finfish, shellfish, and other invertebrates could at least be doubled, as could the total value of the industries to the county" by these techniques (QRC Research Corporation, 1978). This study purposes mussell, crab, and seaweed farming; salmon ranching; improved processing facilities to eliminate most fish waste and refine it for sale at higher prices; exploratory fishing and facility improvement; stream rehabilitation; and improved salmon and steelhead culture facilities.

4.4 RECREATION

4.4.1 Resources. Recreation resources may be natural features of the environment, man-altered natural features, or man-made facilities. The abundant recreation resources on the Pacific Northwest coast fall primarily in the former two categories.

4.4.1.1 Recreational Opportunities. A low intensity of residential, industrial, and commercial land use combined with an excellent natural setting has resulted in an abundance of outdoor recreational opportunities throughout the Pacific Northwest Coastal Region. Large stretches of land remain substantially undeveloped and are ideal for many outdoor recreational activities. Agriculture (see Section 4.5) and urbanized areas (see Section 4.9.2) are not significant land uses in the region. Although private timber lands (see Section 4.2) are extensive, many timber companies have made their lands available for recreatonal use and have opened campgrounds (Coos, Curry, Douglas EIA, 1977). A large part of the land is federally-owned and administered by the U.S. Bureau of Land Management and the U.S. Forest Service. Much of this land, in addition to federal, state, and county land specifically set aside for recreation and parks, is available for low intensity recreation use. Public recreation areas, other points of interest, and facilities are mapped for each state by state transportation departments, the U.S. Forest Service, the U.S. Geological Survey, and the National Park Service.

The most significant feature of the natural setting is the Pacific Ocean. The Ocean coastline, beaches, and harbors provide for a variety of recreational activities. Inland, the forests and mountains also offer camping, hiking, and hunting opportunities. Additionally, the preserved natural scenic beauty of most of the coastline from Cape Flattery to Cape Mendocino makes pleasure driving an important recreational activity along U.S. #101 and other coastal roads. Sports fishing resources, both ocean and freshwater, are among the most significant generators of recreational activity in the region.

4.4.1.2 Developments. Recreational areas range in intensity of development from man-made facilities to untouched natural settings. Many major facilities are only slightly altered, including most state and national parks, forests, recreational areas, wildlife refuges, and other federally-owned lands. Federally owned land (especially in the central portion of the Oregon Coast) is administered by the Bureau of Land Management and is largely undeveloped and open to the public for recreational activities (U.S. Dept. of the Interior, 1970, and Schmisseur and Boodt, 1975). National Forests, another significant occupier of land along the coast (see Table 4-3, Section 4.2.1.2) are also open to the public for various recreational uses.

Improvements to recreation areas include boat launching facilities, campsites, picnic areas, trails, marinas, access roads, etc. In addition to these alterations of the natural setting, a number of service activities support the users of recreational activities. These include hotels and motels, restaurants and bars, gasoline stations, golf courses, museums, marinas, and charter boat services (Schmisseur and Boodt, 1975).

Unique or particularly attractive recreational areas along the coast include the Olympic National Park, the ten National Wildlife Refuges, the Redwood (State and National) Parks, the Oregon Dunes National Recreational Area, the Kalmiopsis Wilderness Area, and the numerous state parks. (See Figure 3-7 and related discussion in Section 3.5 of this volume.) The Olympic National Park covers 893,000 acres of mountains, lakes, forests, and rivers in Clallam and Jefferson Counties. An arm of the park stretches along most of the Pacific coastline of those counties. The redwood parks include the Redwood National Park and five Redwood State Parks (Del Norte Coast, Grizzley Creek, Humboldt, Jedediah Smith, Prairie Creek) in Humboldt and Del Norte Counties. The parks protect the world's tallest trees, and provide an important coastal tourist attraction. Including the controversial addition of 48,000 acres and a 2,000 acre scenic corridor in 1978, the total area of the Redwood National Park (originally set aside in 1968) is approximately 110,000 acres (U.S. Department of the Interior, personal communication, 1978).

The Oregon Dunes National Recreation Area, established in 1972, occupies 40 miles of beaches and dunes between Coos Bay and Florence in Coos, Douglas, and Lane Counties in Oregon (Coos, Curry, Douglas EIA, 1977). The Kalmiopsis Wilderness Area is a completely undeveloped reserve in Curry

County, Oregon, which may be expanded by addition of an area currently under the RARE II (Roadless Area Review) program of the U.S. Forest Service (under consideration in early 1979) (USDA, 1978A and 1978C).

In addition, numerous city parks provide camping, swimming, and fishing facilities.

4.4.1.3 Demand and Supply Factors. Long-run demand for recreational services depends directly on the amount of leisure time and personal income available to the potential market population. Overall trends in the U.S. indicate that leisure time and personal income are rising so it can be expected that long-term recreation demand will increase (Schmisseur and Boodt, 1975). For the study area, this increase can be especially significant due to the growth in nearby population centers around Puget Sound in Washington and in the Willamette Valley of Oregon. The coastal area's natural recreational advantages (discussed in Section 4.4.1.1 and 4.4.1.2) place it in an ideal position to satisfy an increasing demand for recreation. In addition, the two National Parks and the Oregon Dunes National Receation Area have made the coastal area more attractive to long-distance vacationers (QRC Research Corporation, 1978; U.S. Army Corps of Engineers, 1975C). Increasing population leisure time, and income can also have an effect on recreational resource supply. Higher use levels or expansion of man-made facilities could compromise the overall attractiveness and natural recreational resources of the area, increasing local economic and environmental costs. Expansion of tourism, is, however a potential economic benefit to the region. Thus, careful examination of the economic benefits and environmental interactions of new development is necessary. (This is discussed further in Sections 4.4.5.3 and 4.4.5.5.)

4.4.1.4 Regulations and Controls. The regulations and controls of recreational activities are of two distinct types: i.e. governing or protecting individual recreational activities such as fishing and hunting; and controlling for recreational developments having an effect on recreational resources. Development decisions can be made on the local, state, and national levels. In 1972, the National Coastal Zone Management Act (CZMA) was passed by the U.S. Congress to insure effective management, protection, and development of national coastal resources. Financial assistance has been extended to the states for development of state coastal management programs and the formation of estuarine sanctuaries (U.S. Department of Commerce, 1977D).

Congress has also shown concern for resource preservation in its decision to expand the Redwood National Park, which was protected as a recreational resource at the expense of forestry resources (U.S. Department of the Interior, pers. comm., 1978). The Federal government also showed an interest in preservation of recreational and aesthetic resources with the creation of the Oregon Dunes National Recreation Area in 1972.

State and local development policies with regard to recreation vary. The California Coastal (Smith) Act of 1976 requires coastal communities to adopt local coastal programs in conformity with the state coastal policies. Articles Six and Seven of the Act limit new development in the coastal zone (including Humboldt and Del Norte counties) to existing developed areas. Article Three deals specifically with recreation:

> Ocean-front land suitable for recreational use and upland support areas will be generally protected for such uses. The use of private lands suitable for visitor-serving commercial recreational facilities shall have priority over private residential, general industrial or commercial development but not over agriculture or coastal-dependent industry. Increased recreational boating will be encouraged. (Article 3 - California State Senate Bill 1277, 1976).

Local jurisdictions (including Humboldt and Del Norte Counties) have until January, 1981 to complete local coastal programs in conformity with state goals (California Senate Bill 1277, 1976).

Unchecked urban growth in the 1960s and early 1970s has been a recognized problem for the Oregon coast (Oregon State Coastal Conservation and Devlopment Commission, 1975). Oregon's Coastal Management Program, adopted in January, 1977, set a number of goals concerning urban growth, land use planning, and recreational and environmental resource preservation (Oregon State Land Conservation and Development Commission, 1976) with the intention of serving as a comprehensive plan for development and preservation decisions for the Oregon Coast. Specifically, the objectives included the creation and maintenance of "a balance between conservation and development needs" and avoidance of "irreversible damage to the ecological and environmental qualities" of the coastal zone. Policy recommendations included management of coastal resources on both a statewide and a watershed basis due to the complex interrelations of the resources and the origin of many recreational and other development pressures outside the coastal zone.

The Washington State Shoreline Management Act of 1971 and the Coastal Zone Management Program, approved in June, 1976 - the first coastal program in the nation to receive funding under the CZMA - have also established goals and policies for coastal resource development and preservation. Particularly at issue in this state are dredging activities and urban expansion in Willapa Bay and Grays Harbor (U.S. Army Corps of Engineers, 1976C and 1976H; Washington State Department of Ecology, 1976).

4.4.2 Tourism. Tourism is probably the most difficult of the region's basic industries to quantify and evaluate due to the problem of establishing which activities and what part of those activities are associated with this industry. Tourists spend money on a number of services including lodging, food and drink, fuel, clothes, and recreation. With the exception of lodging, these services are also purchased by local residents. Relatively good data are available on the total value and employment associated with these services; however, almost no data exist on the percentage of those services that result from tourism as opposed to local demand or business travel. Since it is only the non-local demand that is of concern here, it becomes necessary to make estimates of the percentage of total food purchases, lodging, fuel, etc., that result from tourist activities. All estimates made here or referred to are highly speculative and should therefore be treated with caution.

4.4.2.1 Tourist Volume, Activities, and Origins. Information on tourist activities and origin could best be obtained from survey data. Unfortunately, this form of data is not plentiful for the coastal region. Visitor-day data are maintained by the Recreation Departments in each state, the National Park Service and, on a 12-hour day basis, by the U.S. Forest Service. Such data, however, give only a part of the picture of use levels in natural areas required to fully assess natural systems impacts of recreation. Other data, such as traffic counts and lodging and sales taxes provide some indication of overall tourism for assessment of economic effects.

The Oregon Highway Division keeps traffic counts at selected points throughout the State of Oregon and surveys selected travelers to obtain additional information. Some trends can be surmised. Table 4-28 contains estimates for the number of out-of state visitors in each state.

TABLE 4-28. ESTIMATED TOTAL VISITORS AND PLEASURE VISITORS FROM OUT-OF-STATE TO CALIFORNIA, OREGON, AND WASHINGTON, 1965 to 1973. Data are in thousands. (From Travel Trends in the U.S. and Canada, 1973, and Oregon State Highway Division, as reported in Kuhn et al., 1974).

	ALL TYPES			PLEASURE VISITORS		
Year	California	Oregon	Washington	California	Oregon	Washington
1965	n/a	n/a	8400	7229	5792	n/a
1966	14300	n/a	8200	n/a	6547	n/a
1967	n/a	n/a	8600	n/a	7083	n/a
1968	16100	9092	9100	n/a	7550	n/a
1969	n/a	9179	9600	n/a	7710	n/a
1970	n/a	9083	10100	n/a	7614	n/a
1971	n/a	10540	10500	n/a	9093	6200
1972	n/a	11702	n/a	n/a	9630	n/a
1973	n/a	10492	n/a	n/a	5889	n/a

With the exception of the year 1973, when the gasoline shortage crippled the travel industry, there has been a continuous increase in the number of out-of-state visitors to the three West Coast states. Although the study region comprises only a portion of each state, it seems reasonable to conclude from these data that tourist travel has also been increasing steadily along the coast since 1965.

Data on the origin of tourists are also limited. For coastal Oregon (9-county area including Lane, Western Douglas, Josephine, and Jackson Counties), it has been estimated for 1973 that 35 percent of total recreational expenditures are by out-of-state visitors, 11 percent by intra-coastal travelers, and the remaining 54 percent by travelers from the rest of the state (Schmisseur and Boodt, 1975). State of Oregon campground utilization information indicates that California was an important origin of travelers to the Oregon coastal area.

Some data exist to indicate the travel patterns of the Oregon residents who seem to be responsible for the greatest share of expenditures on recreation along the Oregon Coast. For the northern Oregon coastal counties (Clatsop, Tillamook, and Lincoln), Multnomah County, which includes Portland, provided the largest number of tourists in 1969. This indicates that Portland area residents tend to travel to the most accessible parts of the coast. For the southern coastal counties (Coos and Curry) the largest number of recreational visitors was from the adjacent counties of Josephine and Jackson (for Curry) and Lane and Douglas (for Coos) (Schmisseur and Boodt, 1975).

Although similar data are not available for Washington and California, it may be possible to make some assumptions based on the Oregon data. The most significant population centers in Washington are on Puget Sound. Although the recreational areas of the northern Washington coast (including the Olympic National Park in Clallam and Jefferson Counties) are closer to the population centers, they are not easily accessible. By automobile, the most accessible part of the coastal area to Seattle and Tacoma is the southern half of the Washington coast. This assertion is supported by the relative popularity of the southern state parks near Willapa Bay and Grays Harbor as compared to those of the northern Washington Coast (Washington State Office of Program Planning and Fiscal Management, 1975). Long Beach State Park in Pacific County was the most popular day park in the state in 1974.

A difference between Washington and Oregon coastal recreation is the existence of competing opportunities along Puget Sound. Seattle and Tacoma area residents have the option of visiting Puget Sound recreational areas rather than traveling to the coast. A similar option is not readily available to Willamette Valley residents. Puget Sound state parks are also among the most popular in Washington.

Out-of-state visitor stays in Oregon and Washington average 3 to 4 days (see Table 4-29). The same source gives a seven day average stay in California. The Redwood Coast is clearly not typical of other California recreation areas. These stays are, in any case, not all spent in one place. The data in Table 4-30 indicate that intra-state journeys in Oregon are most likely to have a coastal destination if the length of stay is between two and four days. The number of stays of two weeks or more are assumed to be insignificant, reflecting the lack of resort development on the coast. Neither set of data directly indicates the average length of coastal stays. It may tentatively be concluded that, in Oregon at least, coastal vacations have approximately a three day average length of stay.

Data on recreational activities pursued by tourists are also not readily available. Many sources indicate that sports fishing (especially salmon fishing) is the major activity which draws tourists (see Section 4.3.3 Sports Fishing). Pleasure boating, hunting, and camping are also noted as attractions. Beach activities (swimming, sunning, hiking, picnicking) are important throughout the area. Razor clamming is an important recreational activity in the Willapa Bay and Grays Harbor areas (U.S. Army Corps of Engineers, 1976C and 1976H).

TABLE 4-29. AVERAGE LENGTH OF STAY AND SIZE OF PARTY FOR SELECTED STATES. (From Travel Trends, 1973, in Kuhn et al., 1974.)

State	Average Number of Days Per Stay	Average Number of Persons Per Party	Date of Data
Alaska	13.0	2.6	1971
California	7.0	2.1	1968
Colorado	5.5	3.0	1971
Florida	12.0	2.9	1970
Hawaii	8.0	1.6	1971
North Dakota	1.9	3.3	1971
Utah	1.2	2.8	1972
Oregon	3.4	2.7	1971
Washington	4.2	2.5	1972

TABLE 4-30. PERCENT OF INTRASTATE OREGON TRIPS HAVING COASTAL DESTINATIONS BY LENGTH OF STAY, 1973. Note: The coastal area includes Clatsop, Tillamook, Lincoln, Coos, Curry, Josephine, Jackson, and Douglas Counties. (From Schmisseur and Boodt, 1975.)

Length of Stay	% of Oregon Trips Having Coastal Area Destination
less than 1 day	30.5
1 day	35.5
weekends	47.5
3 - 4 days	44.0
5 - 13 days	40.0
2 weeks or more	45.5

Evaluating the relative significance of these activities is impossible without more complete data. Some generalizations, however, can be made. Tourist activity is seasonal. Greatest activity is during the summer with a peak in August (Kuhn et al., 1974). Winter sports are not important in Coastal Oregon (Schmisseur and Boodt, 1975). Water-related activities (fishing, boating, swimming, and other beach activities) appear to dominate coastal recreation. Camping, hunting, hiking, and other land-oriented activities are of secondary importance.

4.4.2.2. Tourist Accommodations and Expenditures. More data exist on the type of accommodations and breakdown of expenditures of coastal tourists. Table 4-31 indicates the distribution of visitor party days by type of lodging for Oregon and coastal Oregon during 1972. There is greater use of camping on the coast than in the state as a whole. Camping tends to be a less expensive form of lodging than hotel/motel lodging.

TABLE 4-31. ESTIMATED PERCENTAGE DISTRIBUTION OF OUT-OF-STATE VISITOR PARTY DAYS IN OREGON AND COASTAL OREGON BY TYPE OF LODGING, 1972. (From Battelle Institute, 1973, data in Kuhn et al., 1974.)

Area	Motel/Hotel	Friends	Camping	Other[1]
Coastal Oregon[2]	35.5	14.3	40.3	9.9
Oregon	43.8	26.4	17.3	12.5

[1] Includes trailer parks, second homes, no lodging.

[2] Clatsop, Lincoln, Tillamook, Coos, and Curry Counties.

Table 4-32 contains estimates of out-of-state visitor spending along the Oregon coast and in the state as a whole in 1972 broken down by expenditure type. Expenditures on lodging in the coastal area are only slightly lower than for the rest of the state. Additionally, the percentage of restaurant expenditures is greater on the coast than for the state as a whole. This is surprising in light of the difference in the use of campgrounds by coastal tourists and by tourists of the whole state (see Table 4-31). Campers tend to spend less on food and drink than other tourists (Kuhn et al., 1974)

As expected, grocery purchases are a larger share of tourist expenditures on the coast than elsewhere in Oregon. Campers are more likely to prepare their own food than motel and hotel users.

A study of the Lower Umpqua River (Winchester Bay) area of coastal Douglas County in Oregon also reported expenditures by tourists (Schmisseur et al., 1975). Tourists were classified in two groups by type of activity, either "fishing" or "camping and vacationing" (i.e. non-fishing). Table 4-33 lists the results of the survey which indicates that sports fishermen spend less on lodging than do other tourists. Sport fishermen, however, spent more on trailer parks, groceries, tackle, and boat charters for a total per visitor day 50% higher than non-fishermen.

TABLE 4-32. ANNUAL ESTIMATED EXPENDITURES BY OUT-OF-STATE TRAVELERS FOR OREGON AND COASTAL OREGON, 1972. Data are in thousands of dollars. (From Battelle, 1973, data in U.S. Army Corps of Engineers, 1976G.)

Type	COASTAL OREGON Amount	COASTAL OREGON % of Total	OREGON Amount	OREGON % of Total
Restaurant	30,115	23.0	125,610	22.5
Lodging	23,375	17.8	104,020	18.6
Groceries	20,581	15.7	71,589	12.8
Recreation	12,815	9.8	36,684	6.6
Gas & Oil	9,595	7.3	50,992	9.1
All Others	34,705	26.4	169,433	30.4
TOTAL	131,186	100.0	558,328	100.0

TABLE 4-33. WINCHESTER BAY, OREGON, EXPENDITURES BY ACTIVITY. (From Schmisseur et al., 1975.)

Activity	Lodging	Eating and Drinking	Service Stations	Operations	Other Retail Services	Total (Dollars)
Fishing	22.9	13.6	10.0	21.9	31.6	$7.94
Camping and Vacationing	32.4	14.2	16.4	-	37.1	$4.57

Evaluating the overall economic importance of tourism is a difficult task because of the data limitations and the problem of ascertaining which activities belong in this industry. Because of its completeness, employment data will be used for this purpose (see following section). A 1973 Tillamook County Oregon, input-output study estimated that 9.8% (12.1 million) of the county's total exports were recreation and tourist expenditures (Table 4-34). Recreation and tourism ranked third after Wood Products (49.3%) and Agricultural Products (16.1%), but ahead of Commercial Fishing (Youmans et al., 1977) in Tillamook County.

TABLE 4-34. TILLAMOOK COUNTY TOURIST-RELATED INDUSTRIAL SECTOR EXPORTS, 1973. (From Youmans et al., 1977.)

Sector Name	Percent of Total County Sales to County Residents	Percent of Total County Sales to Non-county Residents (exports)
Formal Tourist Lodge	5.4%	94.6%
Campgrounds	10.8%	89.2%
Sports Fishing & Marinas	18.2%	81.8%
Cafes and Taverns	68.8%	31.2%
Service Stations	62.7%	37.3%
Retail and Wholesale	83.4%	16.4%

4.4.2.3 Employment. Data used for estimating tourist-related employment on the coast are from County Business Patterns for 1975 (U.S. Department of Commerce, Bureau of Census, 1977E). This set of data has been chosen because it is the most up-to-date uniformly collected data for the study area. In addition, data are available up to three digit S.I.C. (Standard Industrial Classification) industries, which allow for accurate estimates of tourist-related employment. County Business Patterns data are tabulated from payroll tax returns, i.e. this census only counts employees who work for employers who make quarterly tax returns. Additionally, a number of employers, family businesses, for example, do not report payrolls. Finally, data is collected for payrolls of the second week in March only. Since tourist-related employment is highly seasonal, with a peak in late summer, this data collection method will be likely to underestimate the number of tourist industry employees. Given similar seasonality characteristics of all major export base industries (forestry, agriculture, commercial fishing), an adjustment would probably not aid in determining the relative importance of the tourist industry.

Five Standard Industrial Classifications have been chosen to cover tourist-related employment: gasoline service stations (S.I.C. 554), eating and drinking places (S.I.C. 58), hotels and other lodging (S.I.C. 70), food stores (S.I.C. 54), apparel and accessory stores (S.I.C. 56), and amusement and recreation services (S.I.C. 79). Tourists undoubtedly are served by employees in other classifications (see Kuhn et al., 1974), but probably all important tourist-related employment sectors are included in these categories. A possible addition is the museum, botanical and zoological sector (S.I.C. 79). However, employment in this sector was negligible along the coast and has not been included.

A 1973 Tillamook County economic survey collected data on sales local industries made to county residents and non-county residents (Youmans et al., 1977). For estimating tourist-related employment, sales to non-county residents can be assumed to be sales to tourists in the relevant sectors (i.e. the six classifications listed above). The percentage of relevant classifications sold to county and non-county residents (exports) for Tillamook County are listed in Table 4-34.

Based on the Tillamook study, the following percentages have been allocated to tourist industry employment: gasoline service stations-35%, eating and drinking places-30%, hotels and other lodging-95%, food stores-20%, apparel and accessory stores-10%, and amusement and recreation-50%. All estimates were rounded to nearest 5%. Combining formal tourist lodges and campgrounds results in 93.9% exported, hence the estimate of 95%. Food stores, apparel and accesory stores, and amusement and recreation are best possible estimates taking into account a number of factors.

Table 4-35 presents the estimate of tourist-related employment by sector and county for the study region.

Lincoln County, Oregon has a particularly high concentration of tourist industry employment. Grays Harbor County has the largest number of tourist industry employees of the Washington coastal counties. This county is also the most accessible of all the coastal counties to Puget Sound population centers. The large number of tourist industry employees in Clallam County may be related to tourist centers along the Strait of Juan de Fuca as well as within the study region boundaries.

According to these estimates, the tourist industry ranks second behind the forestry industry in total employment for the study area. (Commercial fishing and tourism appear to employ approximately the same number of people.) The total employment figure should be treated with caution, however, in light of the data limitations discussed earlier, the most serious of which is seasonality. Figure 4-9 estimates Oregon coastal travel industry employment by quarter for 1973. The graph shows that employment estimate as high in the third quarter as it was in the first (Kuhn et al., 1974). If these figures are reliable, it is likely that coastal county tourist industry employment increased to 11,000 during the summer months of 1975.

TABLE 4-35. TOURIST INDUSTRY EMPLOYMENT PACIFIC NORTHWEST COAST, 1975. (Computed from data in U.S. Department of Commerce, 1977D.)

	EMPLOYMENT	% OF TOTAL EMPLOYMENT
Clallam	637	7.7%
Jefferson	175	8.9%
Grays Harbor	745	4.8%
Pacific	155	5.6%
Wahkiakum	45	6.7%
Washington Coast Total	1757	6.9%
Clatsop	512	8.1%
Tillamook	253	8.4%
Lincoln	933	17.2%
Coos	501	4.0%
Curry	223	9.3%
Oregon Coast Total	2422	8.2%
Del Norte	232	7.0%
Humboldt	1294	5.9%
California Coast Total	1586	6.3%
STUDY AREA TOTAL	5765	6.9%

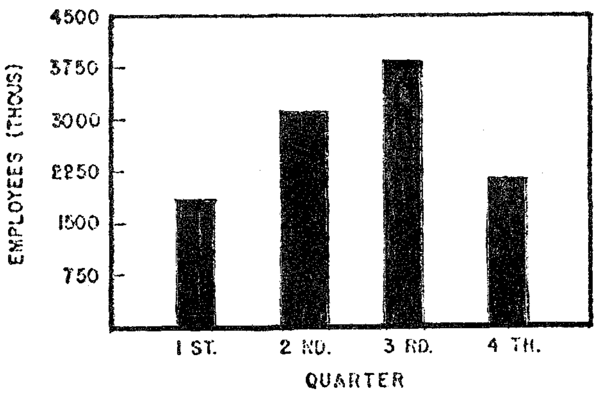


FIGURE 4-9. QUARTERLY TOURIST EMPLOYMENT ESTIMATES, OREGON COAST, 1973. (From Kuhn et al., 1974.)

The view is held by many that, despite the large number of tourists who vacation in the study area, the overall economic impact on the area is minimal or may even represent a net loss. An Oregon State Univeristy Department of Economics study concluded that revenues derived from state supported tourist facilities were smaller than the costs incurred in providing the services (U.S. Army Corps of Engineers, 1975E) because of the nature of tourist activities along the Pacific Northwest Coast. Tourists who come to the study area for sports fishing, hiking, hunting, or camping usually bring their own lodging (tent, trailer), food, and equipment (rifles, fishing poles, rafts, etc.). The few purchases made on the vacation area itself are usualy for gas and some food. Additionally, tourist-related employment is unstable, highly seasonal, low-paying, and in low-skilled occupations such as waiters and waitresses, tour guides, and motel attendants. The seasonal nature of the industry also puts undue burdens on governmental services such as police, fire, and health.

This assertion is difficult to evaluate without additional data. Whether tourism is economically beneficial to the study area is an important topic for further study. The Tillamook County study (Youmans et al., 1977) implies that non-resident tourism is an export industry (over 12 million dollars of business in 1973). County Business Pattern Payroll data for 1975 indicate, however, that for Humboldt County tourist industry employees had an average annual salary of $5,180 as compared to an all-industry average of $9,810. This differential holds true for the entire study region (U.S. Department of Commerce, 1977D). Although the tourist industry employs a large number of workers, it contributes a proportionately smaller amount of income to the study area. These data tend to support the OSU Department of Economics' assertion that tourism is economically detrimental to the study area. Further investigation is needed.

4.4.3 Second Homes.

4.4.3.1 Number and Location. The number of second homes appears to be increasing in accessible parts of the coast. Coastal Oregon and Washington had year-round housing unit-vacancy rates far in excess of the average listed for each state in the 1970 Census of Housing. Lincoln County has the largest number of second homes along the Oregon Coast (1768 in 1970) and probably the largest concentration in the entire study area. The proximity of Portland and the rest of the Willamette Valley explains this concentration (U.S. Army Corps of Engineers, 1976G). Nearly 20% of Tillamook County homes were reported in the Census of Housing to be second homes in 1970. Counties farther away from Portland tend to have fewer second homes. Only 2.7% of Curry County homes and 1.1% of Coos County homes were second homes in 1970. These figures were below the state average of 2.8% and do not appear to be increasing (Kuhn et al., 1974).

Along the Washington coast, second homes appear to be increasing in number in Grays Harbor and Pacific County (Washington State Department of Commerce and Economic Development, 1977). Clallam and Jefferson Counties also contain a significant number of second homes. Most of these, however, appear to be outside the study area.

No data were available for the second home industry in the California counties in the study region. Their great distance from population centers suggests that second homes are not common in these areas.

4.4.3.2 Employment. Employment resulting directly from second home construction and occupancy is difficult to quantify. The construction of second homes creates employment and income for parts of the study region. Second home occupants (usually for the summer) spend significant amounts on goods and services. Unlike tourism, most goods and services are locally purchased, providing employment and income to the study area (Kuhn et al., 1974). The second home industry is considered to be basic since the source of spending is income earned outside the study region.

4.4.4 Retirement. A large number of retired persons have made the coastal area their home during recent decades. It is believed that enough retired persons live on the coast to warrant special analysis. Although it may seem unusual to include retirement in the category of export-base industries, there are a number reasons for doing so. Many retired persons receive income support from retirement annuities (Social Security, pensions, life insurance annuities, etc.). From the economist's point of view, these payments represent a net inflow of income to the study area. Retired persons spend this income on goods and services which support businesses and industries in the study region. Retirement income also has a multiplier effect on local business and income.

In addition to government and private annuities, the elderly often receive special government services such as health care, reduced transportation fares, welfare, etc. Often the sources of income for these services are the federal and state governments. In these cases, a large retirement population can attract additional government income to the study area. However, when local sources are used to support elderly services, this population can cause an income drain, thereby dampening local business activity. Further analysis is required to determine whether the "government effects" of the elderly are positive or negative with respect to the local economy.

The absolute number of retired persons in the study area cannot be determined from available data; however, certain data can be employed to evaluate trends in the number of retired persons along the coast. 1970 U.S. Census data indicate that for the Oregon coast (including the five counties of the study area plus Douglas and Lane) 11.8% of the population was 65 years of age or older and that this percentage represents a migration of elderly to the coast rather than (or in addition to) a loss of younger people. The percentage was larger for coastal Oregon than for the State of Oregon. See Section 4.10 for additional details. Between 1958 and 1973 the number of persons receiving Social Security increased by an average of 5% per year along the Oregon coast. This compares to an average overall population increase of only 3% on the coast and an average increase of 1.9% of people 65 years of age or older in the nation as a whole (Kuhn et al., 1974).

Lincoln County, Oregon, appears to have a particularly heavy concentration of elderly residents (U.S. Army Corps of Engineers, 1976G) as the median age of people in Lincoln County was 38.2 years in 1970, almost ten years older than the Oregon median. The high proportion of elderly in Lincoln County suggests that this population is attracted to areas with many recreational opportunities. In the section on commercial fishing (4.3), it was noted that retired persons often use fishing as an income supplement. Lincoln County has been identified as an excellent salmon and trout fishing area.

4.4.5 Summary and Effects.

4.4.5.1 Summary. An excellent natural setting for recreational activities combined with limited competing uses (agriculture, urban, and industrial development) allow for numerous recreational opportunities on the coast. In addition to the availability of these opportunities, recreational use depends on their accessibility to a sizable population which has the time and income to enjoy them. Population centers along Puget Sound and in the Willamette Valley appear to have these characteristics. Additionally, several resources in the area (the Redwood and Olympic National Parks, and Oregon Dunes National Recreation Area) are attractive to national vacationers.

The tourist industry is increasing along the coast as a result of favorable supply and demand factors. Tourism is particularly important in areas of the coast most accessible to Portland and Seattle-Tacoma areas.

The size and growth of the tourist industry may be overstated in terms of its overall economic impact on the study area. Employment is sizeable (either second or third in rank among the basic industries), but unstable, highly seasonal, and unskilled. The income directly contributed by tourism is not comparable with its employment levels and wages are well below average.

Tourist expenditures in the study area are relatively low. This is a function of the type of recreational activities pursued. Camping, fishing, and hunting require relatively little expense for lodging and restaurants. Many tourists bring their own food, shelter and recreational equipment. Sports fishing appears to generate more purchases at the trip's destination than other outdoor recreation activities typical of the region. Tourism may be an economically disadvantageous activity. There is speculation that the total cost of tourist activities (maintenance of facilities, access roads, etc.) outweighs the income.

Second homes and retirement appear to provide a more stable source of income to the coastal communities than tourism. The absolute volume of these industries is difficult to estimate but appears to be growing, originating, like tourism, principally in the Willamette Valley and Puget Sound population centers.

4.4.5.2 Multiplier Effects. The 1973 Tillamook County Study (Youmans et al., 1977) calculated income multipliers for several recreational sectors as follows: formal tourist lodging, 2.35; informal tourist lodging, 2.73; sport fishing and marinas, 2.54; cafes and taverns, 2.80; service stations, 2.31; and other retail and wholesale sales, 1.76.

Multiplier values are moderate with the exception of retail and wholesale trade. A low multiplier in this sector is not unusual, however.

A business multiplier (the change in revenue for all sectors of the economy resulting from a dollar change in revenue from out-of-county for a given sector) has been calculated for the lodging sector in Lincoln County (Schmisseur et al., 1975). This value is the highest for all sectors in the economy. Lodging which already was important in Lincoln County's economy (there are more units in Lincoln than any other Oregon coastal county) becomes even more significant with its large multiplier effects. This is more evidence for the overriding importance of recreation in Lincoln County and for the need to increase overnight accommodation throughout the region if tourism is to become a net revenue-generating industry.

Multipliers are not available for California and Washington coastal counties.

4.4.5.3 Natural Systems Effects. Recreation can have both negative and positive effects on the natural environment. Preservation of recreational resources is compatible with preservation of the natural environment. The unaltered setting is the main attraction of the study area to tourists. Emphasis on recreation protects the natural setting from alternative uses such as agriculture, mining, and forestry.

Adverse effects are also possible. If the area becomes popular for recreational activities, environmentally damaging development can take place. To an extent, this is already happening with the growing popularity of second homes and retirement living along the coast. Increased lodging units and seasonal or permanent residential development and associated service activities contribute to the various natural environmental effects of human settlement. These effects include accelerated erosion and sedimentation during construction in areas of steep terrain and friable soil; increased water demand and possible effects on surface and groundwater resources; and water pollution from concentration of septic tanks, primary treatment plants, and solid waste disposal. In addition, increased access to natural areas can bring increased fire danger, water quality changes, wildlife depletion, and other changes. Such impacts are discussed in more detail by John Grahm Co. (1976) and Simmons (1974). For discussion of possible impacts of second home development and recreation use, see Eisenhower Consortium for Western Environmental Forestry Research (1975).

One aspect of recreation which has recently been suggested as potentially harmful is the effect of off-road vehicles on wildlife. Little work has been completed in the region, but Neil et al. (1975) will introduce the reader to research on the matter.

4.4.5.4 Socioeconomic Effects. The possible natural system impacts of recreation are also accompanied by socioeconomic costs for public services and forest and other wildland management costs. Some of these are discussed in Eisenhower Consortium for Western Environmental Forestry Research (1975), Kuhn et al. (1974), and in U.S. Department of Commerce, Office of Coastal Zone Management (1977D).

There is considerable land use competition between recreation and some economic activities, although compatibility exists with other activities. Recreational uses are incompatible with mining and industrial development. Agriculture alters the natural setting and may restrict public access to potential recreational areas. Agriculture does preserve open space, however, and for this reason is compatible with passive activities such as driving for pleasure. Commercial and sports fishing are closely tied to recreation; ports, marinas, and fish hatcheries, apart from supporting fishing activities, are in themselves important tourist attractions (QRC Research Corporation, 1978). Growing forests offer a variety of active and passive outdoor recreation opportunities. Logging operations, are generally not compatible with recreation and clearcutting can diminish attraction for tourist, as well as wilderness activities. An example of conflicts between the forest industry and recreation occurred recently (1977-78) with the expansion of the Redwood National Park in Humboldt County. The National Park Service requested the expansion to protect redwoods within the park from erosion effects of logging activities. The forestry industry objected to the loss of timber resources (U.S. Department of the Interior, pers. comm., 1978). The redwoods are one of the primary recreational resources along the Pacific Northwest Coast and one of the largest generators of tourism from out-of-state. The U.S. Congress authorized the expansion in early 1978.

4.4.5.5 Future Economic Importance. Future growth in the recreation industry is expected as population in the Northwest and West Coast continues to grow. Leisure time and income are increasing nationally. With the recent addition to the Redwood National Park and associated publicity, that area should grow as a natural tourist attraction. The opening of the Oregon Dunes National Recreation Area should have a similar effect (Coos, Curry, Douglas EIA, 1977).

Attempts are being made to lessen the seasonal instability of the tourist industry. Discussion is under way to create off-season recreational attractions (see QRC Research Corporation, 1978; U.S. Army Corps of Engineers, 1975B). If efforts at expanding winter activities are successful, a positive effect on employment income in the industry can be expected. Most economic development plans (QRC Research Corporation, 1978; Broida et al., 1975, Coos, Curry, Douglas EIA, 1977) stress the need to increase length of stay to generate a greater volume of local tourist expenditures.

4.4.5.6 External Factors Affecting the Industry. Recreation demand in the area will be influenced by the interaction of continued quality of the natural environment, development of recreation area, lodging, and other facilities, and changes in population growth rates, travel costs, and expendable incomes. Planning and resource management decisions affecting forests, fisheries, access, and residential management will play an important part in determining the extent to which economically valuable recreation can be encouraged without increasing natural and socioeconomic environmental costs. Broida et al. (1975) point out, however, that "tourism may not be the best industry to rely on for a resurgence of the Del Norte economy. The data on room occupancy tax collections evidence erratic growth, even when seasonally adjusted. More importantly, the industry has shown itself to be extremely vulnerable to energy crises. Over-reliance on tourism will only serve to make the Del Norte economy more dependent on factors outside the County's control".

4.5 AGRICULTURE

Agriculture has historically been important to several small areas of the Pacific Northwest Coastal Region. Readers of the following section, however, should keep in mind the general predominance of the forest and forest products industry when reviewing the relative importance of agriculture in the regional economy as a whole.

4.5.1 The Resource.

4.5.1.1 Land Suitable for Agriculture. The Coastal Region contains relatively little highly productive agricultural land. The Soil Conservation Service, USDA, has devised a general system of the eight broad soil capability classes, those suitable for cropland classes being:

Class I: Very good cultivable land, can be cultivated very intensively.
Class II: Good cultivable land, can be cultivated intensively.
Class III: Moderately good cultivable land, possibly poorly drained and requiring careful management.
Class IV: Fairly good cultivable land but with severe limitations, suitable for occasional cultivation only.

Land in Classes V through VII is not suitable for any intensive uses but may provide grazing of varying carrying capacity for sheep or beef cattle.

Since this classification system is extremely general, the process of soil formation complex, and the effect of man's technology great, the actual productive capacities of soils within a class can vary widely from field to field (Franklin and Dyrness, 1973; U.S. Department of Agriculture, 1975B).

About one-half of the non-forested land in the Region is devoted to some type of pasture. The location of the soil associations most likely to contain prime (Class I and Class II) soils are tabulated for Oregon and Washington in Pacific Northwest River Basins Commission (1970, Volume IV). Class I and II soils are generally located along the narrow river valleys and surrounding estuaries. The same volume maps the general location of land in agricultural use, including pasture and range land, as well as cropland.

The entire coastal area has unique characteristics which affect the success of the agricultural industry. A discussion of these unique characteristics may be found in Moreland/Unruh/Smith, Architects and Planners (1975). In summary, these characteristics include:

(1) Marine Climate. In addition to pasture, certain crops, such as artichokes, Christmas trees, and berries are particularly well-suited to the heavy rainfall, frequent cloud cover, high relative humidity, and low average temperatures of the marine climate. The potential for crop diversification is high, provided management expertise is practiced.

(2) Diversified Soils. Soils on stream flood plains and alluvial fans, stream terraces, and marine terraces include sandy or silty loam soils which are fine textured and well or moderately well drained, providing the major source of agricultural lands. The source areas, however, also include poorly drained clayey loams, requiring draining (and diking in the case of some stream flood plains) for intensive use. Soils in estuary tidelands are limited by tidal overflow and poor drainage but have been diked in many areas for improved pasture. Sandy dune lands are unsuitable for agriculture, as are most upland areas, although smoother topography in the coastal mountains may be used for orchards, berries, small grains, cattle grazing, or sheep pastures.

(3) Dissected Topography. The Coastal Region is characterized by rugged and dissected terrain with narrow valleys although some smoother areas are present in the interior mountains. This topographic form produces relatively small, isolated agricultural land areas which frequently are linear in form as they follow the river valleys or the depositional sea terraces along the coast. The relatively small areas useful for agriculture are more conducive to supplementary or part-time farming than to the economics of large-scale agriculture.

(4) Distance from Urbanized Area. The Coastal Region's agricultural lands experience isolation from extreme urban expansion pressures and problems of unrestricted public access to range land. The area has a relatively low population density with most urban areas not expanding at a rate comparable to cities in the Willamette Valley and Puget Sound regions. Urban and builtup land appears to have encroached on agriculture in several areas, however, according to Soil Conservation Service data (in Kuhn et al., 1974).

4.5.1.2 Farm Characteristics. Average farm size nationwide has been increasing and the number of farms has been declining over the past decade, largely as a result of increasing economies of scale. On the Oregon and Washington and Northern California coast, most counties showed not only a decline in the number of farms between 1969 and 1974 but also a decline in average farm size (OIW, 1977). This reversed the trend to increased farm size evident between 1959 and 1969. Table 4-36 indicates the rates of change by county. Exceptions include Humboldt County, where an increase from 716 to 860 acres from 1965 to 1976 may reflect the increasing importance of cattle ranching. Other exceptions are Clatsop and Curry Counties in Oregon.

Comparison of changes in the number and average of farms with the value of agricultural products in Table 4-36 suggests that statewide in Oregon and Washington, significant agricultural productivity increases occurred between 1969 and 1974. In all the coastal counties in those states, except Grays Harbor, Coos, and Tillamook, the lost acreage has also resulted in lost revenue.

With the exception of larger dairy farms, specialty and fruit farms, and some of the livestock ranges, farming is a part-time endeavor on the Oregon Coast (Kuhn et al., 1974). It is estimated that no more than a fourth of the operators are solely dependent upon income from farming, and only about 45 percent are commercial operations. The others are part-time or part retirement farms. It is not known if this pattern also holds for Washington and Northern California. Most part-time farmers work as loggers or in a job related to the forest industry. Small acreages are used to produce products for their own consumption or as a supplemental source of income. Only about 16 percent of the area capable of producing agricultural crops is in cropland (Pacific Northwest River Basins Commission, 1971). Part-time farm operation is a major reason for the declining farm size on the Oregon Coast (Kuhn et al., 1974).

TABLE 4-36. ANNUAL AVERAGE RATES OF CHANGE IN FARM CHARACTERISTICS AND PRODUCTION VALUE, 1969-1974. (From Oceanographic Institute of Washington, 1977, and California State, 1974 and 1977.)

AREA	NUMBER OF FARMS	LAND IN FARMS	MARKET VALUE OF AGRICULTURAL PRODUCTS SOLD
Washington State	-0.9	-1.0	5.8
Jefferson	3.3	-3.1	-1.1
Clallam	-2.6	-2.2	-6.1
Grays Harbor	0.9	-3.2	1.5
Pacific	-0.5	-2.4	-7.9
Wahkiakum	-3.8	-4.2	-3.4
Oregon State	0.6	0.3	3.5
Clatsop	-0.3	2.4	-6.2
Tillamook	-1.1	-1.8	2.2
Lincoln	0.5	-5.0	-9.6
Douglas	2.9	0.3	-0.8
Coos	1.2	-4.2	-4.1
Curry	-1.3	0.5	-0.1
California State			
Del Norte	0	-50.9	N/A
Humboldt	-1.2	0.4	N/A

4.5.1.3 Development Constraints. Although much of the available land is suitable for agricultural use, there are many factors which limit conversion from one land use to another.

One reason for non-conversion to agriculture is the pressure in some parts of the region for expanded urban development. Table 4-37 indicates the estimated increase in built-acres by county on the Oregon coast between 1958 and 1967.

A second major hindrance to greater utilization of this agricultural land resource is that two of the major agricultural regions of the United States, the Willamette Valley and the Sacramento Valley, are located much closer to the major West Coast markets than agricultural land in the study region. This places the area at a transportation disadvantage when attempting to compete for these markets. The result is that the area's agricultural produce costs more at the market place unless local farmers are willing to accept less for their efforts.

TABLE 4-37. URBAN AND BUILT-UP LAND, 1958 AND 1967. (Data from Soil Conservation Service, 1971, contained in Kuhn et al., 1974.)

AREA	1958 ACRES	1967 ACRES	% CHANGE
Clatsop	9,219	9,216	0.0
Tillamook	7,377	9,611	30.3
Lincoln	11,371	12,573	10.6
Coos	15,000	44,562	197.1
Curry	6,712	8,560	27.5
Coast Total	49,679	84,522	70.1

The neighboring Willamette Valley is generally recognized as one of the best agricultural regions in the United States and is used for a wide variety of production, including considerable livestock grazing. However, as the Willamette Valley becomes more intensively utilized for crops and urban expansion, the more extensive use of livestock grazing will be displaced. As this occurs, the study area should then be able to increase its production of livestock (Coos, Curry, Douglas EIA, 1977).

This potential for livestock rearing brings up another factor affecting the potential for increased agricultural activity. Over 90% of the cropland on the coast has been in long term hayland. Potentially, this land could be used more intensively for the production of row crops. Since most of the hay from these lands is used to support the coastal livestock industry, if the current level of livestock production is to be maintained, it would be necessary to either find a new livestock feed source or to increase the yield from the lands left in hayland (Moreland et al., 1975). In addition to market constraints, attempts to develop more employment-intensive crop production, such as vegetables, in Northern California and Oregon are limited by lack of venture capital, technological assistance, diseases that flourish in the wet climate, the cost of approved pesticides, and environmental regulations (QRC Research Corporation, 1978; Kuhn et al., 1974).

Approximately 168,000 acres of cropland in the coastal area of Oregon and Washington are subject to frequent flooding. Similar problems are experienced around the lower reaches of the Smith and Eel Rivers, California. Because of inundation by ocean tidal waters, flooding from rapid runoff and poor drainage, many areas of land have never been developed for cropland. Some wet soils have been drained to a degree suitable for the crop grown or are being used for purposes that do not require drainage. Dikes and tidegates do not always provide adequate protection from flooding and many areas were reported in 1971 as entirely without protection (Pacific Northwest River Basins Commission, 1971). Many river terrace and bottom lands support rich dairy pasture. Flooded and rainsoftened ground requires removal of cattle in winter, however, in order to protect the pasture. Presumably because of the resulting increased cost of dairying, in addition to market considerations, beef cattle production is increasing in importance in these flat areas (QRC Research Corporation, 1978).

In addition to drainage, another potential approach to increasing agricultural output in the coastal zone is to irrigate the currently dry land suitable for irrigated agriculture. Much of this land, however, is presently forested and its highest economic use may not be for agricultural purposes. There appear to be adequate water supplies in the coastal zone to support increased irrigation. For further discussion of drainage and irrigation practices in the area, see Pacific Northwest River Basins Commission (1971, Appendix XIII).

4.5.2 Agricultural Production.

4.5.2.1 Products. The primary products of the region are meat and dairy products. Livestock are mainly beef cattle and calves and dairy cattle. Locally important production of sheep, goats, and poultry also occurs. Beef cattle are becoming increasingly important because they require less care and equipment expenditure than dairy cattle. Beef cattle are also replacing sheep. While sheep do well in the area, environmental restrictions on predator control are leading to increased predation upon lambs (QRC Research Corporation, 1978).

Crop sales comprise a relatively small share of overall regional agricultural sales. The most extensively grown crops are pasture, hay (clover and legume mixture), and silage. These provide a major feed base for dairy and livestock farms. Most of the pasture and forage crops are grown on the flood plains adjacent to major streams. On suitable bottom lands and low terraces, specialty crops such as cranberries, other berry crops, lily bulbs, and flowers are grown. In addition, in a few areas, cool climate crops such as artichokes and broccoli and other vegetables are being grown on a trial basis. These crops, however, are subject to several limitations, as discussed in 4.5.1.3. Exceptions are the crops of green peas and potatoes in Grays Harbor County (U.S.D.A. Statistical Reporting Svc., 1976). Both the profile of crop production and the share of total production accounted for by crops vary between the counties in the region. Single crops, such as cranberries, may comprise the majority of sales in individual Watershed Units.

Woodlots on farms have contributed to the agricultural economy. In some cases, a portion of timbered farmland is sold to a lumber company; in others, trees are either sold standing or harvested for use as wood products (Pacific Northwest River Basins Commission, 1971). Firewood is also cut and sold. Woodlots occur on most farms in the uplands and consist primarily of fir, spruce, hemlock, and alder, all of which are now in heavy demand. The Humboldt County Economic Development Action Plan, 1978, mentions, however, that environmental regulations restrict logging of woodlots to supplement farm incomes (QRC Research Corporation, 1978). Christmas tree cultivation also occurs in the area.

4.5.2.2 Volume and Value. The volume of agricultural goods produced usually expressed in bushels, tons, number of livestock, etc., may serve as an indicator of the wellbeing of farm economy. Volume itself is affected by the land and water environment, soil quality, erosion, rainfall, and other factors. Volume, therefore, can be useful in gauging the socioeconomic impact of plans and policies which affect the agricultural environment. It must be kept in mind, however, that volume is also affected by other market conditions, including technological improvements, the price and supply of labor, capital, and equipment in addition to the national and international food supply situation.

Measures of volume vary by commodity, preventing comparison among commodities. Further, for certain crops, production may be expressed only in dollar value per year rather than in bushels or tons per acre.

Data on the volume of farm products in the Pacific Northwest Coastal Region are incomplete. Existing data take the form of actual counts (number of hogs, bushels of apples, etc.) or of estimated gross sales. Actual counts are not available for every county in the region for all commodities, and it is necessary to standardize annual sales figures by employing a consumer price index deflator in order to make year-to-year comparisons meaningful. Data by county and commodity are not consistently available. Only in Oregon have output estimates been standardized to permit comparisons. Detailed analysis by OSU Agricultural Extension Service will be found in Kuhn et al. (1974).

Table 4-38 indicates estimated trends in total agricultural output on the Oregon coast between 1959 and 1973. It shows that the overall increase was due to gains in only two counties, Tillamook and Coos. Declines in Clatsop and Lincoln Counties are believed to be due to the loss of agricultural land over the period.

Livestock and livestock-related production are the primary farm activities in the Coastal Region. Dairy products are of particular importance in Coos, Curry, and Tillamook Counties, Oregon, Jefferson County, Washington, and Humboldt County, California. Dairy products represented approximately 25%, 51%, and 70% of agricultural sales in Coos, Curry, and Tillamook Counties, respectively, in 1975 as compared to 8.5% for Oregon as a whole. Dairy products continue to grow in Coos and Tillamook Counties. They have remained stable in Curry County and steeply declined in Clatsop and Lincoln Counties.

TABLE 4-38. TOTAL REAL GROSS FARM SALES, OREGON COASTAL COUNTIES, 1959-1973. Data are in thousands of dollars, 1967 prices. Computed from OSU Extension Service estimates by Kuhn et al., 1974.)

County	1959	1963	1969	1973
Clatsop	4,139	3,429	2,328	1,950
Tillamook	7,493	8,067	9,755	12,213
Lincoln	2,394	2,341	2,139	2,017
Coos	6,591	6,055	7,966	10,878
Curry	2,759	3,003	2,444	2,960
Coastal Total	23,376	22,895	24,632	30,018

Between 1969 and 1975, revenue from the sales of dairy products in real dollars increased 88.7% in Coos and 77.9% in Curry, while total farm revenue increased only 75.0% and 42.5% in Coos and Curry, respectively, during that period. Actual counts of cows on the Oregon Coast indicate that increases in output occurred despite a 32% decrease in the number of milk cows and heifers two years old and older, from 1950 to 1970. Milk production per cow in Oregon increased from approximately 6,000 to 9,000 pounds over the same period (Coos, Curry, Douglas EIA, 1977). A similar trend has occurred in Washington which is second only to California in terms of milk production per cow. Washington State production per cow rose from 12,500 pounds in 1972 to 13,500 in 1976 (U.S. Department of Agriculture Statistical Reporting Service, 1976). Coastal Northern California is not as productive as other parts of California, however.

Other livestock related production of primary concern occurs in Clallam County, Washington and Humboldt County California (beef ranching) and Jefferson County (poultry farming). The Humboldt Coast agricultural lands are 50% in beef cattle and river bottom areas are 30% in beef cattle. The number of animals is increasing in the region. Humboldt County cattle increased in all areas of the county from 48,000 in 1970 to 70,500 in 1974 (QRC Research Corporation, 1978). However, livestock operations are becoming less profitable as fuel and operating costs rise and environmental restrictions on stream development for livestock water, predatory animal control, and range improvement burning are imposed.

Crop production is second in importance to livestock along the coast. In 1975, Coos County produced 52.6% of all crops grown in Oregon coastal counties, yet crops only represented 21.7% of total agricultural production in Coos County, the remainder being livestock and livestock products (Coos, Curry, Douglas EIA, 1977). In addition, about half of the revenue attributed to crop production in Coos County came from farm forestry (Coos, Curry, Douglas EIA, 1977). Annual sales figures for Oregon coastal counties indicate that crops have decreased in significance relative to livestock from 1969 to 1975 while increasing in relative importance in Oregon as a whole. This appears to be due to a non-increasing productivity in crop farming as compared to a rapidly increasing productivity in livestock activities. For example, the average annual yield for hay in Oregon (in tons/acre) has remained constant since 1966, while productivity in dairy farming has increased steeply during this period. Taking into account constant yield and a slight decrease in acres of hay harvested along the coast, it is not difficult to understand the large decrease in relative production of hay.

Fruit and berry production is of special importance in many of the coastal counties. The cranberry crop is the principal agricultural product of Grays Harbor and Pacific Counties, Washington, and is also produced in Coos County, Oregon. Other orchard crops include pears, cherries, and apples. Cranberries appear to be one of the few crops that have increased in yield over the recent years. The Coos County yield increased during the 1960's, from approximately 71 barrels/acre to 90 barrels/acre (Coos, Curry, Douglas EIA, 1977).

4.5.2.3 Employment. Agricultural employment along the coast is concentrated in Tillamook and Coos counties, Oregon, in Humboldt County, California, and in Grays Harbor, Clallam, and, to a lesser degree Pacific, Counties in Washington. Data on agricultural employment are limited. They are either not included in reports of covered employment or are grouped with forestry and fisheries statistics so that trends are difficult to determine without species surveys. In addition, part-time farming distorts agricultural employment estimates as it does the fishing employment estimates.

Oregon State Employment Division data suggest that in 1972, agricultural employment represented 5.0% of total employment in the five Oregon coastal counties (see Table 4-39). The range was estimated to be from 13.4% in Tillamook County to 2.3% in Lincoln County. California Employment Development Department figures for the same year show agriculture with a 4.0% share of Humboldt County's total employment. No figures for the Washington Coastal counties or for Del Norte County, California are available.

Agricultural employment exhibits a somewhat less severe seasonal fluctuation than the forest and fisheries industries, varying by approximately 20 percent from the annual average. Employment is above average in June through September and equal to or below average in other months. Some counties show a more extreme pattern. Curry County employment for example, reaches nearly 40 percent above average in October, due to Easter Lily bulb harvesting (see Figure 4-10).

A significant decrease in agricultural employment occurred in all counties between 1940 and 1972, largely as a result of increased productivity. The overall decline in the five Oregon coastal counties totalled -36% (Kuhn et al., 1974).

TABLE 4-39. AGRICULTURAL EMPLOYMENT ON THE OREGON COAST, PERCENT CHANGE AND SHARE OF TOTAL EMPLOYMENT, 1940 AND 1972. (From 1940 Census and Oregon State Employment Division, in Kuhn et al., 1974.)

AREA	AGRICULTURAL EMPLOYMENT 1940	AGRICULTURAL EMPLOYMENT 1972	PERCENT CHANGE 1940-1972	TOTAL EMPLOYMENT 1972	AGRICULTURE AS PERCENT OF TOTAL, 1972
Clatsop	653	560	-14.2	11,860	4.7
Tillamook	1033	820	-20.6	6,130	13.4
Lincoln	748	210	-71.9	9,310	2.3
Coos	1,535	910	-40.7	22,810	4.0
Curry	389	280	-28.0	4,980	5.6
Coast	4,358	2,780	-36.2	55,090	5.0

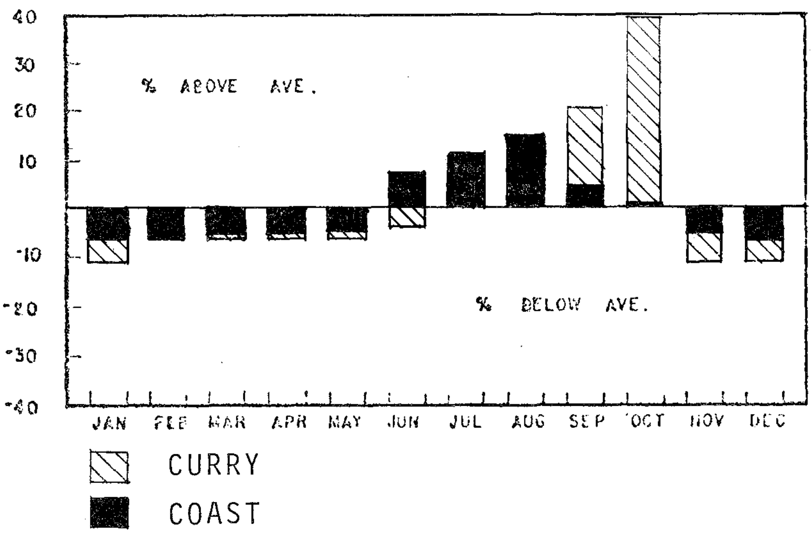


FIGURE 4-10. SEASONALITY OF EMPLOYMENT ON THE OREGON COAST AND CURRY COUNTY, OREGON. (From Kuhn et al., 1974.)

4.5.3 Agricultural Processing.

4.5.3.1 Products, Value Added, and Volume. The most important coastal region processed food products include frozen and preserved cranberries in Grays Harbor County; flavoring extracts and syrups in Clatsop County; dairy products, including cheese in Tillamook and Coos Counties; miscellaneous foods in Lincoln County; and fresh and processed milk in Humboldt County.

For the most part, value added and volume-produced data for agricultural products processing are combined with the same data for fish products processing, bakery products, and other food products. Some gross estimates are available for various geographic areas (i.e., individual states, the Columbia-North Pacific Region, and the U.S.), but no estimates with sufficient level of detail are readily available for the specific study region. Extensive, specific data relating to the portion of total "food and kindred products" which is the direct result of agricultural activities are available only on a limited basis.

4.5.3.2 Employment and Income. Agriculture is also responsible for employment in the coastal fruit, vegetable, dairy, and meat processing firms. The coastal processing firms in Oregon employed about 1,150 persons in 1972 (Kuhn et al., 1974). This amounted to approximately 30% of total food and kindred products employment reported for that year.

It should be noted that food and kindred employment declined in seven out of the ten Oregon and Washington coastal counties between 1970 and 1975, while other non-agricultural employment increased. Only Tillamook County showed an increase (OIW, 1977). A general downward trend in coastal farm output in the early 1970's indicates a high degree of linkage between coastal farming and the local processing activities. From employment data on food processing, it would appear that seasonal fluctuations and annual trends correspond to agricultural employment cycles.

County Business Patterns data (U.S. Department of Commerce, 1977D) give some indication of the importance of agricultural processing in those counties with high levels of employment. In most counties, actual counts are suppressed to avoid disclosure. The fact that the data are collected out of season (March 12) suggests that agricultural processing could reach 760-1,600 in the peak month (June) with an annual average of between 580 and 1,030. Comparison with Oregon State Employment Division data for 1975 suggests that the upper figure in the range is the more accurate of the two. The total, nevertheless, is under 1% of total employment on the coast. (See Table 4-40.)

TABLE 4-40. POSSIBLE RANGE OF AGRICULTURAL PROCESSING EMPLOYMENT, 1975. (From U.S. Department of Commerce, 1977D.)

County	Total Establishments	Employment Size Classes					Employment (Possible Range)
		1-9	10-19	20-49	50-99	100-249	
Clallam	-						
Jefferson	-						
Grays Harbor	2	1				1	101-258
Pacific	-						
Wahkiakum	-						
Clatsop	1				1		97*
Tillamook	1					1	100-249
Lincoln	7	5		2			54*
Coos	4	2	1	1			67*
Curry	-						
Del Norte	-						
Humboldt	3			1	1		70-148
TOTAL							489-873
ADJUSTED AVERAGE ANNUAL TOTAL							577-1030

* Indicates actual value.

Food processing activity, like agricultural employment, has generally been declining on the coast, largely as a result of productivity increases. An annual decline of 2.1% was estimated by Kuhn et al. (1974) for the period from 1958 to 1972.

4.5.3.3 Distribution and Markets. Data on distribution and marketing of farm products and food processing products are not abundant. A 1977 survey of Tillamook County's economy determined that local processors purchased 67% of milk produced by Tillamook dairy farmers (Youmans et al., 1977). A 1967 study estimated that dairy products processed in the Oregon coastal area were distributed in the following manner: 20% was consumed locally; 28% was shipped elsewhere in Oregon; 20% was shipped elsewhere in the Columbia-North Pacific Region; and the remainder (30%) sent elsewhere in the U.S. (Northwest Resource Program Group, Natural Resource Economic Division, 1973, in Kuhn et al., 1974.)

4.5.4 Summary and Effects.

4.5.4.1 Summary. As the previous discussion has indicated, employment in agriculture on the Pacific Northwest Coast is relatively high in comparison to value of output (fisheries employment is low in comparison to value of output). Output increases have accompanied declines in employment and moderate output increases are expected to continue. In both value and employment, however, agriculture has made only a small contribution in most counties to offsetting declines in lumber employment and income.

4.5.4.2 Natural and Socioeconomic System Effects. Few sources have been found to document and/or quantify the natural systems effects of agricultural practices in the region. Among those which must be considered are the changes to watersheds by flood control, drainage, and irrigation systems. The two latter actions are discussed in Pacific Northwest River Basins Commission (1971). Flooding has resulted in severe costs to coastal farmers, dairy farmers in the Eel River flood plain, Humboldt County, and other areas. Pesticides, fertilizers, and agricultural (mainly dairy) effluents have effects on water quality and direct and indirect wildlife effects. A study of pesticides used in the coastal zone is found in Barbe and Snow (no date).

John Grahm Co. (1976) and Simmons (1974) report some generalized natural system effects of agriculture, while Albrecht (1971) reviews effects on soils.

While the overall socioeconomic value of agriculture in terms of income and employment is low, agriculture increasingly supports retired residents or supplements the income of workers in other industries (Kuhn et al., 1974). It is also an important component of the visual environment, with implications for the recreation industry. Measures to protect prime agricultural lands are an important means of preventing scattered urban development.

4.5.4.3 Outlook. The reasons for limited output increases, including distance from markets, increasing urbanization, climate, soil and drainage factors, lack of capital and technological support, rising operating costs, and environmental controls, have been identified in earlier portions of this section.

The major opportunity for increasing both the value of output and employment appears to be in intensive nursery, fruit, and vegetable crops (Barbe and Snow, n.d.; QRC Research Corporation, 1978; Kuhn et al., 1974). The region has the potential for both cool season vegetables and berries and for greenhouse agriculture. The primary requirements are for capital and technological support and with increasing market demand and implementation of economic program recommendations for enterprise development (see QRC Research Corporation, 1978) these may become more available. Labor supply and training programs and funding and legal mechanisms to support cooperative farming and marketing are also recommended.

An essential support to any such efforts are planning and zoning programs to protect farmers both from encroachment by urban settlement, and the associated assessment and tax increases.

4.6 EXTRACTION AND MINERAL INDUSTRIES

This section, as explained in Volume 1, Conceptual Model, Section 4.6, includes a variety of diverse activities which are combined for convenience because of frequently similar interactions with natural systems (see Volume 1, Figure 4-10, the Extraction and Mineral Industrial Model). Certain extractive activities are based in external market demand. Other extractive or mineral industry activities either serve the local market directly (such as sand and gravel extraction) or support other basic industries (such as dredging for navigation).

4.6.1 Resources. Known mineral resources in the coastal region are generally not of major importance. Sand and gravel as a source for construction aggregate are found in most of the twelve counties and comprise the bulk of extractive activities. In several Watershed Units these are the only currently commercially valuable minerals. Due to the low value of construction materials, their weight, transportation costs, and relative abundance in other areas, they are normally produced and consumed locally. As a result they do not meet the definition of a basic economic sector. Rock crushing is necessary to supply aggregate in those counties, such as Coos and Lincoln Counties, Oregon, which are deficient in gravel (Schmisseur and Boodt, 1975). Non-energy mineral and metal deposits of potential commercial value include basalt found in Grays Harbor, Pacific, and Wahkiakum Counties, Washington, and some copper and manganese deposits also found in coastal Washington and in Humboldt County, California (Washington State DCED, 1977A, B, and C; QRC Research Corporation, 1978). (See also Coos, Curry, Douglas EIA, 1977.)

The most potentially valuable mineral deposits in the region occur in the black sands along the Coos County coast both on and off shore. Gold, platinum, titanium, zirconium, and chromite have been extracted from these deposits in the past. Chromite reserves appear to be most abundant. The sands are estimated to be capable of yielding a total of 456,000 long tons of chromite (Schmisseur and Boodt, 1975; Pacific Northwest River Basins Commission, 1970). In addition, Coos County appears to have potential for important reserves of copper and nickel (Schmisseur and Boodt, 1975). Chromite and nicket also occur in Del Norte County, California. Nickel deposits are currently being evaluated for possible production. The County's chromite deposits are its most abundant mineral resource and are feasible for economic development. In 1945-46, Del Norte County's production equalled 50% of the United States' domestic production of nickel (Broida et al., 1975). Portions of the Six Rivers National Forest may contain nickel deposits also (U.S. Department of Agriculture, 1978D).

There are currently no energy-producing activities either based on local or imported fuel sources in the coastal region. No known reserves of oil, coal, or natural gas exist in coastal Washington (Washington State DCED, 1977 A, B, and C). A number of oil and gas wells have been drilled in geologically promising areas of coastal Oregon. No commercial quantities have yet been discovered. Large areas of shelf lands are yet to be explored, however, and prospects for discovery are considered good (Schmisseur and Boodt, 1975). Coos County, Oregon, has two known coalfields which may each contain at least 50 million tons. Quality, accessibility, and physical structure of the fields all limit commercial value at present, however (Kuhn et al., 1974; Schmisseur and Boodt, 1975). In the future, the commercial production of coal may be limited by competition from petroleum products delivered by ship to coastal ports, natural gas pipelines, and by discoveries of offshore oil and gas deposits. While no natural gas is currently shipped to the area, a liquified natural gas (LNG) terminal has been constructed at Newport in Lincoln County, Oregon (Oregon Land Conservation and Development Commission, personal communication). The accompanying on-shore facilities for handling and distributing the LNG would be a source of basic employment should the terminal go into use since it could be expected that this energy source would serve an area larger than the coastal region.

The shipping industry's requirements for sufficient channel depths to accomodate large ships and berthing requirements for recreational and fishing boats have been satisfied by periodic dredging which provides some hydraulic fill materials and filled land for potential construction. Dredging's impact on river, estuarine, and coastal water quality and habitats is an issue which is dealt with in Section 4.7.

4.6.2 Production, Employment, and Income. The relative importance of the extraction and minerals industry in the coastal region as a whole is indicated by employment figures. The mineral industry employed between 90 and 150 people in the twelve counties of the study area according to 1975 County Business Patterns data (U.S. Department of Commerce, 1977D). Exact figures were withheld in all but Coos County and Tillamook County to avoid disclosure. In these two counties, 25 and 29 workers, respectively, were employed in mining. Not more than four workers were employed in Del Norte County, despite its potentially valuable resources and their past significance.

Data are not plentiful on income attributable to the mining industry. Again, most figures are not disclosed for reasons of confidentiality. Lincoln County showed $367,000 labor and proprietor income from mining in 1970 and $778,000 in 1974. Both figures are less than 1% of total income for the County for each each year. Wahkiakum County showed a mining income under $50,000. Coos County income was less than 1/10 of total county income (OIW, 1977).

Data on volume and value of extraction activity are also not readily available. Coos County and Curry County production had a combined dollar value of approximately $3.5 million, insignificant in comparison to other basic industries. Volume appears to depend directly on construction needs since the primary production is of sand, gravel, and rock.

4.6.3 Summary and Effects.

4.6.3.1 Distribution, Markets, and Multiplier. Raw data are non-existent on distribution and marketing of mineral production. However, it is reasonable to assume that nearly all mineral production is for local use in the construction field. Given both the small size of the extraction industry and the low percentage of output exported, it can be safely concluded that minerals are at present an unimportant source of export income.

4.6.3.2 Natural System and Socioeconomic Effects. As is indicated in Section 4.6 of Volume 1, Conceptual Model, controls on extraction of sand and gravel deposits outside the region, such as the Willamette Valley, could lead to expanded demand for exports despite the weight and normally low value of these minerals.

Extraction of sand and gravel from marine terraces and extraction of minerals from beach sands alters the substrate and habitats, and processing activities have effects on water, air, noise, and visual quality of the environment.

The natural system effects of dredging are discussed in Section 4.7. Dredging has major economic benefits to the region's predominant forest products export sector and to the commercial and sports fishing industries. At the same time, however, adverse effects on aquatic wildlife result in economic costs which, while apparently offset by the benefits to the forest products and shipping industries, are nevertheless important (see U.S. Army Corps of Engineers, 1976C and 1976H, for discussion of these tradeoffs). Additional information on potential deleterious effects are given by John Grahm Co. (1976) and Simmons (1974).

4.6.3.3 Future Outlook. Transportation costs to major manufacturing centers are a severe limit on commercial utilization of the region's mineral resources. A further limitation is the price structure of imported ores, such as chromite, which gives little incentive to develop domestic resources. Minerals could become a more important economic sector if foreign sources become less reliable or less abundant, or if products can be locally refined or manufactured into higher value products for which transportation costs are relatively low.

4.7 TRANSPORTATION

4.7.1 Resources. Transportation resources consist both of the natural opportunities (terrain and coastline) for development of transportation routes as well as terminals and the facilities themselves. A dominant characteristic of the Pacific Northwest Coastal Region is the suitability of the coast and of the resource-based industries to development of ports. Waterborne transportation has become a basic industry (see Volume 1, Conceptual Model, Section 4.7). This section also covers other modes and aspects of the industry, since they are partially basic in nature. For location and description of routes and facilities, see U.S.G.S. maps of the region and individual county general or transportation plans (Loy et al. 1976; Plank et al., 1975; U.S. Army Corps of Engineers, 1975F; OIW, 1977).

4.7.1.1 Land Transportation. Highways serve trucks for freight transport and autos for business and recreational use. U.S. 101, a primary two-lane coastal route, traverses the entire coastal region from Cape Mendocino to Cape Flattery. Interstate 5, another north-south route, does not enter the coastal region, but provides controlled access high-speed transportation with access to coastal centers by way of east-west feeders. There are also two-lane access roads from major inland markets (Seattle, Tacoma, Portland, and Eugene) to coastal communities. Some of these, such as Highway 38 and Highway 42 connecting Interstate 5 with U.S. 101 in Coos County, Oregon, are narrow. Access to Seattle by Jefferson and Clallam County residents is quickest by ferry across Puget Sound.

Principal railroads in or near the study area are the Burlington Northern, the Chicago, Milwaukee, St. Paul and Pacific, the Southern Pacific, and the Union Pacific. Amtrak runs a passenger train from Vancouver to San Francisco via Seattle and Portland. Approximately a dozen smaller lines also serve the coastal region. Several areas, again including Curry County, Oregon, have no rail service. Other areas, such as the Coos Bay area, are affected by high rail tariff rates (see Coos, Curry, Douglas EIA, 1977).

4.7.1.2 Air Transportation. Four small commercial airports directly serve the Coastal Region. The busiest airport which carries the most traffic along the coast is in North Bend, Oregon, near Coos Bay. Other commercial airports are found in Grays Harbor, Washington; Clatsop County, Oregon; and Eureka, Humboldt County, California. Major commercial airports (Seattle-Tacoma and Portland) are readily accessible to ports of the coastal area. Each county (except Wahkiakum) along the coast has at least one basic utility airport.

4.7.1.3 Water Ports and Shipping. A number of excellent natural harbors serve the study area. Ports have great significant in the coastal economy, giving an industrial locational advantage to the coastal region over inland locales for certain activities. The ports are especially important with respect to the forest products industry.

The busiest commercial ports along the Pacific Northwest Coast, in terms of all grade tonnage are Coos Bay and Astoria, Oregon, Humboldt Bay, California, and Grays Harbor, Washington (OIW, 1977). The major commodity handled by the ports is forest products. Coos Bay is recognized as the largest forest products storage port in the nation (U.S. Army Corps of Engineers, 1975B). Additionally, there are a number of small commercial and recreational ports along the coast. Major ports on Puget Sound (Seattle, Tacoma, and Everett), on the Strait of Juan de Fuca (Port Angeles), and the Columbia River (Portland) also indirectly serve the study area.

Rivers are another important water transportation resource. The Columbia River, a major commercial waterway, empties into the Pacific at the border of Washington and Oregon, providing ocean-going vessels with access to Portland. Numerous smaller rivers (the most important are the Coquille, Umpqua, Chehalis, and Willapa Rivers) provide transportation routes for forest products sent from inland sources to coastal ports, in addition to supporting fishing and recreational activities. Inland ports, such as Coquille and Myrtle Point along the Coquille River, Oregon, principally serve the forest industry (U.S. Army Corps of Engineers, 1975E).

Dredging activities are necessary in order to keep both ports and rivers open to transportation. The effect on the environment of the effort to maintain sufficient channel and harbor depths is discussed in Section 4.7.4.

4.7.2 Transportation Resource Use. The factors which affect choice of transportation modes and routes in the Coastal Region are related both to the characteristics of goods to be transported and a variety of other internal and external price, regulatory, and market conditions.

4.7.2.1 Demand and Supply Factors. A short discussion of supply and demand factors affecting the transportation industry can be found in Volume I, Conceptual Model. Data on this subject cannot be summarized because transportation use is strongly tied to the goods and activities employing particular transportation modes. In turn, the supply and demand for forest, fish, and agricultural products and recreational activities depend on national and world markets as well as local industrial conditions. Since the Coastal Region is dominated by the forest and forest products industry, the transportation industry depends heavily on the requirements of that industry. Transportation resource use also depends on the level of imports into the study area and the level of intra-regional activity. These factors depend on prices and supply set by external market conditions and on consumer income within the study area.

The level of international prices can also affect transportation activity along the coast. For example, an unfavorable relative price increase might reduce the demand for American goods and could cause a decline in the tonnage of cargo shipped from coastal ports. A secondary influence is that of demand for specialized forest products, notably pulp and paper, on the ports which engage in coastwise transportation of lumber and woodchips to processing centers such as pulp mills.

4.7.2.2 Regulation, Controls, and Competition. Regulation and control have a particularly important effect on the volume, price, and availability of various modes of transportation. National regulation of trucking and rail transportation by the Interstate Commerce Commission and of airlines by the Civil Aeronautics Board significantly affects the number of carriers, user rates, and routes available. It is generally accepted in regulation theory that changes in regulatory prices would affect the relative volume of transportation use by mode.

Transportation in the coastal area is affected by international agreements and tariffs. For example, easing of trade restrictions with Far Eastern nations could increase the volume of cargo handled by coastal ports.

Internal controls, such as user charges for ferries, toll bridges, and ports, also affect transportation volume. In Jefferson and Clallam Counties in Washington, a local survey indicated that businessmen felt excessive Puget Sound ferry prices inhibited economic activity (Washington State DCED, 1977A). Disadvantageous rail tariff rates can influence the volume of economic activity at transportation terminals. Lumber tends to be shipped from Roseburg, Oregon, to Portland rather than to the equidistant Coos Bay because rates to Coos Bay are nearly 60% higher (Coos, Curry, Douglas EIA, 1977).

Motor fuel taxes and load limits, which vary by state, also have an effect on volume and modal distribution of traffic. An increase in motor fuel tax by a state would be expected to result in a shift of carrier traffic away from trucking to alternative modes. Road construction, rail right of way, airport, and water port and navigation improvements could also be expected to increase carrier volume for the relevant mode. Changes in transport technology also affect coastal harbor, waterway, and port developments. Ground transportation improvements which reduce transportation costs will continue to lessen the value of port facilities. This is particularly true of ports which handle regional cargoes. The continued introduction of giant ocean-going barges, super tankers, etc., will also lessen the need for a large number of closely spaced ports. Both types of transportation improvement favor the development of large, specialized, regional, deep water ports, which would place many of the Oregon smaller ports along the Pacific Northwest Coast at an economic disadvantage (Schmisseur and Boodt, 1975).

Institutional agreements, primarily longshore union rules, are presently preserving the cargo handling function of many of Oregon's smaller ports. As these restrictions are modified, it is expected that the development of specialized, regional, deep water ports will be given further impetus.

Each port along the coast is under the control of a port district. These districts develop and maintain facilities and provide the labor to serve the market for water transportation and other port activities.

Besides the provision and maintenance of dock, maintenance, and other facilities, the primary contribution of the area's port districts, with the assistance of the U.S. Army Corps of Engineers, is the maintenance and improvement of channel depths.

4.7.2.3 Markets and Modal Split. In general, the Coastal Region's shipments to and from other western U.S. coastal ports and foreign countries are made by water. Most water-borne imports are of petroleum and petroleum products from domestic sources. In 1975, domestic petroleum represented 81.6% of all Coos Bay receipts and 61.5% of all Astoria receipts. Shipments from the ports (mainly of forest products) go predominantly to foreign ports although coastwise traffic in woodchips is also significant. The majority (89.9%) of exports from Coos Bay and Astoria were to foreign destinations. The percentage of foreign exports from Grays Harbor, Washington, and Humboldt Bay, California, is unknown (see Table 4-41).

Truck and rail transit are, with the exception of Canadian sales, obviously confined to domestic markets. Most domestic shipments of forest products go by rail. Eastward shipments of other products from the ports made are both by road and rail.

TABLE 4-41. MAJOR PORT FREIGHT TRAFFIC, 1975. Data are in thousands of short tons. (From Oceanographic Institute of Washington, 1977.)

Port	Domestic & Foreign Receipts	Domestic & Foreign Shipments	Total Domestic Trade	Total Foreign Trade	All Trade
Coos Bay, Oregon	314.75	3649.7	737.4	3227.C5	3964.45
Astoria, Oregon	42.3	1144.8	82.4	1104.7	1187.1
Grays Harbor, Washington	n/a	n/a	n/a	n/a	2587.1
Humboldt Bay, California	n/a	n/a	n/a	n/a	1357.5

n/a = Not Available

4.7.3 Volume. Data on volume of goods transported (all modes) are available only on an aggregate statewide level and would not be of value here. The kind of data needed for an ecological characterization concern the volume of each commodity transported in each Watershed Unit by mode. Only partial data by commodity are available for the Coastal Region counties.

Forest products appear dominant in Washington, comprising approximately 98% of all tonnage shipped from Grays Harbor in 1973. (U.S. Army Corps of Engineers, 1976C). Table 4-42 shows water transportation activity by commodity for the Oregon coastal zone (including ports in Douglas and Lane counties) for the years 1958-1972. Clearly, forest products also dominate the shipping activity in this area comprising 80.4% of all commodities shipped from Oregon coastal ports in 1958. This share had grown to 84.9% by 1972. The huge increase in "other wood products" beginning in 1965 represents increased shipments of wood chips. Previously discarded, wood chips became valuable in the making of paper when wood prices sky-rocketed. By 1972, other wood products had nearly eclipsed the traditional leader, "rafted logs", in volume shipped.

It is clear that, at least for the coastal counties in Oregon (and very likely for Washington and California counties as well), ports that have traditionally been active in transport of rafted logs are likely to have experienced a decline in recent years while ports that have made the switch to wood chips should have continued to prosper. This assertion is supported by trends in Oregon coastal ports. A 53.7% decline occurred in Lincoln County's shipping activity from 1965-1972 (Kuhn et al., 1974). In 1972, 32.8% of total activity was in rafted logs and none was in the "other wood products" classification. Coos Bay experienced an increase in volume of cargo handled of 32% from 1965-1972. Much of the increase was due to the growth in wood chips. "Other wood products" increased in volume from 117,000 short tons in 1965 to nearly 3 million in 1972 (data from Kuhn et al., 1974). A study of the relationships of the forest industry to waterborne commerce in Coos Bay has projected a continued rapid increase in wood chip activity (Coos, Curry, Douglas EIA, 1977).

Although it is clear that the great majority of commercial waterway shipping is involved with wood and wood products in the Coastal Region, there are no data to substantiate the generally accepted assumption that most wood products are shipped by water rather than by some other mode. Most studies simply assert this belief (e.g. "A significant share of the forest products industry is also dependent upon the ports" (Kuhn et al., 1974). It is clear from other studies that trucking and rail transportation also play a role in wood products transportation. Just how important these modes are in the region as a whole, however, cannot be estimated without additional study. Traffic studies on Highway 42, which connects the Coos Bay area with Interstate 5, have counted trucks carrying logs and wood chips (OIW, 1977).

TABLE 4-42. TONNAGE BY COMMODITY HANDLED AT OREGON COASTAL PORTS, 1958-1972. Data are in thousands of short tons. (From U.S. Army Corps of Engineers Data in Kuhn et al., 1974.)

YEAR	RAW & PROCESSED FISH (08, 2031)	SAND AND GRAVEL (14)	FOOD PRODUCTS (Other 20)	LOGS (2411)	RAFTED LOGS[1] (2412)	LUMBER (2421)	PLYWOOD (2432)	OTHER WOOD PRODUCTS (Other 24[2])	PULP AND PAPER (26)	PETROLEUM PRODUCTS (29)	ALL OTHER	TOTAL
1958	48	1,190	x	193	4,765	1,605	7	117	28	308	187	8,348
1959	43	641	1	169	4,592	1,630	27	31	30	366	158	7,688
1960	47	587	x	177	4,782	1,785	20	20	45	357	138	7,958
1961	36	489	x	461	4,830	1,445	22	34	53	384	241	7,995
1962	37	1,132	x	274	5,000	1,600	22	92	37	399	22	8,615
1963	37	828	x	487	4,734	1,601	20	145	26	401	35	8,314
1964	41	557	x	752	5,543	1,777	23	95	221	474	47	9,530
1965	44	909	x	662	5,316	1,699	50	758	95	526	51	10,110
1966	217	635	2	942	10,809	1,219	91	1,030	77	468	151	15,621
1967	52	1,443	5	1,180	6,248	1,080	101	1,905	127	478	102	12,722
1968	57	337	22	1,450	5,867	1,312	34	2,341	144	488	824	12,876
1969	43	579	13	1,216	5,121	1,157	28	2,451	248	454	66	11,376
1970	37	551	24	1,480	3,323	1,131	23	2,514	181	445	296	10,005
1971	26	1,177	40	1,357	7,210	989	31	2,346	171	446	249	13,962
1972	38	932	50	1,826	3,505	1,273	71	3,100	197	454	278	11,622

Another study (Coos, Curry, Douglas EIA, 1977) suggests that where mills are served by rail, (providing freight rates are competitive), a substantial share of the volume of wood and forest products exports would be shipped by rail. In Douglas County, for example, which lies mainly to the east of the Coast Range, it has been estimated that 90% of forest product exports are shipped to national markets by rail. Many of the coastal counties, however, are either not served by rail or placed at a disadvantage by freight rate structures. The same study also notes that the distance of Coos and Curry Counties from the Interstate system and the poor quality of Highways 42 and 38 which trucks must travel to reach it, create higher transportation charges.

4.7.4 Employment. The relationship of employment in transportation to volume transported is important in evaluating the social and economic effects of measures that might curb or increase transportation activity (such as the decision to dredge a channel). Figure 4-11 compares volume of waterborne transport and water transportation employment for the Oregon coast between 1958 and 1972. Despite sharp fluctuations in shipping activity, employment has remained at approximately the same level. It appears that water transport employment is not primarily dependent on shipping volume.

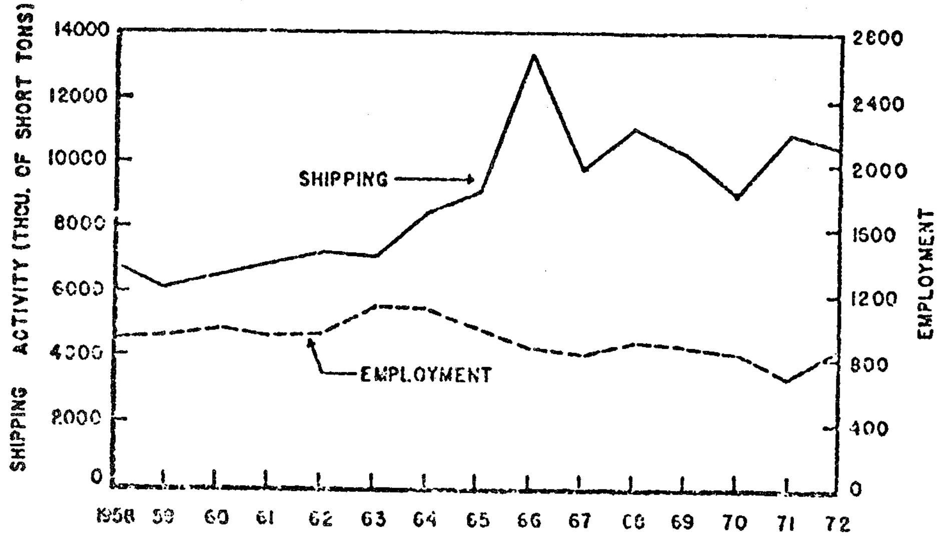


FIGURE 4-11. SHIPPING ACTIVITY AND WATER TRANSPORTATION EMPLOYMENT ON THE OREGON COAST, 1958-1972. (From Kuhn et al., 1974)

Another measure is the ratio of transportation employment to overall employment. Most state employment data use the Standard Industrial Classification (S.I.C.) categories at the single digit level. This means, unfortunately, transportation is grouped together with communication and utilities. The grouped data still have some value, however (see Table 4-43).

The tri-state coastal county ratio of transportation, communication, and utilities (TCU) to total employment is somewhat less than the national and state ratios. Noticeable are the higher figures for Coos, Humboldt, and Grays Harbor counties, which have busy port facilities. No explanation could be found for the high percentage in Wahkiakum County. In general, the relatively small percentage of TCU employment in the study area and the unresponsiveness of transportation employment to variation in shipping activity indicate that transportation employment is not a particularly reliable indicator of socioeconomic change.

Data comparing TCU employment and income in the Oregon and Washington coastal counties for 1970 and 1975 as a percentage of the two-state coastal total showed only a slightly higher percentage for income than for employment (OIW, 1977). These data indicate that transportation, communication and utilities produced income at approximately the same ratio per employee as other industries. Additionally, the average annual percentage change (1970-74) is close to the figure for all industries. It can be concluded that no unusual income effects can be expected from a change in transportation employment along the coast.

TABLE 4-43. TRANSPORTATION, COMMUNICATIONS, AND PUBLIC UTILITY EMPLOYMENT (TCU), 1973. (From Washington State Employment Securities Department, California State Employment Development Department, Oregon State Employment Division, pers. comm.)

COUNTY	TCU EMPLOYMENT	% OF COUNTY EMPLOYMENT
Washington		
Clallam	647	4.3
Jefferson	70	3.0
Grays Harbor	1001	4.0
Pacific	142	1.9
Wahkiakum	107	6.6
Oregon		
Clatsop	376	3.1
Tillamook	148	2.3
Lincoln	327	2.7
Coos	1197	5.2
Curry	131	2.5
California		
Del Norte	288	6.7
Humboldt	1979	7.0
Coastal County Total	5413	3.8

4.7.5 Value Added. Data on value added in the Census of Manufacturers (U.S. Department of Commerce, 1974C) are also classified into transportation, communications, and utilities and would not be meaningful for this study.

Value added in the transportation industry is derived not only from actual carrying costs by the various modes but also handling costs at ports, air fields, warehouses, and rail and truck terminals such as loading, unloading and storage.

4.7.6 Summary and Effects.

4.7.6.1 Summary. The transportation industry is a small but basic activity in the coastal study area. Health of the industry depends on the health of local industrial production (mainly forestry) and local consumption patterns. The coast is not a transportation center for other regions. Its main assets are its ports which provide an economically advantageous resource for the export of wood and forest products and other locally produced goods. The coastal ports also serve as a reception point for local petroleum and gas needs. Transportation employment and income are a small part of the total coastal economy (no more than 6%) and appear to be fairly stable.

4.7.6.2 Multiplier Effects. Limited data on a transportation multiplier for the coastal region indicate that it is fairly small. A 1977 calculation for Tillamook County, Oregon, placed the transportation industry income multiplier (alone) at 2.138, along with non-basic activities such as retail or wholesale sales and automobile sales.

4.7.6.3 National System Effects. Despite its apparent subordinate status in the socioeconomic system, transportation has effects on natural systems. A major impact may be attributed to water transportation-related dredging activities which are discussed in several documents including Environmental Impact Statements for: Grays Harbor, Willapa River and Harbor, and the Chetco, Coquille, and Rogue River Estuaries and Port Orford (U.S. Army Corps of Engineers, 1976C, 1976H, and 1975D), as well as in Krenkel et al. (1976).

Accidental spills of deleterious substances (oil and toxins) can also have serious environmental consequences in inland as well as coastal and oceanic zones. The literature on this topic is extensive and not reported to any great deal in this study. A review of the oil impact literature is provided by Beak Consultants (1975). Additional references are given in the marine mammals and sea birds species of concern accounts in Part 2 of this volume, and in Simmons (1974).

Roads and their construction and maintenance have extensive effects on natural systems. Bolsinger (1973) reports roads are the principal cause for loss of commercial timberlands in Washington and Oregon. As previously discussed in the forestry section (4.2), roads and road construction are a major source of erosion, siltation, and mass wasting in the region. Impacts of roads are reported in the following sources: Tillman et al. (1976); EPA (1975A); Leedy (1975); and Sidhu and Case (1977).

4.7.6.4 Dredging. The short-term and long-term effects of dredging are dependent partly upon the method of dredging, the type of disposal operations, and characteristics of bottom materials. Changes due to channel maintenance dredging are similar in type to those resulting from widening and deepening of channels and the necessary increased maintenance, but differ in intensity and scope (U.S. Army Corps of Engineers, 1976C). There are also differences in the degree of change between areas which have historically been dredged and those which have not.

The actual movement of material accompanying estuarine dredging operations has been shown to be small relative to natural movement. Similarly, changes in water movement and quality conditions have not been found to be small (U.S. Army Corps of Engineers, 1976C). Increased stratification of salt and fresh water and increased upstream extent of salt water intrusion is estuaries and rivers, while not accompanied by a large increase in total estuarine salt content, may produce changes in the biological community.

The main adverse effect of dredging is increased turbidity, hopper dredging resulting in higher levels than pipeline dredging, and in decreases in dissolved oxygen. Reduction in pH and increase in toxicants such as sulfide (although not pesticides and trace metals) may occur in dredging plumes.

Among the changes which may occur as a direct result of dredging are: stress on salmonids from reduced oxygen and clogging of gills by turbidity (U.S. Army Corps of Engineers, 1976C); avoidance of dredging plumes by adult salmonids, affecting migration and predation; severe stress on juveniles unable to avoid the dredged area; and increased juvenile crab mortality and mutation (Krenkel et al., 1976).

For more information on dredging and its impacts in the region's estuaries, see especially OSU (1977A, B, and C), ACOE (1976-1977), and Slotta et al. (1974). Ellinger and Snyder (1975) present an annotated bibliography on biological impacts of dredging in the Pacific Northwest. Additional references can be found by searching the key word (descriptor) field for DREDGING and IMPACT in the Annotated Bibliography (Volume 5).

4.7.6.5 Disposal of Dredge Spoils. Disposal sites are generally on land or in deep water rather than in estuarine locations. Deep water disposal will affect organisms in the area through smothering and may alter species composition if particle size or organic content are changed. Frequently, however, dredged sediments are swept away from disposal sites by currents, creating effects similar to those of dredging. Unless sediments are swept seaward, this could affect the productivity of oyster beds and other commercially or ecologically valuable habitats. The turbidity caused by both dredging and disposal also could affect primary producers such as phytoplankton and eelgrass. On-shore disposal in wetlands can temporarily eliminate vegetation and alter elevation and soil composition with long-term effects on species composition. The altered land may, however, become suitable for other uses although the wetland habitat will be lost. Water quality deterioration may also result from sediment runoff from shoreline-dredged material disposal areas unless they are properly located and diked to prevent such return (U.S. Army Corps of Engineers, 1975B). Darnell (1976) provides an extensive treatment of the effects of filling on wetlands. Ellinger and Snyder (1975) include references on dredge spoil dumping in their extensive annotated bibliography for the region.

4.7.6.6 Side Effects of Dredging. Various natural and socioeconomic side effects of first time or maintenance dredging can be identified. Increased shipping and boating activities may bring economic benefit. Greater pollution hazards may result, however, from oil and gas spillage, discarded litter, and, until 1980 when new EPA discharge regulations go fully into effect, sanitary waste. Benefits to forest product activities will accrue from increased capacity through ease and lowered costs of transportation, permitting expansion if adequate timber supplies are available. Varying effects on fisheries may be anticipated, depending upon local conditions. These include increased productivity due to greater accessibility to ocean fishing grounds and increased berthing, or reduced estuarine fishery resources. Conflicts with some recreation and tourism values may occur due to aesthetic and ecological changes. Other recreation values may be enhanced by increased boating access and the secondary urban development stimulated by any increase in economic activity.

4.8.1 Total Basic Employment Multiplier. Table 4-44 lists the coastal region's basic industries as previously defined and discussed in this study. The remainder of the table includes a calculation of employment for the basic industries and a computation of a basic employment multiplier.

The employment calculations use 1975 County Business Patterns data (U. S. Department of Commerce, 1977D) grouped by Standard Industrial Classification (S.I.C.). This is the most up-to-date uniformly collected data for the 12 county study area. Employment data are compiled from payroll tax forms and represent total employment as of March 12, 1975. A number of shortcomings are inherent in these data. Total figures do not include government workers, railroad workers, and self-employed persons. Family and other unreported employment also is not included. Additionally, because the data include employment for only one day of the year (March 12) they do not reflect seasonal trends. For these reasons, both total and basic unemployment are understated. An important advantage of these data, however, is the inclusion of employment data at the two-digit and three-digit S.I.C. level, allowing identification of basic industry activities (such as "ship and boat building and repair") that would otherwise be lost in a larger grouping.

TABLE 4-44. BASIC EMPLOYMENT IN COASTAL STUDY AREA, 1975. Forestry and Forest Products (For), Fisheries (Fish), Recreation (Rec), Agriculture (Agri), Extraction and Mineral Industries (Ext), Transportation (Trans). (From U.S. Department of Commerce, 1977D.)

(Code)	S.I.C. Sectors	For	Fish	Rec	Agri	Ext	Trans	Total Study Area Employment
(-)	Agriculture, Forestry, Fishing	x	x		x			1305
(-)	Mining					x		174
(20)	Food and Kindred Products		x		x			2675
(24)	Lumber and Wood Products	x						22868
(25)	Furniture and Fixtures	x						175
(26)	Paper and Allied Products	x						3868
(29)	Petroleum and Coal Products					x		60
(32)	Stone, Clay and Glass Products					x		176
(373)	Ship and Boat Building and Repairing						x	128
(42)	Trucking and Warehousing (50%)						x	728
(44)	Water Transportation						x	369
(554)	Gasoline Service Stations (20%)			x				282
(58)	Eating and Drinking Places (20%)			x				1268
(70)	Hotels and other Lodging			x				2245
(79)	Amusement and Recreation Service (20%)			x				101
Total Basic Employment								36422
Total Employment (Basic and non-basic)								83984
Basic Employment Multiplier								2.31

Table 4-44 lists all S.I.C. sectors relevent to basic industries for the coastal study area. Some classifications contain components for more than one basic industry. For example, "food and kindred products" (S.I.C. 20) contains both agricultural and fisheries employment. Industries also include more than one classification. Extraction and mineral industries include "mining," "petroleum and coal products" (S.I.C. 29), and "stone, clay, and glass products" (S.I.C. 32).

Allocating industry employment to basic and non-basic categories is a significant problem in employment base studies. In Volume One of this study, a basic industry was defined as "one that imports money from outside an area through the production of goods and services for export" (see Volume 1, Conceptual Model, Section 4.1.3). It is clear that portions of output of each basic industry are purchased and consumed locally. Data on industrial output by destination of sales are not collected on a region-wide basis; however, some local input-output or import-export studies do exist, such as that for Tillamook County (Youmans et al., 1977). An input-output study required first-hand surveys of local businesses and would be very costly for an area as large as the Pacific Northwest Coastal Region. For the limited purpose of calculating a basic employment multiplier, generalizations by S.I.C. classification are usually sufficient. In this study, S.I.C. sectors are allocated wholly to basic or non-basic industries, excepting transportation and recreation.

For transportation, only half of trucking employment is considered basic. A large share of carrying activity by this mode involves imports and does not bring money into the area. Water transportation, on the other hand, is nearly all export oriented (see Section 4.7). For this reason, only 50% of "trucking and warehousing" employment is allocated to basic, along with 100% of water transportation and "ship building and repair."

Recreation has previously been defined as tourism, second homes, and retirement (see Section 4.4). The predominant component is tourism, however, and this study has classified recreation in terms of tourist expenditures for fuel, food, and lodging. Lodging is represented by "hotels and other lodging" (S.I.C. 70). Food and fuel have been included in "eating and drinking places" (S.I.C. 58) and "gasoline service stations" (S.I.C. 554). An estimate of only 20% basic employment in each classification is used because employment in these classifications appears to depend on local population and does correlate well with "hotels and other lodging." "Amusement and recreation services" (S.I.C. 78) have also been estimated at only 20% basic. Most of these services (bowling alleys, movie houses) appear to serve the local population.

Total employment in basic industries in the study area is calculated to be 36,422 of a total overall employment of 83,984. The basic employment multiplier of 2.31 means that for every person employed in a basic industry there are one and one-third employees in service industries. This figure can be used as a rough approximation of the effect of a change in basic employ on service employment. Analysis of a policy that results in an increase or reduction in employment in basic industries should take into account the service employment that depends on the basic sector.

It should also be noted that the multiplier will vary between counties within the coastal region. Examination of employment data for counties suggests that in an area such as Curry County, which has a relatively low share of total basic employment in forestry and forest products, the resource-based employment multiplier may be as low as 1.86 (or 1.52 if all government is counted as basic). The process of tracing through industrial output to determine whether it is exported or consumed locally is, however, extremely costly and would probably prove to be practical for localized impact studies only. Table 4-45 gives basic employment multipliers calculated for each county from 1970 Census data by Ashby and Cartwright (see Bell, 1977). These figures are based on gross groupings of activities and are, therefore, only approximations. They provide, nevertheless, both a check on the calculations in Table 4-44 and an indication of the range of multiplier variation between counties.

4.8.2 Employment Activities by Service Group.

4.8.2.1 Wholesale and Retail Trade. The retail and wholesale trade sector is non-basic, providing goods and services to the coastal population for local consumption. With the exception of goods and services sold to tourists, this sector generates no income for the coastal economy. Wholesale and retail trade activity is dependent upon income-producing sectors for its existence. Basic activities generate income and attract a population whose consumption demands support the trade sector.

The retail and wholesale trade sector multiplier is ordinarily the smallest among all industries. The coastal region appears to be in conformity with this trend. The business multiplier (the change in sales of a dependent sector activity caused by a one dollar change in sales in another sector) for retail and wholesale trade tends to be one of the smallest in each county in the region. The multiplier was estimated at 1.66 in Clatsop County and 1.51 in Lincoln County

TABLE 4-45. BASIC EMPLOYMENT MULTIPLIERS FOR PACIFIC NORTHWEST COASTAL COUNTIES, 1970. Multiplier is computed by dividing Total County Employment by the sum of employment in agriculture, forestry, and fishing, mining, manufacturing, and the federal military. (From Bell, 1977.)

County	Basic Employment Multiplier
Clallam	2.78
Jefferson	2.94
Grays Harbor	2.58
Pacific	2.19
Wahkiakum	1.69
Clatsop	3.08
Tillamook	2.37
Lincoln	3.47
Coos	2.46
Curry	2.09
Del Norte	3.25
Humboldt	2.76

(Schmisseur and Boodt, 1975). An income multiplier of 1.76 for this sector in Tillamook County was calculated by Youmans et al. (1977). They also calculated that only 16.6% of retail and wholesale output was sold to buyers from outside the County. The multipliers and export figure indicate that the wholesale and retail trade sector comprises highly localized activities.

Data on business multipliers for other sectors in Clatsop and Lincoln counties indicate that although the wholesale and retail sector does not generate much activity in other sectors, it is highly reactive to sales increases in those sectors. For example, a one dollar increase in sales in the lumber business in Clatsop County produces a 14¢ increase in retail and wholesale business activity. A one dollar change in commercial fishing produces a 29¢ increase in trade. Consistently the retail and wholesale sector is at or near the top in reaction to activity level changes in other sectors. (The only category that is consistently more reactive is household income.) These data indicate the great dependency of the retail and wholesale trade activity on other sectors (Schmisseur and Boodt, 1975).

The implications of this dependent relationship for assessment of natural systems effects are important. Any proposal which increases the activity of a basic sector (such as forestry) will increase, through the multiplier effect, the level of retail and wholesale trade. That generally means an increase in urban activities, and accompanying development, population, waste, etc. These activities also have environmental effects which must be taken into account.

4.8.2.2 Government Employment. The classification of government employment as basic or non-basic is open to debate. Government becomes a basic resource when the amount of government expenditures and employment in the region exceeds the total taxes collected so that there is a net flow of money into the regional economy. These calculations require very detailed data. A discussion of the sources and importance of government employment and expenditures to the Oregon coast may be found in Kuhn et al. (1974).

Federal Government. The significance of the federal government to the economy of the study area varies by location. Federal government employment as a percentage of total employment ranged from 1% to 2% for coastal counties in 1973 with the exception of Clallam County which had 6% federal employment. Most of Clallam's federal employees were in the military. Federal employment represented 3.1% of total employment for the nation as a whole (Washington State DCED, 1977A; Kuhn et al., 1974; California State Statistical Abstracts, 1978). From these data it appears that the federal government is not a significant source of income for the study area.

Another measure of the federal government's significance is the level of federal per capita expenditures. These data can verify or refute the conclusion in the previous paragraph. If federal expenditures are relatively high in the study are, the federal government might be considered a basic industry despite the low employment as a percentage of total employment. This can occur because federal employee payrolls are often only a small part of total federal expenditures for a specific area. For example, federal payrolls in Oregon represented only 15% of total expenditures (Kuhn et al., 1974, from Federal Outlays in Oregon, 1971). Per capita expenditure figures for the Oregon coastal counties show that all counties except Curry were below the national per capita average in 1971. Particularly high per capita expenditures relative to the national average occurred in the Departments of Interior and Transportation for the Oregon portion of the study area. Per capita defense expenditures, however, were very low bringing the overall average down below the national figure. Although comparable data were not readily available for California and

Washington coastal counties, it is believed that a similar pattern would be found and that the federal government can be classified in the non-basic sector.

State and Local Government. The state and local government sector is a much more important employer than the federal government in the study area as well as in the nation as a whole. Most of the employees in this category, however, are employed in local government and education. Generally, the state employment level is similar to that of federal employment in the study area (Kuhn et al., 1974; Washington State DCED, 1977A, B, and C; California State, Statistical Abstracts, 1978).

State employment, like federal employment, is less significant in the Oregon coastal counties than in the state as a whole. In 1973, state government on the Oregon coast accounted for 2.5% of total employment. In all of Oregon, state government employed 3.9% of all employees. 1975 data for Humboldt County, California, also show that the ratio of state employment to total employment is smaller in the coastal county than in the state as a whole.

Information about state expenditures by county are extremely difficult to obtain. An extensive effort to gather data in Oregon on state expenditures (Kuhn et al., 1974) received incomplete responses from state agencies. The typical fluctuations caused by changing policies may explain the unavailability of expenditure data. They are needed, however, to evaluate the relative importance of state expenditures in the coastal counties.

Local governmental expenditures vary by county. Services provided by local governments and boards of education primarily serve the local population and must be considered non-basic activities. Three factors affect the level of expenditures in any jurisdiction. Expenditures depend on the tax base and tax rates. The tax base is a function of the level of socioeconomic activity, which is, in turn, dependent on basic industries. Tax rates are politically determined. The size of government transfers from state and federal sources also affect the expenditure level. The size of grant revenue sharing and other funds flowing to a locale depend on a wide and changing variety of factors.

4.8.2.3 Other Non-Basic Employment. Also included in the non-basic sector are construction, non-basic manufacturing, utilities, communications, local transportation, and business and professional services.

Construction has generally been the second largest component of this sector after trade. It is also the most volatile component, being a very accurate reflection of changing national economic conditions as well as of expansion or decline in the basic economy of coastal communities. The share of total employment represented by construction is generally lower on the coast than in the United States as a whole, reflective of the differing growth rates. In 1972, it amounted to 2.62% on the Oregon coast, compared to 3.86% for the state as a whole. Lincoln County, with considerable recreational and second home construction, had the highest share of the five Oregon coastal counties, 3.95%. County Business Patterns data also show Grays Harbor and Pacific Counties, Washington, with high proportions of construction employment.

Non-basic manufacturing, including such activities as local dairies, printers, machinery building and repair, support the local population and basic industries. Employment in these activities amounted to approximately 2% of total employment between 1958 and 1972 on the Oregon coast (Kuhn et al., 1974). The remaining share of other non-basic employment is in local transportation and utilities.

4.8.3 Summary. The economies of the Pacific Northwest Coastal counties are heavily resource-based and therefore oriented to export markets. One result of this specialization is a production-consumption imbalance which forces most counties to import the majority of the goods they consume. Such imports represent massive leakages of spending power and potential employment out of the economy.

A symptom of this imbalance is the fact that all of the counties have an exceptionally high percentage of payroll employment in manufacturing activities. For most major urban-industrial centers, the manufacturing share ranges from about ten to twenty percent. By comparison, the figures on the Pacific Northwest Coastal range up to about 25 percent (Tillamook County, Oregon). Lincoln County with its important recreation and fisheries and more limited forest and forest products activities, has the lowest share (approximately 20%).

The difference between production and consumption makes the level of economic activity in the service sector highly dependent on the ability of the export industries to bring spending power into the economy.

The predominance of the forest industry makes the region particularly vulnerable to fluctuations in the national economic condition. The industry is dominated by the cyclical swings in housing construction.

The outlook for the forest industry, discussed in Section 4.2.5, suggests severe economic dislocations in the future. A combination of factors is involved: diminished timber supply on private lands; after other increasing logging and transportation costs, environmental controls on logging operations and watershed management; multiple use priorities for public forest lands; and continued productivity increases and accompanying employment losses.

Several activities which could be encouraged to bolster employment and income in traditional industries have been recommended in economic plans for the area. These include extensive utilization and processing of hardwoods. Tanoak is the most common underutilized hardwood which can be used for furniture, particle board, pulp, and charcoal. Red alder is being cut for furniture in Oregon and Washington. Other species such as madrone, other oaks, and chinquapin in California could be clipped or cut into short lengths for parquet flooring as well as providing fuelwood.

Exploratory fishing, ocean ranching, hatchery improvements, mariculture and aquaculture, improved harbor facilities, and processing of fish waste and trash fish to eliminate polluting wastes have all been recommended to enhance the economic position of ocean fishing.

4.9 SOCIAL AND CULTURAL SYSTEMS

4.9.1 Social and Demographic Character.

4.9.1.1 Overall Employment Patterns. The economic activity of the region has been indicated by the previous discussion of outputs of goods and services. Due to variations in data presentation between states and the need to estimate employment in certain industries, a composite picture of the relative employment levels in each industry is difficult to determine. Kuhn et al. (1974) arrived at the totals for the five Oregon coastal counties shown in Table 4-46.

TABLE 4-46. EMPLOYMENT ESTIMATES FOR THE OREGON COAST, 1958 AND 1973 WITH PROJECTIONS TO 1985. (From Kuhn et al., 1974, with data from U.S. Department of Commerce, 1977D.)

SECTOR	1958	% OF TOTAL	1973	% OF TOTAL	1985	% OF TOTAL
Agriculture	4,568	10.0	2,990	5.3	3,050	4.8
Fishing and Fish Processing	1,744	3.8	2,932	5.2	2,655	4.1
Forestry and Forest Products	13,453	29.5	11,769	20.9	8,746	13.7
Recreation	794	1.7	2,675	4.8	4,079	6.4
Water Transportation	909	2.0	972	1.7	900	1.4
Federal and State Government	1,097	2.4	2,387	4.2	3,778	5.9
Local Government	4,349	9.5	7,298	13.0	10,715	16.7
Trade and Services	15.016	32.9	20,370	36.2	24,244	37.9
Other Non-Basic Sectors	3,744	8.2	4,897	8.7	5,843	9.1
Total Employment	45,670	100.0	56,290	100.0	64,010	100.0

The table indicates that 37.9% of total employment was accounted for by the resource-related basic industrial sectors in 1973. This percentage, however, was down from 47% in 1958. Kuhn et al. (1974) projected, using an econometric model, a further decline to 30% in 1985. Based on figures developed or assembled for the current study, it appears that the Washington and California coasts would show similar patterns. While recreation is the fastest growing sector, it is apparent that it is not replacing losses in other industries.

4.9.1.2 Employment and Income. Personal income, which can be converted into per capita personal income, is also an excellent measure of an area's economic activity. Personal income reflects levels of pay and skill in local industries, unemployment patterns, and participation of residents in the labor force.

Growth of personal income in the Oregon coastal region lagged behind the rates for both Oregon and the U. S. as a whole from 1950 to 1969. The ratio of earnings per worker in the coastal region declined relative to the U. S. figure from 1.09 in 1950 to 0.83 in 1969. This is probably a reflection of a shift in this area toward a tourist (service) type economy during the 1960's (Schmisseur and Boodt, 1975). Also important to the area's personal income level is the increasing number of property owners who are only part-time residents. Other contributing factors to reduced average per capital income levels are the growing retirement population, high unemployment levels, and seasonal unemployment patterns in the basic industries of forestry and forest products and fisheries. Each one of the twelve coastal region counties had per capita personal income below the state average in 1969 (see Table 4-47). Estimates for later years have shown no overall change in this relationship. With the exception of Jefferson County, the Washington coastal county per capita income figures in 1969 were substantially higher than each of the Oregon county figures. The discrepancy between coastal county and state per capita income, however, was greater in Washington than in Oregon. This is probably due to the greater level of industrialization in the Puget Sound area of Washington which produces a relatively high state average per capita income.

The incidence of poverty is an important aspect of the Coastal Region's socioeconomic character. The percentage of families below the poverty level as defined by the 1970 Census exceeded the state percentages in each county except Clatsop and Coos Counties, Oregon. (These two counties and Curry County also had 1969 per capita income levels very close to the state average.) On the whole, both income levels and the percentage of families above the poverty level were higher in the coastal region in 1969 than in some rural counties to the east, such as Douglas, Josephine, and Lane Counties in Oregon.

TABLE 4-47. COASTAL REGION AND STATE INCOME LEVELS, 1969 AND 1974. (From U. S. Department of Commerce, 1970; Washington State DCED, 1977A, B, and C; Bureau of Business Research, University of Oregon, 1977; California State, 1976.)

AREA	PER CAPITA PERSONAL INCOME 1969 ($)	MEDIAN FAMILY INCOME 1969 ($)	HOUSEHOLDS WITH BELOW POVERTY LEVELS INCOME 1969 (%)	TOTAL PERSONAL INCOME 1974 ($ MILLIONS)	PER CAPITA PERSONAL INCOME 1974 ($)
Clallam	3,439	9,213	14.9	203.5	5,126
Jefferson	3,051	8,848	15.3	54.4	4,672
Grays Harbor	3,419	9,220	16.9	310.1	5,115
Pacific	3,378	8,575	17.2	79.9	4,924
Wahkiakum	3,542	9,078	14.9	20.1	5,549
State of Washington	3,893	10,407	12.7	n/a	5,713
Clatsop	3,150	9,430	8.6	148.3	5,055
Tillamook	2,843	8,014	11.1	82.6	4,465
Lincoln	2,897	7,909	11.0	124.9	4,625
Coos	2,999	9,243	8.1	273.7	4,556
Curry	3,022	8,544	11.6	61.4	4,406
State of Oregon	3,163	9,489	8.0	12,176.0	5,398
Humboldt	3,015	8,919	10.2	514.2	4,911
Del Norte	2,825	9,154	9.7	74.0	4,774
State of California	3,632	10,732	8.4	126,116.7	6,041

The foregoing sections on the region's basic industries have indicated that seasonal unemployment is a fact of life for many workers. Table 4-48 shows the actual (not seasonally adjusted) deviation from average unemployment levels in 1975 in each county. Overall unemployment levels tend to be higher than the state averages, as illustrated by Table 4-49. Unemployment levels also vary widely from year to year due to the cyclically unstable nature of resource-based industries. The forestry and forest products industry, for example, has traditionally been affected by national economic trends and monetary policy as reflected particularly in housing activity and construction materials demand. Fisheries are affected by cyclical changes in the fisheries biomass. Agriculture is affected both by weather conditions which show

TABLE 4-48. UNEMPLOYMENT LEVELS IN THE COASTAL REGION, 1975.
Note: Seasonal patterns vary by county, so highest and lowest months shown are not always the same calendar month. (From California State Employment Development Department, 1977; Washington State Employment Security Department, 1976; Oregon State Employment Division, 1977.) (Data are in percent of labor force.)

Area	Annual Average	Highest Month	Lowest Month
Clallam	11.2	13.5	9.0
Jefferson	12.5	15.9	9.8
Grays Harbor	12.4	15.3	9.7
Pacific	11.2	12.9	9.7
Wahkiakum	7.6	N.A.	N.A.
State of Washington	7.2		
Clatsop	10.8	17.0	6.4
Tillamook	14.5	21.3	9.6
Lincoln	10.7	14.2	7.5
Coos	14.5	18.3	11.4
Curry	13.6	20.8	8.5
State of Oregon	10.6		
Humboldt	14.9	19.5	12.0
Del Norte	N.A.	27.7	16.5
State of California	9.9		
U. S.	8.5		

TABLE 4-49. AVERAGE ANNUAL UNEMPLOYMENT. (From Washington Employment Security Department; Oregon Department of Human Resources, Employment Security Division; California Employment Development Department; various years.) (Data are in percent of labor force.)

County	1972	1973	1974	1975	1976
Clallam		8.0	7.3	11.2	9.1
Jefferson		8.1	7.8	11.9	9.5
Grays Harbor		8.9	8.9	12.5	7.9
Pacific		8.0	7.9	11.2	9.9
Wahkiakum				7.6	
State of Washington	9.5	7.7	7.2	9.5	-
Clatsop	7.9	7.1	7.5	10.8	9.3
Tillamook	6.0	5.9	10.6	14.5	10.1
Lincoln	7.0	6.4	8.1	10.7	9.4
Coos	8.8	7.2	9.1	14.5	11.7
Curry	6.8	7.3	9.0	13.6	12.3
State of Oregon	5.9	-	7.5	10.6	-
Del Norte					
Humboldt	9.4	10.9	12.2	14.9	12.3
State of California	7.6	7.0	7.3	9.9	9.2
U.S.			5.6	8.5	7.7

apparently cyclical variations and by changes in pricing policy. Even recreation is strongly affected by weather conditions and the factors affecting the fish population as well as by levels of disposable income relative to travel costs.

The Humboldt and Del Norte County labor market areas of the California Employment Development Department, which are among the most heavily dependent on forestry and forest products, have been classified as areas of persistent unemployment. Humboldt County's rate in 1975 was 46% above the California rate and 60% above the U. S. rate. In 1974, the percentage differences were 66% and 115% respectively (California State Employment Development Department, 1976). This county has consistently exhibited one of the highest levels of unemployment in the region, a problem now exaggerated by expansion of the Redwood National Park and its effects upon forestry. Del Norte County's unemployment levels swing cyclically and seasonally in a manner even more extreme than that typical of Humboldt County (Broida et al., 1975). While these two counties represent perhaps the most severe problems, many other coastal counties are not significantly better off.

4.9.1.3 Labor Force Participation. Per capita income is a function not only of industry employment levels and pay scales but also of the number of family members who work. The number of persons employed or looking for work comprises the labor force.

Labor force participation rates are a measure of the degree to which the human resources of an area are being utilized and the level of employment opportunity in an area. With the exception of Coos County, Oregon, Table 4-50 shows that rates for males in the coastal counties were slightly lower than the average for the state. In addition, in all areas of the Coastal Region except in Clatsop County, Oregon, the rate for females was considerably lower than state and national norms.

The 1970 Clatsop County female labor force participation rate was relatively high because of employment opportunities for women in the seafood processing plants in Astoria (Kuhn et al., 1974). It should be noted that the previous section showed a higher average per capita personal income in Clatsop County than elsewhere on the coast. The next highest participation rate for women in Table 4-50 is for Lincoln County, which is specialized in recreation and tourism in which opportunities for female employment are good. The low figures for men in Lincoln and Tillamook Counties probably reflect the concentration of retired people in those counties. Many other coastal areas have a significant number of women who are potential labor force participants promising a potential labor supply to future expansion or establishment of labor-intensive industries in the area.

Little is known about the economy of Wahkiakum and why so few women should participate in its labor force. It is also not known why this county should have the highest per capita personal income of all twelve counties, and the lowest unemployment rate in 1975, the only year for which data are available.

TABLE 4-50. MALE AND FEMALE LABOR FORCE PARTICIPATION RATES, 1970.
(From U.S. Dept. of Commerce, 1970, Census of Population.) (Data in percent.)

AREA	MALE	FEMALE
Clallam	72.6	33.4
Jefferson	68.2	30.5
Grays Harbor	74.9	36.6
Pacific	68.2	34.5
Wahkiakum	74.7	26.6
Washington	77.6	40.7
Clatsop	73.1	40.6
Tillamook	70.8	36.8
Lincoln	67.2	37.9
Coos	77.6	35.3
Curry	74.2	34.3
Oregon	74.6	40.5
Del Norte	75.4	38.8
Humboldt	70.6	36.5
California	77.6	42.2

4.9.1.4 Population. In general terms, the region is lightly populated, rural, and slow-growing. The only counties to have experienced a period of rapid growth comparable to more urbanized areas of the West Coast are Curry County, Oregon, and Del Norte County, California, both of which more than doubled in size during the 1950's. Table 4-51 shows Clallam and Jefferson counties as experiencing the highest growth rates since 1960. This growth, however, was mainly due to high levels of in-migration to the eastern portions of each county beyond the boundary of the coastal region defined for this study (Washington State DCED, 1977A). With the exception of these two counties, most recent growth within the region has been due to natural increase rather than migration. Pacific County, for example, experienced almost no net in-migration between 1970 and 1975, while Grays Harbor County had a net out-migration of 742 people during that period (Washington State DCED, 1977B). See Volume 1, Section 4.1.5 for a general discussion and model of the components of population change.

Most population increases or losses in the Coastal Region have been traceable to changes in the employment situation in local basic industries. The decline of Clatsop County's population in the 1950's, for example, was due to loss of local military installation activity, while the concurrent rapid growth in Curry County was due to a major increase in "furniture, lumber, and wood products" employment. In the following decade, however, employment losses in that industry caused a 7% population decline (Kuhn et al., 1974). A loss of 1000 persons each in two communities (Port Orford and Powers) due to closure of a plywood mill and a saw mill have caused major concern in Curry County (U.S. Department of Agriculture, 1978C). Such examples illustrate the vulnerability of these small coastal region communities to changes in single industries.

TABLE 4-51. POPULATION AND POPULATION CHANGE BY COUNTY, 1950-1976. (From U.S. Department of Commerce, Bureau of the Census, 1950, 1960, and 1970. 1976 figures from Washington State DCED, 1977A, 1977B; Oregon State Employment Division, 1977; and California State, Statistical Abstract, 1977.)

Area	1950	1960	% Change	1970	% Change	1976	% Change
Clallam	26,396	30,022	13.7	34,770	15.8	39,800	14.5
Jefferson	11,618	9,639	-17.0	10,661	10.6	11,800	10.7
Grays Harbor	53,644	54,465	1.5	59,553	9.3	60,500	1.6
Pacific	16,558	14,674	11.4	15,796	7.6	15,800	0.0
Wahkiakum	3,835	3,426	10.7	3,592	4.8	3,682	2.5
Washington	2,378,963	853,214	19.9	3,409,161	19.5		
Clatsop	30,776	27,380	-11.0	28,473	3.9	29,300	3.1
Tillamook	18,606	18,955	1.9	18,034	-4.9	18,500	0.9
Lincoln	21,308	24,635	15.6	25,755	4.5	27,600	7.1
Coos	42,265	54,955	30.0	56,515	2.8	59,500	5.6
Curry	6,048	13,983	131.8	13,006	-7.0	14.100	7.1
Oregon	1,521,341	1,768,675	16.2	2,091,385	12.6		
Del Norte	8,078	17,800	120.0	14,580	-18.8	15,700	7.9
Humboldt	69,975	104,900	51.5	99,692	-5.0	106,100	6.4
California	10,586,223	15,717,204	48.5	19,957,304	26.9		
Coastal County Total	309,107	374,834	21.3	380,427	1.5	402,382	5.8

In general, since 1960, the population of urban areas in the Coastal Region has increased more rapidly than that of rural areas. More specifically, the areas within the coastal counties oriented toward recreation and retirement industries have tended to grow faster than those devoted to manufacturing (Kuhn et al., 1974). In counties historically influenced by fluctuations in resource industries, tourism has enabled many small coastal towns to stabilize or even increase population levels (Washington State DCED, 1977B). In Lincoln County, for example, Toledo, a manufacturing center, had an annual rate of decline in population of 0.3% (for a total of -3.7%) from 1960 to 1973. Over the same period, the Waldport and Delake areas, both tourist and recreation oriented, grew by 14.5% and 30.0% respectively (Kuhn et al., 1974).

4.9.1.5 Age Composition. The coastal region has large concentrations of elderly people and smaller concentrations of young people and people in the prime working age group (25 to 44) than the three states as a whole (Kuhn et al., 1974; Washington State DCED, 1977A, 1977B). The reason appears to be the out-migration of young people. The pattern is particularly important in Oregon which itself had fewer young people and more elderly people than the U. S. as a whole in 1970. Clearly another reason for this pattern is the growing settlement of retired persons in the region. In the five Oregon coastal counties, the retired population grew from 6.8% of total population to 14.7% between 1958 and 1973 (Kuhn et al., 1974). The same source projects a growth to 19.5% by 1985.

The region's age structure is different for several reasons. Retired people rely heavily on outside income in the form of investments, social security, or welfare payments. A considerable part of the region's income is therefore derived from federal transfer payments. Secondly, the age structure influences the level of demand for locally provided services. Thirdly, if an area is to expand economically, there is a need for an adequate labor force and skills. It is the middle-aged and parents of young children who usually can supply these needs (Schmisseur and Boodt, 1975). Continued out-migration of young adults and parents of young children in response to employment opportunities elsewhere affects the region's prospects for economic expansion.

4.9.1.6 Racial Composition. American Indians represent the predominant minority in the coastal areas of Washington, Oregon, and California. The coastal region traditionally and culturally is associated with various American Indian groups, including the Klamath, Coos, Tillamook, Siletz, Quinault, Hoh, Quillayute, Ozette, and Makah Indians. Spanish Americans are also important in some areas and, together with Asians, appear to be increasing as a percentage of the population. Civilian labor force, employment, and unemployment data for 1975 indicate that minorities, American Indians especially, have an employment problem, as evidenced in Clallam County where minority unemployment was over 40% (Washington State Employment Security Department, 1976).

4.9.1.7 Educational Characteristics. Educational characteristics provide an index of an area's occupational skills and ability to adapt to change. In all coastal counties, median school years completed by adults in 1970 were lower than state norms, ranging generally from 12.0 to 12.2 compared with figures of 12.3 in Oregon and 12.4 in Washington and California. While the differences are not great, data on this parameter would ordinarily show minimal variance. In some counties, including Curry and Tillamook, males have significantly less education than the national norm (U.S. Department of Commerce, 1970). An Oregon study also shows that the coastal region counties in general have lower education participation than the state norm (Schmisseur and Boodt, 1975). The figures are probably depressed by the high proportion of retired persons. Educational levels are important to the region's adaptability, however. Higher education facilities, such as community colleges, have potential to increase local occupational skills. Major institutions, such as Humboldt State University, also have a stabilizing influence on the economy (California State Employment Development Division, 1976). (Additional data on educational levels will be found in OIW, 1977, Volume X.)

4.9.1.8 Housing Characteristics and Demands. The employment supported directly or indirectly by the region's basic industries (including the second home industry discussed in Section 4.4.3) creates housing demands, as mentioned in Volume 1, Conceptual Model, Section 4.1.5. Throughout the region, the actual number of housing units is substantially higher than would be expected using standard methods of estimation, including household size and typical vacancy rates. 12.4% of units were shown by the 1970 census to be vacant year-round, compared with 8.2% in Washington and 5.9% in Oregon (see Table 4-52). The high vacancy rates are not explained by the use of seasonal or vacation housing which accounted for only 2.4% of all units (OIW, 1977). Clatsop, Tillamook, Lincoln, Jefferson, Pacific, and Grays Harbor Counties all had rates of vacant units far above the rates in Oregon and Washington. Recent information on housing is extremely scarce, making interpretation difficult.

Projections of housing unit growth from 1975 to 1990 prepared for Oregon and Washington counties by Bonneville Power Administration show an estimated increase in the 10 counties of approximately 23% (OIW, 1977). This is a little under an average annual growth rate of 1% per year (rather higher than the rate of employment increase projected for some counties in the region in such studies as Kuhn et al., 1974).

TABLE 4-52. SELECTED HOUSING CHARACTERISTICS FOR COASTAL REGION COUNTIES, 1970. (From U.S. Department of Commerce, Bureau of the Census (Census of Housing), 1970.)

AREA	ALL UNITS	SEASONAL AND MIGRATORY UNITS	% OWNER OCCUPIED	% RENTER OCCUPIED	% VACANT YEAR-ROUND	TOTAL YEAR-ROUND UNITS
Washington Coastal Counties	48,854	1,258	63.4	24.9	11.5	47,596
Washington	1,220,475	16,288	61.3	30.5	8.2	1,204,187
Oregon Coastal Counties	57,030	1,306[1]	60.4	26.4	13.1	55,724
Oregon	744,616	9,373	62.2	31.9	5.9	735,243
California Coastal Counties	40,563	167	56.3	35.6	6.2	40,396
California	6,996,990	20,246	51.8	42.5	5.8	6,976,744

[1] 61% of these units are in Lincoln County.

4.9.2 Land Use Patterns.

4.9.2.1. Existing Land Use. The strong dependence of the Pacific Northwest Coastal Region on resource-based or extractive industry, rather than diversified manufacturing, results in land use with a lightly populated, rural character. Average density is approximately 23 persons per square mile. Figures for the states of Washington, Oregon, and California are 51, 22, and 126 per square mile respectively.

A detailed and up-to-date inventory of coastal region land use is apparetnly unavailable. Some sources, including the U.S. Departments of Agriculture (see data in Kuhn et al., 1974) and Commerce (Bureau of the Census, Census of Agriculture, 1969 and 1974), provide comprehensive surveys. Land use classes covered, however, are quite restricted and data are not recent. Other sources, such as special county planning inventories, are in certain cases more up-to-date and detailed. Land use classes and survey methods differ, however, making county-by-county comparisons difficult. Examination of trends over time is also difficult for the same reasons.

Table 4-53 provides the only available summary of recent data. (It should be noted that Del Norte and Humboldt County data, in particular, require updating.) Only three broad categories can be compared. The "Other Uses" category contains water and recreational areas and therefore cannot be interpreted as urban land use.

TABLE 4-53. LAND USE BY MAJOR CATEGORY, PACIFIC NORTHWEST COASTAL REGION. Data are in thousands of acres. Note: Comparison of 1967 with 1974 Census of Agriculture data for Humboldt County indicates a major increase in farm and range acreage. Recent forest acreage figures are required to confirm this, since a conversion from forest is implied. Forest land data from U.S. Forest Service, Oregon, 1973 (Bassett and Choate, 1974A and B), Coos, Curry, 1975 (Bassett, 1977). Farmland data from Census of Agriculture, 1974 (Department of Commerce, 1977D). Humboldt County data from U.S. Soil Conservation Service, (USDA, 1967), and Del Norte County data from Broida et al. (1975.)

COUNTY	TOTAL LAND AREA	FOREST[1] LAND ACRES	%	FARM[2] LAND ACRES	%	OTHER USES ACRES	%
Clallam	1,121.6	971	86.6	21.7	1.9	128.9	11.5
Jefferson	1,155.3	1,031	89.2	7.6	0.7	116.7	10.5
Grays Harbor	1,222.3	1,107	90.6	36.0	2.9	79.3	6.5
Pacific	581.2	535	92.1	20.9	3.6	25.3	4.4
Wahkiakum	166.8	149	89.3	11.8	7.1	6.0	3.6
Washington Coastal Total	4,247.2	3,793	89.3	98.0	2.3	356.2	16.8
Clatsop	548.8	487	92.8	18.0	3.4	19.8	3.8
Tillamook	713.6	644	90.2	33.3	4.7	36.3	5.1
Lincoln	630.4	574	91.1	17.9	2.8	38.5	6.1
Coos	1,031.0	868	84.2	102.0	9.9	61.0	5.9
Curry	1,038.1	949	91.4	72.0	6.9	17.1	3.6
Oregon Coastal Total	3,937.9	3,522	89.4	243.2	6.2	172.7	4.4
Del Norte	644.4	571	88.6	15.2	2.4	58.2	9.0
Humboldt	2,295.2	1,866	81.3	349.0[3]	15.2	80.2[4]	3.5
California Coastal Total	2,939.6	2,437	82.9	364.2	12.4	138.4	4.7
Coastal Region Total	11,124.7	9,752	87.7	705.4	6.3	667.3	6.0

[1] Includes farm forest land.

[2] Includes cropland, pastureland, and other farmlands, but excludes forestlands.

[3] Predominantly rangeland.

[4] Estimate by EDAW, Inc. (50 Green Street, San Francisco, CA 94111)

Those more detailed data which are available suggest that Grays Harbor and Coos Counties contain the greatest proportion of built-up land of the twelve counties. A relatively large proportion of settlement is in rural areas and small towns. The major population centers, however, are the port cities of Aberdeen and Hoquiam on Grays Harbor, Astoria, Newport, Coos Bay, Brookings, Crescent City, and Eureka. These cities are the location of most manufacturing and processing industry in the region.

Forestlands average, very approximately, close to 90% of total land area, ranging from 81% to 92%. The largest acreage in farmland occurs in Humboldt County which has extensive rangeland. Comparison of 1967 Soil Conservation Service data with 1974 Census of Agriculture data shows an increase from 349,000 to 508,000 acres in agriculture in Humboldt county. 1976 forest acreage figures are awaited to determine if this change represents a major reduction in forest acreage. Agricultural acreage is a quite insignificant share of total acreage in all other counties except for Wahkiakum, Coos, and Curry.

4.9.2.2. Land Use Trends. Small towns and suburbs surrounding some of the cities are expanding and (as noted in Section 4.9.1.2) increasing urbanization is occurring in coastal communities throughout the region where tourism, second home, and retirement homes are important. Pressure for urbanization on the Oregon coast has been documented in detail by the Oregon Land Conservation and Development Commission (Pacific Planning Associates, 1975). Plans are in preparation for the Washington and California coastal zones. The trend has been for development to occur in a leap-frog pattern, reducing the efficiency of use, and the environmental quality of both developed and intervening vacant areas and leading to profound changes in the total environment. Modification of shoreland vegetative cover, neglect of special geologic hazards, modification of runoff patterns, increased pollution, sedimentation of coastal and estuarine waters, and competing or conflicting uses are major consequences of recent development along the coast (U. S. Department of Commerce, 1977D). The natural systems effects of urban settlement are further discussed in Section 4.9.2.4 and in McHarg (1969).

With the apparent exception of Humboldt County, mentioned above, forest and agricultural acreage has been diminished over the past ten to fifteen years as urban development has expanded, and the extent of conversion can only be generally indicated. The Environmental Impact Statement on the State of Oregon's Coastal Management Plan (U. S. Department of Commerce, 1977D) indicates land use patterns and ownership in coastal Oregon have shifted markedly since the mid-1960's. Table 4-54, taken from data collected for the EIS, suggests the extent of land use change in two Oregon coastal counties. In general, the study states, there has been a strong decline in forest and agricultural lands and a lesser decline in lands used for public service activities.

Reflecting an increase in recreational (second-home) use in the coastal zone, there has been a significant decline over the last eight years in the number of parcels owned by residents in the coastal zone. An increasing number of parcels are owned by persons residing in the Willamette Valley and even outside of the State. The mean size of parcels in all land use categories is also decreasing. Finally, the assessed property values are increasing at a rate exceeded in Oregon only by the heavily urbanized Portland metropolitan area. These changing patterns reflect the problems which face Oregon's coast: maintaining the natural resource base necessary to support a diverse and healthy economy and environment. The proliferation of individual land parcels and owners, many of whom place a seasonal stress on local facilities while contributing only marginally to the economy, is one problem the Oregon Coastal Management Program is intended to address (Oregon LCDC, 1976).

TABLE 4-54. CHANGE IN COASTAL LAND USE: ESTIMATED NUMBER OF PARCELS AND PERCENT OF PARCELS BY LAND USE CLASS, 1967 - 1973. Totals may not agree due to weighting and rounding of data. Separate runs were made of three sets of data and each produced values that were rounded and weighted leading to minor discrepancies. (From U.S. Department of Commerce, 1977D.)

LAND USE CLASS	ABSOLUTE CHANGE (NO. OF PARCELS)			PERCENT CHANGE		
	LINCOLN CO. SUBAREA	TILLAMOOK CO. SUBAREA	COMBINED AREA	LINCOLN CO. SUBAREA	TILLAMOOK CO. SUBAREA	COMBINED AREA
A. Single family residential	616	525	1146	27.34	39.41	31.90
B. Multifamily residential	25	42	67	100.00[1]	2100.00[1]	248.15[1]
C. Commercial	87	85	172	71.31	188.89	102.38
D. Industrial	19	0	19	27.14	0.00	26.39
E. Idle or vacant	65	-599	-534	1.54	-18.03	-7.05
F. Agriculture with residence	-50	-9	-62	-58.82	-11.25	-35.63
G. Agriculture without residence	-770	-24	-797	-91.56	-21.24	-82.59
H. Forest land	-17	1	-15	-29.82	1.01	-8.98
I. Recreational	23	2	25	85.19	9.01	50.00
J. Public service facilities	2	-23	-21	9.52	-48.94	-30.43

[1]Exceptionally high value due to weighting of data.

Coastal management policy in the states of Washington and California, as in Oregon, is directed to concentrating development in existing urban areas and planning land use based upon environmental and economic suitability.

In addition to the spread of urban settlement, an increasing portion of the Pacific Northwest Coastal Region is being taken out of direct resource production for various environmental preservation programs. Among these programs are the expansion of the Redwood National Park and possible creation of new wilderness areas or maintenance of existing roadless areas after evaluation of RARE II proposals (U.S. Department of Agriculture, 1978A-D). In addition, establishment of refuges or natural recreation areas further reduces productive or developable areas. Examples include three wildlife recreation areas acquired along the perimeter of Grays Harbor estuary, Washington, and the National Estuarine Sanctuary on South Slouth of Coos Bay, Oregon. Such changes in land use or ownership status have established economic as well as environmental, aesthetic, or passive recreational benefits.

Major economic and employment adjustments are necessitated by such wide-ranging actions as the Redwood Park expansion. Nevertheless, the presence of additional widely publicized areas with public access is expected to increase tourism and lengthen stays in the area. Increased hunting and non-consumptive uses of wildlife such as birdwatching and photography also have an economic value. The U. S. Army Corps of Engineers (1976C) reports that these activities were valued at $290,000 and $160,000 respectively in Grays Harbor County in 1975. There are other social and economic benefits associated with preservation. These include the protection of the environmental requirements of productive resources in order to prevent the long term loss of employment due to resource exhaustion. In addition, it is the stated policy of the Oregon Coastal Management Plan (Oregon LCDC, 1976), to maximize the net benefits of aesthetic, cultural, historic, ecological, recreational, and economic values.

4.9.2.3 Natural System Effects of Settlement. The literature on the effects of development on natural resources is extensive. A preliminary listing of studies can be found in the Annotated Bibliography key word (descriptor) index under IMPACT. General texts which treat the subject include Simmons (1974), Detwyler (1971), John Grahm Co. (1976), Darnell (1976), and Real Estate Research Corporation (1974).

ECOLOGICAL CHARACTERIZATION
OF THE
PACIFIC NORTHWEST COASTAL REGION

VOLUME TWO
CHARACTERIZATION ATLAS -
REGIONAL SYNOPSIS

Part Two

SPECIES OF CONCERN

SPECIES OF CONCERN

A number of organisms within the region are of significant interest or concern, either because of commercial value (e.g. Douglas fir, Dungeness crab), recreational value (e.g. black-tailed deer, salmonids), rare, endangered, or threatened status (e.g. Columbian white-tailed deer, bald eagle), or community dominance (e.g. eelgrass, western hemlock). Many species fall into more than one of these categories such as Douglas fir, which is a commercial species and a dominant species in many second growth forests, or salmon, which are of both recreational and commercial significance.

Section 3.4 of this volume discusses Species of Concern in a general way and provides data on harvest and catch by areas and by species for commercial and recreational plants and animals, as well as access to pertinent literature for these and the rare, endangered, or threatened species.

Seventeen species of plants and animals, plus three groups of species (insects, sea birds, and marine mammals), have been selected for more detailed treatment of their biology and relationships with human activities. Table 1 provides a list of these species or groups in the order in which they are presented in this Part of Volume 2. Extra pages were omitted for future additions to these descriptions.

TABLE 1. SPECIES OF CONCERN. The following species or groups are discussed in detail in this Part 2 of Volume 2. These species accounts, presented in order as below, are prepared as notes to the population model (see Figure 1.)

			PAGES
PLANTS			
	trees:	Douglas Fir (Pseudotsuga menziesii)	P-11 to P-17
		Oregon Myrtle (Umbellularia californica)	P-21 to P-22
		Port Orford Cedar (Chamaecyparis lawsoniana)	P-31 to P-33
		Red Alder (Alnus rubra)	P-41 to P-43
		Redwood (Sequoia sempervirens)	P-51 to P-53
		Sitka Spruce (Picea sitchensis)	P-61 to P-63
		Western Hemlock (Tsuga heterophylla)	P-71 to P-73
		Western Red Cedar (Thuja plicata)	P-81 to P-85
ANIMALS			
	invertebrates:	Dungeness Crab (Cancer magister)	A-11 to A-14
		Insects	A-21 to A-24
	fish:	Chinook (Oncorhynchus tshawytscha)	A-31 to A-34
		Coho (Oncorhynchus kisutch)	A-41 to A-43
	birds:	Bald Eagle (Haliaeetus leucocephalus)	A-51 to A-53
		Sea Birds (Alcids, Shearwaters, Petrels, Gulls, etc.)	A-61 to A-66
		Snowy Plover (Chadaerius alexandrinus)	A-71 to A-73
		Spotted Owl (Strix occidentalis caurina)	A-81 to A-84
	mammals:	Black-tailed Deer (Odocoileus hemionus columbianus)	A-91 to A-96
		Columbian White-tailed Deer (Odocoileus virginianus leucurus)	A-101 to A-104
		Marine Mammals (Cetaceans, Seals, Sea Otter)	A-111 to A-113
		Roosevelt Elk (Cervus canadensis roosevelti)	A-121 to A-122

The individual species accounts follow an outline based on the population model discussed in Section 3.4 of Volume 1 and shown here as Figure 1. A general description (1) is given first, followed by discussions about (2) population (size and range), (3) migration (if applicable), (4) external population factors (applicable to those that migrate), (5) reproductive rate (fecundity, sexual notes, nesting, seed production), (6) growth rate (data where available, plus information on feeding habits), (7) death rate (mortality, major predators or diseases), (8) carrying capacity, (9) limiting factors (nutrients, habitat, mortality factors), (10) human activities (use and/or impacts), and (11) natural perturbations. Definitions and brief comments on these ten components of the model (other than general description) are found in Section 3.4 of Volume 1.

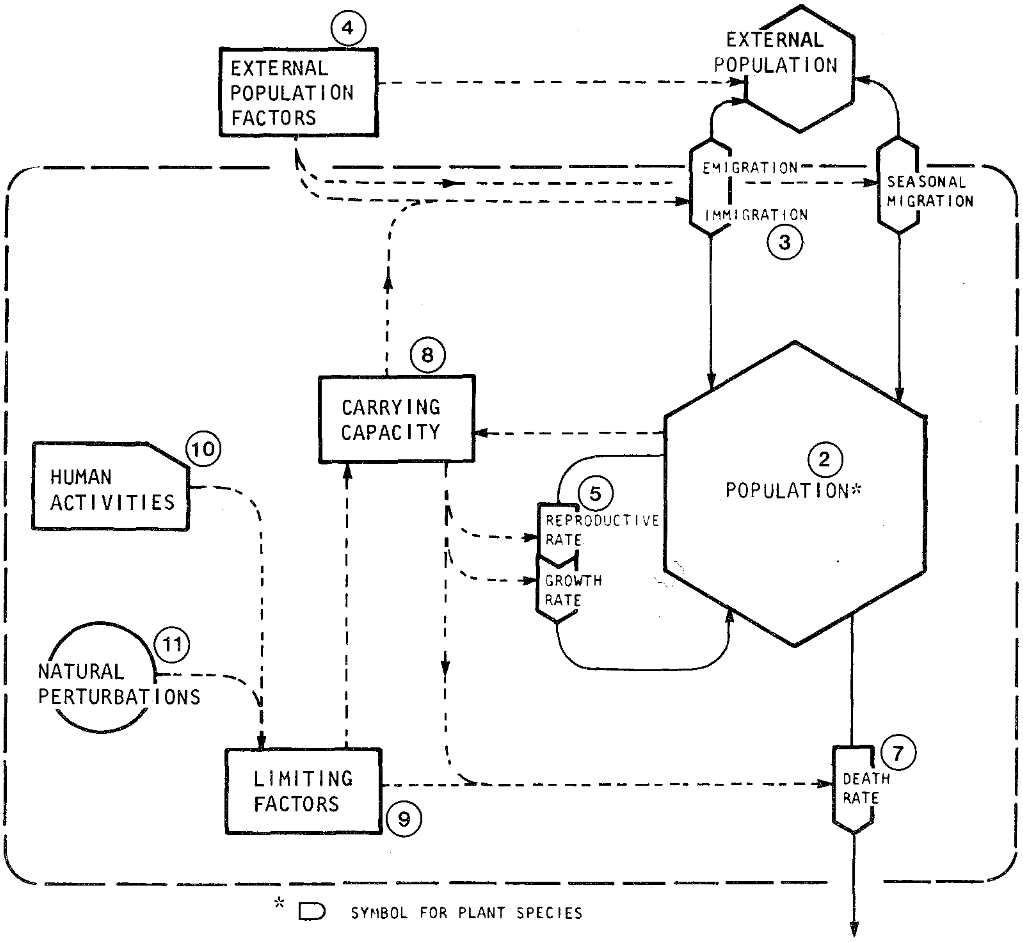


FIGURE 1. SPECIES POPULATION MODEL. A number of internal, environmental, and external factors influence or impinge on a given population. These are discussed in Section 3.4 of Volume 1 and form the basis for presentation of the Species of Concern data in this part of Volume 2. Numbers of items in the species accounts are as shown in the model (#1 is General Description). Habitat data will be found with factors 2, 3, 6, 8, and 9; nutritional information, primarily in 6, 8, and 9.

The three group accounts (insects, sea birds, and marine mammals) do not follow the population model outline, but rather present general information pertinent to these important species groups.

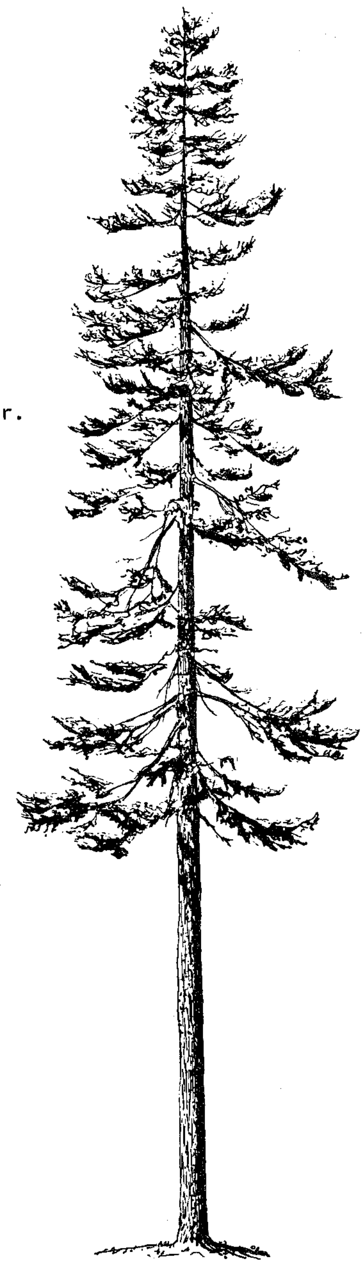
Page numbering in this part of Volume 2 follows a different system than employed elsewhere in this study. As shown in Table 1, the species accounts are divided into plants (P-designator) and animals (A-designator) and are presented in alphabetical order within subgroups of these two headings (trees, invertebrates, fish, birds, mammals); each account begins with a different unit of ten. For example, Douglas fir begins on page P-11 (P for plant, first 1 for Douglas fir account, second 1 for first page of same) and ends on page P-17; the next account, Oregon myrtle, begins on page P-21, and so on; black-tailed deer begins on page A-91 (A for animal, 9 for the 9th animal account, 1 for first page) and extends through page A-96. The name of the species or group being discussed can be found at the top of every page in the accounts.

All of the species discussed in these pages are entered in the Annotated Species List with a status designator: R for rare, E for endangered, T for threatened, P for peripheral, I for endemic, G for game, C for commercial or potentially commercial, and X for pest. The ASL can be searched by species, watershed, zone, habitat, trophic level, status, or any combination thereof. See Volume 5 for more information on this system.

DOUGLAS FIR - Pseudotsuga menziesii

1. General Description

Douglas fir is a large fast-growing commercial timber tree that is found throughout the region in lowland and slopes. It is a seral species in most of the Western Hemlock and Sitka Spruce Zones but is part of the climax community in the Mixed Evergreen Zone. The tree can grow to a height of 100 meters (330 ft) or more with a diameter of over 5 meters (16 ft), breast high, and is long-lived - to over 1,000 years. In acreage and volume it is the dominant tree species of the region. Nearly all of the private and the majority of the publically-owned commercial timber lands are managed for Douglas fir production.



Douglas fir is found in abundance throughout the study area, its range extending from Central British Columbia south to Central California in the coastal region and south into Mexico in the Rockies.

2. Population

The growing requirements of Douglas fir cause it to be found predominantly in even-aged, single-species stands in the Western Hemlock Zone. In the Mixed Evergreen Zone, it is found in mixed forests with tanoak, madrone, and Port Orford cedar, where it is a climax species. Its relative shade-intolerance prevents its growth under an established forest canopy; this species can become established when relatively large breaks in the overhead shade occur.

Table 1 presents population data available for pure, even-aged stands of Douglas fir.

The figures in Table 1 illustrate the effects of shade-intolerance, not competition. No data were found on populations of Douglas fir in virgin forest. However these figures are from an area described as "fully stocked (natural)" (McArdle et al., 1961). Figure 1 presents curves of this data for all five site classes.

3. Migration N/A

4. External Population Factors N/A

5. Reproductive Rate

Seed is produced annually; there is a crop failure about once every 4 to 5 years, and a heavy crop every 5 to 7 years. Seed retains viability for only one year. Trees do not become infertile with age; but there is no seed production before about the 10th year. There are heavier crops in poor sites and in mixed-species stands. Seed production per tree averages 4,000 for 15 year old trees, 40,000 for 100-200 year old trees, and 7,000 for 600 year old trees (Isaac, 1943).

The rate of restocking from neighboring stands is variable. On northern exposures, with favorable site, a clear area can be well stocked up to 1/4 mile (0.4 km) from seed source two years after clearing. The same exposure, with a severe summer climate, can take 10 years to adequately restock from 1/4 mile (Isaac, 1930).

6. Growth Rate

Douglas fir is a very rapid-growing and productive tree. Information on growth rate is summarized in Tables 2 and 3, and Figure 2. Table 2 indicates growth rate in early periods for different site classes while Table 3 provides volume growth information for more mature stands. Figure 2 indicates predicted height growth under optimal conditions over time.

The age of maximum volume growth is considered to be 90 years; however, authorities differ on this figure.

TABLE 1 POPULATION OF DOUGLAS FIR, BY QUALITY OF SITE[a] AND AGE. (From McArdle and Meyer, 1930.)

Age (years)	Site Class V: Average Diameter		Site Class V: Population		Site Class III: Average Diameter		Site Class III: Population		Site Class I: Average Diameter		Site Class I: Population	
no./acre	in	(cm)	no./acre	(no./ha)	in	(cm)	no/acre	(no./ha)	in	(cm)	no./acre	(no./ha)
20	1.5	(3.8)	5500	(2200)	3.4	(8.6)	1460	(594)	5.7	(14.5)	571	(231)
100	10.5	(26.7)	352	(143)	16.9	(42.9)	184	(75)	29.4	(74.7)	75	(30)
160	14.2	(36.1)	225	(90)	22.8	(57.9)	117	(47)	37.2	(94.5)	48	(19)

[a]Stands are divided into five classes, I being the best quality, V the worst.

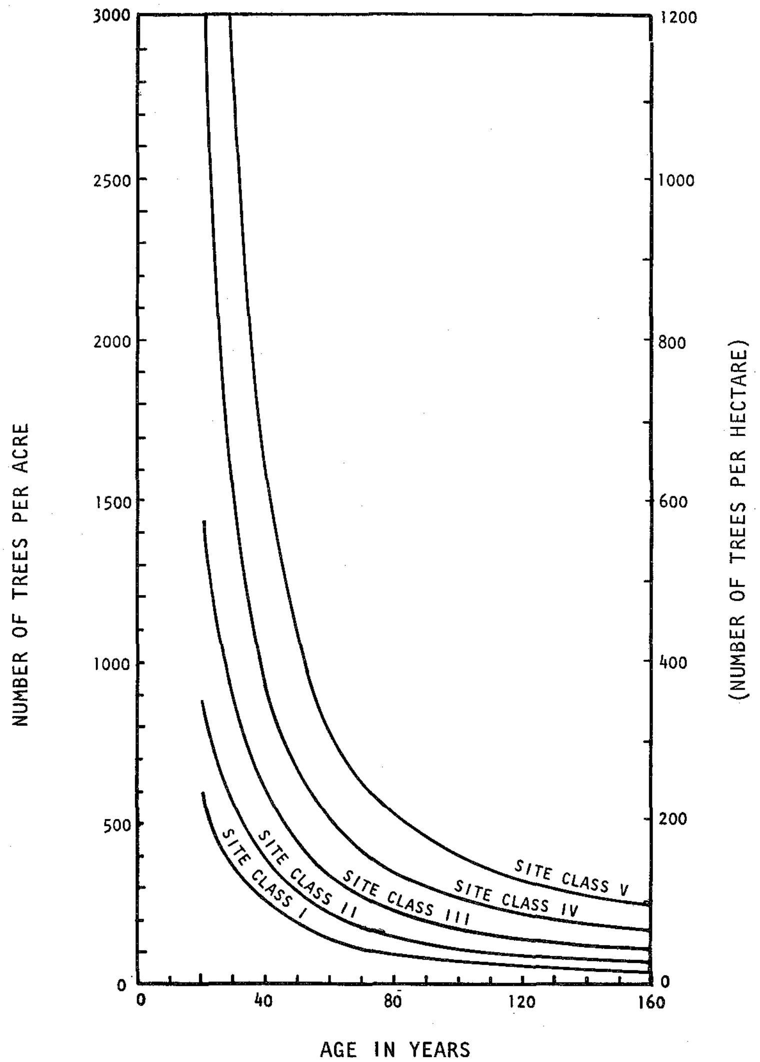


FIGURE 1. DENSITY AS A FUNCTION OF SITE CLASS AND AGE IN DOUGLAS FIR. (From McArdle and Meyer, 1930.)

TABLE 2. YOUNG (FIRST SEVEN YEARS) DOUGLAS FIR GROWTH RATES. (From McArdle and Meyer, 1930.)

Site Class [a]	Average Growth ft/year	(m/year)
I	0.8	(0.2)
III	0.4	(0.1)
V	0.3	(0.09)

a See Table 1.

TABLE 3. ANNUAL VOLUME INCREMENTS IN A MATURE DOUGLAS FIR STAND (From McArdle and Meyer, 1930.)

Age	Site Class I [a]		Site Class III		Site Class V	
Years	cu ft/yr	(cu m/yr)	cu ft/yr	(cu m/yr)	cu ft/yr	(cu m/yr)
90	198	(5.5)	138	(3.9)	56	(1.6)
160	148	(4.1)	103	(2.9)	42	(1.2)

[a]See Table 1.

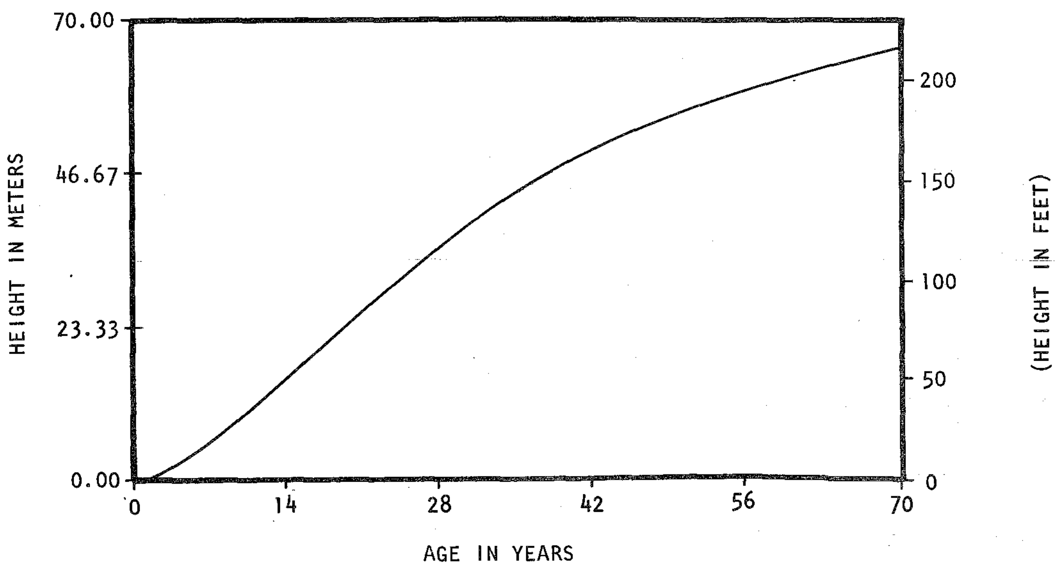


FIGURE 2. PREDICTED CUMULATIVE HEIGHT GROWTH OF DOUGLAS FIR IN AN OPTIMUM ENVIRONMENT. (From Edmonds, 1974.)

7. Death Rate

Douglas fir are long-lived with trees over 800 years old common, and some individuals being over 1,000 years old. The mortality rates are high in early stages, drop to low levels during maturity. In terms of timber volume cost, however, rates increase towards old growth due, in part, to increased mortality and the larger volume of individual trees as indicated in Table 4.

TABLE 4. CUMULATIVE MORTALITY OF DOUGLAS FIRS (IN TERMS OF VOLUME LOST). (From McArdle and Meyer, 1930.)

Age Years	Site Class I	Site Class III	Site Class V
80	22%	21%	23%
160	38%	37%	31%

The following are important causes of Douglas fir death:

windthrow (little quantitative data);
fire;
insects: Douglas fir beetle (Dendroctonus pseudotsugae),
fir borer (Melanophila drummondi);
trunk and root rots (may be very effective in killing trees):
- Fomes pini;
- Poria weirii;
- Polyporus schweinitzii;
- Fomes subroseus.

Much seed destruction occurs as a result of the activities of a number of animals. The following insects, which undergo periodic population explosions, may be responsible for destroying up to 75% of a seed crop (30,000 seeds) (Isaac, 1943):

fir cone moth (Barbara colfaxiana);
fir seed chalcid (Megastigmus spermotrophus);
fir coneworm (Dioryctia abiedella);
fir cone looper (Eupitheria spermaphaga);
gall midges (Itonidae).

Douglas fir seed is also known to be part of the diet of numerous common birds, as well as the following mammals, whose fluctuations in mass population have been correlated with the wealth or dearth of Douglas fir seed:

Douglas squirrel (Tamiasciurus douglasii);
Townsend chipmunk (Eutamias townsendii);
deer mouse (Peromyscus spp.);
Trowbridge shrew (Sorex trowbridgii).

In years of medium or light seeding the seed-eating animals appear to account for all seed produced; only in years of heavy seeding is there a germinative surplus.

The following factors account for mortality among seedlings:

1 excessive temperature at soil surface (above 125°F or 50°C, which is often observed in clearcut regions);

2 frosts;

3 excessive evaporation (causing soil moisture to fall below critical 10% level);

4 damping-off fungus (Armillana mellea) (in old growth stands);

5 mice (which may consume over 50% of young seedlings);

6 erosion (especially in environments altered by man).

8. Carrying Capacity

The carrying capacity of an environment of this species has been approximated from the greatest observed growth of Douglas fir in pure, even-aged, fully stocked stands, as shown in Table 5.

TABLE 5. OBSERVED MAXIMA OF CARRYING CAPACITY FOR DOUGLAS FIR (AGE 160 YEARS). (From McArdle and Meyer, 1930.)

Site Class[a]	Volume of Wood cu ft/acre	(cu m/ha)
I	24,660	(1700)
III	16,490	(1150)
V	8,000	(560)

[a]See Table 1.

At 160 years, the annual increments of growth show no sign of decrease; hence some authorities have estimated the maximum production in site class areas as 40,000 cubic feet per acre (3,000 cu m/hectare). Figure 3 presents yield curves for all five of McArdle's site classes.

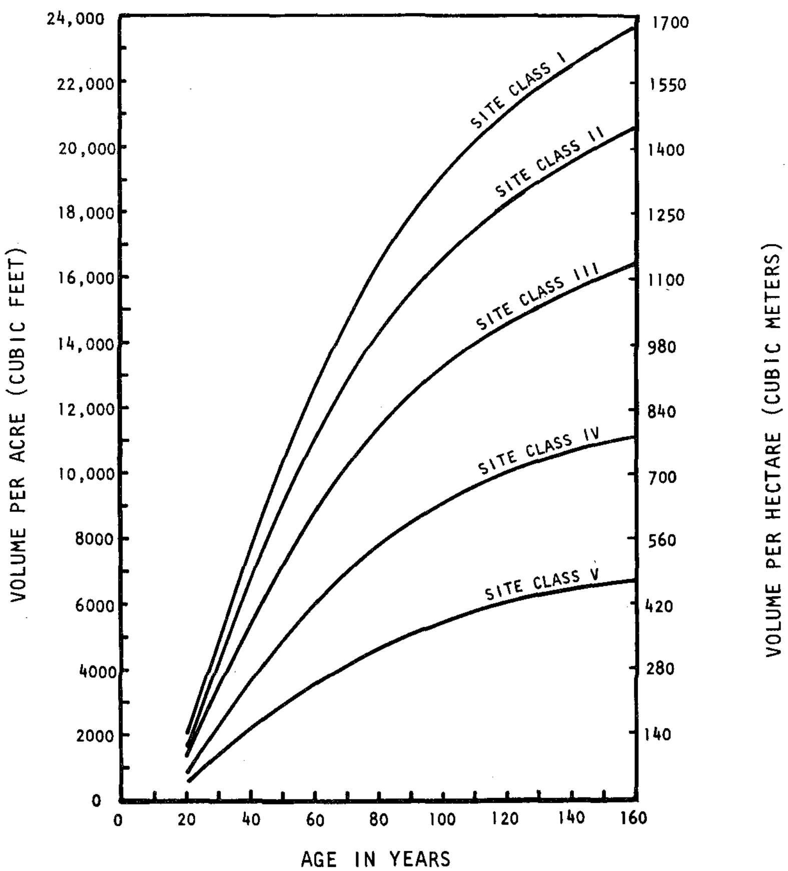


FIGURE 3. TOTAL YIELD OF DOUGLAS FIR AS A MEASURE OF CARRYING CAPACITY. (From McArdle and Meyer, 1930.)

These data are not strictly a measure of carrying capacity, but of the ability of Douglas fir to make use of environmental resources. The point in their growth where Douglas fir make the most efficient use of their resources is not known.

DOUGLAS FIR, continued

Douglas fir populations in the region are maintained above the natural carrying capacity of the region through silvicultural practices such as clearcutting, planting, fertilizing, and weeding of other species. In an unmanaged situation, a large portion of the current Douglas fir forests would revert to other forest types.

9. Limiting Factors

Climate: Rainfall in the Douglas fir's range is between 20 and 100 inches (50-250 cm); the best growth occurs with about 60 inches (150 cm) of annual rain. Temperatures within its range appear not to be a limiting factor, although extreme frosts and extreme soil temperatures can kill young seedlings.

The effect of moisture stress and temperature on Douglas fir photosynthesis (Figure 4) shows reduction in actual photosynthesis from potential expected under optimum conditions for the Coast Range in Oregon.

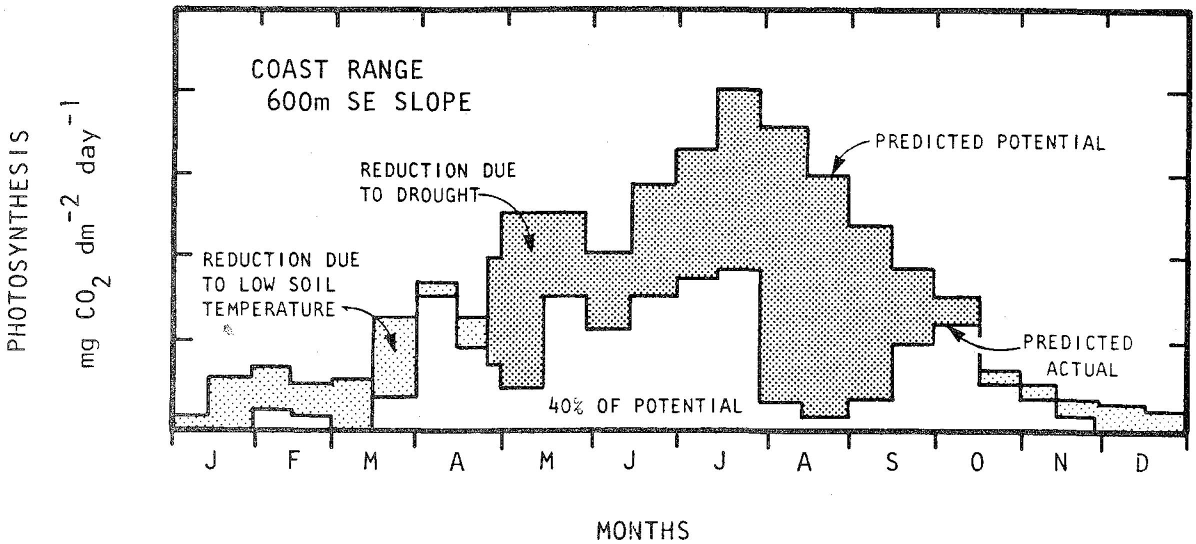


FIGURE 4. PREDICTED POTENTIAL AND ACTUAL PHOTOSYNTHESIS IN DOUGLAS FIR. (From Edmonds, 1974.)

Soil: Poor drainage or soils with an impervious layer near the surface will limit Douglas fir growth (Fowells, 1965). Its best development occurs on relatively deep, sedimentary-origin soils, such as the Melbourne, Olympic, and Astoria series.

Elevation: Douglas fir is found from sea level to about 4,000 feet (1200 m) in Washington, to about 5,000 feet (1500 m) in Oregon, and to around 6,000 feet (1800 m) in California.

Light: Douglas fir is fairly intolerant of shade and typically does not reproduce under a closed canopy.

A summary of limiting factors and their effects are given in Table 6.

10. Human Activity

Douglas fir, as the main timber tree of the United States, is very closely managed in most of the forests in the study area and has undergone significant genetic manipulation which has resulted in greatly reduced genetic variation. Great quantities are cut each year, mostly by the clearcutting method. Its occurrence has been greatly increased through silviculture practices. It is the principal species which supports the forest industry in the region.

TABLE 6. THE INFLUENCE OF SEVERAL FACTORS ON DOUGLAS FIR REGENERATION AND GROWTH. Combinations of factors are more influential than single factors in limiting growth. (From USDA, 1976A.)

Factor	Influence (+ Positive, - Negative)
Soil Depth:	
Relatively Deep	+
Shallow	-
Aspect:	
N, NW, NE, E, SE	+
S, SW, W	-
Slope:	
Gentle, Moderate	+
Steep (e.g. 70%)	-
Elevation:	
Low, Middle	+
High (e.g. above 5,000 feet or 1500 meters)	-
Precipitation:	
High	+
Low (e.g. less than 30 in/yr or 75 cm/yr)	-

11. Natural Perturbations

Periodic insect blights, wind throw, forest fires, and landslides are perturbations which significantly affect Douglas fir. Douglas fir under natural conditions was dependent on such perturbation for its occurrence, as it is a seral species over much of its range and requires open areas for regeneration.

OREGON MYRTLE or CALIFORNIA LAUREL - Umbellularia californica

1. General Description

The species is polymorphous and grows in both shrub and tree forms depending on environmental conditions. The scientific name has been preceeded by at least five other combinations (Jepson, 1910) and the plant is known by a plethora of common names. It is distinguished by yellow-green leaves 3 to 6 inches (8 to 15 cm) long and 0.5 to 1.5 inches (1 to 4 cm) wide which remain on the tree or bush for two years (Baerg, 1973). When crushed the leaves have a strong odor of camphor. The bark is reddish-brown and scaley on the trunk, becoming smoother on limbs. Under exceptional conditions it grows to heights of 80 feet (25 m); enormous trees, with a diameter up to 11.7 feet (3.5 m) and 175 feet (50 m) in height, have been recorded (Fowells, 1965).

2. Population

Oregon myrtle is widely distributed from the Rogue River, Douglas County, Oregon, south to San Diego County, California, a range of 11° latitude. It is found in two fairly distinct regions within this range - a coastal distribution and an inland Sierra Madre distribution in California (Fowells, 1965). South of the San Francisco Bay Area its distribution becomes scattered.

Oregon myrtle reaches maximum development in protected bottom lands of southern Oregon and northwestern California (Jepson, 1910). It is typically found in mixed species composition but pure stands occasionally occur. Extensive stands have been eradicated and turned to farmland (Fowells, 1965).

In pure stands densities have been measured at 320 trees per acre (130 per hectare) in favorable conditions (Fowells, 1965). In shrub state densities are probably greater.

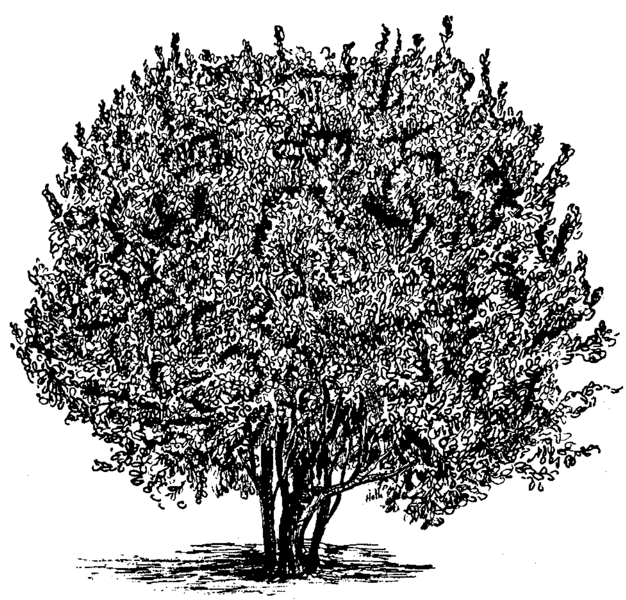
3. Migration N/A

4. External Population Factors N/A

5. Reproductive Rate

The species flowers often and profusely, usually between December and May, with flowers appearing later on annual growth (Fowells, 1965). Pollination depends primarily upon insects.

Each flower cluster has from four to nine flowers but usually only one to three fruits set (Jepson, 1910). Trees do not appear to fruit abundantly until they are 30 to 40 years old (Fowells, 1965). Characteristic seed crops per acre or individual are not well documented. Seeds fall to the ground in the fall, and are distributed by water, gravity, and small mammals.



Viability of seeds under natural conditions is thought to be transient (Fowells, 1965). What may be more critical is the lodging of the seed on a disturbed site, or an area that has been silted, as covered seeds germinate best.

Oregon myrtle also reproduces asexually, sprouting prolifically from stems, roots, collar, stump, and trunk. Fallen live trunks are frequently enveloped in such a growth.

6. Growth Rate

The Oregon myrtle's growth rate is site specific and is greatest in the southwest Oregon and northwest California coast in Watershed Units 6S, 7, 8, 9. Even on good sites it is considered to be a slow grower, but 1 to 2 feet (0.3 to 0.6 m) of growth per year can be expected with good conditions in pure stands (Fowells, 1965). In a stand with trees 64 to 98 years old, d.b.h. was from 9 to 24 in (23 to 60 cm) (Fowells, 1965). Trees do not appear to reach sexual maturity until 30 to 40 years of age. The growing season is typically April through September.

7. Death Rate

The seed nuts are consumed in great quantity by rodents and hogs. Dusky-footed wood rats feed on them extensively (Baily, 1936). Hogs can gain good weight on the seeds but the meat acquires a peculiar taste.

In closed canopies the laurel is not tolerant of its own dense shade and seedlings die before they reach the sapling stage.

The tree is susceptible to windthrow and snow breakage. High winds with heavy precipitation, and/or snow, increases damage. The tree is readily molded by wind (Jepson, 1910).

Because of its thin bark it is readily top-killed by fire, but root sprouts can successfully reestablish the myrtle; it often becomes a dominant shrub on burnt-over areas in its range.

Over 40 species of fungi have been recorded on the laurel, but only a few are restricted to the tree. Damage is typically light on live trees. Leaf blights occur occasionally, but cause little mortality (Fowells, 1965). Wood rot by the saprophytic rainbow fungus (Polystictus versicolor) is common on dead myrtles and on wood in storage.

The species has no current serious insect enemies. An imported scale (Icerya purchasi) was once a serious problem but is now under control through biological means (Fowells, 1965). A leaf miner (Cameraria umbellulariae), a leaf beetle (Dichelonyx valida), and a bark scale (Aspidiotus camelliae) are common on this species but only cause minor damage.

The tree is heavily utilized by black-tailed deer in the northern coast range of California (Longhurst et al., 1952) but little mortality to adult trees occurs.

8. Carrying Capacity

Conditions which establish optimum carrying capacity are discussed in the limiting factors section to follow. Because much of the prime bottomlands habitat for the laurel has been converted to agriculture, carrying capacity for the tree form has been greatly reduced.

9. Limiting Factors

Climate: The species is found through a wide range of climatic conditions ranging from cool-humid to hot-dry. It endures temperature extremes varying from -6°F to 114°F (-21 to 45°C). Average rainfall varies from 25 to 71 in (63 to 180 cm) through its range, with 4 to 13 in (10 to 33 cm) falling during the growing season. In the southern extent of its range it is probably limited by moisture, while probably being limited by cool temperatures near its northern boundary.

Soils: Similarly to climate, the species is found in a wide variety of soils and textures as long as soil moisture is constant and plentiful (Fowells, 1965). It is found on alluvium, sedimentary soils, and volcanic soils (Fowells, 1965) and on older formations of the Siskiyou Mountains including serpentine (Whittaker, 1954). Optimum growth and development occur on alluvial and valley bottom soils that are occasionally inundated by high water, e.g. within the flood plain. In drier climates it is frequent on gravelly outwashes at mouths of canyons.

Elevation: Like climate and soils, it is found over a wide range of elevations within the study area. It is found from sea level to 4,000 feet (1200 m) but on interior sites it is found as high as 6,000 feet (1800 m). Low elevation conditions on the Pacific slopes are optimal for most strains, although particular strains can do well in other conditions.

10. Human Activities

All parts of the Oregon myrtle have had extensive use. Extracts of the wood, leaves, and fruit have strong chemical properties and have been used for tea, medicinal purposes, seasoning, and vermin control. The species is highly valued as a decorative wood and is a favorite for gunstocks, wooden bowls, lamps, trays, carvings, and other items (Hirsch, 1970). Its commercial range includes Southwest Oregon and Northwest California. In 1969 250,000 miscellaneous turnings, 1,500 gunstocks, and 750 coffee tables were produced from myrtle wood (Hirsch, 1970).

Much of the prime myrtle growing areas have been converted to agricultural production (Fowells, 1965).

11. Natural Perturbations

Windthrow appears to be the most serious mortality factor. (See Death Rate.)

PORT ORFORD CEDAR - Chamaecyparis lawsoniana

1. General Description

This tree has flattened branches with dark green foliage which closely resembles western red cedar; however the underside scales are distinctly marked by bright silvery x's. Port Orford cedar grows to 200 feet (60 m) in height and from 4 to 6 feet (1.2 to 1.8 m) in diameter (Fowells, 1965). It can develop a long clear bole and often has a moderately buttressed base. Six to ten inch (15 to 25 cm) thick, silver-brown fibrous bark that is vertically ridged is typical of old growth, while young trees have much thinner bark. Port Orford cedar usually has a full crown with short pendant branches.

2. Population

Port Orford cedar has a very limited natural range and is restricted to a 130 mile (210 km) swath from Coos Bay, Oregon, south to Mad River, California, and is usually found within 40 miles (65 km) of the coast line (Fowells, 1965). It is found further inland in the Siskiyou Mountains on protected sites and is also found in isolated pockets near Mt. Shasta and the Trinity Mountains of Northern California. The tree has been domesticated and some seventy varieties are widely used for horticultural purposes. Port Orford cedar spans the area of most rapid transition between the California flora and the Pacific Northwest flora (Fowells, 1965).

This species is rarely found in pure stands in natural conditions and is associated with a wide range of other species including Douglas fir, western red cedar, grand fir, Sitka spruce, redwood, tanoak, Pacific madrone, and others. Densities have been measured at 550 to 820 stems per acre (220 to 330 stems per hectare), as indicated in Table 1.

3. Migration N/A

4. External Population Factors N/A

5. Reproductive Rate

Port Orford cedar is a prolific seed bearer. Observations have documented 598,000 and 1,268,000 seeds/acre (242,000 and 513,000 seeds/hectare) in two experiments (Fowells, 1965). The germination rate is low (less than 50%).

Heavy crops occur every four to five years. Failures are rare. Trees begin to bear as early as eight years. The volume produced is greatest at 100 years, but continues high for centuries.

Seeds are dispensed by wind only to a moderate extent since they are both smaller and twice as heavy as western red cedar seeds (which themselves are not much dispersed).

6. Growth Rate

The tree reaches a reproductive stage early, with seed production documented at eight years of age (Fowells, 1965).

Early growth is moderately rapid, at least until the tree is overtopped and loses sunlight. Growth will continue unchanged if full sunlight is available. Some growth and size information for plantations and natural stands are given in Tables 2, 3, and 4.

7. Death Rate

Rodents seem not to eat the seeds; in years of food scarcity they may be eaten by squirrels. The cones are occasionally attacked by a gall midge (Janetiella siskiyou) which, however, causes only slight damage (Fowells, 1965).

The main enemies of seedlings are heat and drought; like western red cedar, the tree is highly moisture-sensitive. Mortality of seedlings over ten years in an Oregon plantation at elevations of 700-1000 feet (200-300 m), was found to be 44% for NW aspect, 75% for SE aspect, or 60% combined (Ruth, 1957).

TABLE 1. POPULATION IN YOUNG STANDS OF PORT ORFORD CEDAR IN WESTERN OREGON. (From Fowells, 1965.)

		Total Stand (All Species)		Port Orford Cedar Only					
	Stand Age	Density		Density		Average Diameter		Average Height	
Location	Yrs	Stems Per Acre	(Stems Per Hectare)	Stems Per Acre	(Stems Per Hectare)	In	(cm)	Ft	(m)
Coos-Curry County Line-----	44	750	(300)	610	(250)	9.3	(24)	73	(22)
Coos-Curry County Line-----	43	690	(280)	560	(230)	8.5	(22)	72	(22)
Coos County Forest---------	36	1,360	(550)	820	(330)	6.3	(16)	51	(16)
Coos County Forest---------	40	1,140	(460)	550	(220)	7.2	(18)	52	(16)
Port Orford----------------	61	680	(275)	590	(240)	11.1	(28)	74	(23)
Port Orford----------------	57	670	(270)	600	(240)	12.4	(31)	73	(22)

TABLE 2. COMPARISON OF AVERAGE GROWTH OF DOUGLAS FIR AND PORT ORFORD CEDAR[a]. (From James, 1958.)

Tree Type	Growth Rate Ft/yr	(m/yr)
Douglas Fir	1.4	(.43)
Port Orford Cedar	1.2	(.37)

[a] Averages for 26 plantations with ages ranging from 8 to 26 years.

TABLE 3. AVERAGE HEIGHTS OF PORT ORFORD CEDAR IN PLANTATIONS. (From Hayes, 1958.)

Age (Years)	Height Feet	(Meters)
14	32	(10)
19	40	(12)

TABLE 4. AVERAGE SIZE OF PORT ORFORD CEDAR IN NATURAL STANDS. (After Fowells, 1965, and Hayes, 1958.)

Age (Years)	Height Feet	(Meters)	Diameter Inches	(cm)
36	51	(16)	6.3	(16)
61	74	(23)	11.1	(28.3)
100	--	--	10.7	(27.2)
173	--	--	19.6	(49.8)
251	--	--	30.7	(78.0)

Animal damage to older seedlings seems very great in this species. It is preferred as food over most of the associated species. Fraction of trees showing animal damage at five years was 70% for Port Orford cedar, while only 20% for Douglas fir (Ruth, 1957).

In spite of the sensitivity of Port Orford cedar seedlings, however, its overall mortality rate was comparable to that of Douglas fir in one study (Hayes, 1958). Mortality rates of 65% for Port Orford cedar and 61% for Douglas fir were found in 26 plantations, ages 8 to 26 years.

Like western red cedar, Port Orford cedar is susceptible to windthrow because of its shallow root system.

Young trees have thin bark and are easily killed by fire; old trees are thickbarked and very resistant to fire damage.

Port Orford cedar is attacked by serious root rot, Phytophthora lateralis, a fungus, pathogenic only to Chamaecyparis spp.; the Port Orford cedar is the most susceptible of the genus. Since its establishment in the early 1950's at Coos Bay, Oregon, the disease has steadily advanced. It is spread by aquatic spores, only exceptionally by air, causing up to 100% mortality (Hunt and Dimcock, 1957).

8. Carrying Capacity

Data on maximum size of Port Orford cedar stands are scanty. The highest volume-growth figures available are given in Table 5; note that these apply to a young stand, with volumes that may be expected to increase greatly in the next 200 to 300 years (to perhaps 28,000 cu ft/acre, or 2000 cu m/ha), although yields may decrease.

TABLE 5. YIELD OF YOUNG STANDS OF PORT ORFORD CEDAR IN WESTERN OREGON. (From Fowells, 1965.)

Location	Stand Age	Total Stand (All Species)		Port Orford Cedar Only							
		Basal Area		Basal Area		Average Diameter		Average Height		Volume	
	Yrs	sq ft/a	(sq m/ha)	sq ft/a	(sq m/ha)	in	(cm)	ft	(m)	cu ft/a	(cu m/ha)
Coos-Curry County Line--	44	408	(94)	287	(66)	9.3	(24)	73	(22)	7,230	(500)
Coos-Curry County Line--	43	348	(80)	222	(51)	8.5	(22)	72	(22)	6,360	(450)
Coos County Forest------	36	298	(69)	179	(41)	6.3	(16)	51	(16)	3,490	(250)
Coos County Forest------	40	312	(72)	157	(36)	7.2	(18)	52	(16)	2,930	(200)
Port Orford-------------	61	490	(113)	383	(90)	11.1	(28)	74	(23)	11,980	(840)
Port Orford-------------	57	548	(126)	503	(115)	12.4	(31)	73	(22)	13,800	(970)

The species is probably below carrying capacity due to extensive mortality caused by *Phytophthora lateralis*, a killing root rot.

9. Limiting Factors

Range: The tree has a very limited range, growing only in the 130 mile (210 km) strip between Mad River, California, and Coos Bay, Oregon. Inland, scattered stands are found in sheltered areas of the western face of the Siskiyou and coast ranges. Altitudinal range extends from 0 to 5000 feet (1500 m) near the coast.

Climate: The Port Orford cedar's range includes 65 to 100 inches (165-250 cm) precipitation (only 20% in July and August) and temperatures above 0°F (-18°C).

The tree is cold-sensitive and damage has been reported from unseasonable cold. The cold wave of November, 1955, killed up to 100% of young Port Orford cedars on plantations in Oregon. Mortality was 26% among trees of 25 years of age (Hunt and Dimcock, 1957).

Light: Shade is not a limiting factor. Cedar is very shade tolerant and will grow and mature in the understory. It responds well to release from shading. The tree is longer-lived than most of its associates (e.g. Douglas fir) and will often persist in the understory until overshadowing trees die, to be released at that time. Thus stands of over 400 years of age are often mostly cedar and hemlock.

Soils: This species grows on many kinds of soils but is most abundant on medium textured soils of the coastal terrace and on sandy and clay loams of the coast range. It also grows on marginal sites such as swampy soils, dry rocky ridges, and serpentine soils (Fowells, 1965).

10. Human Activities

Port Orford cedar is a highly valued timber tree, although its future is now in jeopardy due to root rot. It has been commercially planted in some areas, and is also planted world wide as an ornamental. The wood is used in boat construction, and, like the western red cedar, has antifungal toxins within the wood which inhabit wood rot. However the wood is stronger and harder than western red cedar. It is the principal species used by arrow shaft manufacturers (Hirsch, 1970).

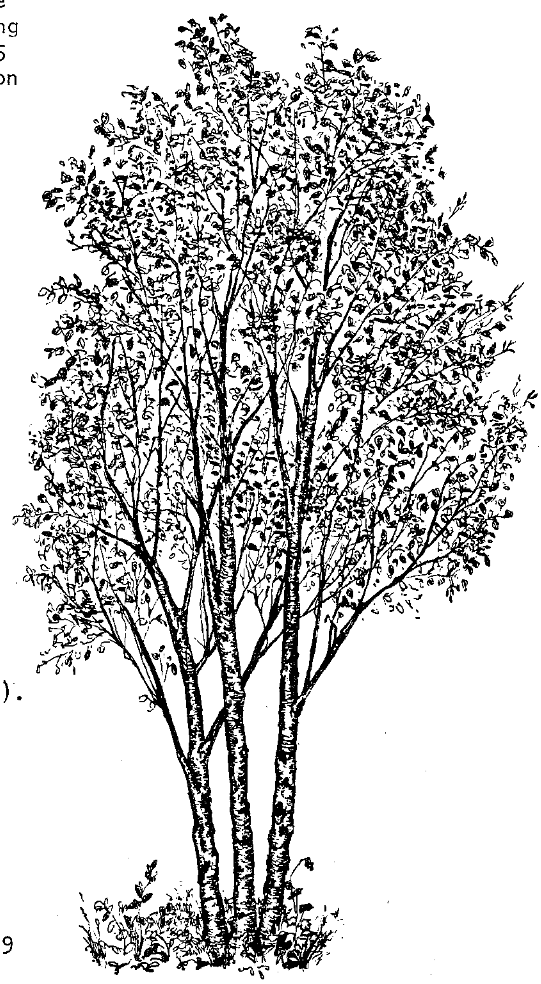
11. Natural Perturbations

The Port Orford cedar is moisture sensitive and subject to drought mortalities. It has no tap root and is subject to wind throw. Young trees are readily killed by forest fires, but old growth is not. The trees are long-lived and are a major component of old growth in areas where they occur. While not seriously attacked by insects, a root rot, *Phytophthora lateralis*, is seriously decimating the Port Orford cedar throughout its natural range.

RED ALDER - <u>Alnus rubra</u>

1. General Description

Red alder is a short-lived, deciduous, rapid-growing, early and mid-seral species common in the Western Hemlock, Sitka Spruce, and Redwood Zones of the study area. It is the most plentiful and commercially important hardwood of the Northwest (Arno and Hammerly, 1977). It is a straight-trunked tree 90 feet (30 m) tall with a narrow dome-like crown and smooth thin greyish bark often covered with lichens (Baerg, 1973). The leaves are 2 to 4 inches (5 to 10 cm) long and are smooth above and with short hairs on the veins of the underside. Male catkins are 5 to 6 inches (13 to 15 cm) long, while female fruiting bodies, resembling miniature gymnosperm cones, are 0.5 to 1 inch (1 to 2.5 cm) long. At 17 stations in Oregon and Washington leaf bud burst was between March 21 to April 25, and leaf fall was completed from September 18 to November 24 (Fowells, 1965). Recently, Pacific Northwest Forest and Range Experiment Station (1977) has published a bibliography concerning the ecology of red alder.



2. Population

The range of this species is restricted to the coastal areas from the northern portion of the Alaska panhandle, south to the San Francisco Bay area, intermittently to Point Conception - a latitude range of 16° (Fowells, 1965). It is typically restricted to within 100 miles (160 km) of the coast at elevations below 2,500 feet (750 m). It is common in lowland forests throughout the study area, particularly on clearcut areas and riparian habitats. Since it is a seral species, clearcutting practices have increased the frequency and extent of stands. Generally, the species is topped by Douglas fir at about 25 years after initiation of the stand. In the Sitka Spruce Zone, alder stands are longer-lived and can dominate a site for 50 years or longer (Frankin and Dyrness, 1973).

3. Migration N/A

4. External Population Facts N/A

5. Reproductive Rate

Fowells (1965) reports that the initiation of flowering ranged from February 14 to May 4th and fruit ripening occurred between August 5 and October 29 for 17 stations in Oregon and Washington.

Seed production begins at approximately 10 years and extends through maturity. It is a prolific seeder and typically bears a good crop about every fourth year (Fowells, 1965). Crop failure is infrequent and seed predation is moderate.

The seeds are very light (666,000 seeds/lb or about 1,500/g) and are extensively disseminated by wind, thereby establishing natural regeneration throughout its range. Seeds germinate freely under conditions of abundant soil moisture and cool temperatures. Regeneration is favored by clearcutting or large group cutting (Haddock, 1948; Tarrant, 1961). Any activity which bares the mineral soil and allows direct overhead light will enhance regeneration.

6. Growth Rate

The species exhibits a very rapid growth in its earlier stages. First year shoots are 6 to 18 inches (15 to 45 cm) tall and growth may be as much as 5 feet per year (1.5 m/yr) for the next 10 years, reducing to 2 to 2.5 feet per year (0.6 to 0.8 m/yr) thereafter (Fowells, 1965). Growth on good sites after 25 years is documented in Table 1.

TABLE 1. AVERAGE HEIGHT AND DIAMETER OF OLDER RED ALDER STANDS ON GOOD SITES IN NORTHERN PUGET SOUND. (From Johnson et al., 1926.)

Age	Height		D.b.h.	
years	ft	(m)	in	(cm)
25	78	(24)	10	(25)
30	82	(25)	11	(28)
35	86	(26)	12	(30)
40	90	(27)	13	(33)
45	94	(29)	14	(36)
50	98	(30)	16	(41)
55	101	(31)	17	(43)
60	105	(32)	18	(46)

At Grays Harbor, Washington (Watershed Unit 2) radial growth began on April 7 in 1953, and on May 6 in 1954 (a late year). Duration of growth is approximately 130 days (Fowells, 1965).

Maximum height is 100 to 130 feet (30 to 40 m) with a diameter of 24 to 30 inches (60 to 75 cm).

7. Death Rate

For its first 40 years, red alder is relatively free from disease, insects, or other damaging agents, excluding mortality caused by natural thinning. Trees which fail to maintain a position in the canopy quickly die (Berntsen, 1961).

Seeds are seldom eaten by small mammals. The deer mouse only occasionally takes seeds if other food sources are in short supply (Moore, 1949).

Whiteheart rot (Fomes igniarius) is the most prevalent and destructive disease on live trees, particularly on over-aged or injured trees. Two cankers (Didymosphaeria oregonensis and Hymenocheate agglutinans) attack young trees, stunting growth and causing deformation.

Tent caterpillars (Malacosoma pluviale and M. disstria), a saw fly (Memichroa crocea), and a flea beetle (Altica ambiens) occasionally attack foliage over large areas. However, mortality is low and trees recover rapidly. Some flat-headed borers and ambriosa beetles attack the wood of injured red alder but do not typically kill the tree. The alder bark beetle (Alniphagus aspericollis) often attacks and kills weakened trees (Fowells, 1965).

Fire damage to red alder is atypical due to lack of flammable debris beneath alder stands. In fact, red alder is sometimes used as a firebreak (Johnson, 1917).

Red alder is short-lived, seldom attaining an age of 100 years.

8. Carrying Capacity

Optimum conditions of mineral soil, high moisture, cool temperatures, and high light intensity have been expanded through disturbance in urban fringe areas, as well as clearcutting forestry practices. Herbicides typically are used, as red alder is often considered an undesirable competitor with preferred conifer species (Newton and Norgren, 1977). The subject is discussed in greater detail in the ecosystems model of the second growth hardwood habitat within the Western Hemlock Zone and is reviewed by Newton and Norgren (1977).

Red alder also fixes nitrogen and is thought to physically and chemically improve soil conditions for conifer growth (Fowells, 1965). Newton et al. (1968) have found that red alder could fix as much as 300 pounds of nitrogen per acre per year (330 kg/ha/yr). However other studies (Tarrant and Miller, 1963) report rates of 36 pounds per acre per year. Newton and Norgren (1977) report red alder has the capacity to supply N to the soil by fixation as a substitute for fertilizers but the practical technology to take advantage of this capability has not been developed.

9. Limiting Factors

Climate: Red alder prefers a humid to superhumid climate with an annual rainfall no less than 25 inches (60 cm) unless supplemented by frequent fog or high humidity (Fowells, 1965). Extreme low temperatures much below 0°F (-18°C) or extended periods near 0°F (-18°C) limit its range. Average annual temperature extremes vary from 0°F to 105°F (-18°C to 40°C).

Soils: Red alder grows on a variety of soils ranging from gravel to sand or clay. It is typically prevalent on soils with poor internal drainage (Fowells, 1965) but is not found on lands which are consistently flooded (Johnson et al., 1926). The species is prevalent on most alluvial soils and extends upland to the point where increased drainage becomes limiting.

Elevation: Within the study area this species grows to 2500 feet (750 m) with best stands below 1300 feet (400 m). It seldom is found on steep south or southwest facing slopes because of moisture deficiency (Fowells, 1965).

10. Human Activities

Red alder is a hot, clean-burning, crackle-free firewood that is extensively used in the study area. The wood is easily worked and readily takes a stain and is used for furniture manufacturing. Also, it is frequently used as a slope stabilizer on road cuts.

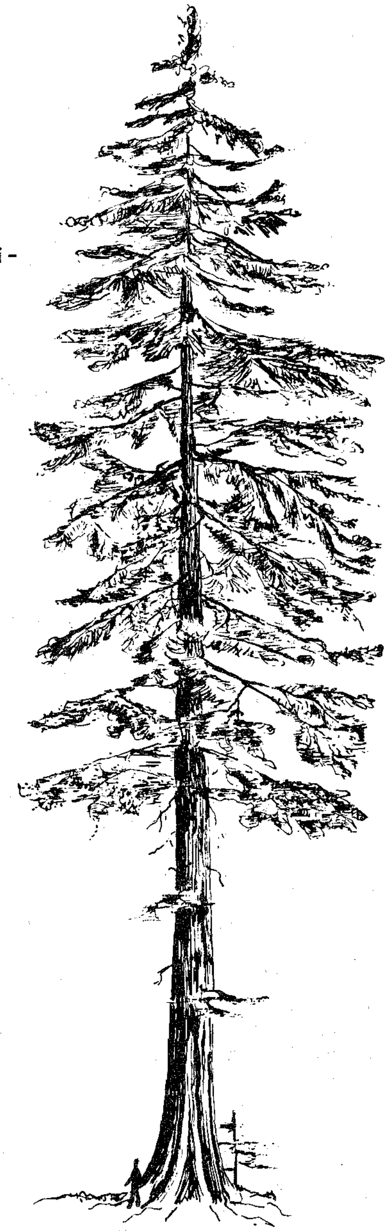
In recent years there has been increased interest in using red alder as a biological fertilizing agent (Newton and Norgren, 1977), as well as a possible biological fuel source (Inman, 1977).

11. Natural Perturbations

Red alder, an early sere short-lived species, is dependent on perturbations for its existence. It grows well on sites that have been subject to mass wasting, logging, burning, bulldozing, etc., and frequently establishes single-species dense stands on such sites, particularly under conditions of high moisture and cool temperatures. (See Death Rate.)

REDWOOD - Sequoia sempervirens

1. General Description



The redwood is the tallest and most massive tree in the study area. In fact members of this species are the tallest individual trees in the world and are only surpassed in mass by its genus mate, the giant sequoia (Sequoia gigantea). Redwood trees over 200 feet (60 m) tall are common. Trees over 300 feet (90 m) in height are often found in deep alluvial valley soils. The tallest tree recorded was 368.7 feet (112 m) in 1956 (Fritz, 1957), while the American Foresters Society (Pardo, 1978) reports a 362 foot (110 m) tree in Humboldt Redwood State Park. The tree has fibrous reddish-brown bark that is deeply furrowed and very thick. Buds are scaly. Alternate leaves are needle-like, flattened, and in two rows (Fowells, 1965). It is the dominant tree where found and is the climax species in the Redwood Zone.

2. Population

Redwood grows from the Chetco River drainage in Southwest Oregon to Sonoma County, California; south of Sonoma County groves become intermittent (Fowells, 1965). It grows in an irregular coastal strip approximately 450 miles (700 km) long, and 5 to 35 miles (8 to 56 km) wide. On alluvial sites redwoods grow in massive and dense stands. In old growth, merchantable trees vary from thirty to fifty per acre with gross volume ranging from over 100,000 board feet of saw timber on sloped lands to as much as 1,000,000 board feet per acre in scaled logs on good alluvial sites (Browne, 1914; Fritz, 1929, 1930, 1957; U.S.D.A., 1908).

A common misconception of redwood stands is that they are single-aged, or overaged and decadent. Redwood stands typically have a wide range of ages and include vigorous as well as decadent trees (Fritz, 1929).

Young stands are considerably denser than old growth. An average well-stocked acre supports nearly 1,000 stems at twenty years including 500 dominant and codominant trees (Fowells, 1965). Foresters encourage heavy stocking because of the low light tolerance and the ability of such stands to support a large number of dominant and codominant trees (Person and Hallin, 1939).

3. Migration N/A

4. External Population Factors N/A

5. Reproduction

Redwoods reproduce through a sexual process culminating in seed production and seedlings. Vegetative reproduction is also significant (see Note #6). Redwoods characteristically bloom between late November and early March, although flowering is often completed by January. Viability of seeds is reported to be related to weather conditions during flowering. Wet conditions are less desirable than dry conditions, as optimal dispersal of pollen occurs under dry conditions (Lott, 1923). Cones mature in the fall following flowering, typically between early September and late November (Metcalf, 1924; Geiger, 1926).

Redwoods produce abundant seeds in most years (Show, 1932; Fritz, 1958). The trees begin to bear seeds at approximately twenty years of age with optimum seed bearing between 60 and 100 years (Fowells, 1965). The viability of the seeds seems to peak when the tree is older - over 250 years of age. Very old trees (1,200 years and older) are often sterile or no more than three percent viable while the twenty year old trees are likewise largely unviable (1%) (Lott, 1923; Metcalf, 1924).

Germination of seeds is typically low. However, when obviously defective seeds are removed from the sampling, germination rates may be as high as seventy percent (Boe, 1961). Larger sized seeds are typically more likely to germinate (Person and Hallin, 1939). Seeds do not store well with viability generally lost completely after five years (Schubert, 1952).

Seeds generally disseminate in winter. They are small and light but fall at relatively fast rates (4.9 to 20.5 feet per second) and have a limited dispersal capability. Reseeding capability is 200 feet (60 m) uphill and 400 feet (120 m) downhill under average conditions (Person and Hallin, 1939). For the purpose of natural regeneration, clearcuts should be no larger than thirty to forty acres in a square or round cut (Boe, 1961). In partial cuts, recommended seed tree densities are four per acre on north facing slopes and eight per acre on south facing slopes (Person and Hallin, 1939).

Mineral soils are the favored seed bed but seeds germinate in duff or logs in full sunlight or shade as long as adequate moisture is available. Seedling survival is closely tied to ground moisture. Late spring and early fall rains may be critical to their survival.

6. Growth Rate

Redwood trees grow very rapidly. Seedlings frequently grow 18 inches (0.5 m) in the first year, with trees four to ten years old growing 2 to 6.5 feet per year (0.6 to 2 m) (Fritz, 1929; Jepson, 1910). Dominant trees on good sites grow 100 to 150 feet tall (30 m to 45 m) at fifty years and 165 to 220 feet tall (50 to 65 m) at 100 years (Boe, 1960). Yield of second growth redwood stands ranges from 56,000 board feet per acre on poor sites to 350,000 board feet per acre on good sites at 100 years. Average annual increment of growth for stands under management is estimated at 2,400 board feet per acre per year (Lindquist and Palley, 1961).

The redwood also reproduces asexually through vegetative reproduction. This species can be propagated by cuttings with no special treatment (Metcalf, 1924; Fritz, 1929).

Stumps sprout rapidly following cutting. Very large stumps are less likely to sprout than younger, smaller stumps. In one study 81 percent of the stumps less than 56 inches (1.5 m) in diameter sprouted, while only 35 percent of stumps over 126 inches (3 m) sprouted (U.S.D.A., 1963). Such sprouts are very rapid-growing, commonly attaining 24 to 36 inches at the end of the first year. However in Mendocino and Humboldt Counties, such sprouting typically results in only 8 percent of full stocking (Person, 1937).

7. Death Rate

Moisture stress is the principal cause of mortality for seedlings, while fire is the principal cause of mortality for young second growth trees (Fowells, 1965). Trees under twenty years old are highly susceptible to fire and can be killed outright by a single fire. Once a tree is large (100 years or older), factors of mortality become very low as the tree suffers from no killing disease or insect blight and becomes very resistant to fire. The tree has also adapted to silting conditions and is able to reestablish surface root systems if buried, which happens frequently in alluvial stands (Fritz, 1934). Redwoods have been able to tolerate siltation resulting in a thirty foot (9 m) elevation change over a period of several hundred years.

Heart rots do not kill most trees but do cause extensive culls. A brown cubical rot, Poria sequoiae, is common in the southern part of its range but a white ring rot, Poria albipellucida, is more common in the study area. Twig and branch cankers (Coryneum spp.) attack young seedlings and saplings, particularly in plantations (Fowells, 1965).

Insects are common on redwood but cause limited damage. Major pests include a flat-headed twig borer and girdler (Anthaxia aeneogaster), two bark beetles (Phloesinus sequoiae, Phloesinus cristatus), and the pitch moth (Vespamima sequoiae).

The stripping of bark by black bear is considered a serious problem causing mortality in some areas (Fritz, 1951A). Trees ten to thirty years of age are most frequently attacked and damaged.

Redwoods are fairly windfirm, old trees rarely being thrown unless seriously undercut by heart rot and fire (Fowells, 1965). Young trees are better than average in windfirmness.

8. Carrying Capacity

Optimal conditions for this tree are described in the following section on limiting factors (Note #9). As described in the previous discussion on growth rate, (Note #6), the trees are capable of formidable growth and massive standing biomass (1,000,000 board ft/acre).

9. Limiting Factors

Redwood requires considerable precipitation and moisture. Precipitation ranges between 25 and 122 inches (60-300 cm) and falls principally as winter rains. Frequent summer fogs are of critical importance to the survival of redwoods. The fog reduces summer hydration stress by decreasing transpiration and evaporation and by adding moisture through fog condensation in crown and subsequent drip. Late spring and early fall precipitation is critical to seedling survival. Optimal sites for redwood are alluvial soils of the Hugo, Josephine, Melbourne, Empire, Sites, and Larabee series (Fowells, 1965). Best stands are developed on flats and benches along larger streams, moist coastal plains, river deltas, moderate western slopes, and valleys opening to the ocean.

Redwoods are found from sea level to 3,000 feet (900 m) but are more common between 100 feet and 2,500 feet (30-750 m). They are apparently very sensitive to ocean salt spray and do not typically grow on hillsides directly facing the ocean (Fowells, 1965; Jepson, 1923). In the northern part of its range the redwood is found on all aspects but becomes limited to western or northern exposures at the southern portions of its range.

Redwoods are tolerant of competition and are efficient photosynthesizers in low light conditions (Fowells, 1965). They can withstand suppression of light almost indefinitely. Small trees over 400 years of age respond with rapid growth if released from competition and not injured during logging (Fritz, 1940; Merril, 1953). Old trees (1,000 years) responded to reduced competition caused by right-of-way clearing with an increased growth rate from 30 rings per inch to 6 rings per inch (Fritz, 1951B).

As discussed in the section on death rate (Note #7), mortality factors for old growth are very limited. Man is the principal agent of mortality, other than natural senescence.

10. Human Activities

Redwood is a highly valued, sought-after, commercial forest tree. It is the principal commercial species in Watershed Units 8 and 9. Numerous state parks have been established for protection of old growth stands, and the establishment of the Redwood National Park has further protected additional stands within the region (see Figure 3-5A in Part 1 of this volume). Section 4.2 in this volume (Part 1, Chapter 4) discusses redwood harvesting and the effects of park formation in this area.

11. Natural Perturbations

Once well-established, neither wind, nor fire, nor flood, nor bugs fall this giant. It is not subject to windthrow, fire damage, insect infestation, disease, or even burial.

SITKA SPRUCE - Picea sitchensis

1. General Description

Sitka Spruce is the largest of the spruces. Mature old growth trees are impressive with a swollen buttressed base, diameters over ten feet (3 m) and a height of well over 200 feet (60 m). The tree is long-lived, often reaching an age of 700 to 800 years (compared to 400 to 500 years for western hemlock). It is found along a very narrow coastal strip from Northwestern California to Southern Alaska (Fowells, 1965). Its 1,800 mile (3000 km) range is closely associated with the coastal fog belt; in the study area it is usually found within 20 miles (50 km) of the coast. It is the dominant tree in the Sitka Spruce Zone, but may be found along river valleys in the Western Hemlock Zone. The species reaches maximum development in rainforests of the Olympic Peninsula and on the Queen Charlotte Islands of the coast of British Columbia. Harris and Ruth (1970) have compiled an extensive bibliography on the species.

2. Population

As indicated in the general description, the tree is common along an 1,800 mile (3000 km), albeit narrow, range. Like other trees, densities are greater in young stands and decrease with maturation. A well-stocked 147 year old stand in Oregon had 76 stems per acre. Along with western hemlock it is a co-dominant species of climax stands in the Sitka Spruce Zone.

3. Migration N/A

4. External Population Factors N/A

5. Reproductive Rate

Sitka Spruce is a prolific seed producer with production beginning in 20-40 year stands. Failures are rare, and there is a good crop every three to four years. The highest recorded crops are of the order of 1,000,000 seeds per acre (400,000/ha) in pure stands (Fowells, 1965). Seed viability averages 55.6%, with seed fall occurring in late October and November (Fowells, 1965).

Seed dispersal has been documented as far as 114 miles (183 km) from seed source (James, 1958), but seed fall is much greater under forest. Average rate of fall has been estimated at 3.1 feet per second (1 m/sec) (Siggins, 1933). Natural reforestation is expected on clearcuts as large as 80 acres (30 ha).

Seedlings will germinate in almost any seedbed, provided there is abundant moisture. Partial shade is optimal. Sitka spruce out-competes its most common associate, western hemlock, on mineral soils, but does less well on organic soils as a seedling.

6. Growth Rate

Maximum growth rates are observed on the Olympic Peninsula and on the Queen Charlotte Islands, British Columbia. Sitka spruce is faster growing than either western hemlock or western red cedar and responds well to release. On better sites mean annual gross growth is about 2,000 board feet (international rule) per acre (about 160 cu ft/a, or 10 cu m/ha) with an 80 to 90 year rotation. Incremental growth for younger trees is given in Table 1, while Table 2 provides growth in diameter for older trees.

7. Death Rate

Seed destruction by seed chalcids (Megastigimus piceae, Torymus spp.) may be serious in epidemic years. Other damage comes from cone moths (Laspeyresia youngana, Heinnichia fuscodorsana), chipmunks, squirrels, mice, and shrews.

TABLE 1. TYPICAL INCREMENTAL GROWTH FOR MID-AGED SPRUCE. (From Godman, 1949.)

Age (years)	Diameter Increment In	(cm)
45-65	3.8	9.6
60-80	3.3	8.1
74-94	2.1	5.3

TABLE 2. DIAMETER AS A FUNCTION OF AGE FOR TYPICAL SITKA SPRUCE OLD GROWTH STANDS. (From Englerth, 1947.)

Age (years)	Diameter Increment In	(cm)
147	34	(86)
189	37	(94)
250	37	(94)
403	51	(130)
468	63	(160)

7. Death Rate, continued

The primary killers of seedlings are evaporation and drought (in the south), and cold (in the north). Hence, Sitka spruce is found more thickly on northern exposures in the southern end of its range, and more thickly on southern exposures in the northern end of its range.

Windthrow is an important agent of mortality in older stands. Sitka spruce is susceptible because of its shallow root system, sometimes as shallow as 6.5 inches (17 cm). However it is more windfirm than western hemlock. Most blowdown losses occur on the north and east boundaries of clearcuts particularly if the edge is on a north facing slope (Ruth and Yoder, 1953).

Sitka spruce is very susceptible to infection following injury. A study of decayed trees in Southeast Alaska showed the following organisms to be present (in order of significance):

1. *Polyporus schweinitzii*,
2. *Polyporus borealis*,
3. *Fomes pinicola*,
4. *Polyporus sulphureus*,
5. *Fomes pini*.

These five caused approximately 80% of identified Sitka spruce diseases. In Oregon and Washington, Wright and Isaac (1956) report 58% of scars in partially cut stands were infected with brown crumbly rot (*Fomes pinicola*). Decay increases with age and about one-quarter of the wood in 500-year-old trees is defective.

Insects may be serious in epidemic years. Fowells (1965) documents the following as most significant:

Sitka spruce weevil (*Pissodes sitchensis*), killing younger trees;

Spruce aphid (*Alphis abientina*), often very serious along tidelands;

Blackheaded budworm (*Acleris variana*), in Alaska;

Sitka spruce beetle (*Dendroctonus obesus*).

8. Carrying Capacity

The maximum observed numbers and volumes in spruce-hemlock coastal forests are given in Table 3.

TABLE 3. MAXIMUM OBSERVED VALUES FOR SITKA SPRUCE IN SPRUCE-HEMLOCK COASTAL FORESTS. (After Fowells, 1965.)

Age (years)	Number of trees per acre	(per ha)	Height ft (m)	Diameter in	(cm)	Volume cu ft/a	(cu m/ha)
89[a]	--	--	--	--	--	10,060	(700)
147[b]	76	(31)	210	34.3	(87.1)	28,900	(2000)

[a] 45% of forest was Sitka spruce. Total volume for forest was 22,350 cu ft/acre (1500 cu m/ha).

[b] 85% of forest was Sitka spruce. Total volume was 34,000 cu ft/acre (2400 cu m/ha).

9. Limiting Factors

Climate: Sitka spruce requires a humid, maritime climate. Rainfall varies from 50-150 inches (125-380 cm) per year. Even in the most northerly part of the range, the climate is mild; average January temperatures are above 20°F (-7°C) (Fowells, 1965).

The spruce is resistant to salt spray, as are its seeds, which gives it a competitive advantage on headlands, dunes, and other seaside locations.

Soils: The tree grows best on soils with high organic content and good drainage. Sitka spruce will grow - but only poorly - in thin, rocky soils. Western red cedar or western hemlock, which require less nourishment, are predominant on thin rocky soils or poorly-drained soils. Sitka spruce requires acidic soil with a pH of 4.0 to 5.7.

Light: Sitka spruce is shade tolerant, more so than Douglas fir but less than western red cedar or western hemlock. Sitka spruce is essentially a subclimax tree in much of its range, but since it lives 700 to 800 years, two generations of hemlock or cedar may be necessary to succeed it. On the coast, however, Sitka spruce is a climax species.

10. Human Activities

Sitka spruce, since it is light and strong, was harvested heavily during World Wars I and II because it was a prime source of wood for aircraft. It is no longer used for such purposes, but is well-suited for ladders, folding bleachers, and racing shells. Also the wood has high resonant qualities and is used in musical instruments such as guitars and pianos.

The Sitka spruce forests were heavily logged during the war years, but demand has been reduced more recently. It is still an important timber tree on the Olympic Peninsula. Old growth stands occur in the Olympic National Park. Outside of federal lands old growth stands are rare.

11. Natural Perturbations

The tree is subject to the factors identified in the earlier mortality section. Sporadic insect blights occur, as does mortality from rots. The tree is highly susceptible to fire, but fires are infrequent in the humid conditions under which it thrives.

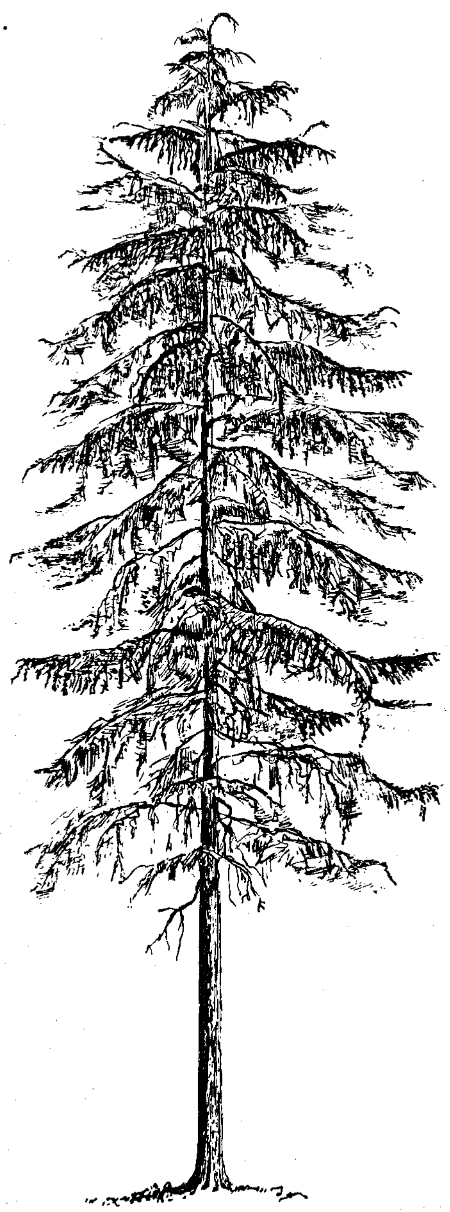
WESTERN HEMLOCK - *Tsuga heterophylla*

1. General Description

Although the western hemlock is not as large and does not grow as old, or as quickly, as its associates (Arno and Hammerly, 1977), its ability to grow and survive in heavy shade establishes it as the dominant climax species throughout the Western Hemlock Zone and much of the Sitka Spruce Zone. The tree is readily recognized by its drooping tip, as well as the small, flat, blunt needles with whitish bands beneath. The boughs have a characteristic spray or fern like appearance. The tree grows to a maximum size of 200 feet (60 m) with a diameter of 3 to 4 feet (1 m) (Arno and Hammerly, 1977). The bark is dark reddish-brown, scaley, and thin.

2. Population

Western hemlock has an extensive range which is separated into two major portions. The coastal portion of its range extends from Kodiak Island, Alaska, to near Cape Mendocino, California (Fowells, 1965). It also grows inland from a scattered pattern along the Canadian/American border in Northeastern Washington, Northern Idaho, and Northwestern Montana north to the Selkirk Mountains of British Columbia. Stand densities for western hemlock are high (Arno and Hammerly, 1977). Density of trees for a given site is dependent on the age of the stand, as well as the quality of the stand. Young stands have higher densities than older stands and good quality stands have lower densities but larger trees. Stands at twenty years may have densities of 2,000 trees per acre (800 per ha) (Fowells, 1965). Table 1 provides density and volume data for 100 year old fully-stocked stands of different qualities.



3. Migration N/A

4. External Population Factors N/A

5. Reproductive Rate

Western hemlock is a prodigious seed producer and typically outproduces all of its associates (Fowells, 1965). Each western hemlock cone carries 30 to 40 1/16 inch (1.5 mm) single-winged seeds (300,000 per pound or 150,000 per kg) (Arno and Hammerly, 1977). Seeds are produced every year, with heavy crops produced every third or fourth year (Fowells, 1965).

Hemlock seeds have fairly good dispersal characteristics. When released at 200 feet (60 m) in a 12.5 mph (20 kph) wind, seeds were dispersed as far as 3,800 feet (1200 m), although the majority of the seeds fell within 2,000 feet (600 m) (Isaac, 1930). Seed fall under a dense stand is 10 to 15 times as great as areas in clearcuts 400 feet (120 m) or greater from the forest edge (Fowells, 1965).

Western hemlock seeds are very tolerant of soil conditions and germinate and survive over a wide variety of seedbed conditions (Fowells, 1965).

6. Growth Rate

Growth for western hemlock seedlings is slow. On the Oregon coast three year old seedlings were only 6 to 7 inches (15 to 18 cm) tall (Baker, 1949). Near Grays Harbor, Washington, two year old planting stock grew only two inches (5 cm) in two years (Worthington, 1955). Once established, however, seedlings can grow up to two feet (60 cm) per year in full overhead light.

In young stands (23-yr), wood volumes of 400 to 2,600 cubic feet per acre (30 to 180 cu m/ha) can be expected. Table 1 documents the yield for 100 year old stands. Old growth stands may have half this volume in commercially valuable wood (Anderson, 1956).

Hemlock has been documented to respond well to release (removal of competition, such as shading) at 50 years of age, but in Alaska response at 100 years was poor (Andersen, 1956; Taylor, 1934).

TABLE 1. AVERAGE TREE DIMENSIONS, DENSITY, AND TIMBER VOLUMES PER ACRE FOR FULLY STOCKED 100-YEAR OLD WESTERN HEMLOCK STANDS IN OREGON AND WASHINGTON. (From Barnes, 1962.)

Site Class[a]	Average d.b.h.[b]		Average Height		Density[c]		Volume		
	Inches	(cm)	Feet	(m)	No. Trees Per Acre	(No. Trees Per Hectare)	Cu Ft/acre[b]	(Cu m/ha)[b]	(International rule)/acre[c]
I---------	23.2	(58.9)	200	(60)	121	(49)	25,300	(1800)	187,000
II--------	21.6	(54.9)	170	(52)	137	(55)	21,400	(1500)	157,000
III-------	19.4	(49.3)	140	(43)	166	(67)	17,400	(1200)	129,000
IV--------	16.5	(41.9)	110	(34)	213	(86)	13,300	(900)	98,000

[a] Stands are divided into five classes, I being the best quality, V the worst. See Table 4-1 in Section 4.2.1.2 for description of this classification system.

[b] All trees 1.6 inches (4 cm) d.b.h. and larger.

[c] All trees 6.6 inches (17 cm) d.b.h. and larger.

7. Death Rate

Little is known concerning seed destruction for this species by insects, blight, or other animals. Seed chalcids (Megastigmus spp.) are common on hemlock seeds, but extent of damage is not known. Only a small percentage of total seeds germinate (Fowells, 1965).

Seedlings in clearcuts often get overtopped and smothered by herbs, ferns, and shrubs but may survive on logs and stumps. Animal damage to seedlings is minor, although browsing by black-tailed deer does occur. Snowshoe hare and mountain beaver also feed on seedlings in some areas and mice occasionally chew the bark of seedlings.

Wind is the principal mortality factor in young growth coastal forests (Fowells, 1965). In dense stands many individuals die from suppression during stand development (Fowells, 1965). Fire can kill both young and old trees due to thin bark and heavy foliage (Arno and Hammerly, 1977).

Several trunk, butt, and root rots infect western hemlock, particularly in older growth. Fomes annosus, F. pini, Poria weirii, P. subacida, Echinodontium tinctorium, and Polyporus circinatus are the most common (Fowells, 1965). Dwarf mistletoe (Arceuthobium campylopodum) also is a common parasite on western hemlock and reduces growth and increases mortality, particularly on old growth.

Western hemlock is susceptible to insect attacks. The most notable species are hemlock looper (Lambdina fiscellaria), black-headed budworm (Acleris variana), western larch roundheaded borer (Tetropium velutinum), and the hemlock sawfly (Neodiprion tsugae). In the period between 1925 and 1965, four or five major outbreaks of the hemlock looper have occurred (Fowells, 1965). The black-headed budworm defoliates but does not usually kill trees. However, the western larch round-headed borer often attacks and kills trees which have been defoliated by other insect species (Fowells, 1965).

8. Carrying Capacity

Optimum conditions for reproduction and growth are discussed in the limiting factors section to follow. The western hemlock has both biological and physiochemical requirements which establish carrying capacity. Good moisture, lack of forest fires or other perturbations, and climax conditions are optimum for western hemlock. Due to current forest management practices which favor Douglas fir, populations of western hemlock are below the carrying capacity of the study area.

9. Limiting Factors

Climate: The tree thrives in humid, mild conditions typical over much of the Pacific slope, with frequent fogs and rain during the growing season. This species can tolerate temperatures from well below zero to 100^{o}F or greater (less than 20 to 40^{o}C or greater). However over most of its range temperature variations are more moderate.

Soils: Western hemlock is noted for growing well over a wide variety of soils, but grows best on deep, internally well-drained soils under high rainfall conditions, or deep organic soils with adequate moisture. Soil pH is typically between 4.5 and 5.0 in the study area (Fowells, 1965). Nutrient demands of western hemlock are thought to be less than its associates (Edmonds, 1974).

Elevation: Western hemlock is typically found and grows best below 2,000 feet (600 m) in the study area (Fowells, 1965). On inland sites (e.g. Idaho) it is found at higher elevations, up to 5,000 feet (1500 m).

Light: Although western hemlock can grow quite well in full light, its shade tolerance plays an important part in its dominance in old growth communities. Frequently it will be the only tree reproducing beneath closed canopies. This species is a true climax type (Fowells, 1965).

10. Human Activities

Forestry practices which include short rotation periods, clearcutting, and long term reduction of old growth has and will continue to decrease the extent of this species. Until 1920 the tree was considered a "weed" tree but more recently hemlock wood has been found to have a wide range of uses (Arno and Hammerly, 1977). The wood is used for flooring gymnasiums and for pulp, and is a major source of alpha cellulose fiber used in the manufacture of synthetics such as rayon, cellophane, and many plastics.

11. Natural Perturbations

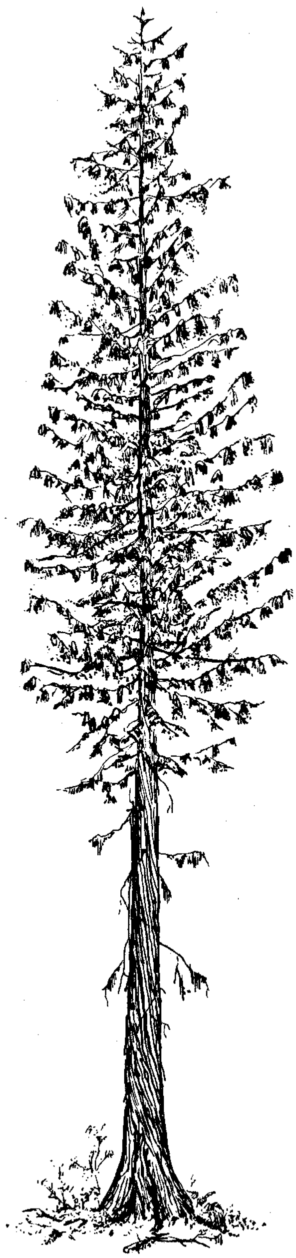
As discussed in the mortality section, hemlock is intolerant of physical perturbations such as windthrow and forest fires as well as biological decimation by rots and insect epidemics. Often rots and insects together cause mortality.

WESTERN RED CEDAR - Thuja plicata

1. General Description

The tree has a heavily buttressed conical trunk that is anchored by a wide spreading but shallow root system (Arno and Hammerly, 1977). Young trees typically have a drooping leader but old growth is frequently spike or snag topped. The bark is thin, reddish, and stringy. Trees grow to massive proportions; two trees growing in the Olympic National Forest have diameters of 20 feet (6 m) with snag tops at 120 and 130 feet (36 and 40 m).

Recently (1974) near Forks in Watershed Unit 1, a tree 19 feet (5.8 m) in diameter and 178 feet (52 m) tall was discovered. Its present market value is estimated at $20,000 (Arno and Hammerly, 1977). Fairly dense stands occur on the Olympic Peninsula on boggy, poorly drained sites (Franklin and Dyrness, 1973).



2. Population

Western red cedar is infrequently found in pure stands. Consequently there is some difficulty in establishing population estimates. Also, little information has been derived from silviculture, as the tree is rarely planted. A typical mature forest on a wet, model site has the attributes given in Table 1.

TABLE 1. POPULATION DATA FOR WESTERN RED CEDAR.[a] (From McMinn, 1960.)

Site	Population per acre	(per hectare)	Age years	Average Height ft	(m)	Average Diameter in	(cm)
1	88	(36)	200	125	(38)	38	(97)
2[b]	68	(28)	270	196	(60)	30	(76)

[a] Stands were approximately 85% western red cedar, 10% Douglas fir, and 2% western hemlock.

[b] Quality of site 2 was lower than site 1.

The tree has a fairly extensive range, divided into two separated tracts. The coastal tract encompasses the whole of the study area and extends inland in Washington and Oregon to the eastern slopes of the Cascades as well as north to Sumner Straight, Alaska (Fowells, 1965). The inland tract is on the western slopes of the Rocky Mountains in Montana and north. Within this study area this species is most frequent on the Olympic Peninsula in Watershed Unit 1.

Extent and acreage of old growth throughout its range is given in Table 2. Sharpe (1974) documents and maps old growth stands in Oregon, Washington, and Idaho.

3. Migration N/A

4. External Population Factors N/A

5. Reproductive Rate

Western red cedar is a prodigious seed producer ranking second only to western hemlock among its associates. Maximum number of seeds per tree is estimated at 375,000. Recorded seed fall in various stands is given in Table 3.

Crop failures are uncommon; in an eight-year study there were four years of good crops, three years of fair crops, and only one poor year (Haig et al., 1941).

Peak seed fall occurs during November. Cold dry weather with relative humidities of 50% or less is associated with high seed fall rates. Trees have been documented to bear seed at only 16 years of age.

TABLE 2. THE EXTENT OF MATURE WESTERN RED CEDAR COVER TYPE IN NORTH AMERICA TODAY.[a] (From Sharp, 1974.)

State or Province	Area Acres	(Hectares)
Alaska (50 percent or more board-foot volume)	200,206	(81,000)
British Columbia		
Pure cedar (80 percent or more gross volume)	350,000	(142,000)
Leading cedar (20 percent to 80 percent where cedar is the predominant species)	6,800,000	(2,750,000)
Idaho and Montana (mature sawtimber; medium 40-69 percent and well-stocked 70-100 percent)	100,000	(40,500)
Oregon (50 percent or more coniferous with the plurality western red cedar 100 years or older)	133,000	(53,800)
Washington	255,372	(103,350)

[a] Since agencies conduct their forest inventories differently, the criteria for each are cited here.

TABLE 3. SEEDFALL DATA FOR WESTERN RED CEDAR. (After Fowells, 1965.)

% Population *Thuja*	Seedfall per acre	(per hectare)
25%	100,000-1,000,000	(40,000-400,000)
60%	Up to 57 x 10^6	(Up to 23 x 10^6)
100%	60 x 10^6	(24 x 10^6)

Dispersal properties for the seed are poorer than any of its associates (Fowells, 1965). Experiments indicate that seeds do not disperse more than 400 feet (120 m) when released at a 150 foot (46 m) height (Isaac, 1930).

Western red cedar has a higher germination rate - 73% - than any of its associates (Haig et al., 1941).

6. Growth Rate

Trees begin to generate seeds at sixteen years of age. Growth rates are site-dependent and are linked to such limiting factors as moisture and sunlight. Although western red cedar is often considered a slow-growing tree, under full light conditions it grows almost as fast as Douglas fir. The tree is shade tolerant and can grow to maturity in shade. Diameter and height growth for different age classes are given in Tables 4 and 5. Unlike many of its associates, maximum diameter growth is reached at 150 to 200 years. Height growth is sustained at levels from 0.5 feet/year to 1.0 feet/year (15 cm/yr to 30 cm/yr) until extreme old age (Fowells, 1965). Annual incremental growth is reported to exceed decay in living trees with a range of ages from 50 to 450 years.

TABLE 4. INCREMENTAL DATA FOR TYPICAL WESTERN RED CEDAR GROWTH. (From Knapp and Jackson, 1914.)

Growth Type	Age years	Increment/year inches	(cm)
Diameter	20-30	0.34	(0.86)
	60-70	0.20	(0.51)
Height	10-20	24-36	(60-90)
	60-70	7.3	(19)

TABLE 5. CUMULATIVE DATA FOR WESTERN RED CEDAR GROWTH. (From Knapp and Jackson, 1914.)

Age	Height		Diameter		Volume	
years	feet	(meters)	inches	(cm)	cu ft	(cu m)
20	35	(11)	3.6	(9.1)	2.0	(0.056)
50	79	(24)	12.5	(31.7)	27.2	(0.762)
80	101	(31)	19.0	(48.3)	57.0	(1.60)
100	112	(34)	22.0	(55.9)	-not given-	

7. Death Rate

Although the western red cedar is a prodigious seed producer, has little seed predation by rodents, and has a high germination rate, few seeds become established seedlings. Mortalities are listed in Table 6. Early first season losses are due to fungus, birds, insects and shade. Once seedlings begin to harden, they become susceptible to drought. In full sunlight, few seedlings survive high soil temperatures. Fallen leaves of deciduous shrubs are a principal cause of mortality on cutover areas (Fowells, 1965). Under its preferred high humidity conditions the cedar needle spot fungus (Keithia thujina) occasionally reaches epidemic proportions, killing as much as 97% of cedars less than four years of age. Older trees are not similarly affected.

TABLE 6. WESTERN RED CEDAR SEEDLING MORTALITY. (From Haig et al., 1941; Weir, 1916.)

Age	% Dead	Condition
1	44	Clearcut
	97	Dense Shade
6	74	Clearcut

Once the cedar trees pass the critical early stages, mortality is less significant than in competing associates - a factor which establishes the red cedar as a climax species (Fowells, 1965).

Red cedar has few insect enemies, but older trees succumb to the following (Fowells, 1965):

- western cedar borer (*Trachykele blondeli*), in sapwood and heartwood of living, dying, and dead trees;
- amethyst cedar borer (*Samanotus amethystinus*), usually only in injured or dying trees;
- western cedar bark beetle (*Phloeosinus punctatus*);
- western hemlock looper (*Lambdina fiscellaria*), (less injurious);
- cedar twig and leaf miners (*Gnathotrichus* spp., *Trypodendron* spp.), (less injurious).

Cedar is not as susceptible to fungal infections as its associates; growth typically exceeds rot up to the age of 450 years or so (Buckland, 1946). The principal antibiotic agent in western red cedar is B-thujaplicin. Fungal infections, in decreasing order of importance, are the following:

- *Keithia thujina* (only significant in seedlings);
- *Poria asiatica*;
- *Poria weirii*;
- *Fomes pini*;
- *Polyporus balsameus*;
- *Merulius* spp.;
- *Poria subacida*.

8. Carrying Capacity

The capacity of a site to sustain western red cedar is determined by the limiting factors discussed below. Yields on good sites in Southwest British Columbia (at 130 years) have been measured in the vicinity of 10,500 cubic feet per acre (730 cu m/ha) (BCDLS, 1957). Maximum observed volumes for a 200 year stand in optimum conditions were measured at 31,450 cubic feet per acre (2,200 cu m/ha) (McMinn, 1960).

9. Limiting Factors

Climate: High precipitation and humidity are preferred. Rainfall is typically between 30 and 100 inches/year (75 and 250 cm/yr), with three-fourths of the precipitation falling in the wet season (Fowells, 1965). Its altitude range in the Olympic Peninsula is 0-4,000 feet (0-1200 m). Mean annual temperatures vary between 42°F and 52°F (5°C and 11°C).

Soil: Growth is poor on warm or dry soils. The tree will grow on a wide range of soils, thriving on mucky soils. Moist, cool, acid soils establish optimum conditions for western red cedar regeneration. The tree requires less nutrients than Douglas fir, and can grow on quite poor sites if adequate moisture is present. It is more tolerant of standing water than any of its associates, excluding red alder with which it is frequently associated. It is often found growing in swamps and streambeds. Soil moisture in vigorously growing cedar stands is 10-80% (McMinn, 1960). It grows well under conditions of continuous winter standing water. The tree is generally thought to be moisture limited.

Light: Western red cedar is classified as tolerant of variations in light. Trees will grow to maturity in the shade; however, they respond well to release. Seedlings grow best in partial shade.

Disease, Predation, and Parasites: Western red cedar is not as susceptible to disease, predation, or parasites as are its associates. Old and weakened trees do become susceptible however.

10. Human Activities

Cedar wood has become very expensive in recent years. A single large old growth cedar has a market value in the vicinity of $20,000 (Arno and Hammerly, 1977). Hirsch (1970) reports an approximate $100 million production value of shake roof in Oregon and Washington for 1969. Cedar has been extensively logged but is typically not actively regenerated. Consequently, the area in cedar growth is being reduced. Some stands are established through natural regeneration and some stands are protected in the Olympic National Park. Consequently, the tree is not likely to become threatened. There are some complications in the maintenance of old growth cedar as there is an active "black market" in cedar wood through poaching trees from protected lands. As old growth cedar continues to decrease in availability this problem is likely to increase.

11. Natural Perturbations

Seedling mortalities are high and are frequently caused by moisture stress (drought). The tree is highly susceptible to fire damage and is restricted in some areas by frequent forest fires. The longevity and resistance to insect and fungal blight of the cedar are important factors in its ability to successfully compete with its associates. (See mortality section for additional information.)

DUNGENESS CRAB - *Cancer magister*

1. General Description

The Dungeness crab is an important commercial and recreational species in Washington, Oregon, and California waters. During juvenile and adult stages, it is a bottom-dwelling, shallow water species (0 to 10 fathoms, 0 to 20 m) and is typically associated with sandy to muddy bottoms, but is occasionally found in eelgrass.

The Dungeness is one of the largest edible crabs of the United States. A carapace width of seven inches (18 cm) or more and weight over two pounds (1 kg) are common. It is distributed along the shelf from the Aleutian Islands to Magdalena Bay in lower California (Rees, 1963; MacKay, 1942) and is common in estuaries as well as offshore waters from intertidal areas to 93 fathoms (170 m) (OSU, 1971).

2. Population

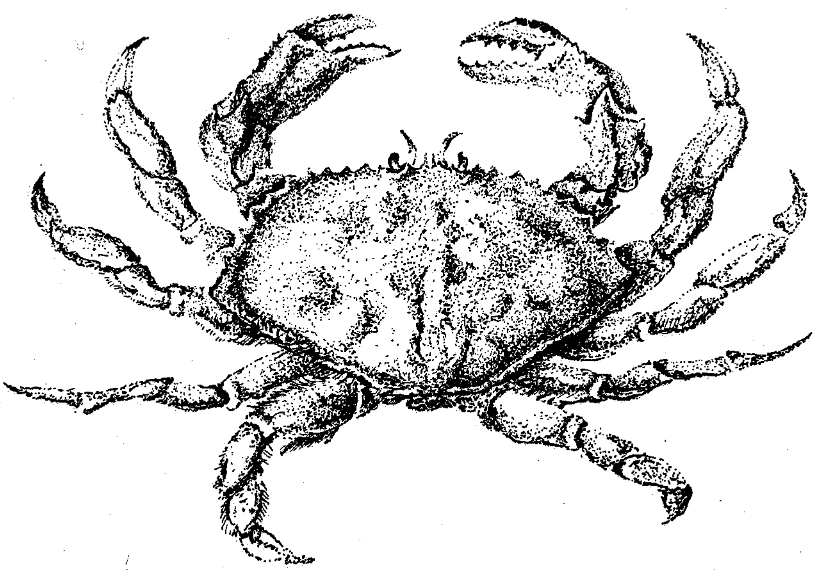
No direct estimates of population levels are available. However, by utilizing catch records, population estimates of the four year age class are made possible. Oregon Fish and Wildlife Commission estimates that 95% of legal males are caught annually, and that a sex ratio of 1:1 is assumed (Snow, personal communication, 1977).

The 1968-1972 average catch for Dungeness crab, including catches in areas south of the study area and Alaska, was 45.3 million pounds (20 million kg) per year (Wise and Thompson, 1977). Within the region during peak years catch is well over 50 million pounds (23 million kg), and is as low as 8 million pounds (4 million kg) during low population periods. Since average adult crabs weigh approximately two pounds (1 kg) and a 1:1 sex ratio is assumed, population of year classes can, perhaps be estimated from the above figures.

High-low catch cycles occur in the order of eight to ten years between peaks as indicated for Northern California in Figure 1. Record catches occurred in California in 1977 and are expected to occur in Oregon in 1978. Unfortunately, little is known about causes of this population cycle. Lough (1974) correlated fluctuations in crab landings with rainfall, and suggested that the amount and timing of rainfall affects the salinity of the estuarine habitats where sensitive crab larvae mature.

3. Migration

Migration is dictated by age, sex, and season. Sex segregation has been documented with the onset of maturity (Cleaver, 1949). In the shelf waters a predominant north to south movement of crabs has been documented during spring and summer. Seasonal onshore-offshore movement is also typical. Distances traveled over a six month period averaged ten to twelve nautical miles (18-22 km). Some individuals apparently move fairly extensive distances, as one individual was found to have traveled some 148 kilometers (80 nm) from Grays Harbor to Tillamook Bay (Cleaver, 1949).



During early life stages, the crab is planktonic and phototropic (i.e., attracted to light). As the larva transforms into a juvenile, it ceases being planktonic, drops to the bottom, and becomes part of the benthos, avoiding light (Cleaver, 1944).

4. External Population Factors

N/A

5. Reproductive Rate

Fecundity is estimated at 1.5 million eggs per female (Moore et al., 1974). Fertilization and hatching rates are undocumented. Mating occurs from April to August, with hatching taking place from December through June (OSU, 1971).

6. Growth Rate

Males and females become sexually mature at three years and two years, respectively (Isakson, 1976C). Age span is from eight to ten years.

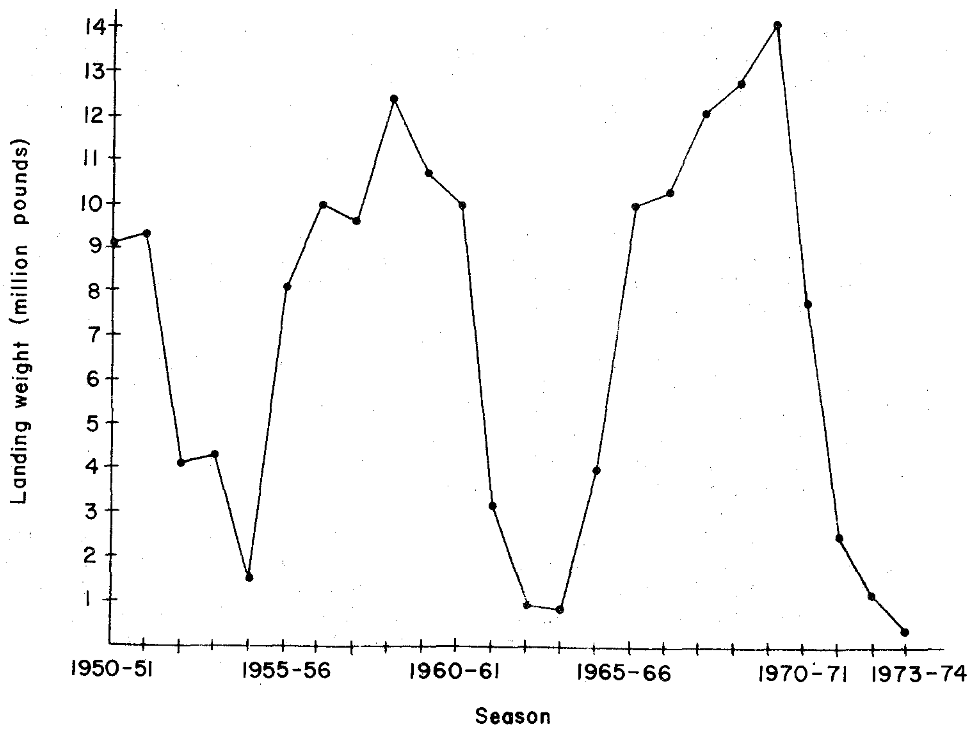


FIGURE 1. **NORTHERN CALIFORNIA DUNGENESS CRAB LANDINGS OVER A 23 YEAR PERIOD.** Data are for ports from Fort Bragg to Crescent City, 1950-51 to 1973-74 seasons. (From Gotshall, 1978.)

During maturation, the crab goes through five zoeal stages and one final megalops stage. These larval stages, which last around 100 days, are first pelagic (planktonic), then benthic. Larvae hatch between December and April, with the megalops stage occurring between May and October. The larvae become juveniles and proceed to an adult stage in two to three years (Isakson, 1976C). Zoea feed on phyto- and zooplankton. Megalops feed on small crustaceans, crab eggs, and plankton. Adult feeding habits are variable, opportunistic, and site-specific. They are primarily predators, but scavenge. Primary food items include clams, fish, isopods, amphipods, and polychaetes, as well as shrimp, small crabs, and barnacles, depending on location and depth. Figure 2 presents stomach content percent occurrence for five depth zones to 300 feet.

7. Death Rate

Mortality is high (99%), but variable, through the larval and juvenile stages. Predation during larval stages is particularly important. Some mortality is caused by the "black spot" or "rust sport" disease and by increased vulnerability during molting. Principal mortality to adults is through the harvest of males by man. Juveniles are taken by large fish.

8. Carrying Capacity

Due to heavy harvesting by man, carrying capacity for Dungeness crab in the adult stage is probably infrequently reached. Carrying capacity for juvenile stages may be limited by availability of estuarine habitat where juveniles congregate (Snow, personal communication, 1977). However, juveniles also use open water habitat and it is not clear what the relative importance of juvenile estuarine use is to the population. Isakson (1976C) indicates channels in mudflat areas are critical habitat for juveniles as escape areas during low tides and during periods of low salinity.

Since little is known about the carrying capacity of the coastal waters for Dungeness crab, one cannot determine whether age classes are above or below this level. Given the fluctuating nature of the population, one would assume population levels may periodically surpass the carrying capacity. However, it may be that temperature, salinity, or predation are instrumental in determining larval or juvenile success and subsequent population levels.

9. Limiting Factors

Factors which limit Dungeness crab populations are not clearly documented. Laboratory studies by Reed (1969) indicate that the optimum range of salinity and temperature for larvae are 25-30 ‰ and 10-13.5°C (50-56°F), respectively. Populations fluctuate widely; the cause of the fluctuation is unknown (see Note #2 - Population).

10. Human Activities

Dungeness crab is harvested both through commercial and sport fisheries, with an estimated 95% of legal-sized males taken through the fishery. Harvest data are given in Section 3.4.1.2 of Chapter 3 of this volume. Due to the sex biology of the crab, this harvest has little effect on the reproductive potential of the population. The Dungeness crab is extremely sensitive to insecticides as are most crustaceans and may have been limited from part of its former range south of the study area through insecticide pollution.

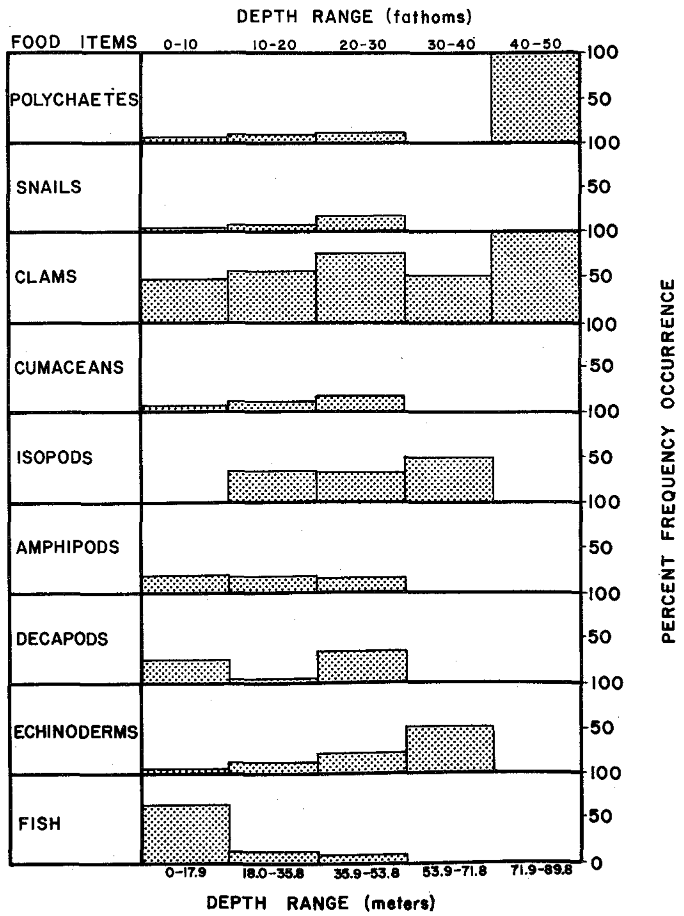


FIGURE 2. FREQUENCY OF OCCURRENCE OF NINE FOOD ITEMS OF THE DUNGENESS CRAB. Data were obtained from stomach contents of crabs caught off Northern California. (From Gotshall, 1977.)

11. Natural Perturbations

Temperature and salinity changes strongly affect breeding and migratory behavior, and may well be implicated in the population fluctuations noted above.

INSECTS

Insects comprise an integral part of virtually all freshwater aquatic and terrestrial ecosystems. Insects are found from below the tide mark to well above timberline. Specific examples of insect species from this continuum have been cited in the Annotated Species List in this study, since various watersheds encompass these extremes. Only Watershed Unit 1 contains elements from both ends of the spectrum.

In nearly all terrestrial and freshwater aquatic communities, insects dominate the second trophic level. They are the principal consumers in both grazing and detrital food webs. In terrestrial communities they are a vital link within food webs supporting song birds, small mammals, and raptors (Strand, 1974; Whitaker and Maser, 1976). In freshwater aquatic systems insects are fundamental to the diet of nearly all predaceous species, including the recreationally and commercially important salmonids, either directly or secondarily by supporting their prey species (Warren, 1971; Moyle, 1976B; Efford and Hall, 1975). A few of the most significant insect species or groups in each habitat have been entered in the Annotated Species List and appear in the Community Composition lists in Volume 3.

Insects are typically the major cause of death for most forest trees. This mortality is usually in conjunction with disease or fungal attack. Insects force damaged or weakened trees to die abruptly and rapidly and thus cease competing with healthy trees for limiting resources, i.e. light, moisture, nutrients, and space (Deyrup, 1975). Consequently, the insects play an important role as natural thinning agents, allowing remaining individuals to better utilize the resources available.

In addition, insects are the principal mediators of the early stages of tree composition and thereby play an important role in nutrient recycling. In other regions insects have proven to be critical as pollinators for numerous vascular plants. This symbiosis is not well documented in the study area but is presumably significant to many species of vascular plants within the region.

Insects show greater diversity of form and habit than any other group of organisms. This diversity has resulted from their evolutionary success in competing with a wide variety of organisms, including other insects. It is estimated that about one million different species of insects have already been described. Some feel that this represents only about 20 percent of the total. Detailed knowledge of the vast majority of insects is lacking or fragmentary at best. Although insects have been studied in a systematic fashion for over 300 years, new information is being added at a rapid rate.

Borror et al. (1976) estimate 88,619 species of insects occur in America north of Mexico. Hatch (1971) cited 4300 species of beetles from the Pacific Northwest in his five-volume study. Extrapolating from these and other figures (Mackerras, 1970; Australia), a reasonable estimate of the number of species of insects in the Pacific Northwest would be 15,000. Since so much remains to be learned about the northwestern fauna, the final number may approach 25,000. These watersheds lie within the Oregonian Province described by Udvardy (1975), which contains a rich diversity of habitats, a diversity reflected in the variety of insects found there. Representative habitats, and some of the insect components both those reported and those which are likely to be found, will be discussed.

1. Subtidal. Although many insects (estimates range from 25,000 to 30,000 species), have been able to colonize the aquatic environment (Cheng, 1976), few occur in the marine habitat. Those few that are known are found chiefly in warmer, tropical waters. One species found in this region is *Trichocorixa verticalis californica* Sailer, a species of water boatman (Hemiptera: Corixidae). This insect occurs in some tide pools and might be found in eelgrass beds. Although thought to be chiefly herbivorous, information is now available to suggest that some species are partially or entirely predaceous (Scudder, *in* Cheng, 1976). Only detailed studies of individual species will solve these problems. The gut contents of a sub-species of *Trichocorixa verticalis* from saline lakes in British Columbia chiefly contained remains of midges belonging to the family Chironomidae.

2. Intertidal. A remarkable number of insects are intertidal in nature. The dominant orders found there are the beetles (Coleoptera) and the flies (Diptera), with representatives of a few other orders (Hemiptera and Trichoptera). Most of the available information on the Coleoptera concerns distribution and species identification rather than their biology. Representatives of the Staphylinidae, or rove beetles, are commonly found in our region. Moore and Legner (in Cheng, 1976) state that these beetles feed on Crustacea and other organisms found in the seaweed, salt marshes, and rocky shorelines. A few are known parasites of flies breeding in the wrack line. Beetles are confined chiefly to the zone close to the tide line. Representatives of the Diptera (flies) range over a wider area. Some immature stages of the Chironomidae occur below the low tide mark (Hashimoto, in Cheng, 1976). Most Chironomidae larvae are believed to feed on algal debris, although a few are known to be omnivorous. Some of these insects have undergone drastic morphological modifications for marine life in tropical waters. In our region, a common sight is a group of large, black midges (Paraclunio alaskensis) running and flying over the surface of rocks freshly exposed by the retreating tide. The adults emerge as the tide receeds, mate and lay eggs before the tide again returns to cover the rocks.

3. Coastal Lakes. These lakes generally are associated with active or stabilized sand dunes. Coastal lakes have a complete complement of aquatic insects. In the water are found herbivores, chiefly mayflies and caddisflies. Although some representatives of both these taxa are predators, most utilize plant materials of a wide variety. Conspicuous too are the Hemiptera, particularly the Corixidae, or water boatman. Adults and immature stages occur together. The Coleoptera are represented by a variety of families, chiefly Hydrophilidae and Haliplidae. Some members of the latter family are regarded as omnivorous. A variety of Diptera also occur in these lakes. Because of the biting habits of the adults, mosquitos are perhaps the most conspicuous to humans. Their aquatic larvae strain planktonic materials from the water. Chironomidae larvae are abundant on the bottom throughout most lakes.

Some predators are found in such ponds and lakes. Under the water are the immature stages of Odonata (dragonflies), some species reaching two inches (5 cm) in length. In the water column are found adult and immature diving beetles (Dytiscidae), backswimmers (Hemiptera:Notonectidae), and giant waterbugs (Hemiptera:Belostomatidae). On the surface film proper are found adult whirligig beetles (the larvae occur under water) and waterstriders (Hemiptera:Gerridae). These insects prey on emerging insects as well as insects landing on the water. In the air over the water are dragonflies and damselflies, both of which are efficient aerial predators. Although the species vary, representatives of these taxa are found in most still-water situations.

4. Riverine. Running water creates special adaptive provlems for insects and, at the same time, creates new environments for further exploitation. The great variety of insects living in streams and rivers attests to their ability to utilize this habitat. Some of the aquatic insects found in streams and rivers are either the same or very similar to those found in still water. By occupying habitats under stones, or on the edge or behind obstructions, they occupy habitats virtually identical to a pond/lake situation except that the habitat is located in running water. Some Hydrophilidae, Corixidae, Notonectidae, mayflies, and dragonflies are included in this group, both herbivores and carnivores are represented. Many true flies, beetles, caddisflies, mayflies, and stoneflies are not particularly well-adapted for running water but are found only in streams and rivers. They avoid the swifter current by positioning themselves on the downstream side of rocks, logs, etc., essentially out of the current. Naturally, they are not exempt from the influence of the current for they must come up through the water column to emerge. Many of these insects are grazers on the "aufwuchs" - attached materials on the substrate. While this material is chiefly composed of plant life, some smaller animals may also occur there. A smaller but very distinct group of insects, chiefly immature stages of Diptera, Ephemeroptera, Trichoptera, Plecoptera, and Coleoptera - a few adult beetles are included - have been able to occupy habitats receiving rather extensive effects of the current. Their body shape is usually modified to reduce resistance to the current; in some that are flattened, the shape utilizes the passing current to maintain their position (some mayflies true flies, and beetles). An amazing variety of attachment devices have evolved. While some of these insects feed on the attached materials or are predaceous on other insects, many utilize the passing water column as a source of food, straining or filtering out a variety of food materials. On the surface of the water are found a few predators such as whirligig beetles, some waterstriders (where the current is not too strong) and veliids. Adult dragonflies and damselflies are conspicuous predators in the air over the water. Emerging adult stoneflies, true flies, and subadult and adult mayflies are often seen in the air in large numbers at certain times of the season and the day. The coastal streams considered in this study are unusually rich in insects, reflecting the general productivity of their watersheds.

5. Sand Dunes. Detailed knowledge of the insects of the sand dunes of this region is still largely lacking. Increased interest in endangered species and critical areas is calling attention to these fragile habitats.

A few insects are especially adapted for dune life and have color patterns blending in with the sand or pale hairs to achieve the same result. Others have special modifications for walking on the sand. Still others have evolved very efficient water conservation systems to permit them to survive. The proximity to the ocean and the frequent fogs generally means that the coastal dunes, at least in the Northwest, are not entirely comparable to inland dunes in the Great Basin. Only detailed investigations will reveal just how the insect faunas will vary. These studies remain to be done.

The characteristic vegetation of the coastal dunes - beach grass, *Arctostaphylos*, and shore pine - all have their characteristic insect inhabitants. Chinch bugs (*Blissus* spp.) feed on the beach grass (a curious situation since the common beach grass is an introduced species and the bug is a native). The kinnikinnick supports leafhoppers, small moths, and seed bugs, among others. The dense mat holds moisture and allows for the accumulation of some organic material. The shore pine (*Pinus contorta*) supports a moderately rich insect fauna, both herbivores and predators. Aside from the insects of economic importance on the pine, such as bark beetles and other wood borers, or defoliators, the other insect fauna is still largely unknown. Some recently collected species appear to be undescribed. As the dunes proceed towards complete stabilization, the insect fauna becomes more characteristic of a coastal forest.

6. Coastal Grasslands. This habitat is not as well represented in the study area as it is to the south. However, some grasslands do exist, some natural, others the result of removal of the forest or shrub cover. The lowlands associated with the river mouths often have extensive grassland/pasture habitats. Although most of the grasslands have been heavily influenced by the activities of man, there are small patches that have been relatively untouched. The so-called salt-spray meadows are an example. The only insect in Oregon proposed for endangered status under the U.S. Endangered Species Act (but not yet placed on it) is a sub-species of checkerspot butterfly confined to such coastal meadows. As an aside, it is interesting to note that some grass cultivars were derived from native coastal species of grasses (e.g. Astoria Bentgrass). Some characteristic grass insects include the plant bugs (Miridae) and leafhoppers (Cicadellidae). A number of characteristic species occur there. Due chiefly to the activities of man, a number of introduced plants are found in the pasture situation. Some, like tansy ragwort, are considered of economic importance because of their toxicity to cattle and horses. Several insects have been introduced in an effort to control the plant. These include the cinnabar moth, tansy flea beetle, and a seed fly. Gorse is a serious weed along the coast and several weevils have been introduced to help control it but have had relatively little impact. Scotch broom is considered both an ornamental and a weed, depending on where it grows. Although no insects have been introduced in a deliberate fashion to control this plant, a number of species of insects found on the plant in Europe now occur along the West Coast. Because of the disturbed character of the coastal grasslands, the insect fauna is a curious mixture of native and introduced species.

7. Coastal Lowland Forests. Most of the coastal lowland forests have been cut over and represent second growth habitats. Patches of original forest exist. All of the important timber trees of the region occur in these forests and, as such, major insects associated with them are usually well known. *Western Forest Insects* (Furniss and Carolin, 1977) provides a current treatment of these insects. Included are such pests as bark beetles and flat-headed and round-headed wood borers (which generally go deeper into the wood). Major defoliators, such as tussock moths, western spruce budworms, loopers, and tent caterpillars (all Lepidoptera), plus a variety of leaf-feeding sawflies (Hymenoptera), also are described in the book. Generally, the leaf beetles (Chrysomelidae) confine their attacks to broadleaf species, including willow and alder. Associated with the many herbivorous species are complexes of parasites and predators. Both groups are poorly known. The understory layer, with its characteristic plants, as well as the floor of the forest itself contain many insect species.

8. Coast Range Second Growth - Broadleaf Forests. Since most broadleaf species in the region have not achieved any economic status, except perhaps locally, relatively little is known of their insect fauna. A concerted effort is now being made to study the insects associated with common native trees and shrubs. The results of some of these investigations (particularly the Hemiptera) are included in the Annotated Species List. Of special note is the area included in Watershed Unit 8 and 9, where serpentine soil is involved. This region offers some of the greatest floral diversity in western North America. So much of it is as yet unexplored that only estimates may be made (see for example, Waring, 1969; Whittaker, 1960, 1961; Franklin and Dyrness, 1973; and Barbour and Major, 1977). Because of the close association between insects and plants, the great diversity shown in the flora is almost certain to be reflected in the insect fauna. There are instances of some true faunal relicts in the area. Wygodzinsky (1961) described a species of Lepidotrichidae (Thysanura) from the redwood litter in Northwestern California; the family had been known previously only from Baltic amber. Few areas offer such potential for investigation.

9. Coast Range Evergreen Forests. Since most of the conifer species in the region are utilized for commercial purposes, the insects causing damage to these trees have been extensively studied. The recent book by Furniss and Carolin (1977) provides detailed treatment of most of these species. The parasites and predators of these insect species have received comparatively little attention, however. The recent five-year study of the Douglas fir tussock moth and the new program on the western spruce budworm should provide additional information on these species. As old growth forests are gradually removed and replaced by more intensively managed, shorter cycle forests, the insect problems are changing. Insects associated with seeds and cones will require greater attention as will insects more commonly associated with younger trees. While most of the species involved have been studied, the consequences of these changing forest practices are not well understood. Already, problems associated with intensive seedling generation are occurring and are being investigated. Studies are underway on the hemipteran fauna of conifers. Many are predators of aphids, scale insects, and other insects on conifers. The most abundant and/or significant insect pests of commercial tree species in the region are discussed in the Species of Concern accounts for each tree species under Note #7-Death Rate.

The understory, likewise, has received little attention but some preliminary studies are being made of the insects on rhododendron as well as some other shrub species. As yet we know little of the changes that might occur in the fauna of a given host plant as the geographical range changes. One such study is underway on the Miridae associated with *Pinus contorta*. The forest floor still remains virtually unknown, although considerable diversity does exist.

10. Subalpine-Alpine Habitats. These habitats are found only in Watershed Unit 1. The Olympic Mountains contain some true boreal plant elements. Some of these occur as far south as Saddle Mountain and Mary's Peak, Oregon. In several instances, insects share a similar range. The isolation of the mountainous regions, particularly as the glaciers retreated, resulted in the fragmentation of the fauna in those scattered locations high enough to maintain subalpine and alpine environments after the glaciers were gone. The excellent dating procedures now available, coupled with the proximity of the Olympic Mountains to the North Cascade Mountains make the Puget Sound area unusually attractive for studies involving distribution of subalpine and alpine insects, and, where appropriate, associated plants. Fragmentary evidence suggests a real potential for post-Quaternary faunal movement and speciation studies (e.g. the work of Melville H. Hatch on beetles).

Epilogue. Much work remains to be done before we have a thorough appreciation of the role insects play in the ecosystems of the Pacific Northwest Coastal Region. Some areas offer great potential for original research (Siskiyou Mountains, Olympic Mountains).

CHINOOK SALMON - Oncorhynchus tshawytscha

1. General Description

Chinook salmon is also called king, tyee, blackmouth, and jack salmon. In salt water it is identified by a heavily-spotted tail and the black lower gumline where teeth project from the jaw. Fresh water spawning colors include brown or olive-green with heavy black spotting on back.

2. Population

The chinook salmon is an abundant and commercially and recreationally important fish of the region. Basic life cycle and biological information for the chinook are given in Figure 1 and Table 1. For regional population data refer to Chapter 3, Section 3.4.1.2.

3. Migration

Migration timing and the complete life cycle are indicated by Figure 1. The majority of adult chinook are thought to remain in the upwelling areas off Northern California and off Oregon and Southern Washington. Some portions of the population may travel farther north. Figure 3-4B in Section 3.4.1.2 describes oceanic migration.

4. External Population Factors

The Oregon Fish Commission estimates five chinook salmon are caught by commercial and sports fisheries for each salmon returning to spawn. An estimated 71% of this catch is taken commercially, and 29% is taken by sports fishermen (USDA, 1976).

5. Reproductive Rate

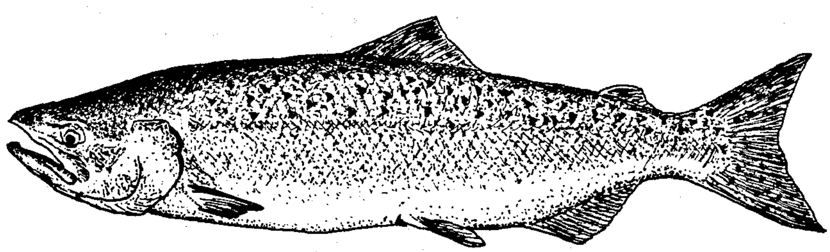
The average number of eggs per female is 4,000, with the majority of natural spawning occurring in larger tributaries in water depths over ten inches (25 cm). Suitable water temperatures for spawning range from 42 to 58°F (5 to 14°C); chinook require a dissolved oxygen of at least 8 ppm. Water velocity required is from 1.0-3.0 feet per second (30-100 cm/sec) over coarse gravel 2-6 inches (5-15 cm) in diameter (Thompson, et al., 1972).

6. Growth Rate

Chinook grow larger than other Pacific salmon mainly because of the two to seven years spent at sea. Maximum size attained is typically 38 inches (97 cm) in length with a weight of 30-40 pounds (14-18 kg) (Scott and Crossman, 1973). However, individuals over 100 pounds (45 kg) and over 50 inches (130 cm) have been caught, but are from more northerly waters (Scott and Crossman, 1973). Chinook usually weigh three to five pounds (1-2 kg) after one year and twenty pounds (9 kg) or more after three years in the ocean. Average spawning adults attain a length of 75 to 80 cm (30-31 in) and nine to ten kilograms (20-22 lbs) (Moyle, 1976B).

7. Death Rate

Survival to smolt under natural conditions is 10% but may vary widely depending on environmental conditions and predation. (Survival to smolt in well-run hatcheries is 80-90%.) Predation by piscivorous fishes, birds, and mammals, as well as disease, are important mortality factors. Mortality is increased by higher temperatures, pH changes, low flows, reduction in dissolved oxygen, and siltation. Of the stock that reaches the sea, only 10% return to spawn. Oceanic losses include natural predation (see Oceanic section, Pelagic food web), harvesting, and disease. The result is a return of approximately one percent. Replacement requires 0.1% returns. The one percent return is subject to wide fluctuation. Survival is dependent on environmental conditions, predation, and disease at any stage of the life cycle and these vary markedly.



Chinook Salmon (Oncorhynchus tshawytscha)

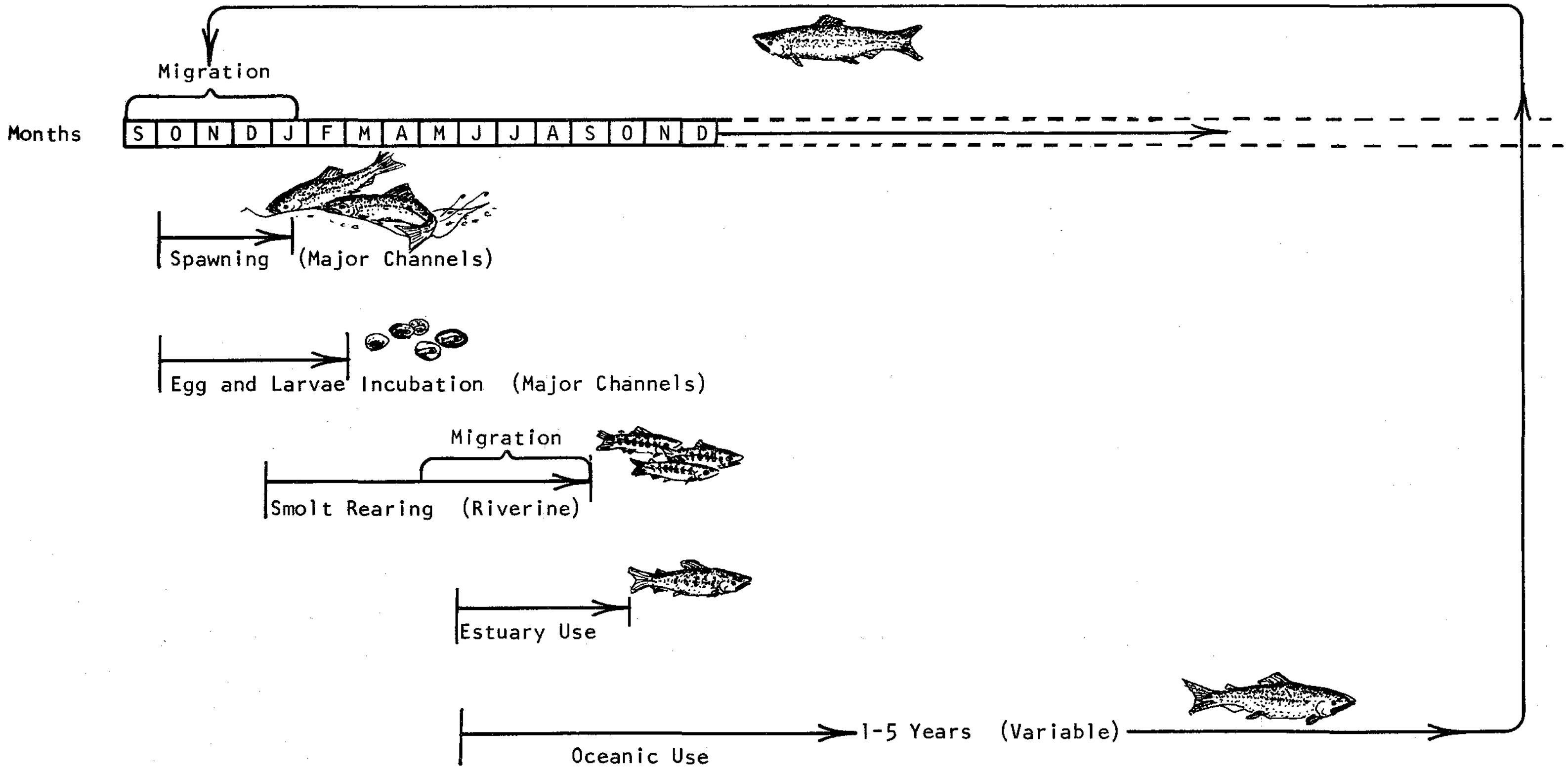


FIGURE 1. GENERAL LIFE CYCLE AND MIGRATION CHART OF CHINOOK SALMON. (From Williams et al., 1975, and Thompson et al., 1972.)

TABLE 1. GENERAL LIFE CYCLE OF CHINOOK SALMON. (From Williams et al., 1975.)

Life Stages	Small Tributary	Large Tributaries and Main River	Estuary	Ocean	General Comments
Mature Adults (spawning)	Some use	30 to 60 days (fall months)			Adults always die after spawning.
Eggs & Larvae (incubation)	Some use	90 to 150 days in gravel (winter months)			Average number of eggs 4,000 per female. Max. 13,500
Juveniles (rearing)	Some use	60 to 120 days (spring months through summer)	30-60 days seaward migration		Limited by loss of spawning and rearing areas.
Growth to Maturity				1-5 yrs 3 yrs typical	Ranges north to Alaskan waters; some Puget Sound.
Maturing Adults		Returning to original spawning grounds to complete life cycle, normally at age 4 years.			Average weights 20-25 lbs. 126 lb. maximum weight.

8. Carrying Capacity

Carrying capacity of the natural streams has been reduced by a number of factors discussed in the following section on limiting factors. Chinook salmon have nearly been eliminated from some rivers and streams in the region, but recent plantings from hatcheries may reestablish runs (USDA, 1976); loss in natural carrying capacity of the region has been compensated to an unknown degree by these hatcheries. Streams have a given amount of spawning area and are able to accept a given number of spawning pairs. Returns greater than this do not directly increase the productivity of the species, although enrichment by carcasses has been thought by some investigators to be a significant nutrient input to streams and lakes and a reversal in the general downstream trend in nutrient flow.

9. Limiting Factors

Water quality, waterflow, passage, and suitable gravel are the principal limiting factors (see Reproductive Rate). Juveniles require a minimum depth of 0.1 to 0.2 feet (3 to 6 cm) for intrastream movement during their rearing period (Thompson et al., 1972). The minimum depth for successful passage of chinook salmon on their spawning runs is considered to be 0.8 of a foot (24 cm) of water (Thompson et al., 1972). Seasonal low flows in July through October are the mosting limiting factor in the region.

Temperatures over 62°F (16°C) can cause direct mortality as well as indirect effects such as increased incidence of disease.

10. Human Activities

Man is actively engaged in managing the chinook resources of this region. Poor logging practices in the past have reduced the carrying capacity of the area (Thompson and Snow, 1974; USDA, 1976). Future public and private logging may continue to reduce the carrying capacity if they result in increased sedimentation, decreased low flows, and increased temperatures. Dams have also eliminated spawning streams and caused increased mortality due to nitrogen bubble disease and injuries to the juveniles moving downstream caused by turbine blades (Fulton, 1970).

11. Natural Perturbations

Successful reproduction is susceptible to low flows and associated high temperatures. Local landslides may also remove portions of a stream from production; barriers, falls, etc., can keep chinook and other salmon from utilizing otherwise suitable spawning areas. Floods can also cause damage if flows get too high.

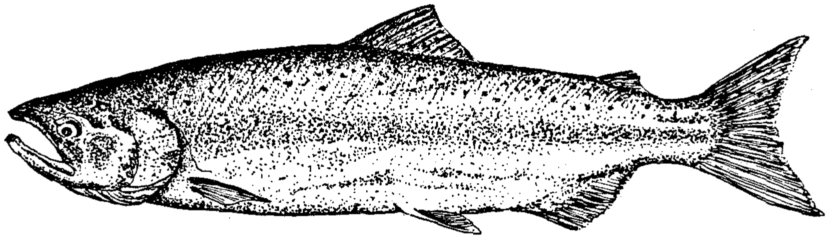
COHO SALMON - Oncorhynchus kisutch

1. General Description

Coho salmon is also called silver, silverside, and hooknose salmon. In salt water it is identified by light spotting on upper part of tail only and a white lower gumline where teeth project from the jaw. Fresh water spawning color is reddish-black on head and back shading to red on side. Coho is one of the most important sport and commercial fishes in the Pacific Northwest.

2. Population

Basic life cycle and biological information for coho salmon are given in Figure 1 and Table 1.



3. Migration

Migration timing and habitat use for a complete life cycle are given in Figure 1. Typically, the majority of coho are thought to remain in the upwelling waters off the coast when not returning inland to spawn, although some portion of the ocean population migrates north. Figure 3-4A in Section 3.4.1.2 (Chapter 3 of this volume) portrays oceanic migration in and near the region.

4. External Population Factors

The Oregon Fish Commission estimates three coho are caught by commercial and sport fishermen for each fish that returns to spawn. Approximately 71% of the catch is taken commercially and 29% is taken by sports fishermen (USDA, 1976).

5. Reproductive Rate

The average number of eggs per female is 3,000 (Williams et al., 1975), with the majority of natural spawning occurring in small streams. Survival to smolts under natural conditions is estimated at 10% but varies widely depending on environmental conditions. Survival to smolts in well-run hatcheries is 80-90%.

6. Growth Rate

Coho spend the first year in the stream where they grow to approximately five inches (13 cm) with weight of about twenty grams (0.7 oz) (see Riverine food webs). Growth in the marine system is rapid with weights of eight to ten pounds (4-5 kg) being reached in two years (Williams et al., 1975). In estuaries, recent studies indicate intensive use of harpacticoid copepods as food by smolts. Coho feed on phytoplankton-based food webs, taking small fishes in the offshore waters (see Oceanic Pelagic food web). They typically remain in the upper thirty meters (100 ft) of the oceanic water column.

7. Death Rate

Predation by piscivorous fish and birds on smolt and fry can be an important factor to survival rates. Death rates are increased by high temperatures and siltation. These combined factors establish the 90% average mortality figure for smolt. In addition, of the fish that reach ocean waters, typically only 10% return to spawn. The remainder are lost through ocean predation, disease, and harvesting, thus establishing a typical one percent return. An average return of one percent is thought to be required for replacement. Survival is dependent on environmental conditions and predation at any stage of its life cycle, and these vary markedly. (See Reproductive Rate and External Population Factors.)

8. Carrying Capacity

Coho are dependent on maintenance of small coastal streams with acceptable water quality and access, as discussed in Limiting Factors. In the ocean, food supply (phytoplankton-based food web) and competition may limit growth, but limiting factors in the marine environment other than temperature are not well documented. Stream carrying capacity has been regionally augmented by hatchery production (see Section 3.4.1.2 in Chapter 3 of this volume).

Coho Salmon (Oncorhynchus kisutch)

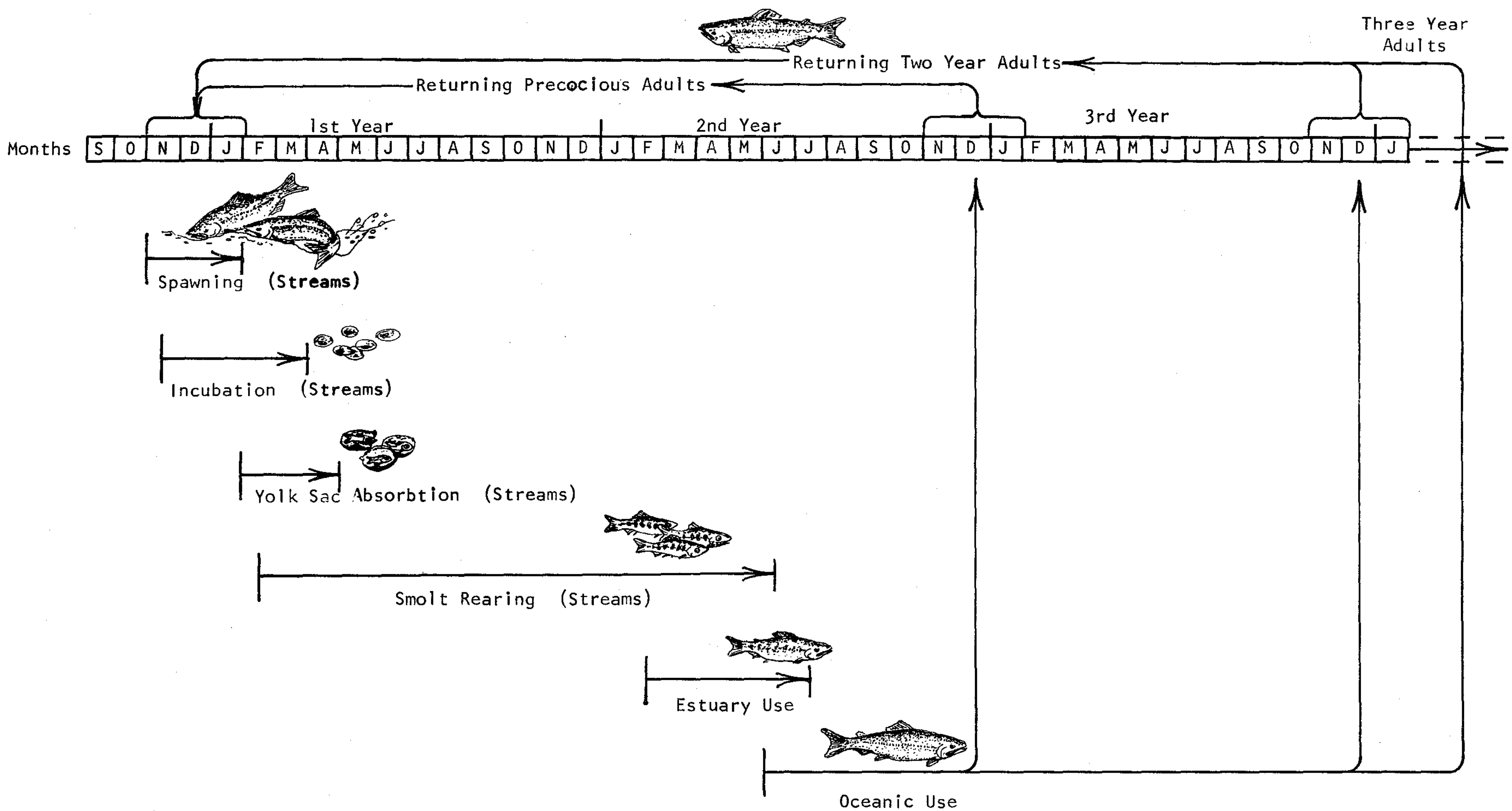


FIGURE 1. GENERAL LIFE CYCLE AND MIGRATION CHART OF COHO SALMON. (From Mahnken and Joyner, 1973.)

TABLE 1. GENERAL LIFE CYCLE OF COHO SALMON. (From Williams et al., 1975.)

Life Stages	Tributaries	Main River	Estuary	Ocean	General Comments
Mature Adults (spawning)	30 to 60 days (late fall through early winter.)	Some use			Adults always die after spawning.
Eggs & Larvae (incubation)	80 to 150 days (winter months)	Inside channels			Average number of eggs 3,000 per female.
Juveniles (rearing)	12 to 14 months, spends entire year in stream.	Some use, extent unknown	30-120 days seaward migration		Populations limited by low summer flow conditions.
Growth to Maturity				Spend 1-2 years at sea, 2 yrs typical.	Ranges north and south in ocean; some in Puget Sound.
Maturing Adults	Returning to original spawning grounds to complete life cycle, normally at age 3 years.				Average weight 8-10 lbs. 31 lbs. maximum weight.

9. Limiting Factors

The most significant limiting factor for coho salmon in this region appears to be low summer flows (Thompson et al., 1972). However, the USDA (1976) documents water temperature increases due to extensive logging, and siltation due to poor road construction, logging, and development practices, all of which have also affected runs. Naturally occurring landslides may also affect the carrying capacity. Generally, the effects of logging on salmonids are highly variable and must be analyzed on a site-specific basis (Moring and Lantz, 1975; Gibbons and Salo, 1973; Crow et al., 1976). Carrying capacity for coho salmon is based on the amount and quality of spawning and rearing habitat. Spawning requirements include clean uncompacted gravel 1/4 to 5 inches (0.5 to 13 cm) in diameter (the extremes are less favorable) and 6 inches to 1 foot (15 to 30 cm) in depth. Dissolved oxygen required is 8 ppm or higher, with a minimum spawning depth of 0.6 foot (18 cm) and water velocity of 1.0 to 3.0 feet per second (0.3 to 1.0 m/sec) as measured 0.4 foot (12 cm) from the bottom (Thompson et al., 1972).

10. Human Activity

Coho are affected directly through sport and commercial harvesting and indirectly through land use practices which alter limiting factors (flow, temperature, sediment, available gravel, passage). These in turn affect the carrying capacity of the area, i.e., its ability to support a viable population of coho. Carrying capacity of the region is thought to have been reduced by poor logging practices (Thompson et al., 1972; USDA, 1976; Burns, 1971), changes in land use, and effects of dams (Fulton, 1970). Loss of carrying capacity has been offset in many places by hatchery production.

Commercial and sport fisheries are strictly regulated so that the necessary numbers of returns to spawning streams are assured. However, open sea fisheries are indiscriminate in terms of specific stocks caught.

11. Natural Perturbations

Successful reproduction is affected by low flows and associated high temperatures. Local landslides may also remove portions of a stream from production; barriers, falls, etc., can keep coho and other salmon from utilizing otherwise suitable spawning areas. Floods can also cause damage if flows get too high.

BALD EAGLE - Haliaeetus leucocephalus

1. General Description

The northern bald eagle is a large raptor. Head, neck, tail, and tail coverts are white and the remaining plumage dark brown on adults. Young have mixed colors with first year young typically completely black and second and third year plumage consisting of mixed black and white underparts, head and neck black, and remainder of the body mixed gray, brown, black, and white (Eaton et al., 1975). The length is 30 to 43 inches (75 to 110 cm) with a wing-spread of 78 to 96 inches (200 to 240 cm) (Udvardy, 1977). The eagle is sexually dimorphic with the female being considerably larger than the male.

2. Population

The bald eagle has an extensive range and breeds from the Aleutian Islands, Mackenzie, Ontario, Quebec, and Newfoundland south to northern California and Florida. In Washington and Oregon most of the breeding population occurs west of the Cascades.

The population of bald eagles, although having been depressed throughout the continental United States, has remained stable in Washington (Eaton et al., 1975). Reichard (1976) reports 20 active eagle nests in Watershed Units 1, 2, and 3, while Thompson and Snow (1974) report 16 eagle nest sites for Watershed Units 3, 4, 5, 6, and 7. However, nationwide (excluding Alaska), the population of bald eagles has dropped from 3,800 in 1963 (Sprunt, 1963) to less than a thousand in 1974 (Laycock, 1974). Figure 1 (Oregon State Department of Fish and Wildlife, 1975; and Washington State Department of Game, 1974) indicates the distribution of known bald eagle nest sites within the study area. Densities are greatest in the northerly portion of the study area. The Washington State Game Department maintains a file on all known bald eagle nests in Watershed Units 1, 2, and 3. The Oregon State Wildlife Research Unit at Corvallis is currently collecting data on nesting sites within Oregon and Washington (Anthony, pers. comm., 1978).

3. Migration

Migration patterns for bald eagles are poorly known. Some birds remain on their breeding grounds throughout the year, while others which breed on less favorable sites often concentrate (5-20 birds) at rivers with substantial salmon runs (where they feed on spawned-out salmon) or at estuaries and rock shores, e.g. Willapa Bay, Grays Harbor, Grenville Point. However, little is known about the destination of breeding areas of the eagles which concentrate in the study area.

4. External Population Factors

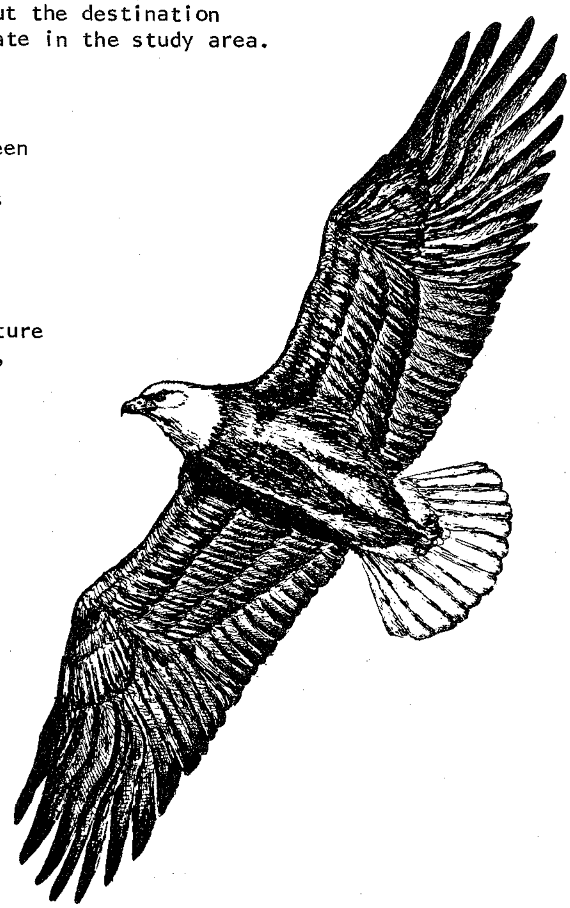
In areas outside the region, bald eagles have been seriously affected by biologically amplified pollutants, principally DDT and its derivatives (Hickey and Anderson, 1968).

5. Reproductive Rate

The eagles do not typically become sexually mature until their fourth or fifth year (Eaton et al., 1975), at which time they lay one or two eggs every other year. They are monogamous and mate for life. The majority of nests are along marine coastlines typically within 200 yards (200 meters) of shore (Reichard, 1976). Nesting usually begins early in February and the eaglets are fledged in July (Reichard, 1976).

6. Growth Rate

This species reaches sexual maturity at 4 to 5 years but reaches weight and size maxima by the first year. Food habits are variable and opportunistic. The eagle scavenges along marine shoreline habitats including sandy beaches, tidal flats, estuaries



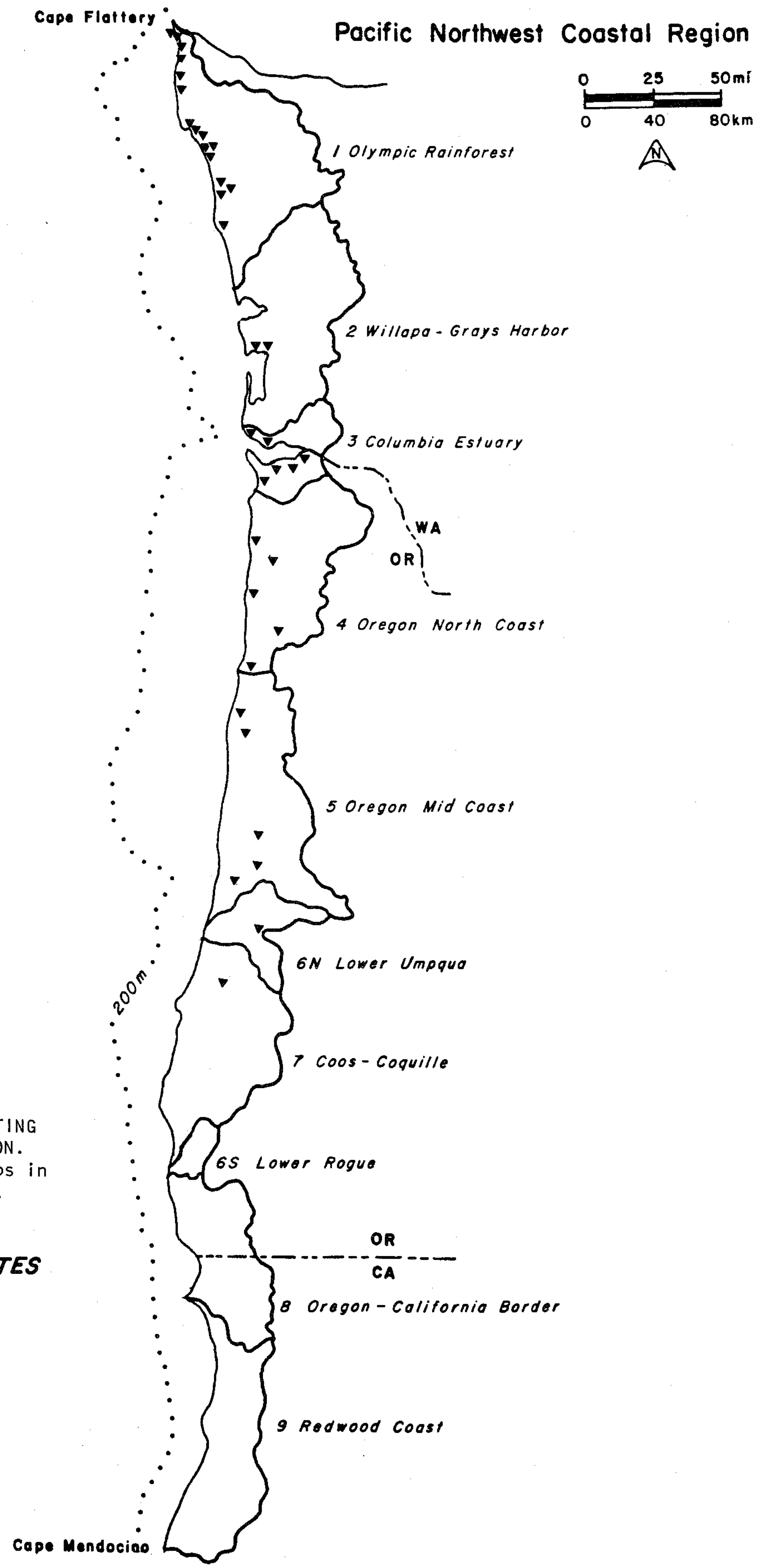


FIGURE 1. BALD EAGLE NESTING SITES IN THE COASTAL REGION. See the Watershed Unit maps in Volume 4 for more details.

BALD EAGLE NEST SITES

and rocky shores (Reichard, 1976). It often feeds on spawned out salmon, molluscs, and small mammals. Occasionally it robs ospreys of their catch.

7. Death Rate

Other than man, adult and juvenile eagles have few enemies. Throughout their range man directly and indirectly has reduced eagle populations by chemical pollutants (principally chlorinated hydrocarbons), destruction of nesting habitat, electrocution, poisoning, and shooting. However, populations at least in the northern portion of the study area appear stable.

8. Carrying Capacity

Carrying capacity for bald eagles is fairly low as they have large territorial requirements (up to 1 square mile). Also the preference of old growth nesting trees within 200 yards (200 meters) of the coast limits nesting sites. In addition, the quantities of salmon which once returned to their native streams to spawn have been reduced, thereby possibly affecting the winter carrying capacity.

9. Limiting Factors

Maximum bald eagle densities are limited by territorial requirements. Welty (1962) reports bald eagle territories are in the order of 2.5×10^6 square meters or approximately one square mile. However, territory requirements vary considerably, often depending on the quality of the environment (Verner, 1975). Lack of suitable nesting sites may also limit population densities. Food supply may limit wintering populations as natural spawning runs have been reduced.

10. Human Activities

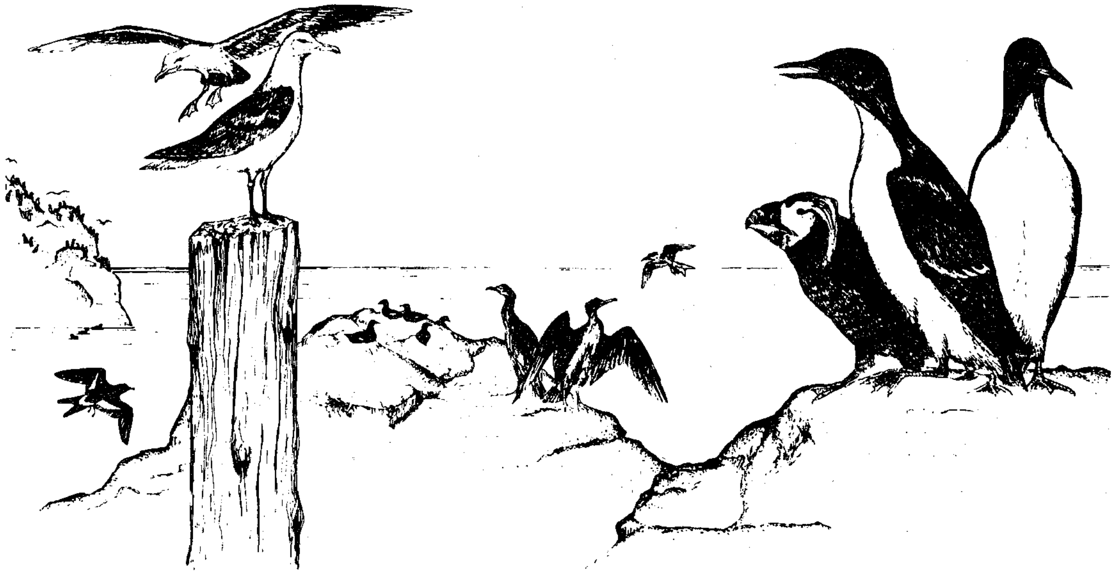
The number of individual eagles within the conterminous United States has dropped from 3,800 to less than 1,000 between 1963 and 1974. The reduction is attributable to man either directly or indirectly. (See Death Rate discussion.) Populations in Washington are reported to be stable (Eaton et al., 1975; Reichard, 1976).

The bald eagle is protected under state and federal laws. In 1978 it was classified as threatened in Washington and Oregon, and endangered in California under the Endangered Species Act. Guidelines have been developed by the Fish and Wildlife Service for its protection (FWS, 1977C; Sayre, 1978). The Forest Service has guidelines for protection on some U.S. Forest Service lands (Forbis, 1975). Eaton et al. (1975) provide additional management recommendations. Most of the recommendations deal with establishing better buffer areas around nest sites, redesigning power line systems to reduce electrocution, and the preservation of concentration areas.

11. Natural Perturbations

Eagles prefer old growth snag trees for nesting, and these are prone to windfall. Fluctuations in food supply will also markedly affect eagle populations.

SEA BIRDS



General Discussion. Many species of water-associated birds are found in the coastal waters of the study area. A complete list of these, along with their relative abundance and seasonality, is provided in the oceanic Annotated Species List. Species accounts have been provided by numerous authors, including Salo (1975), Eaton et al. (1975), Brittell et al. (1976), Rodgers and Douglas (1974), Nehls et al. (1975), Guiguet (1954-1971), and Bent (1919-1968).

Of the many species which inhabit the area, only a few are known to breed in abundant numbers on rocky coastal headlands and islands of the study area. Among these common murre, Leach's and fork-tailed storm petrels, glaucus-winged and western gulls, and pelagic, double-crested, and Brandt's cormorants are the most common. The rhinoceros auklet and tufted puffin are common breeders in the northerly Watershed Units. The common murre is the most abundant breeding sea bird of the area. A few species - notably Caspian tern, glaucus-winged and western gulls - nest on sandy islands in some estuaries, e.g. Columbia, Willapa Bay, Grays Harbor, and Humboldt Bay (Peters et al., 1977; California Coastal Zone Conservation Commission, 1975). Figure 1 shows the general location of sea bird rookeries along the Pacific Northwest Coast; more precise location and sizes of the known breeding colonies are provided for each Watershed Unit on maps in Volume 4. Tables 1, 2, 3, and 4 provide a summary of the sea bird breeding populations of the study area.

Most of the marine birds which breed in the area are colonial nesters, with numbers in some colonies in the tens of thousands and approaching 100,000 in some years. A ten year record of sea bird breeding populations on the Oregon Coast indicates considerable year to year fluctuation in breeding populations (U.S. Fish and Wildlife Service, 1976A). Some common murre breeding areas were recorded as having no breeders on some years and as many as 10,000 in other years. Other species showed similar but less drastic variability on breeding effort.

Relationship to Ecosystem. Sea birds feed primarily on the second, third, and fourth trophic levels of the marine food webs (Sanger, 1972) and have been estimated to take 0.09% of the second level, 0.9% of the third trophic level, and 0.26% of the fourth trophic level in terms of annual production. Adult marine birds are at the apex of food webs and have few predators. Some falcons, including the endangered peregrine falcon, prey on sea birds (Eaton et al., 1975). Sea birds are a principal consumer in the marine ecosystems of the study area (Sanger, 1970).

Population Levels. Relative densities for pelagic birds found off Westport (Grays Harbor - Watershed Unit 2) are given in Figure 2. Estimated densities for the "coastal domain" - as defined by Sanger (1972), which includes the study area - are given in Figure 3. As indicated, there are both resident and migratory populations within the area.

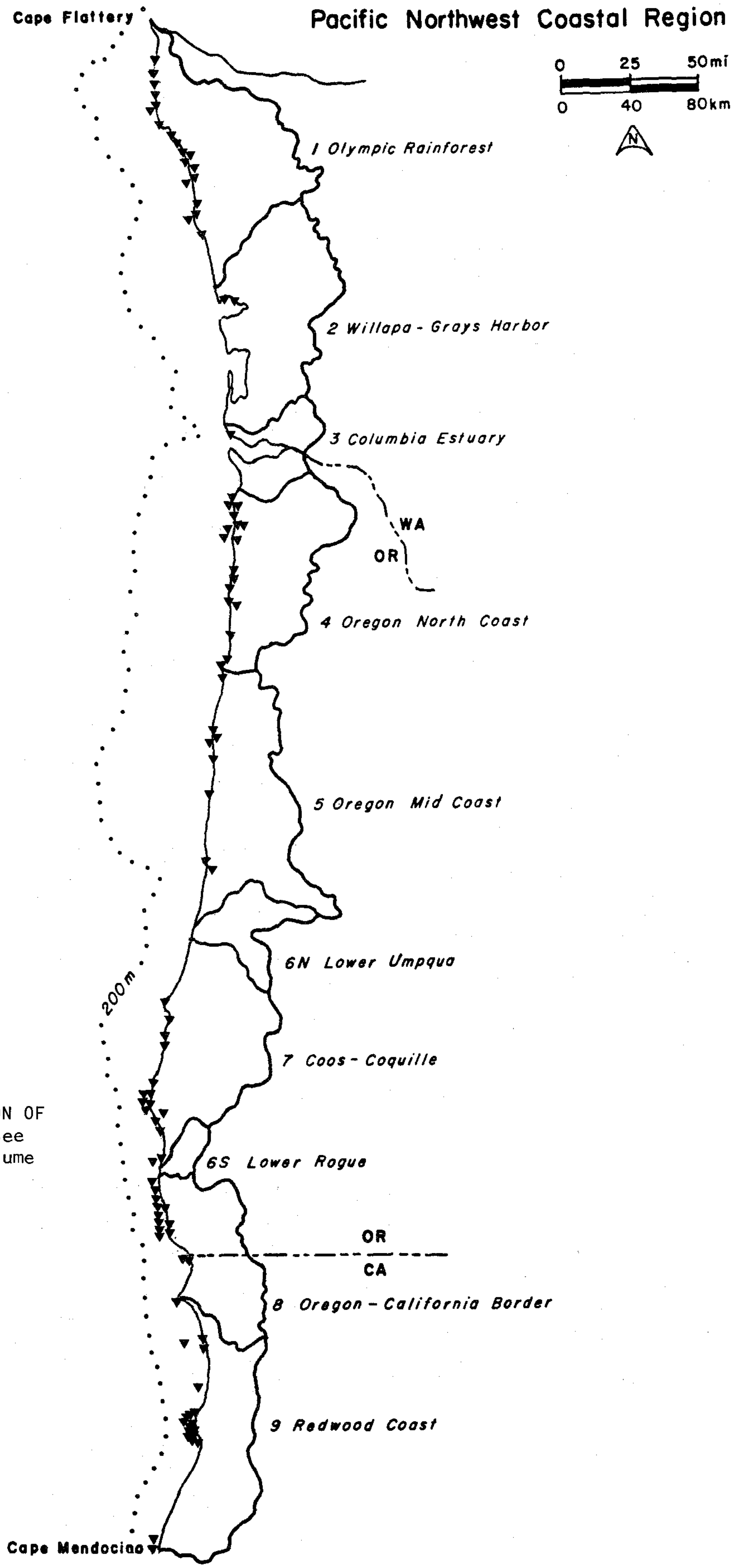


FIGURE 1. GENERAL LOCATION OF SEA BIRD NESTING AREAS. See Watershed Unit maps in Volume 4 for details.

SEA BIRD ROOKERIES

TABLE 1. AVERAGE BREEDING POPULATIONS OF SEA BIRDS ON WASHINGTON ISLAND NATIONAL WILDLIFE REFUGES. (From Frazer et al., 1973.)

SPECIES	BREEDING PAIRS	PRODUCTION/YEAR (# of new indiv.)
Fork-tailed storm petrel	9,000	2,000
Leach's storm petrel	25,000	6,000
Double-crested cormorant	1,000	500
Brandt's cormorant	1,500	700
Pelagic cormorant	4,000	2,000
Black oystercatcher	200	70
Common murre	30,000	12,000
Pigeon guillemot	1,900	300
Cassin's auklet	300	100
Rhinoceros auklet	16,000	9,000
Tufted puffin	24,000	8,000
Glaucous-winged gull	9,200	12,000
Western gull	4,100	1,800
TOTAL	126,200	54,470

TABLE 2. ESTIMATED BREEDING POPULATIONS OF SEA BIRDS ON OREGON COAST.

SPECIES	BREEDING PAIRS
Leach's storm petrel[1]	535,000
Cormorants[2]	9,194
Gulls[2]	7,280
Common murre[2]	122,673
Cassin's auklet[3]	482
Tufted puffin[3]	510-520

[1] One-year sample, by Browning and English (1972).

[2] Nine-year average, ending in 1974, by U.S. Fish and Wildlife Service (1976A).

[3] One-year sample of selected islands in Oregon (incomplete), by Browning and English (1972).

TABLE 3. BREEDING POPULATIONS OF SEA BIRDS OFF HUMBOLDT AND DEL NORTE COUNTIES, CALIFORNIA. Data are from two sources.

SPECIES	BREEDING PAIRS (Source 1)[a]	BREEDING PAIRS (Source 2)[b]
Fork-tailed storm petrel	175	103
Leach's storm petrel	7,500	7,875
Pelagic cormorant	365	561
Brandt's cormorant	1,697	2,212
Double-crested cormorant	120	132
Black oystercatcher	6	6
Western gull	913	1,018
Common murre	39,200	77,700
Pigeon guillemot	308	466
Tufted puffin	29	34
Cassin's auklet	1,025	1,802[c]
Rhinoceros auklet	150	50

[a] From California State Department of Fish and Game (1969-1970).

[b] From Osborne (1972).

[c] Single year sample.

TABLE 4. COLONIAL SEA BIRD BREEDING POPULATION ESTIMATES FOR PACIFIC NORTHWEST ESTUARINE ISLANDS FROM COOS BAY, OREGON, TO GRAYS HARBOR, WASHINGTON.[a, b] (From Peters et al., 1977.)

Location	Species	Breeding Pairs
Coos Bay (9 islands)	None	
Columbia River Mouth (Baker Bay)		
East Sand Island	Western/glaucous-winged gull	1200[c]
Willapa		
Pine Island	Western/glaucous-winged gull	80[c]
Gunpowder Island	Western/glaucous-winged gull Caspian tern	700-1200[d] 100[d]
Grays Harbor		
Rennie Island	None	
Half Moon Island	None	
Goose Island	Western/glaucous-winged gull	2500-3000[c, d]
Sand Island	Western/glaucous-winged gull Caspian tern	800-1000[c, d] 1700[c]
Whitcomb	Western/glaucous-winged gull Caspian tern Ring-billed gull	40[c] 300[c] 3-9[c]

[a] A colony of Caspian terns is known to nest on Sand Island in Arcata Bay, and a colony of double-crested cormorants is known to use the remains of an old Arcata Wharf, but breeding numbers are undocumented.

[b] These data do not include some nesting cormorants on buoys, etc.

[c] This figure was based on active nests.

[d] This figure was based on census of adults.

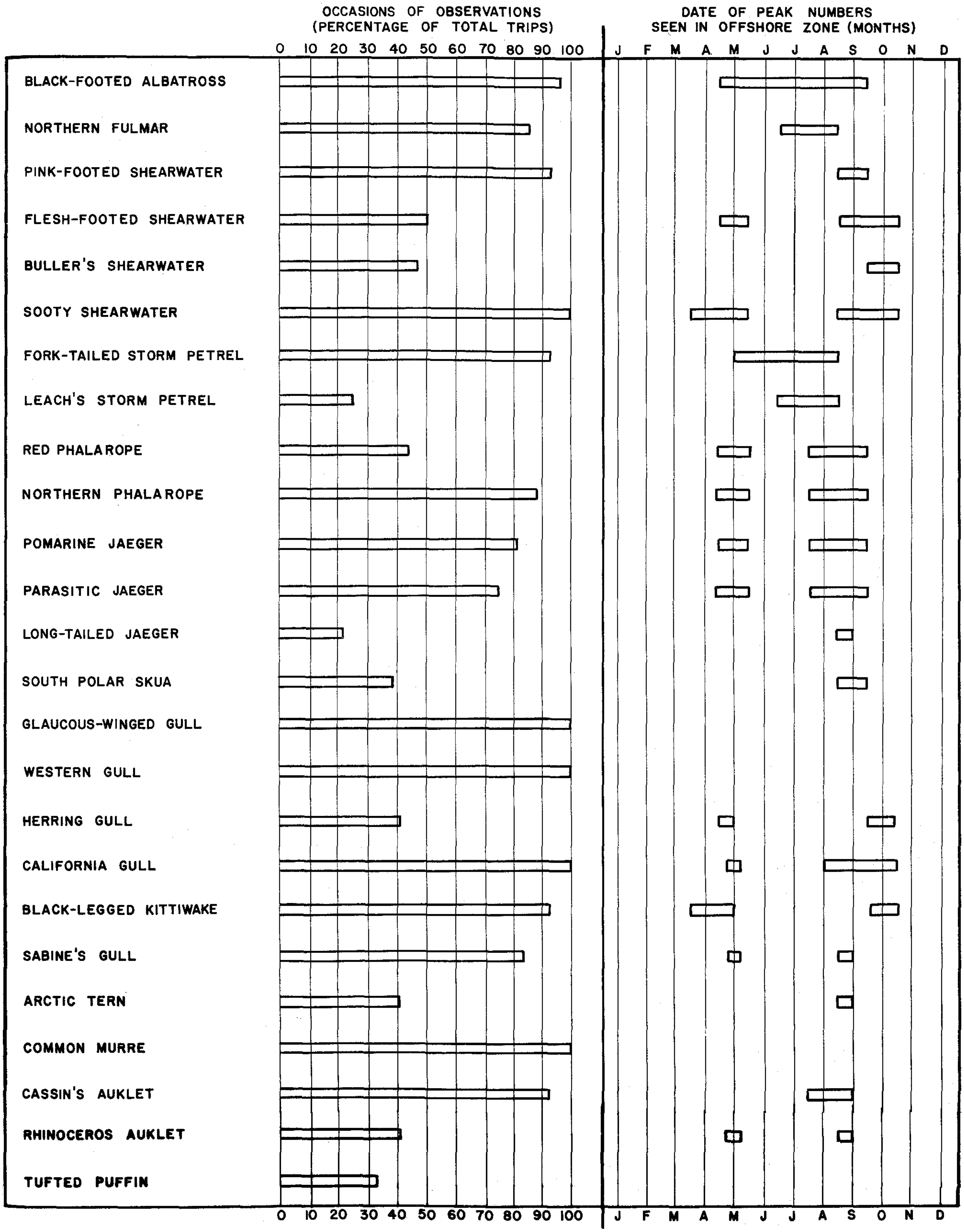


FIGURE 2. SEA BIRD FREQUENCY OF OBSERVATION FOR 42 TRIPS OFF WESTPORT, WASHINGTON. (After Wahl, 1975.)

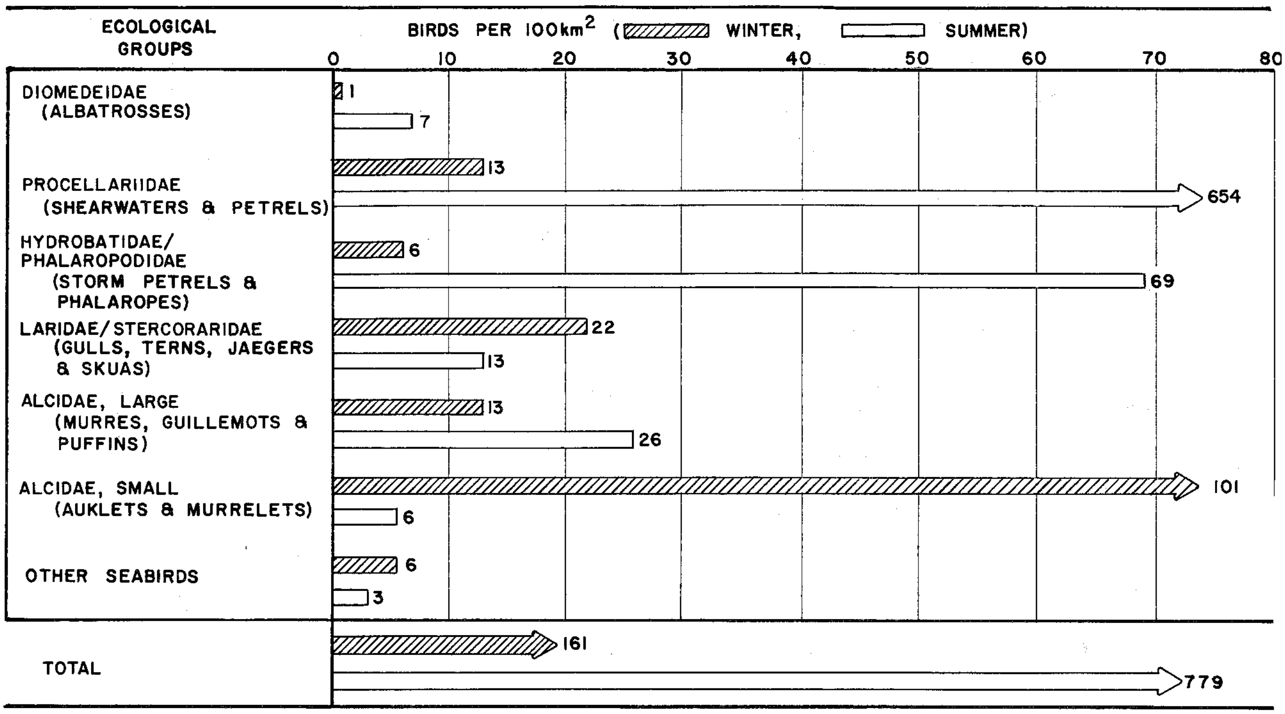


FIGURE 3. SUMMARY OF SEASONAL SEA BIRD ABUNDANCE FOR THE "COASTAL DOMAIN." (After Sanger, 1972.)

Guano deposits have been found on islands off Vancouver Island, B.C., (Campbell, 1976) and have noticable effects on vegetation. Similar conditions can be expected to occur on islands within the study area. The Nature Conservancy (1977) lists Hairy Lasthenia (Lasthenia minor ssp. maritima) as a rare plant that is only found in association with sea bird colony sites, presumably in relation to guano deposits.

Human Impacts and Status. Sea birds are in many ways highly sensitive to deleterious man-caused impacts. Their susceptibility to oil spill effects are well documented (Aldrich, 1970; Beak Consultants, Inc., 1975). King and Sanger (1977) have developed an oil impact index for marine birds which indicates their relative sensitivity. Petrels and alcids have, in addition, low reproductive rates, bearing only one egg per year. Also, being near the apex of food webs, sea birds are sensitive to pollutants which are biologically amplified in the various food chains. Finally, sea birds concentrate during breeding periods in small colonies, with great densities. Under these conditions, their susceptibility is particularly high; even localized pollution events or disturbances can have effects on region-wide populations. In areas outside the region, disturbance of breeding colonies has caused some abandonment by the adults and concomitant increased predation upon young by opportunistic predators such as skuas, gulls, and crows. Peters et al. (1977) surmise that selection of nesting sites on estuarine islands is strongly influenced by human disturbance, i.e. areas frequently or easily visited by people are avoided by nesting birds.

The black oystercatcher, which breeds all along the coast in low numbers, has been unofficially classified as potentially threatened with extinction in Washington State by Brittell et al. (1976), based on low reproductive rates, small population, and restricted habitat (rocky intertidal). However, the population seems to be stable and has historically been at low densities in the region.

Similarly, the Caspian tern is unofficially classified as potentially threatened in Washington State (Brittell et al., 1976), principally due to low numbers, a decline in California populations, and restricted breeding areas (typically estuarine sandy islands). However, this species tends to have a vagrant breeding population, establishing and abandoning breeding sites rather rapidly. The establishment of a breeding colony was first reported in the Washington coastal area in 1957 (Brittell et al., 1976). World-wide, their status is not considered rare, threatened, or endangered.

SNOWY PLOVER - Chadaerius alexandrinus

1. General Description

The snowy plover is a small, plump shorebird with an incomplete breastband which appears as two dark splotches on the upper breast. The crown and back are adorned very much like its surrounding sandy environment and vary from grey to brown.

2. Population

Population estimates for snowy plover in the region are unavailable. However, it is considered rare or in danger of extinction by several authors (Marshall, 1969; Eaton et al., 1975; Dyrness et al., 1975) and is considered "threatened" by the Oregon State Department of Fish and Wildlife (1976B). Figure 1 shows general concentration areas of the species along the coast.

3. Migration

Coastal and interior populations of snowy plover winter along the Pacific coast from the vicinity of the Columbia River south to southern Baja California (Eaton et al., 1975). During severe weather they occasionally gather into small flocks on dry dunes. They are spring and fall migrants along the Washington coast. The populations breed in summer on the coast and in interior alkaline basins and sand dunes (Eaton et al., 1975). North-south movement is presumed to occur, but the range is unknown.

4. External Population Factors N/A

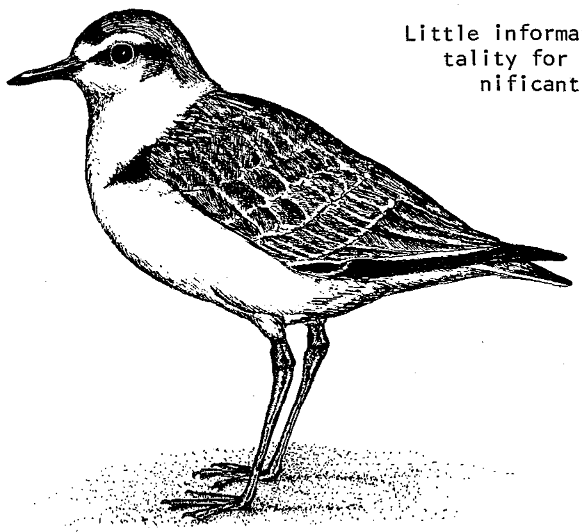
5. Reproductive Rate

The snowy plover is monogamous and lays two to four eggs per clutch, three eggs are most common, and has one clutch per year. Breeding season is in May and June. Preferred nesting habitat is sparsely vegetated, unstable sand just inland from the high tide line. Renesting (after a disturbance) is not documented.

6. Growth Rate

Age at sexual maturity is unknown but is probably one to two years. Food availability does not appear to be an important factor. The plover generally feeds along sandy shores for flies, worms, sand fleas, beach hoppers, and other small crustaceans (Eaton et al., 1975). Small amounts of vegetable matter are also eaten (Eaton et al., 1975)..

7. Death Rate



Little information is available on death rate or causes of mortality for this species. Winter storms are probably a significant factor.

8. Carrying Capacity

The carrying capacity apparently is limited by suitable nesting habitat, which may become increasingly scarce due to vegetation encroachment (Czemeris, personal communication, 1977) and stabilization of dunes (Eaton et al., 1975). Since population numbers are not known, it is impossible to determine whether the existing population is at, or near, carrying capacity. Also, nesting density limits have not been established.

9. Limiting Factors

A suitable breeding and nesting habitat is thought to be the most important limiting factor for the snowy plover throughout its range (Eaton et al., 1975; Marshall, 1969; Pinto et al., 1972). However, large tracts of suitable habitat under protective land status within the region will at least provide the physical requirements for nesting habitat.

10. Human Activity

Encroachment on dunes by recreational housing and other land use changes has depleted breeding habitat over much of this bird's coastal range. The introduction of European beach grass and

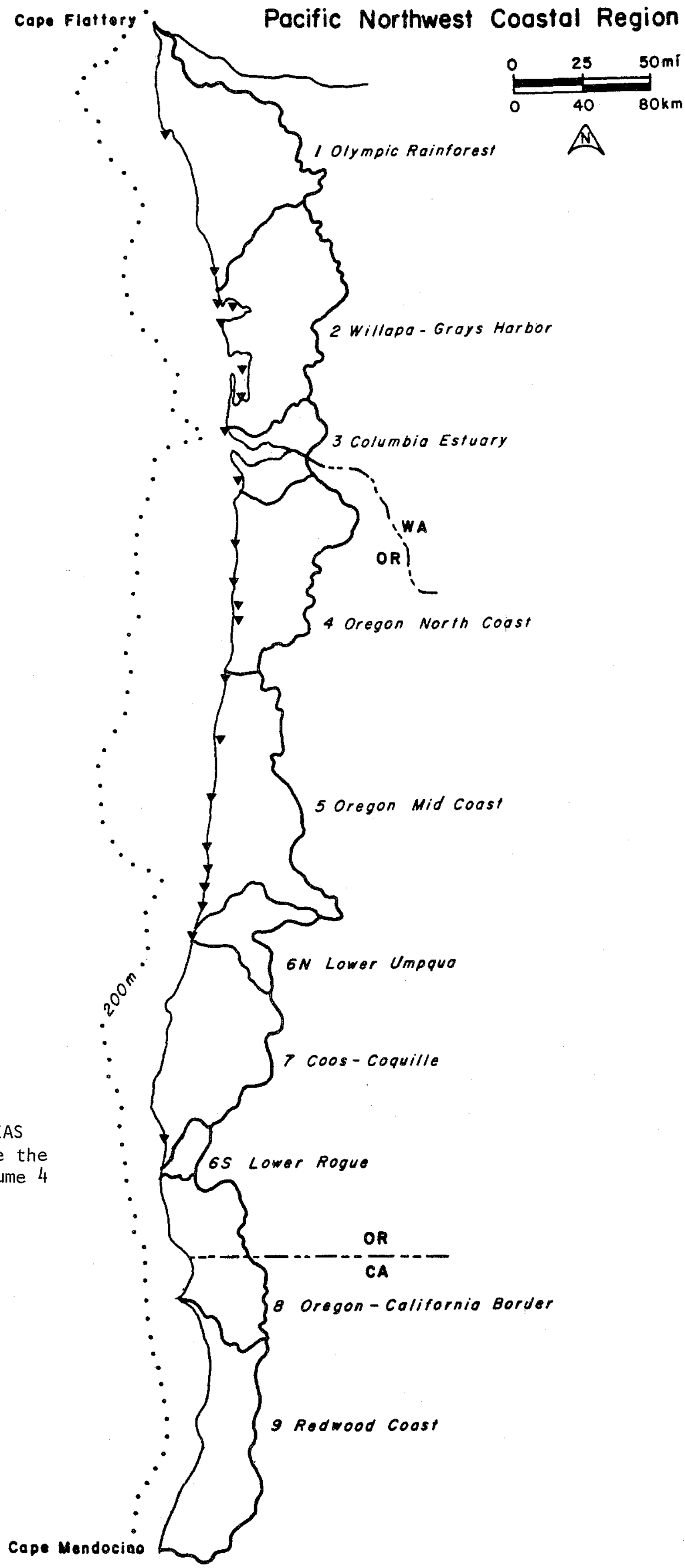


FIGURE 1. SNOWY PLOVER AREAS IN THE COASTAL REGION. See the Watershed Unit maps in Volume 4 for more details.

SNOWY PLOVER CONCENTRATION AREAS

other dune stabilization efforts have further depleted suitable nesting habitat. Recreational use of these areas in May and June may be detrimental to the survival rates of young. Pets and offroad vehicles are more disturbing than human foot traffic (Eaton et al., 1975), as most foot traffic is usually seaward of the nesting habitat.

11. Natural Perturbations

Winter storms are probably an important factor in winter mortality.

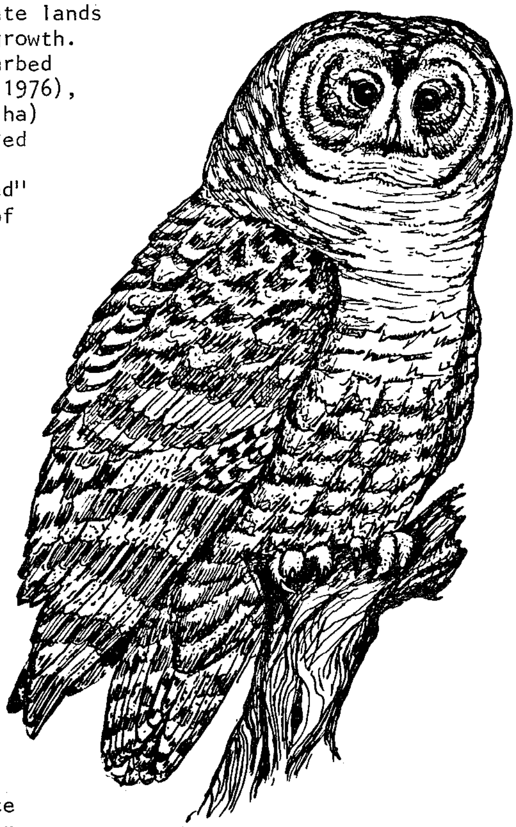
SPOTTED OWL - Strix occidentalis caurina

1. General Description

The spotted owl is large, round-headed with black eyes. The top of the head and back of the neck are spotted with white and the chest is barred horizontally. Its overall aspect is a deep rich brown. The distinction between this subspecies and S. occidentalis occidentalis is not clear and is disputed by some (Forsman, 1976).

2. Population

Population information for the spotted owl is incomplete. Forsman (1976) found 116 pairs and 8 single spotted owls in Western Oregon between 1970 and 1974. No population censuses are available for Washington and California. Viable populations are to be expected in both states as large tracts of lowland old growth forests are protected within the Olympic and Redwood National Parks. Documented nests are given in Figure 1. Likelihood of occurrence on private lands is low (Forsman, 1976) due to lack of extensive old growth. Requirements of 300-600 acres (120-240 ha) of undisturbed lowland old growth forest have been stated (Forsman, 1976), but other sources indicate that 100-200 acres (40-80 ha) are required (Eaton et al., 1975). This owl is classified as "threatened" by the Oregon State Department of Fish and Wildlife. It is listed as "potentially threatened" in Washington by Eaton et al., (1975) and a "species of concern" in Oregon by Dyrness et al. (1975). Other subspecies of the spotted owl are widely distributed along the coast from Southwest British Columbia to Northern California, inland from Central Colorado to Western Arizona and New Mexico; and into Mexico (Eaton et al., 1975; Forsman, 1976).



3. Migration

This owl is sedentary and does not migrate (Eaton et al., 1975; USDA, 1976B). It is nocturnal (Forsman, 1976).

4. External Population Factors N/A

5. Reproductive Rate

Two to three eggs are laid per set, usually two (Eaton et al., 1975; Forsman, 1976). Breeding pairs generally reproduce once per year. However, Forsman documented sporadic breeding, possibly associated with food supply, for a three-year sample in Oregon. The mean number of young produced per nest was 1.61. Once arriving at sexual maturity (three years), the owls are thought to have 5-10 reproductive years (Forsman, 1976).

6. Growth Rate

Adult length ranges between 405-480 mm(15-19 in), with males weighing from 500-700 grams (1.1-1.5 lb). Females are slightly larger and weigh from 550-760 grams (1.2-1.7 lb). They put on nearly all their weight by late in the first fall. Age for reproductive maturation is typically at least three years for large owls. Prey for the spotted owl on the coast of Oregon is given in Table 1. The principal prey is the flying squirrel and other small rodents.

7. Death Rate

Based on a three-year sample, juvenile mortality is around 20% (Forsman, 1976). Adult mortality is lower and in the vicinity of 10% or less per year. Some predation by the Great Horned Owl, particularly upon juveniles, is documented (Eaton et al., 1975; Forsman, 1976), but in general this species has few natural enemies.

8. Carrying Capacity

With its extensive areal requirements, the resultant carrying capacity in suitable old growth habitat would be one breeding pair per 100-600 acres (40-240 ha). Due to the continual depletion

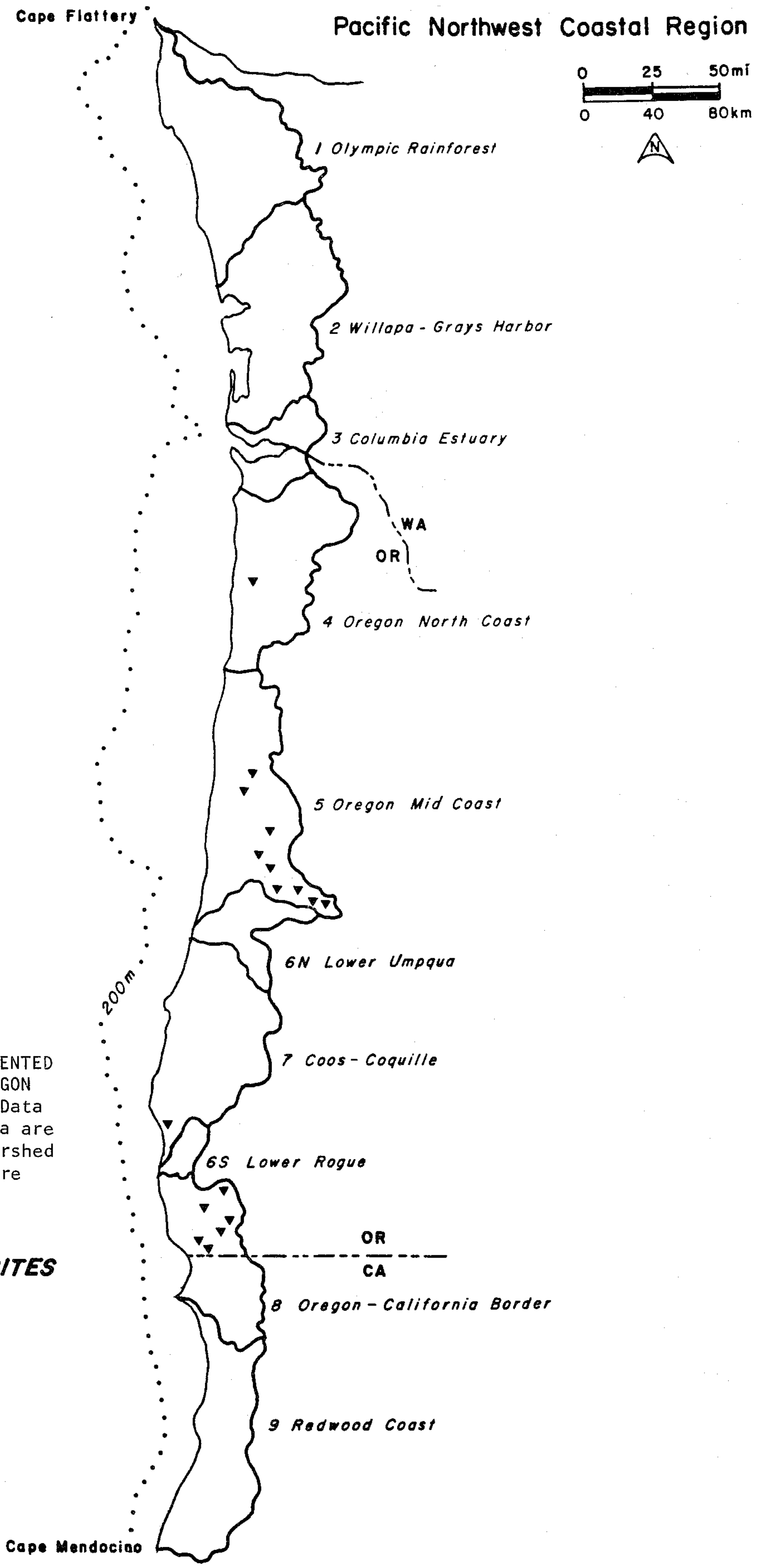


FIGURE 1. LOCATION OF DOCUMENTED SPOTTED OWL NESTS IN THE OREGON PORTION OF THE STUDY AREA. Data for Washington and California are not available. See the Watershed Unit maps in Volume 4 for more details.

SPOTTED OWL NEST SITES

of suitable habitat, existing population numbers are probably greater than the carrying capacity. The displaced populations probably occur in marginal habitats and may not reproduce.

TABLE 1. SPOTTED OWL PREY. Prey occurrence in percent numbers and percent biomass is listed for fourteen pairs of spotted owls in the Oregon Coast Range.[a] (From Forsman, 1976.)

Prey Species	Percent Numbers (n=1,437 prey items)	Percent of Total Biomass (n=102,408 grams)
Mammals		
Flying squirrel	25.56	41.09
Red tree mouse	30.61	11.60
Wood rat	5.49	20.50
Rabbits[b]	1.8	8.88
Deer mouse	12.94	3.99
Western red-backed vole	4.24	1.35
Chickaree	0.69	2.03
Oregon vole	1.32	0.35
Shrews	1.73	0.24
Other mammals	4.45	3.72
Birds		
Small owls	1.18	1.46
Mountain quail	0.13	0.47
Blue grouse	0.20	1.07
Other birds	4.23	2.95
Insects	4.73	0.07
Miscellaneous	0.70	0.14
Total	100.00	100.00

[a]Years of data collection were 1970, 1972, 1973. Principal habitat types were old growth associations of Douglas fir, western hemlock, and western red cedar. Elevations ranged from 25 to 490 meters (80 to 1600 feet).

[b]These were mostly *Lepus americanus*, but samples may have included a few individuals of *Sylvilagus bachmani*.

9. Limiting Factors

The availability of suitable 40-240 hectare (100-600 acre) blocks of old growth forest appears to limit the population. Suitable nesting trees - old growth, topped conifer with a secondary crown - may also limit production (Forsman, 1976).

10. Human Activities

As spotted owls require fairly extensive stands of lowland old growth forest, the widespread. logging which has occurred throughout the study area has probably reduced population numbers. Wilderness areas in lowland and mid-elevation forest lands in Oregon and in Washington's Olympic National Park provide areas of suitable habitat. Spotted owls are also reported to require snags and snag-topped trees, for they are cavity nestors (Silovsky and Pinto, 1974; USDA, 1976B; Forsman, 1976). U.S. Forest Service Guidelines for the Siskiyou National Forest in Oregon require the leaving of all dead snags that are not fire or safety hazards. Specifications are shown in Table 2. Whether such practices will maintain spotted owl populations in cut areas is unknown.

TABLE 2. DENSITY OF SNAGS SUITABLE FOR SPOTTED OWL NEST SITES. Data are from Siskiyou National Forest in Oregon. (From USDA, 1976B.)

Type	Riparian and Meadow Areas		Midslope Areas	
	No. snags/acre	(No. snags/ha)	No. snags/acre	(No. snags/ha)
True Fir Type[a]	6	(15)	3	(7.5)
Douglas Fir Type[b]	4	(10)	2	(5)

[a]Snag life is about 30-35 years.

[b]This includes all softwood forest types other than true fir; snag life is about 50 years.

11. Natural Perturbations

Forest fires, windthrow, and landslides are the major natural occurrences which could affect local populations by destroying habitat and nesting sites.

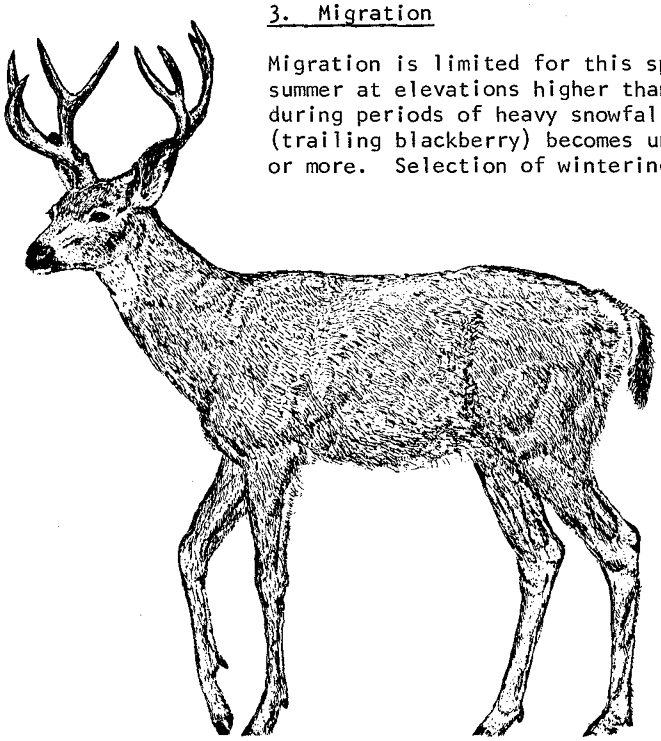
BLACK-TAILED DEER - Odocoileus hemionus columbianus

1. General Description

The black-tailed deer is a subspecies of the mule deer characteristic of the Pacific Coast. It is an important big game mammal with an adult length of 135-180 centimeters (50-70 in) and a weight of 115-207 kilograms (250-450 lb) (Maser et al., 1977). It is a browsing species with a preference for forest edge habitat.

2. Population

Population levels for black-tailed deer in the study area are unknown. Deer densities are thought to range between 5-60 per square mile (2-20/sq km), depending upon proportions of successional stages and their interspersion. Table 1 provides some typical densities for the region. A mixture of small cleared areas with suitable adjacent cover in the ratio of 40/60 is probably optimal and will support the higher densities. Similar ranges of densities are reported for several sites within the study area (Garcia et al., 1976; Brown, 1961).



3. Migration

Migration is limited for this species in the study area. Numbers which summer at elevations higher than 1500 meters (4300 ft) migrate to lowlands during periods of heavy snowfall. Much of their preferred winter food (trailing blackberry) becomes unavailable with a snowfall of 4 inches (10 cm) or more. Selection of wintering sites is reported to be based on supply of preferred forage, minimal duration of snow cover, and protection from cold winds (Dasmann, 1956; Maser et al., 1977). South and southwestern facing slopes are often preferred. Lowland populations remain sedentary. Home ranges measure from 0.6-1.3 kilometers (0.4-0.8 mi) across, encompassing 0.3 to 1.3 square kilometers (0.1 to 0.5 sq mi) (Maser et al., 1977; Dasmann, 1956; Taber, 1956). Bucks move over greater distances, particularly during rutting season.

4. External Population Factors N/A

5. Reproductive Rate

The black-tailed deer is polygamous, with one male able to service several females. Embryos-per-doe ratios vary from 0.45 to 2 depending on age and environmental conditions (principally food). About 45% of the yearling females and 92% of the female two to six age class become pregnant (Maser et al., 1977). Breeding occurs between late October and late December, with maximum activity (75%) occurring between the 10th and 25th of November (Brown, 1961).

6. Growth Rate

Nearly half the females become sexually mature at one year (Brown, 1961; Maser et al., 1977). By the second year both males and females become sexually mature. Both males and females attain physiological maturity (height and weight) in their second year (Brown, 1961). Both sexes attain most of their growth in the first year, and weigh 60 to 85 pounds (25-40 kg) at 1 1/2 years, males being heavier. Males continue to grow slowly through their life span. Specific growth equations have been developed by Wood et al. (1962). Principal food items include trailing blackberry, red huckleberry, salal, vine maple, salmonberry, and red alder (Brown, 1961; Maser et al., 1977). Figure 1 gives seasonal use of favored forage on the Olympic Peninsula. In late summer and fall deer also take tanoak acorns (Maser et al., 1977). The deer typically suffer about a 10% weight loss during winter (Brown, 1961).

7. Death Rate

Few deer reach ten years of age. Maximum mortality occurs during the first year and ranges from 60% the first year to 10% to 20% thereafter, except for male adults. Due to game management regulations (buck only), mortality rates are very skewed and sex-dependent. Once at legal age,

TABLE 1. AVERAGE BLACK-TAILED DEER DENSITY VERSUS SERAL STAGE FOR VARIOUS LOCATIONS. (After Taber, 1973, and Brown, 1961.)

Location	Years after logging													
	0-5		5-10		10-15		15-20		20-25		25-30		...50-55	
	no./ sq mi	(no./ sq km)	no./ sq mi	(no./ sq km)	no./ sq mi	(no./ sq km)	no./ sq mi	(no./ sq km)	no./ sq mi	(no./ sq km)	no./ sq mi	(no./ sq km)	no./ sq mi	(no./ sq km)
Redwood[a]	43	(17)	142	(55)	21	(8)	21	(8)	8	(3)	8	(3)	8	(3)
Douglas fir[a,b]	10-15	(4-6)	15-32	(6-12)	32-60	(12-23)	60-75	(23-29)	55-75	(21-29)	30-75	(12-29)	7-15	(3-6)
Clemons Tree Farms[c]	35	(13)	34	(13)	34	(13)	57	(22)	57	(22)	36	(14)	36	(14)
Olympic Peninsula[c]	20	(8)	22	(8)	22	(8)	26	(10)	26	(10)	15	(6)	15	(6)

[a]From Taber, 1973.

[b]The variation is due to the difference in speed with which trees are reestablished on different sites; where timber regeneration is rapid, deer decline occurs earlier, and where timber fails to regenerate, deer decline occurs later.

[c]From Brown, 1961.

hunting mortality for bucks ranges from 90% to 60% of all mortality. A review of differential mortalities is given by Garcia et al. (1976). Of mortalities not attributed to legal harvest by humans, Brown (1961) documents the following distribution for Washington: killed by automobile and train, 66.3%; illegal killing and poaching, 15.2%; malnutrition and disease, 6.2%; predation, 4.0%; damage control, 3.1%; miscellaneous accidents, 1.6%; undetermined causes, 3.6%. Figures 2 and 3 are indicative of the patterns of mortality for black-tailed deer.

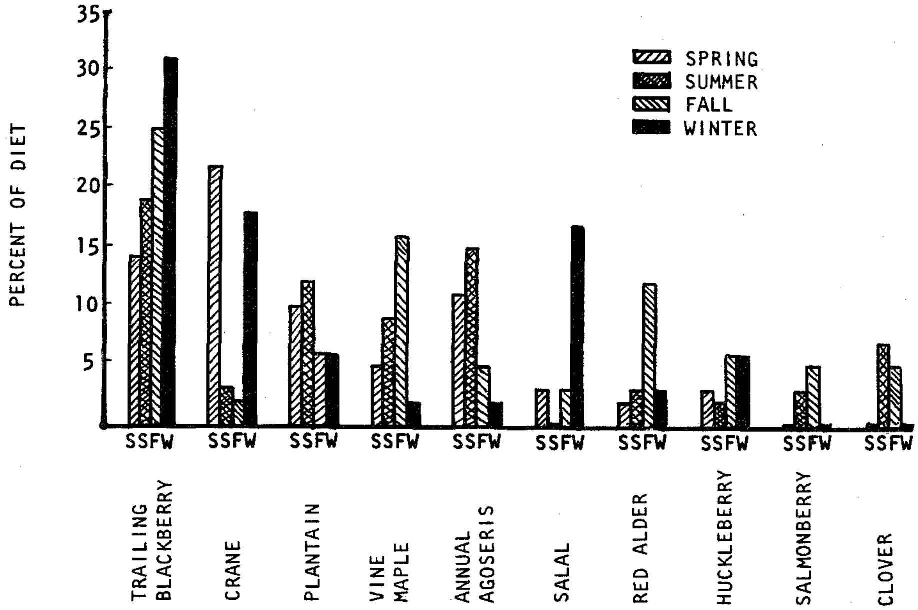


FIGURE 1. SEASONAL USE OF THE TEN MOST IMPORTANT FOOD SPECIES OF BLACK-TAILED DEER AS SHOWN BY FEEDING OBSERVATIONS. (From Brown, 1961.)

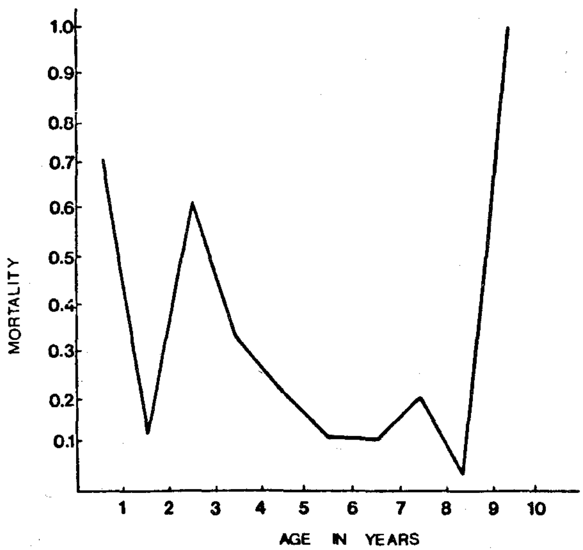


FIGURE 2. MALE BLACK-TAILED DEER MORTALITY VERSUS AGE IN SHRUBLAND. (From Taber and Dasmann, 1957.)

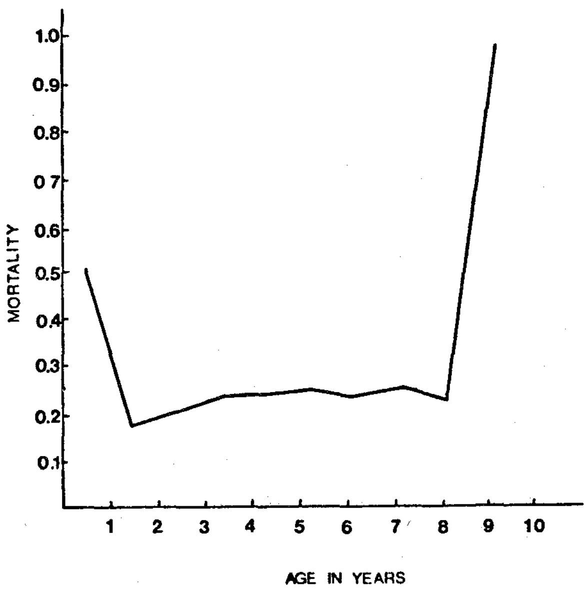


FIGURE 3. FEMALE BLACK-TAILED DEER MORTALITY VERSUS AGE IN SHRUBLAND. (From Taber and Dasmann, 1957.)

8. Carrying Capacity

Carrying capacity of the area for deer is fairly high due to repeated forest fires, logging, and forest management procedures which result in favored habitat conditions. However, of all the habitats used, large expanses of second growth closed canopy forests are least able to support high densities of black-tailed deer. Consequently, extensive large tract clearcutting and consequent succession will result in reduced carrying capacities. Generalized relationship between carrying capacity and succession is given in Figures 4 and 5.

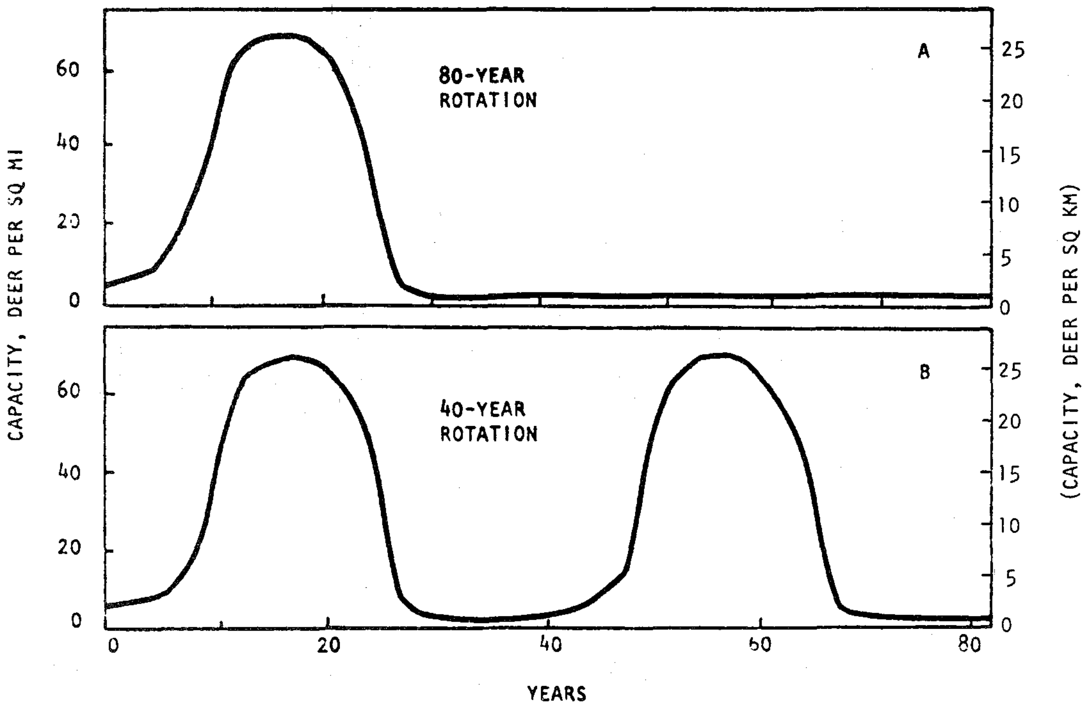


FIGURE 4. BLACK-TAILED DEER CARRYING CAPACITY VERSUS SERAL STAGE FOR 80-YEAR AND 40-YEAR ROTATION FORESTRY PRACTICE IN A COASTAL DOUGLAS FIR FOREST. (From Hansen and Lawrence, 1970.)

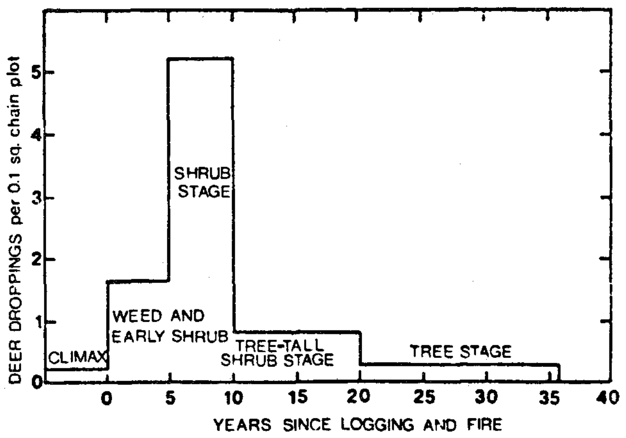


FIGURE 5. CHANGES IN BLACK-TAILED DEER POPULATIONS FOLLOWING LOGGING AND FIRE IN A CALIFORNIA COASTAL FOREST. (From Dasmann, 1964.)

The environmental indices associated with the Western Hemlock succession model indicate maximum browse production during the shrub stage. Figure 6 provides similar information. Since old growth has much more of its nutrient cycling and productivity occurring in the understory (Grier et al., 1974), it is probable that it can support greater density of deer than expanses of closed canopy second growth forest. Table 2 documents change in forage (for Vancouver Island north of the study area) as a function of succession and season.

Since population levels are undocumented for most of the study area, determination of environmental resistance is impossible. Populations in Western Oregon seem to be decreasing (Maser et al., 1977), the result of community changes due to succession. Consequently, one can assume populations to be above the carrying capacity of the environment.

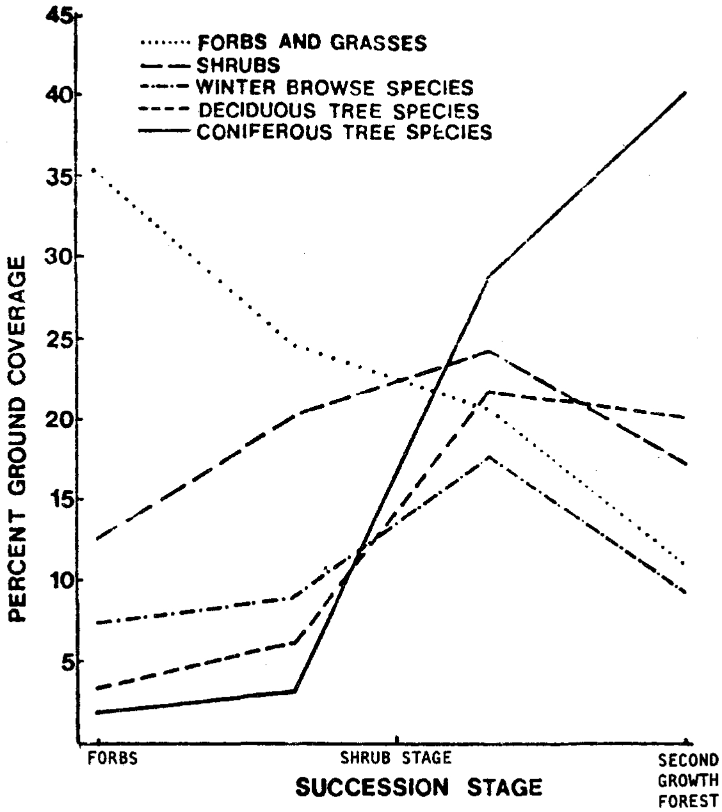


FIGURE 6. GROUND COVERAGE VERSUS SUCCESSION. (From Brown, 1961.)

TABLE 2. WET WEIGHTS OF AVAILABLE BLACK-TAILED DEER FORAGE IN MATURE AND CLEARCUT FORESTS. (From I.D. Smith, 1968.)

Stand succession stage	Summer		Winter	
	lb/acre	(kg/ha)	lb/acre	(kg/ha)
Mature forest	430	(480)	428	(480)
4-year-old cut	948	(1060)	55	(62)
10-year-old cut	1290	(1450)	229[a]	(257)[a]
14-year-old cut	1114	(1250)	343	(385)

[a]9-year-old clearcut.

9. Limiting Factors

Black-tailed deer populations are limited by food and cover, reflected in habitat requirements of both early seral browse and older cover. Openings must be small, as deer typically will not forage more than 200 meters (650 ft) from cover (USDA, 1976B). The availability of forage and cover in winter is typically most limiting. Populations can also be limited by hunting if does are taken.

10. Human Activity

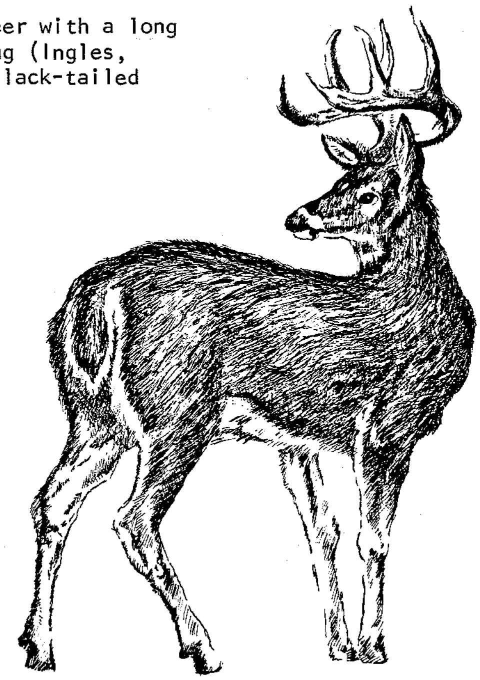
Populations are affected directly through harvest, although production potential is not directly influenced because of polygamous behavior unless females are harvested. Indirectly, initial stages of logging increase the carrying capacity, but as greater areas are clearcut and the cut areas succeed to less productive stages, carrying capacity probably is reduced and populations may decline.

11. Natural Perturbations

Forest fires retard succession to seral stages more favorable to black-tailed deer, with added browse. Severe winters can result in extensive die-offs. Snow-covered food supplies place additional energetic demands on individuals, limiting populations in years with heavy snowfall.

COLUMBIAN WHITE-TAILED DEER - Odocoileus virginianus leucurus

1. General Description



The Columbian white-tailed deer (CWTD) is a medium sized deer with a long white tail that is carried conspicuously raised when running (Ingles, 1965). Its length is about 6 feet (2 m) and, unlike the black-tailed deer, has tines of antlers originating from the main branch with no brow tine. The upper parts of the CWTD's body are brown and its under parts are nearly pure white (Ingles, 1965).

This species is one of approximately 30 races of white-tailed deer, with an extremely limited range (see Figure 1). The species is classified as endangered by the U.S. Department of Interior (as of 1978) and is protected in both Washington and Oregon where it occurs.

2. Population

The population is distributed over two separate areas: one includes the river bottoms and low marshy lands of the lower Columbia River in Clatsop and Columbia Counties, Oregon, and (the major concentration) around the towns of Skamokawa and Cathlamet in Washington (Eaton et al., 1975); the other disjunct population occurs in parts of Douglas and possibly Lane Counties, Oregon, in the Umpqua basin (Eaton et al., 1975) outside of the study area. The Umpqua herd is believed by some authorities to have hybridized, and consequently, to be genetically impure. However, Eaton et al (1975) and Brittell et al. (1976) question this, and consider that the estimated population of 1900 individuals for the Umpqua herd may be part of the CWTD stock.

Several estimates have been reported for numbers of CWTD at the lower Columbia site. U.S.D.I. (1973) reported 100 in Oregon and 150-200 in Washington, but does not document estimation procedures. Most recent estimates indicate 100-200 between Ranier and Knappa, Oregon, with about 40 on Tenasillahe Island (Oregon State Wildlife Commission, 1974). Suring (1974) reports 200 to 300 winter population on a 2,000 acre site on the Washington mainland of the CWTD National Wildlife Refuge. In total, the lower Columbia group numbers 500 or greater. Total population, if the Umpqua herd is included, is 2,400 or more.

3. Migration

The species is sedentary for the most part, although localized movement between cover and forage areas is typical. Suring (1974) reports pastures and meadows are used in spring and summer, while woody cover and associated forage are used in fall feeding, as well as for cover year-round. Interspersion of both habitat types is optimal. The deer are good swimmers and frequently move from island to island (Eaton et al., 1975).

4. External Population Factors N/A

5. Reproductive Rate

Maximum birth rate under optimal conditions is two fawns per doe, with yearlings and very old does typically having a lower fawn-per-doe ratio. Suring (1974) reports much lower rates for the lower Columbia herd and states that few sets of twins are born and that many does are without fawns each year. However, more recent studies (Brittell et al., 1976) indicate a greater fawn-to-doe ratio.

6. Growth Rate

Growth equations for white-tailed deer have been estimated by Moen (1973) as $w\ (kg) = 3.0 + 229\ Td$ for the initial growth phase prior to weaning, and $w\ (kg) = e^{(11.230 + 0.440 \ln Td)}$ (male) to $e^{(11.617 + 0.357 \ln Td)}$ (female) for growth phase II, until maturity (where Td is time in days, and e is the natural log). Sexual maturity is reached in one to two years.

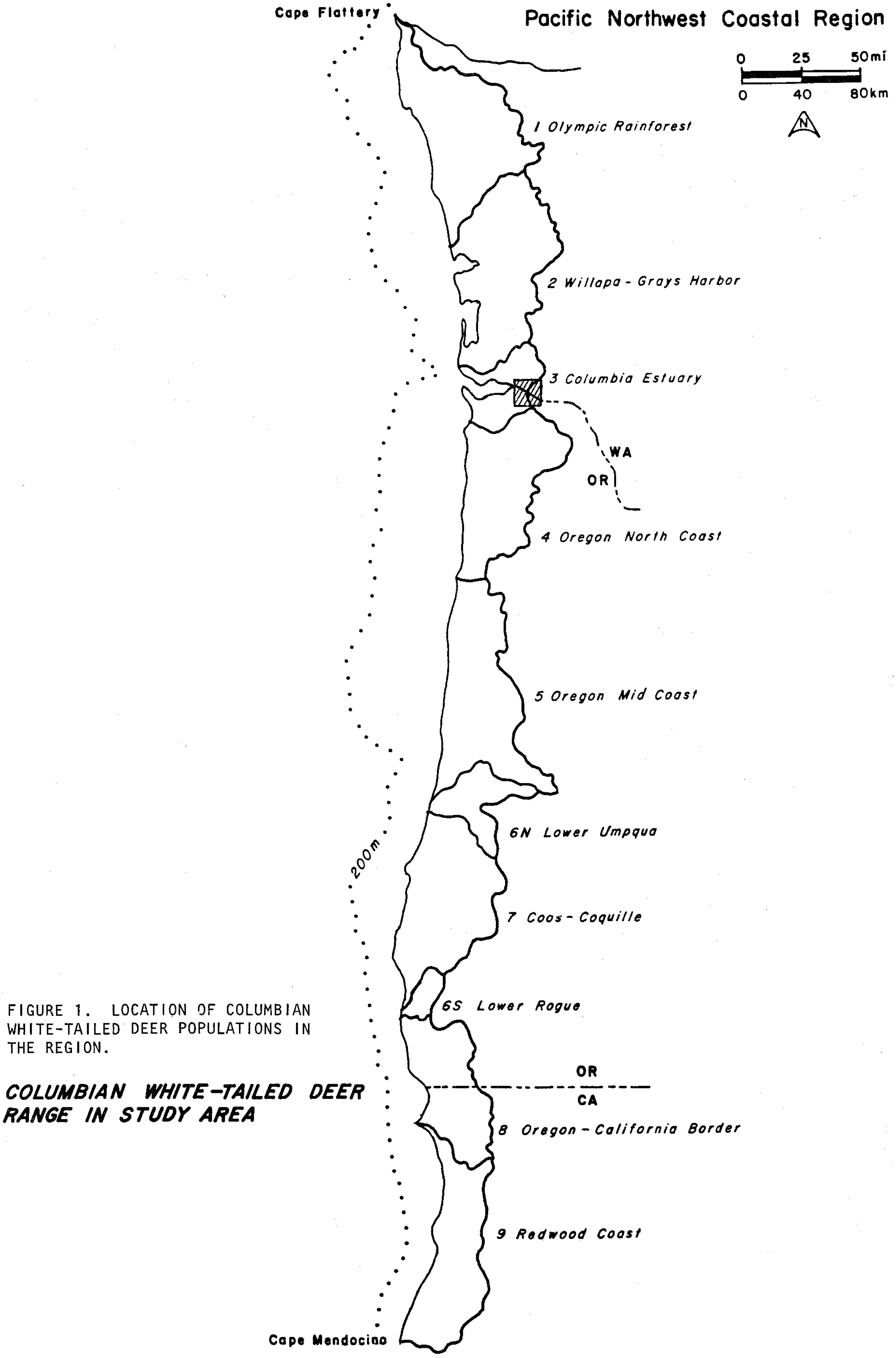


FIGURE 1. LOCATION OF COLUMBIAN WHITE-TAILED DEER POPULATIONS IN THE REGION.

7. Death Rate

Natural predators upon this species have been largely removed by the elimination of natural predators from the lower Columbia area although a few cougar (Felis concolor) may take an occasional deer. Deer typically suffer greater mortality during the first year and again after seven or eight years. Although completely protected, some CWTD which disperse from the refuge area are shot during deer season, but such losses do not seriously affect the status of the lower Columbia population (Brittell et al., 1976). In fact, alleged hunting in Douglas County on the Umpqua herd has been suggested as the cause of higher birth rates and a healthier herd (Brittell et al., 1976).

8. Carrying Capacity

Excluding the Umpqua population, carrying capacity for the CWTD is low, as suitable habitat is limited in extent (lower Columbia and flood plain) and has, until recent times, been reduced by land use changes. Optimal habitat is an interspersion of woodlands and pasture, provided the woodlands are not grazed and the pastures are not overgrazed (Brittell et al., 1976). When either component habitat type dominates, CWTD use and densities are reduced (Suring, 1974). Brittell et al. (1976) suggest that densities in the CWTD Ntional Wildlife Refuge may be higher than optimal and that the numbers of deer may be deleteriously affecting the carrying capacity.

9. Limiting Factors

The population in the lower Columbia area appear to be limited by extent of suitable habitat. The CWTD is an "edge" species and requires both pasture and cover conditions as well as good interspersion of the two. Cover needs to be thick and preferably not grazed (Brittell et al., 1976). The clearing of Puget Island of almost all its woody cover has nearly eliminated use by CWTD.

10. Human Activities

Initial clearing of forested areas within the lower Columbia area probably improved habitat conditions for the CWTD and increased the population. However, as larger amounts of land became cleared, habitat suitability was reduced below initial conditions and the population declined. Such a sequence is typical for edge species in developing areas (Taber, 1973).

As a result of its precarious status, a CWTD-NWR was established in 1972 (Figure 2). The refuge is about 5,200 acres in size and includes Tenasillahe, Hunting, and Price Islands, and a portion of the Columbia River edge in Washington near Cathlamet. A CWTD Recovery Team has been appointed and has developed a recovery plan which includes life history studies, reintroduction into former range, captive herd studies, and de-listing from 'endangered" status (Brittell et al, 1976).

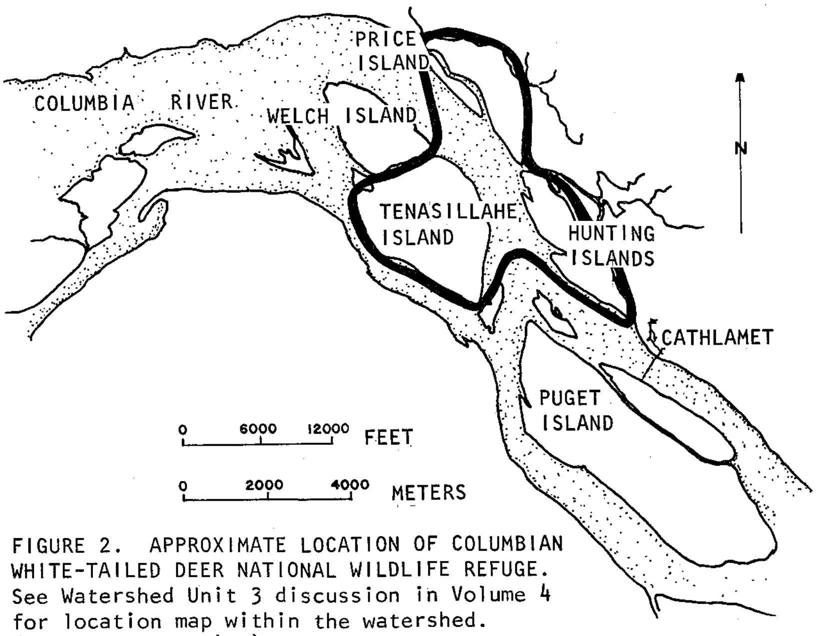


FIGURE 2. APPROXIMATE LOCATION OF COLUMBIAN WHITE-TAILED DEER NATIONAL WILDLIFE REFUGE. See Watershed Unit 3 discussion in Volume 4 for location map within the watershed. (After ACOE, 1974A.)

11. Natural Perturbations

The limited extent and small population size make the race susceptible to natural catastrophies, particularly flooding. However, flood control measures taken along the Columbia reduce the probability of such an event.

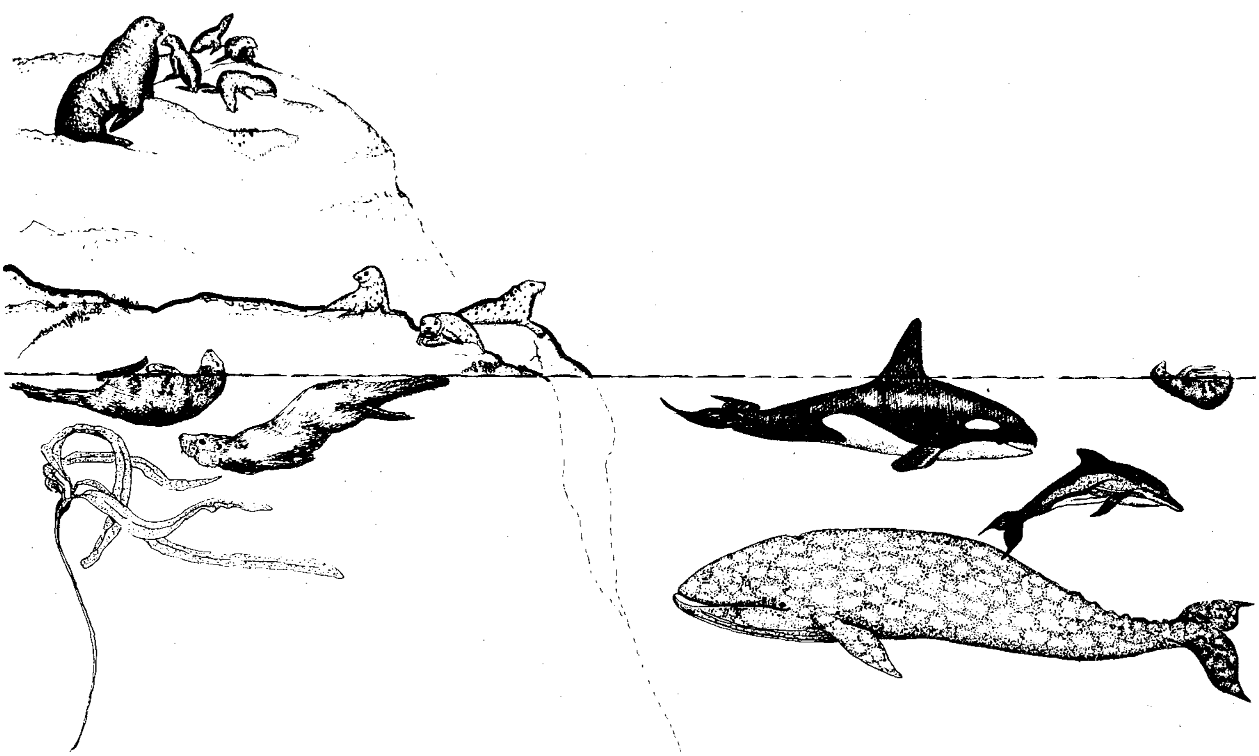
General Discussion. Twenty-three species of cetaceans, one carnivore, and five species of pinnipeds make up the marine mammals found in the coastal waters of the region. The species, along with their status and relative abundance, are listed in the oceanic Annotated Species List in Volume 5. Species accounts are given by Ingles (1965), Pike and Macaskie (1969), Eaton et al. (1975), Isakson (1976A), Larrison (1976), and OIW (1977). Additional literature for specific species is given in the Annotated Species List. General distribution of marine mammals in the region is shown in Figure 1.

The most frequently observed whale of the study area is the gray whale. It is often seen relatively close to shore on its Alaska to Gulf of California annual migration. These whales reproduce in the Gulf of California and feed in the rich Arctic waters of Alaska. Whales are often seen within a few kilometers of shore along the Pacific Coast in April and again in late December (Pike and Macaskie, 1969). Authorities have mixed opinions on whether or not these whales feed during migration. Another fairly common baleen whale of the study area is the Minke whales which is most often found in the summer in coastal waters, singly and in small pods. Several species which were once common in the area are now very rare, e.g. the right whale, the fin whale, and the humpback whale.

Among the toothed whales, the Pacific striped dolphin, the harbor porpoise, and the Dall porpoise are the most common. The top oceanic carnivore of the study area, the killer whale or Orca, is also common within the region.

Of the pinnipeds found in this region, only two - the harbor seal and the northern sea lion - breed in the study area. The northern sea lion breeds on rocky islands of the open coast, while the harbor seals are more likely to use sandy islands in estuaries. Only migratory males of the California sea lion are found in the study area, typically in nearshore rocky areas during fall and winter. Rookeries and hauling out areas for the previously mentioned species are identified in the Watershed Unit discussions in Volume 4. The elephant seal is a pelagic non-breeder (in this region) which occasionally comes to shore in the study area. The northern fur seal is a strictly pelagic, seasonal visitor during the non-breeding periods.

The sea otter, once common along the coast, has not been reported in the 19th century. Since then there have been attempts at reintroduction in Oregon, Washington, and British Columbia waters (OIW, 1977). Populations are low in numbers and scattered within the study area, but are more common farther south in California and north in Alaska.



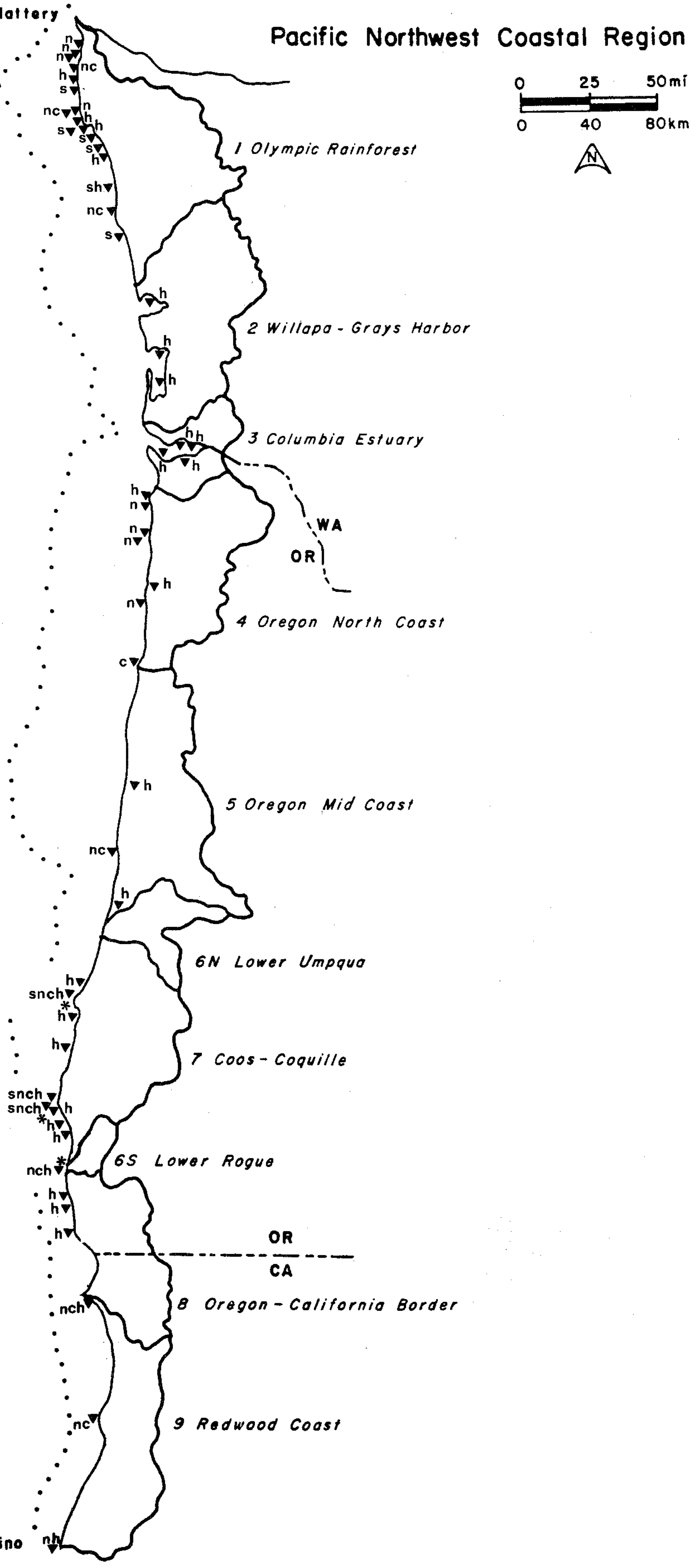


FIGURE 1. MARINE MAMMAL CONCENTRATION AREAS. Whales migrate along the entire coast (see text). (Data from Isakson and Reichard, 1976B (Washington); Thompson and Snow, 1974 (Oregon); California Coastal Zone Conservation Commission, 1975 (California).)

DISTRIBUTION OF MARINE MAMMALS

- h HARBOR SEAL HAUL-OUT AND BREEDING AREAS
- n NORTHERN SEA LION HAUL-OUT AREA
- c CALIFORNIA SEA LION HAUL-OUT AREA
- s SEA OTTER CONCENTRATIONS AND BREEDING AREAS
- * NORTHERN SEA LION ROOKERIES

Status. All the marine mammals of the study area are protected under the Marine Mammals Protection Act of 1972. The baleen whales are protected under the Endangered Species Act of 1973. (See Table 3-X1 in Section 3.4.3 of Chapter 3 and in the Annotated Species List.) Seaward of the study area, the International Whaling Commission regulates harvest of whales, although compliance with regulations is voluntary. The right whale, the fin whale, the blue whale, and the humpback whale are not harvested under regulations of the International Whaling Commission.

Relation to Ecosystems. The role of marine mammals in the ecology of marine systems of the study area is not well documented. Life histories of several species of the toothed whales are little known. Species of the suborder Mysticeti - the baleen whales - are filter feeders living principally on small crustaceans, although small fish and squids are taken by some species of baleen whales. The waters of the study area are probably not very important as feeding areas for these whales; krill and other food sources are not in the density or abundance required. The more important feeding areas for the baleen whales are farther north.

The toothed whales - Odontoceti - are predators, taking prey of higher trophic levels than those taken by the baleen whales. Principally fish and squids are eaten, although the killer whale also takes other marine mammals. The seals - Pinnipedia - take a wide variety of prey including schooling bait fish, commercial and non-commercial larger fish, and molluscs and crustaceans.

The sea otter is considered a keystone species in shallow rocky marine areas by many authorities (Davis, 1977). Its predation on abalone and sea urchins, the principal herbivores in these areas, is thought to play an important role in community structure and homeostasis. In California, increased primary productivity and species diversity in kelp beds have been correlated with the presence of sea otters. Similar findings are reported by Palmisano (1975) and Estes and Palmisano (1974) in Alaska.

Human Impacts. Man has played a significant role in establishing the population status of marine mammals in the study area as well as world-wide. Overharvesting has drastically reduced the population levels of many of the baleen whales, as well as the sea otter. In some cases protective management measures have been effective in reversing this trend, as in the case of the grey whale which has recovered to pre-exploitation population levels (Eaton et al., 1975).

Partial success has been achieved in protection of the sea otter, with viable populations now living in California and Alaska. In 1938 there were an estimated 300 sea otter survivors on the California Coast, and populations had been largely exterminated from Oregon, Washington, and Vancouver Island, B.C. The California population has recovered to an estimated 1800 individuals. In addition some 50 sea otters have been reintroduced on the Oregon and Washington coasts, but, the success of the reintroduction has not yet been determined.

At the other extreme, some of the baleen whales have shown little increase in numbers following protection. Their numbers may have been reduced to a point below the viable population level.

There is considerable competition between several marine mammals and some commerical and recreational fisheries, e.g., competition for pismo clams and abalone with the alleged depletion of stocks of sea otters (Stephenson, 1977; Davis, 1977). Also, fur seals and harbor seals are known to take salmon. Recent increases in harbor seal populations, combined with already keen competition between commercial, recreational, and Indian harvesters for limited numbers of salmon, could limit food resources for these pinnipeds.

Marine mammals are in a position in the food web where biologically amplified pollutants are potentially hazardous (Davis, 1977; OIW, 1977; Gentry and McAlister, 1976). Such accumulation is thought to have caused increased rates of abortions in California seals (Brownell and LeBoeuf, 1971). There is some evidnece that oil contamination causes mortality in fur seals and sea otters (Kenyon, 1969; Kenyon, 1971). The effects of oil on whales and other species of seals is controversial, as reported by the following authors: Kenyon (1971), Brownell (1971), Brownell and LeBoeuf (1971), LeBoeuf (1971), and Smith and Geraci (1975).

ROOSEVELT ELK - Cervus canadensis roosevelti

1. General Description

This wapiti (elk) is a native, large, brownish, hoofed, herding grazer with a length of 200 to 300 centimeters (80 to 120 in) and a weight of 160 to 450 kilograms (350 to 1,000 lb). Males are heavier and seasonally bear a large rack of antlers. They are prized game animals.

2. Population

Population numbers throughout the coast were once high but were nearly eliminated in the early 1900's through indiscriminate hunting and habitat destruction. Since that period they have been reintroduced along the Oregon coast by the Oregon State Wildlife Commission, and are now fairly common throughout the region, although uncommon south of the Coquille River (King, personal communication, 1977). Population densities of 10 per square mile (4/sq km) on good sites and one or less per square mile on less favorable areas are typical for this area (King, personal communication, 1977).

3. Migration

This subspecies of elk does not have strongly differentiated summer and winter ranges. Lowland populations at elevations of 1500 meters (5000 ft) or less are fairly sedentary. Those that summer in higher elevations may move downslope during severe winters. However, this seasonal movement is more pronounced in the Olympic Peninsula herds than in those of Oregon and California. Home range, which is generally viewed in terms of a particular herd, is 1.6 to 3.2 square kilometers (0.6 to 1.2 sq mi), with slightly larger home ranges on flats.

4. External Population Factors N/A

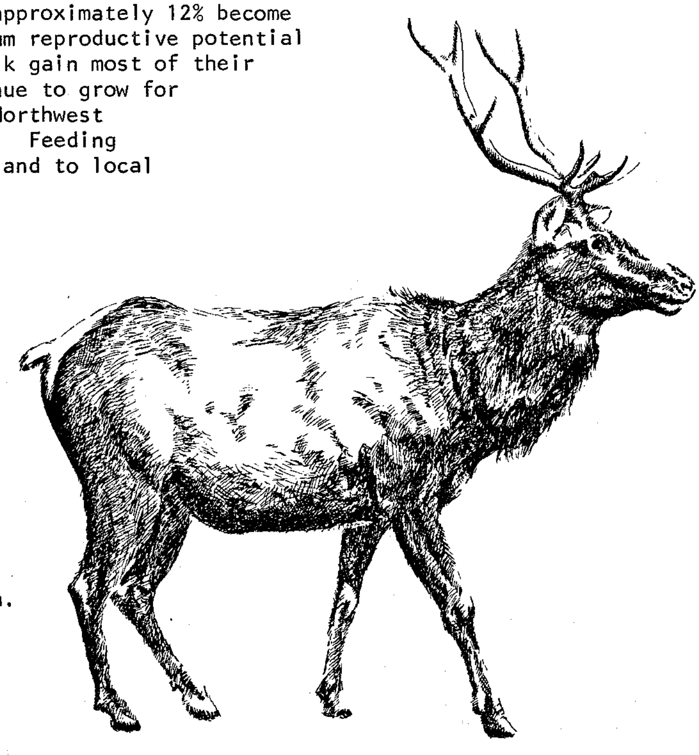
5. Reproductive Rate

Cows typically have only one young per year and rarely twins. Characteristic percentage of pregnant cows by age class is given in Figure 1.

Like many other cervids (ruminant mammals), sexual behavior is polygamous; breeding occurs in the latter part of September through mid October. Calves are born in late May and early June following a 255-275 day gestation period.

6. Growth Rate

Although males may reach sexual maturity prior to four years, they seldom breed due to the aggressive herding behavior of older, larger, and stronger bulls. Females begin to breed at one year, when approximately 12% become pregnant. At four years of age the maximum reproductive potential (50%) is reached (Maser et al., 1977). Elk gain most of their weight in the first year, but males continue to grow for several more years. Food use in coastal Northwest California by season is given in Figure 2. Feeding behavior is subject to annual fluctuation and to local availability of respective forage.



7. Death Rate

The first year of life has the highest death rate (60-70%), with subsequent natural mortality at 10-20% (Bradly, personal communication, 1977). Harvesting also introduced mortality of 50-60% for adults. Wapiti are known to live 19 years or more in the wild. Harvesting of males probably does not affect the productive potential of the population. Poaching and malnutrition (primarily of first year calves) are major mortality factors and have been measured at 18% in northwestern California. In addition, 16% died through accidents (road kills, rutting battles), 6% died of parasites and disease, and 22% died of unknown causes (Maser et al., 1977). The puma is the main natural predator, with black bear taking an occasional calf. These predation rates are not measured, but are probably low in the region as a whole.

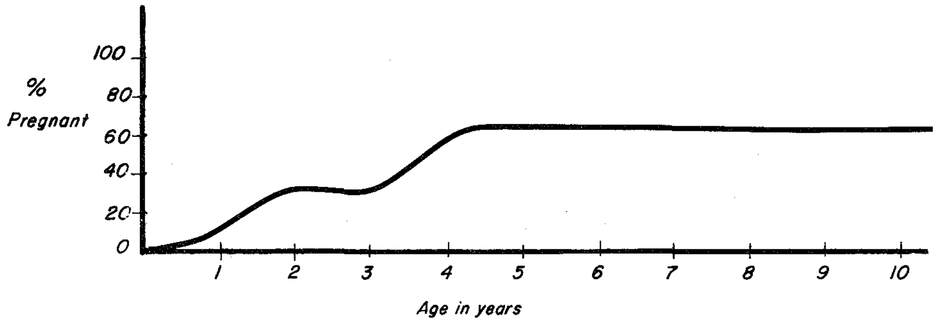


FIGURE 1. PERCENT PREGNANT VERSUS AGE FOR ROOSEVELT ELK. (From Maser et al., 1977.)

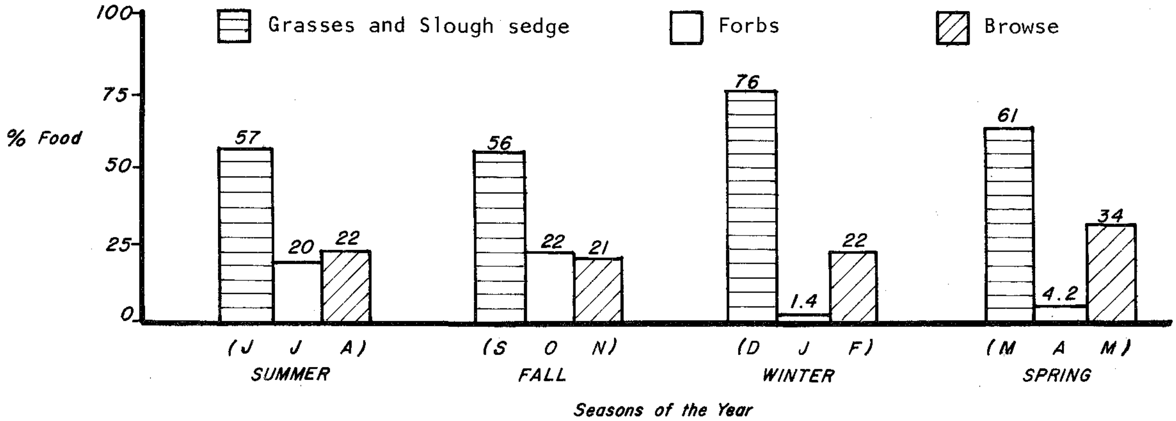


FIGURE 2 . FORAGE OF ROOSEVELT ELK. (After Maser et al., 1977.)

8. Carrying Capacity

Carrying capacity is thought to be maximized by a mixture of 60% clearcut no larger than 400 meters (1200 ft) across and 40% forest of at least eight inch (20 cm) diameter trees.

9. Limiting Factors

Factors which directly limit the population of elk are winter mortality due to malnutrition (particularly of calves) and poaching. Poaching is more serious in areas with easy road access. The availability of food and cover in a suitable mixture also limits elk populations.

10. Human Activities

Elk herds are affected directly through legal harvesting and poaching as well as stocking, and indirectly by land use and management practices which affect the carrying capacity, e.g. logging, silviculture, and fire protection practices. Elk populations were nearly exterminated in the early 1900's, but have been reestablished by stocking and by increasing carrying capacity. BLM and the U.S. Forest Service manage some lands with the object (in part) of sustaining elk populations. The taking of bull elk does not appreciably affect the production potential of the population; cows are usually protected from harvest.

11. Natural Perturbations

Wildfire, windthrow, and insect epidemics change the mix of habitats within an area thereby affecting the carrying capacity for elk. Severe winters combined with loss of optimal lowland wintering areas can potentially seriously affect herds.

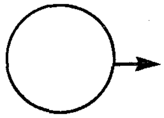
ECOLOGICAL CHARACTERIZATION
OF THE
PACIFIC NORTHWEST COASTAL REGION

VOLUME TWO
CHARACTERIZATION ATLAS -
REGIONAL SYNOPSIS

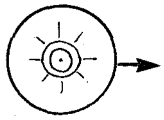
Part Three

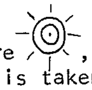
REFERENCE DATA

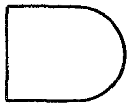
GLOSSARY OF SYMBOLS



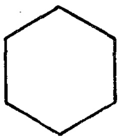
SOURCE OF ENERGY OR MATTER external to the system or portion of a system being modeled. This symbol, and many of the others here, are based on H. T. Odum (1971 and 1972).



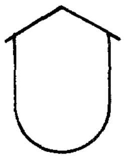
SOLAR RADIATION. The central figure , which is used for the sun in pictorial diagrams, is taken directly from a pteroglyph left by Pacific Northwest Coastal Indians (Meade, 1971).



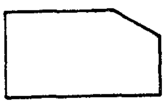
PRODUCER: plant, or plant community. For thermodynamic balance, H.T. Odum (1971 and 1972) often shows heat sinks in connection with this and other symbols. Heat sinks are not used for the qualitative ecosystem diagrams in this report.



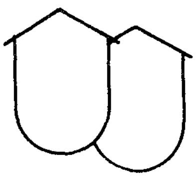
CONVERTER: animal, microbe, or community of animals or microbes; can be consumers or decomposers or both.



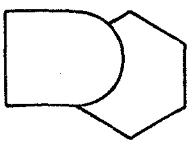
STORAGE COMPARTMENT OR SUBSTRATE.



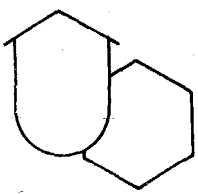
SOCIOECONOMIC ACTIVITY. Used, with labels, to cover the whole range of human activities except for the strictly biological, such as eating.



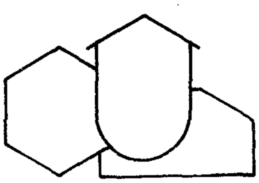
MULTI-COMPARTMENT STORAGE.



BIOLOGICAL COMMUNITY: producers and converters. The boundary between the compartments may be omitted, and their relative positions may vary. Converters may sometimes be presented separately as consumers and decomposers, and sizes of all three components may vary to show relative significance within the particular biological community.



SUBSTRATE-CONVERTER COMBINATION, such as the detritus-decomposer union, where the distinction between the two is not essential for the system being modeled.



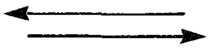
COMPOSITE HUMAN COMMUNITY AND ACTIVITY; a combination of conversion, storage, and socioeconomic functions.

TO DETRITUS. Indicates a flow of material and energy to the non-living compartment. Combines mortality and flow to detritus, thus simplifying models.

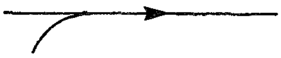
BOUNDARY for the specific ecological unit being modeled.

FLOW PATH FOR ENERGY OR MATTER OR DOLLARS.

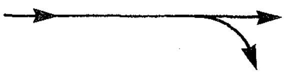
FLOW PATH FOR REGULATING INFLUENCE OR EFFECT (i.e. not flow of energy, matter, or dollars).



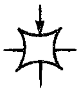
DIRECTIONAL FLOWS.



CONVERGING OR COMBINING FLOWS.



DIVERGING OR BRANCHING FLOWS.

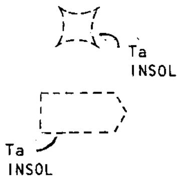


SWITCH. Incoming flow is divided into two or more different paths by a primary regulating process, or goes one way or another depending on the regulating process and its secondary regulating factors.

ONE-WAY VALVE. Flow in one direction along a single path occurs through and is controlled by a primary regulating process, and depends on its secondary regulating factors.

TWO-WAY VALVE. Flow in two directions along a single path occurs through and is controlled by a primary regulating process and its secondary regulating factors. Flow can go either or both directions, e.g., materials in and out. This symbol often represents a complex group of interacting processes.

SEQUENTIAL VALVE. Flow occurs through and is regulated by a a series of primary regulating processes acting in sequence with little or no interaction. (Previous two valves are used for non-sequential or complex interacting processes.)



SECONDARY REGULATING FACTOR. The controlling factors that regulate a primary regulating process (represented by either a switch or a valve, as above). Examples illustrated here represent the regulating factors air temperature (Ta) and insolation (INSOL).

CYCLICAL OR PERIODIC FLOW FROM SOURCE, such as tides, daily and seasonal cycles of the sun, etc.

GAIN AND/OR LOSS OF HABITAT. When not otherwise labeled, the arrow applies to the regulating (or process) value by which it is placed. The arrow points out of the habitat boundary (dotted line enclosing the habitat) for loss, into the boundary for gain.

BOUNDARY BETWEEN ECOSYSTEM MODEL COMPARTMENTS (PHYSICAL-CHEMICAL, BIOLOGICAL, SOCIOECONOMIC).

GLOSSARY OF TERMS

An attempt has been made to use common language, usage, and word forms throughout the volumes of this study, with the American Heritage Dictionary of the English Language (Morris, 1976) as referee. Many terms used in ecology and its component disciplines, however, do not enjoy "hard and fast," universally-accepted definitions, and/or have a variety of meanings depending on usage. For such words, the following definitions are given for the terms as used in this Ecological Characterization of the Pacific Northwest Coastal Region. Where these are taken directly from another reference, citation is given.

ADVECTION. A LOCAL CHANGE IN A PROPERTY OF A SYSTEM THAT TAKES PLACE IN THE PRESENCE OF A CURRENT, AS OF AIR OR WATER; INCLUDES TRANSPORT OF WATER VAPOR, HEAT, SEDIMENT LOAD, SALT CONTENT (SALINITY).

AEROBIC. REQUIRING OXYGEN; REFERRING TO LIFE OR PROCESSES THAT CAN OCCUR ONLY IN THE PRESENCE OF OXYGEN. (COMPARE.....ANAEROBIC.)

ALLOCHTHONOUS. IMPORTED FROM ANOTHER HABITAT, AS OF SOLID MATTER.

ALLUVIAL SOIL. SOIL COMPOSED OF ALLUVIUM AND ORGANIC MATERIAL. (SEE.....ALLUVIUM; COMPARE.....COLLUVIAL SOIL, RESIDUAL SOIL, LOESS SOIL.)

ALLUVIUM. A SURFICIAL DEPOSIT OF WEATHERED EARTH MATERIAL THAT WAS TRANSPORTED AND DEPOSITED BY WATER, SUCH AS FROM FORMER RIVER BEDS, DELTAS, AND FLOODPLAIN DEPOSITS. (SEE.....ALLUVIAL SOIL; COMPARE.....COLLUVIUM, LOESS, RESIDUUM.)

ANADROMOUS. MIGRATING FROM THE OCEAN TO FRESH OR LOWER SALINITY WATERS TO SPAWN. (COMPARE.....CATADROMOUS.)

ANAEROBIC. REFERRING TO LIFE OR PROCESSES THAT OCCUR IN THE ABSENCE OF OXYGEN; ANOXIC; INCLUDES FACULTATIVE ANAEROBES (ORGANISMS THAT DO NOT NEED OXYGEN BUT CAN LIVE IN THE PRESENCE OF OXYGEN) AND OBLIGATORY ANAEROBES (ORGANISMS THAT REQUIRE THE ABSENCE OF OXYGEN); USUALLY ASSOCIATED WITH REDUCING CONDITIONS. (COMPARE.....AEROBIC.)

APPRECIATIVE ACTIVITY. HUMAN RECREATIONAL ACTIVITY WHICH REQUIRES FEW SPECIAL FACILITIES OR EQUIPMENT AND WHICH IS NOT RESOURCE-DEPLETING; INCLUDES SUCH PASSIVE ACTIVITIES AS CAMPING, PICNICKING, OR DRIVING FOR PLEASURE TO VIEW SCENERY, AND SUCH ACTIVE PASTIMES AS BACKPACKING, HORSEBACK RIDING OR BIKING. (COMPARE.....EXTRACTIVE ACTIVITY, EXPRESSIVE ACTIVITY.)

AQUATIC. LIVING, GROWING, OR OCCURRING IN WATER; INCLUDES BOTH FRESH WATER AND MARINE ENVIRONMENTS.

AQUIFER. AN UNDERGROUND AREA (BED OR STRATUM) OF EARTH, GRAVEL, OR POROUS ROCK THAT CONTAINS WATER.

ATLAS. A VOLUME OF TABLES, CHARTS, MAPS, OR SYSTEMATICALLY-ARRANGED DATA ILLUSTRATING A SPECIFIC SUBJECT.

ATMOSPHERE. THAT PORTION OF THE ECOSPHERE COMPOSED OF THE GASEOUS MASS OR ENVELOPE SURROUNDING THE EARTH.

AUTOTROPHIC. SELF-NOURISHING; REFERRING TO ORGANISMS THAT ARE CAPABLE OF CONSTRUCTING ORGANIC MATTER WITH HIGH-ENERGY BONDS FROM INORGANIC SUBSTANCES FOR THEIR FOOD SUPPLY, BY PHOTOSYNTHESIS OR CHEMOSYNTHESIS. (SEE.....PRODUCER; COMPARE.....HETEROTROPHIC.)

BACKSHORE. THE UPPER PART OF A BEACH OR BANK EXTENDING FROM ABOVE MEAN HIGHER HIGH WATER (OR TIDE) TO UPPER BOUNDARY OF GEOHYDRAULIC INFLUENCE (100 YEAR FLOOD/TIDE) (BAUER, 1975). SEE FIG. 2-27 IN MODEL (VOL. 1). (COMPARE.....FORESHORE, NEARSHORE, OFFSHORE.)

BASIC HUMAN ACTIVITY. SOCIOECONOMIC ACTIVITY WHICH PRODUCES, HARVESTS, PROCESSES, OR DISTRIBUTES NATURAL RESOURCES. (COMPARE.....NON-BASIC HUMAN ACTIVITY.)

BATHYMETRY. THE TOPOGRAPHY OF THE SEA FLOOR; THE DETAILED PHYSICAL FEATURES (SUCH AS DEPTH CONTOURS) OF THE SURFACE OF THE SEA FLOOR.

BEACH. AN ACCUMULATION OF UNCONSOLIDATED ROCK FRAGMENTS (SAND, PEBBLES, COBBLES) OR SHELL FRAGMENTS ALONG THE SHORELINE, BOUNDED BY THE MAXIMUM LIMITS OF SHORELINE MOVEMENTS, I.E., FROM LOWEST MEASURED TIDE TO LANDWARD LIMIT OF 100 YEAR STORM TIDE. THIS INCLUDES FORESHORE AND BACKSHORE. (SEE.....SHORELINE, COAST, FORESHORE, BACKSHORE, DUNE.)

BED-LOAD. SAND, GRAVEL, OR HEAVY ROCK FRAGMENTS THAT ROLL, SLIDE, OR BOUNCE ALONG THE BED OF A STREAM, OR ALONG THE BOTTOM OF AN ESTUARY OR THE OCEAN. (COMPARE .....SUSPENDED LOAD, DISSOLVED LOAD.)

BENTHIC. RELATING TO THE BOTTOM OF A BODY OF WATER (LAKE, RIVER, ESTUARY, OCEAN); INCLUDES SUBSTRATE AND OVERLYING PORTION OF WATER WITHIN ONE METER OF SUBSTRATE. (COMPARE.....PELAGIC, NERITIC.)

BENTHOS. BOTTOM-DWELLING ORGANISMS (PLANTS AND ANIMALS), SESSILE, CREEPING, OR BURROWING. (SEE.....BENTHIC; COMPARE.....DEMERSAL.)

BERM. NEARLY HORIZONTAL TERRACE OF SAND ABOVE HIGH TIDE, DEPOSITED AND SHAPED BY WAVE ACTION. IN SUMMER, THE BERM IS LOW AND WIDE, BUT IN WINTER IT IS NARROWER AND HIGHER, INDICATIVE OF THE HEIGHT OF THE WAVES THAT CREATED IT (BASCOM, 1964). THE CREST OF THE BERM IS THE BOUNDARY BETWEEN THE FORESHORE AND THE BACKSHORE. SEE FIGS. 2-27 AND 2-35 IN MODEL (VOL. 1).

BIOCHEMICAL OXYGEN DEMAND (BOD). A MEASURE OF THE AMOUNT OF OXYGEN CONSUMED IN THE BIOLOGICAL PROCESSES THAT BREAK DOWN ORGANIC MATTER IN WATER.

BIOGENOUS. LIVING OR DERIVED FROM LIVING MATTER; ORGANIC. BIOGENOUS DEPOSITS ARE DEPOSITS HAVING MORE THAN 30 PERCENT MATERIAL DERIVED FROM ORGANISMS (HUNT AND GROVES, 1965).

BIOLOGICAL ZONE. AN AREA TYPIFIED BY CLEARLY IDENTIFIABLE GROUPS OF ORGANISMS ASSOCIATED WITH SPECIFIC REGIONAL FEATURES OF CLIMATE AND SUBSTRATE. ELEVATION, SLOPE, AND SOIL TYPE ARE THE MOST SIGNIFICANT SUBSTRATE FEATURES CONTROLLING THE ZONATION OF LIFE FORMS ON LAND. IN THE AQUATIC REGIONS, THE KEY FEATURES ARE TIDES, DEPTH, TEMPERATURE, FERTILITY OF THE WATER, AND TYPE OF BOTTOM.

BIOMASS. THE TOTAL MASS OF ALL ORGANISMS OR LIVING MATTER IN A SPECIFIED AREA OR VOLUME.

BIOME. A LARGE-SCALE ENVIRONMENTAL SUBDIVISION BASED ON DOMINANT VEGETATION AND CONCOMITANT FAUNA OVER LARGE CONTINENTAL REGIONS; THE LARGEST ECOLOGICAL CATEGORY OF ECOSYSTEMS BELOW THE ECOSPHERE LEVEL. (COMPARE.....BIOLOGICAL ZONE.)

BIOSPHERE. ALL LIVING ORGANISMS; THAT COMPONENT OF THE ECOSPHERE MADE UP OF ALL LIFE.

BLOOM. AN EMORMOUS CONCENTRATION OF PLANKTON (USUALLY PHYTOPLANKTON) IN AN AREA, CAUSED EITHER BY AN EXPLOSIVE OR GRADUAL MULTIPLICATION OF ORGANISMS IN RESPONSE TO INCREASED NUTRIENT SUPPLY, AND USUALLY PRODUCING A DISCOLORATION OF THE WATER SURFACE (GROSS, 1972).

BOD. SEE.....BIOCHEMICAL OXYGEN DEMAND.

BREAKER DEPTH. THE STILL WATER DEPTH OVER A SHOALING BOTTOM AT THE POINT WHERE WAVES BREAK (HUNT AND GROVES, 1965).

BROWSE. LEAVES, TWIGS, AND OTHER VEGETATION USED AS FOOD BY BROWSING ANIMALS. (SEE DEFINITION (2) OF.....GRAZER.)

CANOPY. THE TREETOP ZONE IN A FOREST WHERE LIGHT IS NOT A LIMITING FACTOR AND WHERE LIVE BRANCHES AND FOLIAGE OFTEN ARE CONCENTRATED.

CARNIVORE. AN ORGANISM THAT GETS ITS NOURISHMENT BY EATING ANIMAL TISSUE; PREDATOR; A SECONDARY OR HIGHER TROPHIC LEVEL CONSUMER. (COMPARE.....HERBIVORE, OMNIVORE, DETRITIVORE.)

CARRION. (1) DEAD OR DECAYING FLESH (MORRIS, 1976). (2) DEAD ANIMAL MATTER, EITHER A WHOLE OR A PORTION OF AN ANIMAL BODY IN EARLY STAGES OF DECOMPOSITION. (COMPARE.....LITTER.)

CARRYING CAPACITY. THE NUMBER OR BIOMASS OF ORGANISMS WHICH CAN THEORETICALLY BE SUSTAINED IN A GIVEN AREA OR ENVIRONMENT, WITHOUT ADVERSELY AFFECTING THAT AREA.

CAST. SOLID ORGANIC MATTER DISCARDED BY AN ORGANISM, E.G., (1) THE WASTE EXCRETED BY AN EARTHWORM, (2) THE SKIN SHED BY A MOLTING INSECT OR REPTILE, OR THE SHELL SHED BY A CRAB, (3) THE MASS OF FEATHERS, FUR, BONES, AND OTHER MATTER EJECTED FROM THE CROP OF AN OWL, OR (4) THE LEAVES OF ATTACHED SEAWEEDS ADRIFT. (COMPARE.....LITTER, WRACK.)

CATADROMOUS. MIGRATING FROM FRESH WATERS TO WATERS OF HIGHER SALINITY TO SPAWN. (COMPARE.....ANADROMOUS.)

CELERITY. WAVE SPEED RELATIVE TO THE WATER (NOT RELATIVE TO THE BOTTOM).

CHANNELIZED FLOW. RUNOFF OF WATER IN DEFINABLE CHANNELS, AS IN STREAMS AND RIVERS. (COMPARE.....NON-CHANNELIZED FLOW, SURFACE RUNOFF, RUNOFF.)

CLIMATE. THE METEOROLOGICAL CONDITIONS, INCLUDING TEMPERATURE, PRECIPITATION, AND WIND, THAT CHARACTERISTICALLY PREVAIL IN A PARTICULAR REGION (MORRIS, 1976).

CLIMAX COMMUNITY. THE COMMUNITY CAPABLE OF PERPETUATION UNDER THE PREVAILING CLIMATIC AND SOIL CONDITIONS OF A GIVEN AREA. (SEE.....SUCCESSION, SERE; COMPARE.....SERAL STAGE.)

COAST. (1) A LARGE PHYSIOGRAPHIC FEATURE OFTEN EXTENDING SEVERAL MILES INLAND FROM THE SHORELINE (BASCOM, 1964). (2) A STRIP OF LAND OF INDEFINITE WIDTH (MAY BE SEVERAL MILES) THAT EXTENDS FROM THE SEASHORE INLAND TO THE FIRST MAJOR CHANGE IN TERRAIN FEATURES (HUNT AND GROVES, 1965). (3) THE LAND NEXT TO OR NEAR THE SEA; SEASHORE (MORRIS, 1976).

COLLUVIAL SOIL. SOIL COMPOSED OF COLLUVIUM AND ORGANIC MATERIAL. (SEE.....COLLUVIUM; COMPARE.....ALLUVIAL SOIL, RESIDUAL SOIL, LOESS SOIL.)

COLLUVIUM. A SURFICIAL DEPOSIT OF WEATHERED EARTH MATERIAL THAT WAS TRANSPORTED BY GRAVITY FREE-FALL AND NOT BY WATER OR WIND; CHARACTERISTIC PARTICLE SHAPE IS ANGULAR AND SHARP. (SEE.....COLLUVIAL SOIL; COMPARE.....ALLUVIUM, LOESS, RESIDUUM.)

COMMUNITY. A GROUP OF PLANTS AND ANIMALS OCCUPYING A HABITAT AND HAVING CLOSE INTERACTIONS, ESPECIALLY THROUGH FOOD CHAINS AND WEBS.

COMPENSATION DEPTH. THE DEPTH SEPARATING THE EUPHOTIC AND DISPHOTIC ZONES OF A BODY OF WATER, AT WHICH THE ENERGY OF THE PENETRATING SUNLIGHT ALLOWS PHOTOSYNTHESIS TO OCCUR TO A DEGREE JUST SUFFICIENT TO PROVIDE FOR THE MAINTENANCE OF PLANT LIFE.

COMPOUND ESTUARY. A TYPE OF ESTUARY (UNDER THE CLASSIFICATION SCHEME OF BAUER, 1975) THAT CONTAINS OPEN-WATER, STREAMWAY, AND MARINEWAY SECTORS. SEE FIG. 2-23 IN MODEL (VOL. 1).

CONSUMER. AN ORGANISM THAT EATS OTHER ORGANISMS AS A SOURCE OF ENERGY AND NUTRIENTS; INCLUDES HERBIVORES, CARNIVORES, OMNIVORES. (COMPARE.....PRODUCER, CONVERTER, DECOMPOSER.)

CONTINENTAL SHELF. THE ZONE BORDERING A CONTINENT EXTENDING FROM THE LINE OF PERMANENT IMMERSION (LOWEST MEASURED TIDE) TO THE DEPTH (USUALLY ABOUT 200 METERS, 100 FATHOMS, OR 200 YARDS) WHERE THERE IS A MARKED OR RATHER STEEP DESCENT TOWARD THE GREAT DEPTHS (HUNT AND GROVES, 1965).

CONVERTER. (1) AN ORGANISM THAT CANNOT MAKE ITS OWN FOOD, BUT RATHER RELIES ON OTHER ORGANISMS (PRODUCERS OR OTHER CONVERTERS) OR THEIR REMAINS FOR ITS ENERGY AND NUTRIENTS; HETEROTROPH; INCLUDES CONSUMERS AND DECOMPOSERS. (2) FUNCTIONAL COMPONENT (ANIMAL, BACTERIUM, FUNGUS) OF AN ECOSYSTEM WHICH RELIES DIRECTLY OR INDIRECTLY ON STORED CHEMICAL ENERGY SYNTHESIZED BY PRODUCERS (GREEN PLANTS). (COMPARE.....PRODUCER.)

CRYPTOGAM. ANY FLOWERLESS AND SEEDLESS PLANT THAT REPRODUCES BY SPORES, SUCH AS FUNGI, ALGAE, LICHENS, MOSSES, AND FERNS.

CURRENT. A HORIZONTAL MOVEMENT OF WATER, EITHER TIDAL OR NON-TIDAL; CAUSED BY GRAVITY (AS IN STREAMS AND RIVERS), AND DENSITY GRADIENTS AND GLOBAL CIRCULATION (AS IN PERMANENT OCEAN CURRENTS.)

DECOMPOSER. AN ORGANISM THAT BREAKS DOWN DEAD PLANTS (LITTER), DEAD ANIMALS (CARRION), OR THEIR FECES OR REMAINS INTO SIMPLER PARTS FOR ITS NUTRITION. (COMPARE.....PRODUCER, CONVERTER, CONSUMER.)

DEFLATION. THE REMOVAL OF SAND BY THE WIND.

DEFLATION PLAIN. A DEPRESSION WITHIN A DUNE SYSTEM OWING ITS ORIGIN TO EXCAVATION BY WIND.

DEMERSAL. PERTAINING TO SWIMMING FAUNA (NEKTON) LIVING ON OR NEAR THE LAKE OR SEA BOTTOM. (COMPARE.....BENTHOS.)

DETRITIVORE. AN ORGANISM WHICH GAINS ITS NOURISHMENT FROM CONSUMING DETRITUS. (COMPARE.....HERBIVORE, CARNIVORE, OMNIVORE.)

DETRITUS. ALL TYPES OF BIOGENIC MATERIAL IN VARIOUS STAGES OF MICROBIAL DECOMPOSITION AND WHICH REPRESENTS A POTENTIAL ENERGY SOURCE TO CONSUMER ORGANISMS (DARNELL, 1976); INCLUDES CARRION, LITTER, CAST, AND WRACK AS WELL AS PARTICULATE ORGANIC DEBRIS DERIVED FROM DECOMPOSITION.

DIAGENESIS. REACTIONS THAT TAKE PLACE WITHIN A SEDIMENT BETWEEN ONE MINERAL AND ANOTHER OR BETWEEN ONE OR SEVERAL MINERALS AND THE INTERSTITIAL OR SUPERNATANT FLUIDS. DIAGENESIS IS A PROCESS THAT MAKES ROCK OUT OF SEDIMENT BY CHEMICAL REORGANIZATION SUCH AS SOLUTION, PRECIPITATION, CRYSTALLIZATION, RECRYSTALLIZATION, OXIDATION, REDUCTION, ETC. THESE REACTIONS TAKE PLACE AT LOWER TEMPERATURES AND PRESSURES THAN METAMORPHIC REACTIONS (PETTIJOHN, 1957).

DIFFRACTION. THE PHENOMENON BY WHICH ENERGY IS TRANSMITTED LATERALLY ALONG A WAVE CREST. WHEN A PORTION OF A WAVE TRAIN IS INTERRUPTED BY A BARRIER SUCH AS A BREAKWATER, THE EFFECT OF DIFFRACTION IS MANIFESTED BY PROPAGATION OF WAVES INTO THE SHELTERED REGION WITHIN THE GEOMETRIC SHADOW OF THE BARRIER (HUNT AND GROVES, 1965).

DISCHARGE, STREAM OR RIVER. THE VOLUME OF WATER AND SEDIMENTS RELEASED INTO THE RECEIVING BODY OF WATER (LAKE, RIVER, ESTUARY, OR OCEAN).

DISPHOTIC ZONE. THE LOWER ZONE IN A BODY OF WATER BELOW THE COMPENSATION POINT IN WHICH LIGHT ENERGY IS INSUFFICIENT TO MEET THE METABOLIC NEEDS OF PLANT LIFE. (COMPARE.....EUPHOTIC ZONE; SEE.....COMPENSATION DEPTH.)

DISSOLVED LOAD. THAT PORTION OF THE SEDIMENT BURDEN CARRIED BY A STREAM OR RIVER IN CHEMICAL SOLUTION. (COMPARE.....SUSPENDED LOAD, BED-LOAD.)

DISTRIBUTARY. A BRANCH OF A RIVER THAT FLOWS AWAY FROM THE MAIN CHANNEL AND DOES NOT RETURN TO IT, AS IN A DELTA REGION (MORRIS, 1976). (COMPARE.....TRIBUTARY.)

DIVERSITY. SPECIES RICHNESS; THE NUMBER OF SEPARATE SPECIES LIVING IN A SPECIFIED AREA OR VOLUME, AS DETERMINED BY A GIVEN SAMPLING TECHNIQUE.

DOMINANT. HAVING A MAJOR ROLE IN A COMMUNITY BECAUSE OF NUMBER, SIZE, OR ACTIVITY, AS OF PLANTS OR ANIMALS.

DRIFT SECTOR. A UNIT OF COASTLINE OR RIVER BANK WHICH INCLUDES SUPPLY, TRANSPORT, AND FINAL ACCRETION PHASES OF THE LOCAL SEDIMENTATION PROCESS.

DUNE. A WIND-FORMED RIDGE OR HILL OF SAND (MORRIS, 1976). (SEE.....PRIMARY DUNE, STABILIZED DUNE; COMPARE.....BEACH.)

DYSTROPHIC. CHARACTERIZED BY HIGH OXYGEN CONSUMPTION AND POOR BOTTOM-DWELLING FAUNA POPULATIONS, AS OF LAKES.

ECOLOGICAL MODEL. A CONCEPTUAL REPRESENTATION OF ACTUAL ECOSYSTEMS OR THEIR COMPONENT PHENOMENA IN SYMBOLIC TERMS. (SEE.....MODEL.)

ECOLOGY. THE INTERRELATIONSHIPS OF LIVING ORGANISMS TO ONE ANOTHER AND TO THEIR ENVIRONMENT, OR THE STUDY OF THESE INTERRELATIONSHIPS.

ECOSPHERE. THE TOTAL ASSEMBLAGE OF LIVING ORGANISMS AND THE SPACE, ENERGY, AND MATTER NEEDED TO SUSTAIN IT; CONTAINS ATMOSPHERE, LITHOSPHERE, HYDROSPHERE, AND BIOSPHERE.

ECOSYSTEM. A SYSTEM, WITH SPECIFIED BOUNDARIES, OF INTERRELATED ORGANISMS AND THE NON-LIVING ENVIRONMENT SUSTAINING IT; MAGNITUDE CAN RANGE FROM THE MICROSCOPIC TO THE PLANETARY.

ECOTONE. THE TRANSITION AREA OR BOUNDARY BETWEEN TWO BIOMES, ZONES, OR HABITATS.

EFFLUENT. A DISCHARGE OF POLLUTANTS INTO THE ENVIRONMENT (AIR OR WATER), EITHER TREATED OR UNTREATED (STUDDARD, 1974).

EKMAN TRANSPORT. NET MOTION OF AN ENTIRE MASS OF MOVING WATER, WHICH, IN THE ABSENCE OF INTERFERING LAND MASSES, IS DIRECTED NINETY DEGREES TO THE RIGHT (IN THE NORTHERN HEMISPHERE) OF THE DIRECTION OF THE WIND THAT SET IT MOTION (GROSS, 1972). NOTE THAT THE SURFACE WIND DRIFT CURRENT WILL BE ONLY 45 DEGREES TO THE RIGHT OF THE WIND DIRECTION IN THE NORTHERN HEMISPHERE, THE CURRENT DEFLECTING FURTHER TO THE RIGHT WITH DEPTH.

EMERGENT VEGETATION. AQUATIC PLANTS WHICH ARE NOT TOTALLY SUBMERGED; TYPICALLY BEING ROOTED IN AN AQUATIC ENVIRONMENT BUT HAVING MOST OF THE PHOTOSYNTHESIS OCCURRING ABOVE WATER, E.G., CATTAIL, BULRUSH, SEDGE.

ENDANGERED. IN DANGER OF EXTINCTION THROUGH ALL OR A SIGNIFICANT PORTION OF A SPECIES RANGE; A CLASSIFICATION CATEGORY OF THE ENDANGERED SPECIES ACT OF 1973. (COMPARE.....THREATENED.)

ENDANGERED SPECIES. SPECIES CLASSIFIED AS ENDANGERED UNDER THE ENDANGERED SPECIES ACT OF 1973: ANY NATIVE SPECIES OR SUBSPECIES WHICH THE SECRETARY OF INTERIOR, AFTER CONSULTATION WITH APPROPRIATE AFFECTED STATES OR KNOWLEDGEABLE PERSONS, DETERMINES TO BE IN DANGER OF EXTINCTION.

ENDEMIC. NATIVE AND FOUND ONLY IN A SMALL AREA (LOCAL ENDEMIC) OR REGION (REGIONAL ENDEMIC); HAVING A RANGE RESTRICTED TO A PARTICULAR LOCATION OR REGION.

ENVIRONMENT. THE SUM OF ALL EXTERNAL CONDITIONS AND INFLUENCES (MATTER AND ENERGY) AFFECTING OR IMPINGING ON THE LIFE, DEVELOPMENT, AND SURVIVAL OF AN ORGANISM OR GROUP OF ORGANISMS.

ENVIRONMENTAL RESISTANCE. (1) THE DIFFERENCE BETWEEN ACTUAL POPULATION AND CARRYING CAPACITY OF AN AREA; A MEASURE OF DEFICIT OR SURPLUS RESOURCES. (2) SUPPRESSSION OR INHIBITION OF GROWTH BY PHYSICAL OR BIOLOGICAL FACTORS AS A POPULATION INCREASES IN NUMBERS.

EPIBENTHIC. PERTAINING TO NON-SWIMMING FAUNA (BENTHOS) ON THE LAKE OR SEA BOTTOM.

EPIFAUNA. AQUATIC ANIMALS LIVING ON THE SURFACE OF BOTTOM SEDIMENTS. (COMPARE.....INFAUNA, BENTHOS.)

EPIPHYTE. A PLANT THAT GROWS ON ANOTHER PLANT UPON WHICH IT DEPENDS FOR MECHANICAL SUPPORT BUT NOT AS A DIRECT SOURCE OF NUTRIENTS.

EPIPSAMMIC. PERTAINING TO ORGANISMS LIVING ATTACHED TO THE SURFACE OF SAND GRAINS.

ERODABILITY. QUALITY OF ROCK DERIVED FROM ITS CHEMICAL AND PHYSICAL COMPOSITION AND AFFECTING THE RATE AT WHICH IT MAY BE ERODED.

EROSION. THE GROUP OF NATURAL PROCESSES INCLUDING WEATHERING, DISSOLUTION, ABRASION, CORROSION, AND TRANSPORTATION BY WHICH EARTHY OR ROCK MATERIAL IS REMOVED FROM ANY PART OF THE SURFACE OF THE EARTH (MORRIS, 1976).

ESTUARY. A SEMI-ENCLOSED COASTAL BODY OF WATER WHICH HAS A FREE CONNECTION WITH THE OPEN SEA AND WITHIN WHICH SEA WATER IS MEASURABLY DILUTED WITH FRESH WATER DERIVED FROM LAND DRAINAGE (CAMERON AND PRITCHARD, 1963). SEE OTHER DEFINITIONS IN SECTION 2.6 OF MODEL (VOL. 1).

EUPHOTIC ZONE. THE UPPER ZONE IN A BODY OF WATER IN WHICH RADIANT ENERGY PENETRATES IN SUFFICIENT LEVELS TO MEET OR EXCEED THE METABOLIC NEEDS OF PLANT LIFE. (COMPARE.....DISPHOTIC ZONE, COMPENSATION DEPTH.)

EUTROPHIC. NUTRIENT-RICH; CHARACTERISTIC OF OLD OR POLLUTED LAKES, SUPPORTING HIGH BIOLOGICAL PRODUCTION. (COMPARE.....MESOTROPHIC AND OLIGOTROPHIC.)

EVAPOTRANSPIRATION. WATER LOSS BY A PLANT INCLUDING NORMAL EVAPORATION OF WATER THAT DIFFUSES THROUGH THE PLANT SURFACES AND THAT WHICH IS RELEASED BY TRANSPIRATION THROUGH STOMATA OF THE LEAVES.

EXPRESSIVE ACTIVITY. HUMAN RECREATIONAL ACTIVITY WHICH IS DEPENDENT ON MAN-MADE RECREATIONAL FACITIES SUCH AS BOATING, SWIMMING, AND WATER SKIING, AND FACILITY EXPRESSIVE ACTIVITIES SUCH AS COURT GAMES, FIELD GAMES, AND GOLF. (COMPARE.....APPRECIATIVE ACTIVITY, EXTRACTIVE ACTIVITY.)

EXTERNALITY. A SOCIOECONOMIC COST, SUCH AS REDUCED PRODUCTIVITY OR A NECESSARY MITIGATING MEASURE, WHICH IS NOT BORNE BY THE OWNERS OR MANAGERS OF THE ACTIVITY THAT PRODUCES IT.

EXTRACTIVE ACTIVITY. HUMAN RECREATIONAL ACTIVITY WHICH REMOVES RESOURCES; INCLUDES SUCH ACTIVITIES AS ROCKHOUNDING, SPORT FISHING, CLAM DIGGING, AND HUNTING. (COMPARE.....APPRECIATIVE ACTIVITY, EXPRESSIVE ACTIVITY.)

FACIES, SEDIMENT, SAND, OR MUD. A STRATIGRAPHIC BODY DISTINGUISHED FROM OTHERS BY APPEARANCE OR COMPOSTION.

FETCH. IN WAVE FORECASTING, THE CONTINUOUS AREA OF WATER OVER WHICH THE WIND BLOWS IN ESSENTIALLY A CONSTANT DIRECTION. SOMETIMES USED SYNONYMOUSLY WITH FETCH LENGTH (HUNT AND GROVES, 1965).

FIXATION. THE PROCESS IN WHICH GASEOUS SUBSTANCES, ESPECIALLY NITROGEN, ARE REMOVED FROM THE ATMOSPHERE AND INCORPORATED INTO ORGANISMS. (COMPARE.....UPTAKE.)

FLOCCULATION. A LUMPING TOGETHER OF SUSPENDED COLLOIDAL CLAY-SIZED MATERIAL INTO A FLUFFY, SLOW-SETTLING PRECIPITATE. FLOCCULATION OCCURS IN ESTUARIES WHERE FRESH AND SALT WATER ARE MIXED.

FLOOD PLAIN. ALL LANDS THAT MAY BE INUNDATED BY THE MAXIMUM POSSIBLE CALCULATED FLOOD. TERM MAY BE APPLIED TO MARINE AND ESTUARINE BORDERLAND AS WELL AS TO RIVERINE BORDERLAND, AND MAY REFLECT MAXIMUM TIDAL CONDITIONS, AS WELL AS RIVER FLOW CONDITIONS. SEE FIG. 2-27 IN MODEL (VOL. 1).

FOOD CHAIN. A LINEAR SEQUENCE OF PREDATORS AND PREY SHOWING A DIRECT RELATIONSHIP SERIES OF EATERS AND EATEN IN A FOOD WEB AND EXHIBITING THE ENERGY FLOW FROM PRODUCERS THROUGH SEVERAL TROPHIC LEVELS OF CONSUMERS. (COMPARE.....FOOD WEB.)

FOOD WEB. (1) A MODEL SHOWING NUTRITIONAL INTERRELATIONSHIPS OF THE ORGANISMS IN A COMMUNITY, DEPICTING THE WEB-LIKE INTERCONNECTIONS OF THE NUMEROUS FOOD CHAINS OF EATERS AND EATEN; A ROAD MAP OF WHO EATS WHOM. (2) A COMPLEX NETWORK OF PATHWAYS BY WHICH ENERGY MOVES WITHIN A BIOTIC COMMUNITY, FROM PRODUCERS THROUGH ALL THE INTERCONNECTING TROPHIC LEVELS OF CONSUMERS. (COMPARE.....FOOD CHAIN.)

FORB. ANY NON-WOODY (HERBACEOUS) PLANT OTHER THAN A GRASS.

FORESHORE. (1) THE LOWER PART OF A BEACH OR FLOOD PLAIN EXTENDING FROM LOWEST MEASURED TIDE OR RIVER STAGE TO MEAN HIGHER HIGH WATER OR BANK FULL CONDITION (BAUER, 1975). (2) THE PART OF THE SHORE, LYING BETWEEN THE CREST OF THE SEAWARD BERM (OR THE UPPER LIMIT OF WAVE WASH AT HIGH TIDE) AND THE ORDINARY LOW WATER MARK, THAT IS ORDINARILY TRAVERSED BY THE UPRUSH AND BACKRUSH OF THE WAVES AS THE TIDES RISE AND FALL ALSO CALLED THE BEACH FACE (HUNT AND GROVES, 1965). SEE FIG. 2-27 IN MODEL (VOL. 1). (COMPARE.....BACKSHORE, NEARSHORE, OFFSHORE.)

FRACTURED ECOSYSTEM. AN ECOSYSTEM SIGNIFICANTLY ALTERED BY MAN IN WHICH NATURAL PROCESSES ARE SEVERELY DISRUPTED BY IMPROPER MANAGEMENT AND ITS MAJOR IMPACTS, INCLUDING POLLUTION. (COMPARE.....NATURAL ECOSYSTEM, MANAGED ECOSYSTEM.)

FRASS. INSECT FECES.

GRAZER. (1) IN GENERAL ECOLOGY, ANY PRIMARY CONSUMER. (2) IN WILDLIFE ECOLOGY, A HERBIVORE WHICH FEEDS ON HERBACEOUS PLANTS, E.G., GRASSES AND FORBS, AS OPPOSED TO BROWSE.

HABITAT. (1) THE AREA OR TYPE OF ENVIRONMENT WITHIN A BIOLOGICAL ZONE IN WHICH AN ORGANISM, POPULATION, OR COMMUNITY NORMALLY LIVES OR OCCURS. (2) THE SUM TOTAL OF ENVIRONMENTAL CONDITIONS OF A SPECIFIC PLACE THAT IS OCCUPIED BY AN ORGANISM, POPULATION, OR COMMUNITY (STUDDARD, 1974). (3) THE PARTICULAR PREFERRED ENVIRONMENT OF AN ORGANISM. (COMPARE.....BIOLOGICAL ZONE, NICHE.)

HALOCLINE. A VERTICAL SALINITY GRADIENT IN SOME LAYER OF A BODY OF WATER, WHICH IS APPRECIABLY GREATER THAN THE GRADIENTS ABOVE AND BELOW IT; ALSO A LAYER IN WHICH SUCH A GRADIENT OCCURS. SEE FIG. 2-30 IN MODEL (VOL. 1).

HEADLAND. A PROMONTORY OF ROCK ALONG THE COAST THAT IS RELATIVELY RESISTANT TO EROSION.

HERBIVORE. AN ORGANISM THAT GETS ITS NUTRITION BY EATING GREEN PLANT MATERIAL; GRAZER; PRIMARY CONSUMER. (COMPARE.....CARNIVORE, DETRITIVORE, OMNIVORE.)

HERPETOFAUNA. REPTILES AND AMPHIBIANS.

HETEROTROPHIC. OBTAINING NUTRIENTS AND ENERGY FROM ORGANIC SUBSTANCES PRODUCED BY AUTOTROPHIC ORGANISMS SUCH AS GREEN PLANTS; INCAPABLE OF SYNTHESIZING OWN FOOD FROM ENERGY OF SUN. (SEE.....CONVERTER.)

HINDCAST. TO CALCULATE OR ESTIMATE AN EFFECT OR EVENT FROM OBSERVED DATA AS OPPOSED TO PREDICTING (FORECASTING) FUTURE EFFECTS OR EVENTS. HINDCASTING IS USED TO TEST HYPOTHESES IN THE DEVELOPMENT OF PREDICTIVE THEORIES, ESPECIALLY IN THE GEOPHYSICAL SCIENCES.

HOLOPLANKTON. PERMANENT PLANKTON COMPRISING ORGANISMS THAT REMAIN AS PLANKTON THROUGHOUT THEIR COMPLETE LIFE CYCLE (SVERDRUP ET AL., 1942). (COMPARE.....MEROPLANKTON.)

HUMIFICATION. THE PROCESSS OF HUMUS FORMATION BY DECOMPOSITION OF VEGETABLE MATTER.

HUMUS. A BROWN OR BLACK ORGANIC SUBSTANCE CONSISTING OF PARTIALLY OR WHOLLY DECAYED VEGETABLE MATTER THAT PROVIDES NUTRIENTS FOR PLANTS AND INCREASES THE ABILITY OF SOIL TO RETAIN WATER (MORRIS, 1976).

HYDRIC. WET; PERTAINING TO A WET CONDITION, AS IN A HYDRIC HABITAT SUCH AS A SWAMP OR MARSH. (COMPARE.....MESIC, XERIC.)

HYDROLOGIC CYCLE. THE MODEL OF WATER MOVEMENT OR CIRCULATION BETWEEN THE ATMOSPHERE, LITHOSPHERE, AND HYDROSPHERE, INVOLVING PRECIPITATION, PERCOLATION, RUN-OFF, AND EVAPORATION. SEE FIGS. 1-2, 2-15, 2-16, 2-17, AND SECTION 2.4 IN MODEL (VOL. 1).

HYDROSPHERE. THE PORTION OF THE ECOSPHERE THAT IS OR INVOLVES WATER (AS DISTINGUISHED FROM ATMOSPHERE AND LITHOSPHERE AND BIOSPHERE). (SEE.....ECOSPHERE.)

INFAUNA. AQUATIC ANIMALS LIVING BENEATH THE SURFACE OF THE BOTTOM SEDIMENTS. (COMPARE.....EPIFAUNA, BENTHOS.)

INFILTRATION. THE PENETRATION OR PASSING OF WATER INTO SOIL. (COMPARE.....PERCOLATION.)

INSOLATION. INCOMING SOLAR RADIATION OR ITS INTENSITY INCIDENT ON A GIVEN SITE OVER A GIVEN PERIOD OF TIME.

JACKSON TURBIDITY UNIT (JTU). A MEASURE OF THE SUSPENDED PARTICULATE MATTER IN WATER, E.G., CLAY, SILT, FINELY DIVIDED ORGANIC AND INORGANIC MATTER, COLLOIDS, PLANKTON AND OTHER MICROSCOPIC ORGANISMS. AN EXPRESSION OF THE OPTICAL PROPERTY OF A SAMPLE CAUSING LIGHT TO BE SCATTERED AND ABSORBED RATHER THAN BEING TRANSMITTED THROUGH THE SAMPLE. THE TURBIDITY UNIT WAS ORIGINALLY BASED ON A MEASUREMENT MADE WITH THE JACKSON CANDLE TURBIDIMETER EMPLOYING A STANDARD KAOLIN SUSPENSION, NOW LARGELY SUPERSEDED BY A NEPHELOMETRIC METHOD EMPLOYING STANDARD FORMAZIN SUSPENSIONS. THE NEPHELOMETRIC METHOD YIELDS TURBIDITY UNITS APPROXIMATELY EQUIVALENT TO JACKSON TURBIDITY UNITS AND EXTENDS THE RANGE OF SAMPLE MEASUREMENT. PURE WATER HAS ZERO TURBIDITY UNITS, TEST WATER MAY RANGE FROM 0 - >1000 UNITS. (BASED ON TARAS ET AL., 1971, PP. 349-353.)

LACUSTRINE. PERTAINING TO OR LIVING IN, ON, OR UNDER A LAKE OR POND. (COMPARE.....RIVERINE, RIPARIAN, PALUSTRINE.)

LIMITING FACTOR. AN ENVIRONMENTAL PARAMETER WHICH IS OF PRIME IMPORTANCE IN THE REGULATION OF BIOLOGICAL PROCESSES, SUCH AS INDIVIDUAL GROWTH (BIOMASS), POPULATION GROWTH, ETC.

LITHOSPHERE. THE PORTION OF THE ECOSPHERE THAT IS THE SOLID CRUST OF THE EARTH (AS DISTINGUISHED FROM ATMOSPHERE, HYDROSPHERE, AND BIOSPHERE). COMPARE.....ECOSPHERE.)

LITTER. (1) THE UPPERMOST LAYER OF THE FOREST FLOOR OR OTHER TERRESTRIAL ENVIRONMENT GROUND SURFACE CONSISTING CHIEFLY OF DECAYING ORGANIC MATTER (MORRIS, 1976). (2) THE DEAD VEGETABLE (OF PLANT ORIGIN) MATTER, SUCH AS LEAVES, TWIGS, OR WOOD THAT FALLS TO THE GROUND AND ACCUMULATES AS IN (1). (COMPARE.....CAST, WRACK, HUMUS, CARRION.)

LITTORAL. THE BENTHIC ENVIRONMENT IN THE OCEAN FROM THE SHORE TO ABOUT 200 METERS (100 FATHOMS), ARBITRARILY CHOSEN TO REPRESENT THE EDGE OF THE CONTINENTAL SHELF AND ROUGHLY THE LOWER EXTENT OF THE PHOTIC ZONE (SVERDRUP ET AL., 1942). (SEE.....BENTHIC.)

LITTORAL DRIFT. MOVEMENT OF SEDIMENT PARALLEL TO A BEACH, BOTH ALONG THE BEACH FACE AND IN THE SURF ZONE WITHIN THE LONGSHORE CURRENT. NET LITTORAL DRIFT.....REFERS TO THE DIFFERENCE BETWEEN THE VOLUME OF SEDIMENT MOVING IN ONE DIRECTION ALONG A BEACH AND THAT MOVING IN THE OPPOSITE DIRECTION (CAUSED BY SHIFTS IN THE DIRECTION OF WAVE APPROACH) (BASCOM, 1964). (SEE.....LONGSHORE CURRENT.)

LOESS. A SURFICIAL DEPOSIT OF WEATHERED EARTH MATERIAL THAT IS TRANSPORTED AND DEPOSITED BY WIND; CHARACTERISTIC PARTICLE SHAPE SMOOTH AND ROUNDED; SIZE IS FINE. DUNES ARE EXAMPLES OF LOESS. (SEE.....LOESS SOIL; COMPARE.....ALLUVIUM, COLLUVIUM, RESIDUUM.)

LOESS SOIL. SOIL COMPOSED OF LOESS AND ORGANIC MATERIAL. (SEE.....LOESS; COMPARE.....ALLUVIAL SOIL, COLLUVIAL SOIL, RESIDUAL SOIL.)

LONGSHORE CURRENT. THE RESULTANT CURRENT PRODUCED BY WAVES BEING DEFLECTED AT AN ANGLE BY THE SHORE. IN THIS CASE THE CURRENT RUNS ROUGHLY PARALLEL TO THE SHORELINE. THE LONGSHORE CURRENT IS CAPABLE OF CARRYING A CERTAIN AMOUNT OF MATERIAL (HUNT AND GROVES, 1965); ALSO CALLED LITTORAL CURRENT. (SEE.....LITTORAL DRIFT.)

LOWLAND. LOW ELEVATION TERRAIN WHERE ALTITUDE AND SLOPE ARE NOT IMPORTANT ECOLOGICAL FACTORS.

MACROPHYTE, MACROFLORA. PLANT FORMS, INDIVIDUALS OF WHICH CAN BE OBSERVED WITH THE UNAIDED EYE, I.E., WITHOUT USE OF A MICROSCOPE.

MACROPLANKTON. PLANKTON ORGANISMS, MOSTLY ANIMALS 1 MM OR MORE IN LENGTH, TAKEN IN A COARSE PLANKTON NET (SVERDRUP ET AL., 1942). (COMPARE.....MICROPLANKTON, NANNOPLANKTON.)

MAJOR NUTRIENT. CHEMICAL ELEMENT NECESSARY FOR THE GROWTH AND MAINTENANCE OF AN ORGANISM THAT IS REQUIRED IN PROPORTIONS MEASURABLE IN AT LEAST PARTS PER THOUSAND OF DRY TISSUE; INCLUDES, IN ADDITION TO C, H, AND O, THE ELEMENTS N, P, K, MG, CA, NA, CL, AND S FOR MOST ORGANISMS, ALSO SI FOR DIATOMS.

MANAGED ECOSYSTEM. AN ECOSYSTEM SIGNIFICANTLY ALTERED BY MAN IN WHICH ADVERSE IMPACTS (INCLUDING POLLUTION) ARE MINIMIZED BY PROPER MANAGEMENT PRACTICES. (COMPARE.....NATURAL ECOSYSTEM, FRACTURED ECOSYSTEM.)

MARINE. OF, OR PERTAINING TO, THE SALTY WATERS OF THE OCEANS AND ASSOCIATED SEAS OF THE EARTH.

MARINEWAY SECTOR. THAT PORTION OF AN ESTUARY WHICH IS BOUNDED BY LAND, WITH A RESTRICTED OPENING TO THE OCEAN, AND IS NOT A PART OF THE STREAMWAY. THE FLOW IS ESSENTIALLY TIDAL CONTROLLED, AND NOT RIVER CONTROLLED. LAGOONS AND BAYS ARE EXAMPLES OF THE MARINEWAY SECTOR (BAUER, 1975). SEE FIG. 2-23 AND SECTION 2.6.1 IN MODEL (VOL. 1). (COMPARE.....STREAMWAY SECTOR, OPEN-WATER SECTOR.)

MARSH. A LOW-LYING WETLAND CHARACTERIZED BY EMERGENT VEGETATION SUCH AS TYPHA WHICH IS PREDOMINANTLY HERBACEOUS. (COMPARE.....SWAMP.)

MASS WASTING. THE DOWNSLOPE MOVEMENT OF ROCK AND/OR SOIL MATERIAL IN RESPONSE TO GRAVITY. A NUMBER OF DIFFERENT TYPES OF MASS MOVEMENT ARE RECOGNIZED ON THE BASIS OF NATURE OF MOVEMENT, RATE OF MOVEMENT, TYPE OF MATERIAL, AND WATER CONTENT OF MATERIAL. SEE SECTION 2.2.5.7 IN MODEL (VOL. 1).

MEIOFAUNA. DIMINUTIVE ANIMALS SO SMALL THAT ANATOMICAL DETAIL IS NOT VISIBLE TO THE UNAIDED EYE, BUT LARGER THAN UNICELLULAR MICROBES.

MEROPLANKTON. TEMPORARY PLANKTON COMPRISING THE EGGS AND LARVAE OF THE BENTHOS AND NEKTON, SEASONALLY VERY ABUNDANT IN NERITIC WATERS; COMPOSED MAINLY OF DEVELOPMENTAL STAGES OF THE INVERTEBRATES, BUT INCLUDING ALSO THE YOUNG OF FISHES (SVERDRUP ET AL., 1942). (COMPARE.....HOLOPLANKTON.)

MESIC. PERTAINING TO A MODERATE MOISTURE OR PRECIPITATION CONDITION, AS IN A MESIC HABITAT. (COMPARE.....HYDRIC, XERIC.)

MESOTROPHIC. MEDIUM IN NUTRIENT LEVELS; CHARACTERISTIC OF AGING OR PARTIALLY-POLLUTED LAKES, SUPPORTING MEDIUM BIOLOGICAL PRODUCTION. (COMPARE.....OLIGOTROPHIC AND EUTROPHIC.)

MICROCLIMATE. THE CLIMATE OF A SPECIFIC PLACE WITHIN AN AREA, CONTRASTED WITH THE CLIMATE OF THIS AREA AS A WHOLE (MORRIS, 1976).

MICRODETRITUS. EXTREMELY FINE PARTICULATE ORGANIC MATTER DERIVED FROM DISSOLVED ORGANIC MATTER BY AIR BUBBLING, AS IN SURF.

MICROPLANKTON. PLANKTON ORGANISMS, BELOW ABOUT 1 MM IN SIZE, WHICH CAN BE CAPTURED IN A FINE-MESHED PLANKTON NET (MESH APERTURE ABOUT 0.076 MM) (SVERDRUP ET AL., 1942). ALSO CALLED NET PLANKTON. (COMPARE.....MACROPLANKTON, NANNOPLANKTON, ULTRAPLANKTON.)

MIGRATION. THE MOVEMENT OF INDIVIDUALS OR GROUPS BETWEEN AREAS IN RESPONSE TO SEASONAL CHANGES OR STAGES IN LIFE CYCLE.

MINOR NUTRIENT. CHEMICAL ELEMENT NECESSARY FOR GROWTH AND MAINTENANCE BY AN ORGANISM THAT IS REQUIRED IN PROPORTIONS LESS THAN PARTS PER THOUSAND OF DRY TISSUE; INCLUDES FE, MN, CU, CO, ZN, AND MO FOR MOST ORGANISMS; ALSO CALLED TRACE NUTRIENT OR TRACE ELEMENT.

MODEL. (1) A SYMBOLIC REPRESENTATION OF A REAL-LIFE PHENOMENON, EXPRESSED EITHER VERBALLY, GRAPHICALLY, OR MATHEMATICALLY. (2) THE FIRST VOLUME OF THE ECOLOGICAL CHARACTERIZATION OF THE PACIFIC NORTHWEST COASTAL REGION, CONTAINING GENERAL ECOLOGICAL THEORY, BACKGROUND DATA, AND DEVELOPMENT OF MAJOR CHARACTERIZATION MODELS.

MULTIPLIER. SOCIOECONOMIC INDEX OF THE RELATIONSHIP BETWEEN BASIC AND NON-BASIC EMPLOYMENT: THE NUMBER OF BASIC INDUSTRY JOBS, TIMES MULTIPLIER, EQUALS TOTAL NUMBER OF JOBS.

MYCORRHIZA. THE SYMBIOTIC ASSOCIATION OF THE MYCELIUM OF A FUNGUS WITH THE ROOTS OF CERTAIN PLANTS SUCH AS CONIFERS OR ORCHIDS (MORRIS, 1976).

NANNOPLANKTON. VERY SMALL (5 TO 60 MICRONS) PLANKTON WHICH PASS THROUGH A FINE COLLECTING NET AND MUST BE COLLECTED BY CENTRIFUGATION; INCLUDES BACTERIA, SMALL PROTOZOANS, DIATOMS, DINOFLAGELLATES, AND OTHERS (SVERDRUP ET AL., 1942). (COMPARE.....MACROPLANKTON, MICROPLANKTON, ULTRAPLANKTON.) ALSO SPELLED NANOPLANKTON.

NATURAL ECOSYSTEM. AN ECOSYSTEM WHICH HAS NOT BEEN SIGNIFICANTLY ALTERED OR AFFECTED BY MAN. (COMPARE.....MANAGED ECOSYSTEM AND FRACTURED ECOSYSTEM.)

NEAP TIDE. THE DAILY TIDAL CYCLE OF LEAST VERTICAL RANGE. (COMPARE.....SPRING TIDE.)

NEARSHORE. THE MARINE REGION CLOSEST TO SHORE, EXTENDING FROM THE LINE OF LOWEST MEASURED TIDE SEAWARD TO THE DEPTH AT OUTER LINE OF BREAKERS. SEE FIG. 2-27 IN MODEL (VOL. 1). (COMPARE.....FORESHORE, OFFSHORE, BACKSHORE.)

NEARSHORE CIRCULATION CELL. A WAVE-DRIVEN CURRENT SYSTEM IN, AND JUST SEAWARD OF, THE SURF ZONE CONSISTING OF (1) A LANDWARD DRIFT OF WATER THROUGH THE SURF ZONE, (2) LONGSHORE CURRENTS WHICH RUN PARALLEL TO THE SHORE BETWEEN THE SHORE AND SUBMERGED SAND BARS PARALLEL TO SHORE, AND (3) BORDERING RIP CURRENTS WHICH CARRY THE SURPLUS WATER SEAWARD TO JUST BEYOND THE SURF ZONE THROUGH LOW POINTS IN THE SUBMERGED SAND BARS (KOMAR, 1971).

NEGATIVE MATERIAL BUDGET. MATERIAL DEPOSITED IS LESS THAN THE AMOUNT OF MATERIAL REMOVED, AS IN EROSION.

NEKTON. MARINE ANIMALS THAT ARE ABLE TO SWIM AGAINST NORMAL WAVE AND CURRENT ACTION. (COMPARE .....PLANKTON, BENTHOS.)

NERITIC. PERTAINING TO THE MARINE WATERS OF THE PELAGIC ENVIRONMENT OVERLYING THE CONTINENTAL SHELF (SVERDRUP ET AL., 1942). (COMPARE.....PELAGIC, BENTHIC.)

NICHE. (1) THE FUNCTIONAL ROLE OF AN ORGANISM IN A HABITAT; THE PROFESSION OF THE ORGANISM (ODUM, E.P., 1971). (2) THE AREA OR SET OF ENVIRONMENTAL CONDITIONS WITHIN A HABITAT OCCUPIED BY AN ORGANISM (MORRIS, 1976). COMPARE.....HABITAT, BIOLOGICAL ZONE.)

NON-BASIC HUMAN ACTIVITY. SOCIOECONIMIC ACTIVITY WHICH EXCLUSIVELY SERVES THE DEMAND FOR LOCAL GOODS AND SERVICES, RATHER THAN THE HANDLING OF NATURAL RESOURCES. (COMPARE.....BASIC HUMAN ACTIVITY.)

NON-CHANNELIZED FLOW. FLOW OF WATER NOT IN A DEFINABLE CHANNEL. ON THE SURFACE IT IS SURFACE RUNOFF. MOVEMENT OF GROUNDWATER BY INFILTRATION AND PERCOLATION IS ALSO A NON-CHANNELIZED FLOW. (SEE.....SURFACE RUNOFF; COMPARE.....CHANNELIZED FLOW, RUNOFF.)

NON-POINT-SOURCE. A GENERAL AREA OR NON-ISOLATABLE SOURCE OF AIR OR WATER POLLUTION SUCH AS TRANSPORTATION, FUEL COMBUSTION, OR URBAN RUNOFF. (COMPARE.....POINT-SOURCE.)

NOT-SOIL. WETLAND SUBSTRATE WHICH IS TOO DEEP TO SUPPORT EMERGENT VEGETATION (U.S.D.A. SOIL CONSERVATION SERVICE, 1975, AS QUOTED IN COWARDIN ET AL., 1977).

NUTRIENT. AN ELEMENT OR CHEMICAL COMPOUND THAT IS USED TO SUPPORT GROWTH OR MAINTENANCE OF AN ORGANISM. (COMPARE.....MAJOR NUTRIENT AND MINOR NUTRIENT).

OFFSHORE. (1) IN BEACH TERMINOLOGY, THE ZONE EXTENDING SEAWARD FROM THE OUTER LINE OF BREAKERS TO THE SEAWARD EDGE OF THE CONTINENTAL SHELF (HUNT AND GROVES, 1965; INMAN AND BAGNOLD, 1963). SEE FIG. 2-27 IN MODEL (VOL. 1). (COMPARE.....NEARSHORE, FORESHORE, BACKSHORE; SEE...SURF ZONE, BREAKER DEPTH.) (2) IN PLANKTON STUDIES, PERTAINING TO THOSE SPECIES OR COMMUNITIES CHARACTERISTIC OF MARINE WATERS WITH A SALINITY EQUAL TO OR GREATER THAN 32.5 PARTS PER THOUSAND.

OLIGOTROPHIC. NUTRIENT-POOR; CHARACTERISTIC OF YOUNG, CLEAR LAKES, SUPPORTING LOW BIOLOGICAL PRODUCTION. (COMPARE.....MESOTROPHIC, EUTROPHIC.)

OMNIVORE. AN ORGANISM THAT EATS BOTH PLANTS AND ANIMALS. (COMPARE.....HERBIVORE, CARNIVORE, DETRITIVORE.)

OPEN-WATER SECTOR. THE OUTWASH FRINGE OR PLUME OF COASTAL RIVERS AND ESTUARIES. THIS SECTOR OF AN ESTUARY IS BEYOND THE CONFINED BORDERS OF THE MARINEWAY OR STREAMWAY SECTORS. THE EXTENT OF THE OPEN-WATER SECTOR IS EVER-CHANGING AND POORLY DEFINED IN THE FORESHORE, NEARSHORE, AND OFFSHORE COASTAL ZONES (BAUER, 1975). SEE FIG. 2-23 AND SECTION 2.6.1 IN MODEL (VOL. 1). (COMPARE.....STREAMWAY SECTOR, MARINEWAY SECTOR.)

ORGANIC. REFERRING TO OR DERIVED FROM LIVING ORGANISMS; IN CHEMISTRY, ANY COMPOUND CONTAINING CARBON. (COMPARE.....BIOGENOUS.)

OROGRAPHIC LIFTING. LIFTING OF AN AIR MASS PRODUCED BY FLOW OVER MOUNTAINS AND MOUNTAIN RANGES (AS OPPOSED TO LIFTING DUE TO THERMAL EXPANSION OR INTERACTION WITH OTHER AIR MASSES).

PALUSTRINE. PERTAINING TO OR LIVING IN OR BY A SWAMP, MARSH, OR OTHER WETLAND. (COMPARE.....LACUSTRINE, RIPARIAN, RIVERINE.)

PEDOGENIC. DERIVED DIRECTLY FROM ROCK MATERIAL; USED IN SOIL TERMINOLOGY.

PELAGIC. PERTAINING TO THE OPEN SEA, INDEPENDENT OF THE COAST OR BOTTOM; OCEANIC. (COMPARE.....NERITIC, BENTHIC.)

PERCOLATION. THE PENETRATION OR PASSING OF WATER THROUGH THE SOIL. (COMPARE.....INFILTRATION.)

PERIPHYTE, PERIPHYTON. AQUATIC PLANT (PRIMARILY MICROSCOPIC) LIVING ON THE SURFACE OF SUBMERGED OBJECTS.

PERMEABILITY. THE ABILITY OF ROCK TO TRANSMIT WATER UNDER PRESSURE. A ROCK MUST BE POROUS (SEE.....POROSITY) TO BE PERMEABLE, BUT THE REVERSE IS NOT TRUE (GILLULY ET AL., 1959).

PHOTIC ZONE. THE ZONE OF A BODY OF WATER IN WHICH RADIANT ENERGY (SUNLIGHT) PENETRATES; INCLUDES EUPHOTIC AND DISPHOTIC ZONES.

PHYTOPLANKTON. SUSPENDED AQUATIC ORGANISMS WHICH DO NOT REQUIRE A SOLID SUBSTRATE OR ATTACHMENT AND WHICH ARE ABLE TO PHOTOSYNTHESIZE; USUALLY SMALL TO MICROSCOPIC, MAY BE MOTILE.

PIONEER. A PLANT, ANIMAL, OR COMMUNITY THAT FIRST INVADES A BARE AREA IN A SUCCESSSIONAL SEQUENCE OR SERE (E.G., GRASSES ON FOREDUNE, LICHENS ON ROCK).

PISCAVORE. ANIMAL THAT USES FISH AS A FOOD SOURCE.

PLANKTON. AQUATIC ORGANISMS WHICH ARE NOT ATTACHED TO ANY SUBSTRATE AND CANNOT SWIM EFFECTIVELY AGAINST WATER CURRENTS AND WAVES; MAY BE PLANT, ANIMAL, OR PROTIST AND VARY IN SIZE FROM SUB-MICROSCOPIC TO A METER OR MORE (FOR LARGE JELLYFISH AND FLOATING SARGASSUM); DRIFTERS. (SEE.....PHYTOPLANKTON, NANNOPLANKTON, ZOOPLANKTON, MICROPLANKTON, MACROPLANKTON.)

POINT-SOURCE. A STATIONARY, IDENTIFIABLE SOURCE OF AIR OR WATER POLLUTION EMISSIONS OR DISCHARGES, SUCH AS A SMOKESTACK OR EFFLUENT PIPE. (COMPARE.....NON-POINT-SOURCE.)

POLLUTION. THE PRESENCE OF MATTER OR ENERGY WHOSE NATURE, LOCATION, OR QUANTITY PRODUCES UNDESIRED ENVIRONMENTAL EFFECTS (STUDDARD, 1974).

POPULATION. A GROUP OF ORGANISMS OF THE SAME SPECIES, CONFINED TO A DEFINED GEOGRAPHICAL AREA; THE NUMBER OF INDIVIDUALS WHICH SHARE A COMMON GENE POOL.

POROSITY. THE PERCENTAGE OF A ROCK OR SOIL THAT IS REPRESENTED BY OPEN SPACES. THE POROSITY OF SEDIMENTS AND SEDIMENTARY ROCKS DEPENDS UPON THE SHAPE, RELATIVE SIZES, AND ARRANGEMENT OF THE GRAINS, AND THE DEGREE OF COMPACTION AND CEMENTATION (GILLULY ET AL., 1959).

POSITIVE MATERIAL BUDGET. MATERIAL DEPOSITED IS MORE THAN THE AMOUNT OF MATERIAL REMOVED, AS IN SEDIMENTATION. (COMPARE.....NEGATIVE MATERIAL BUDGET.)

PRIMARY CONSUMER. GRAZER, FEEDING ON PLANT (PRODUCER) MATERIAL; HERBIVORE. (COMPARE..... ECONDARY CONSUMER; SEE.....GRAZER.)

PRIMARY DUNE. A DUNE IN FIRST STAGE OF SUCCESSION, INHABITED BY PIONEER SAND-STABILIZING PLANTS (ESPECIALLY THE INTRODUCED EUROPEAN BEACH GRASS); A STRESS STAGE EASILY ERODED, SENSITIVE TO WINTER STORMS AND OVERUSE BY MAN. (COMPARE.....STABILIZED DUNE.)

PRIMARY MINERAL. A MINERAL FORMED DEEP WITHIN THE EARTH AT TEMPERATURES AND PRESSURES VERY MUCH HIGHER THAN THOSE ON THE SURFACE; INCLUDES OXIDES, SILICATES, ALUMINOSILICATES, SULFIDES, AND PHOSPHATES. (COMPARE.....SECONDARY MINERAL.)

PRIMARY PRODUCTIVITY. THE MEASURE OF GRAMS OF CARBON FIXED PER UNIT AREA PER UNIT TIME BY PHOTOSYNTHETIC ORGANISMS (PRODUCERS). (COMPARE.....SECONDARY PRODUCTIVITY.)

PRIMARY REGULATING PROCESS. A PROCESS OR CONDITION THAT IS THE MAJOR CONTROLLER OR REGULATOR OF THE FLOW OF ENERGY AND/OR MATTER THROUGH AN ECOSYSTEM FLOW PATH; USUALLY REPRESENTED IN AN ECOLOGICAL MODEL AS A VALVE OR A SWITCH, AND USUALLY CONTROLLED IN TURN BY ONE OR MORE SECONDARY REGULATING FACTOR(S). SEE GLOSSARY OF SYMBOLS. (COMPARE.....SECONDARY REGULATING FACTOR.)

PRODUCER. AN ORGANISM THAT MAKES ITS OWN FOOD BY CAPTURING THE RADIANT ENERGY OF THE SUN AND STORING IT IN HIGH-ENERGY CARBOHYDRATE BONDS; AUTOTROPH. (COMPARE......CONVERTER.) SOMETIMES CALLED PRIMARY PRODUCER, WITH SAME MEANING.

PRODUCTION PROCESSES. SOCIOECONOMIC ACTIVITY. INVOLVING ANY NECESSARY CONVERSION OF NATURAL RESOURCES TO SUPPLY REQUIREMENTS FOR GOODS AND SERVICES; BASIC HUMAN ACTIVITY.

PSAMMIC. PERTAINING TO ORGANISMS LIVING AMONG THE SAND GRAINS.

PYCNOCLINE. A STEEP, VERTICAL GRADIENT OF DENSITY IN THE OCEAN, SEPARATING THE UPPER, MIXED LAYER(S) FROM THE DEEPER, COOLER, MORE SALINE WATER MASSES.

RARE. HAVING A VERY LIMITED RANGE, OR HAVING A WIDESPREAD RANGE BUT A VERY LOW DENSITY.

REFRACTION. THE PROCESS BY WHICH THE DIRECTION OF A WAVE MOVING IN SHALLOW WATER AT AN ANGLE TO THE CONTOURS IS CHANGED. THE PART OF THE WAVE ADVANCING IN SHALLOWER WATER MOVES MORE SLOWLY THAN THAT PART STILL ADVANCING IN DEEPER WATER, CAUSING THE WAVE CREST TO BEND TOWARD ALIGNMENT WITH THE UNDERWATER CONTOURS (HUNT AND GROVES, 1965).

RELATIVE HUMIDITY. THE RATIO (IN PERCENT) OF THE AMOUNT OF WATER VAPOR IN THE AIR TO THE MAXIMUM AMOUNT OF WATER VAPOR THAT THE AIR CAN HOLD AT A PARTICULAR TEMPERATURE. SINCE WARMER AIR CAN CONTAIN MORE WATER VAPOR THAN COOLER AIR, RELATIVE HUMIDITY DEPENDS UPON THE TEMPERATURE OF THE AIR.

RESIDUAL SOIL. SOIL COMPOSED OF RESIDUUM AND ORGANIC MATERIAL. (SEE.....RESIDUUM; COMPARE.....ALLUVIAL SOIL, COLLUVIAL SOIL, LOESS SOIL.)

RESIDUUM. A SURFICIAL DEPOSIT FORMED FROM WEATHERING-IN-PLACE OF PARENT ROCK MATERIAL (I.E., NOT TRANSPORTED). (SEE.....RESIDUAL SOIL; COMPARE.....ALLUVIUM, COLLUVIUM, LOESS.)

RESOURCE. A PRODUCT OF PHYSICAL OR BIOLOGICAL SYSTEMS WHICH CAN BE UTILIZED BY MAN.

RESPIRATION. PROCESS BY WHICH STORED, CHEMICALLY-BOUND ENERGY IS RELEASED TO BE UTILIZED IN METABOLIC LIFE PROCESSES BY A PLANT OR ANIMAL.

RHIZOSPHERE. THE VOLUME DIRECTLY SURROUNDING THE ROOTS OF A PLANT, IN WHICH ARE FOUND THE SEDIMENT, MOISTURE, GASSES, NUTRIENTS, AND ORGANISMS THAT MAKE UP SOIL.

RIPARIAN. REFERRING TO OR LIVING IN OR BY LAND BORDERING A STREAM, LAKE, OR TIDEWATER. (COMPARE.....RIVERINE, LACUSTRINE, PALUSTRINE.)

RIVERINE. PERTAINING TO OR LIVING IN OR UNDER A RIVER OR STREAM. (COMPARE.....RIPARIAN, LACUSTRINE, PALUSTRINE.)

ROCK FLOUR. FINE SILT FOUND IN SUSPENSION IN GLACIER-FED STREAMS, CONSISTING OF UNWEATHERED FELDSPAR AND OTHER UNDECOMPOSED MINERALS WHICH ARE PRODUCED FROM ROCK FRAGMENTS THAT HAVE BEEN CRUSHED AGAINST EACH OTHER AND AGAINST THE BEDROCK BY THE GLACIER. SOIL MINERALS THAT RESULT FROM CHEMICAL WEATHERING AND HUMUS ARE CONSPICUOUSLY ABSENT IN ROCK FLOUR (GILLULY ET AL., 1959).

RUDERAL. WEEDY; GROWING ON SPOIL OR REFUSE BANKS, OR ON POOR OR WASTE LAND, WHERE NATURAL COVER HAS BEEN DISTURBED, AS BY MAN.

RUNOFF. MEASUREABLE DOWNHILL FLOW OF FRESH WATER FROM A WATERSHED; INCLUDES CHANNELIZED AND NON-CHANNELIZED FLOWS (WHICH SEE) INCLUDING SEEPAGES AND ADDITIONS FROM GROUND WATER.

SALINITY. THE TOTAL AMOUNT OF DISSOLVED SOLID MATERIAL (IN GRAMS) CONTAINED IN ONE KILOGRAM OF WATER. FOR THIS MEASUREMENT ALL ORGANIC MATTER IS OXIDIZED, ALL CARBONATE CONVERTED TO OXIDE, AND ALL BROMIDE AND IODIDE REPLACED BY CHLORIDE (SVERDRUP ET AL., 1942); THE SALTINESS OF A BODY OF WATER.

SALMONID. A FISH OF THE FAMILY SALMONIDAE; INCLUDES THE SALMONS, TROUTS, CHARS, AND WHITEFISHES.

SALT MARSH. A MARSH IN WHICH THE WATER IS SALTY OR BRACKISH, WITH SALINITY GREATER THAN FRESH WATER BUT LESS THAN SEA WATER, AND CONTAINING HALOPHYTIC VEGETATION.

SAPROPEL. THE FOUL-SMELLING, MUDDY REMAINS OF ANAEROBIC DECOMPOSITION, CONTAINING METHANE, AMMONIA, HYDROGEN SULFIDE, AND FATTY SUBSTANCES.

SAPROVORE. AN ORGANISM THAT GAINS ITS NOURISHMENT FROM CONSUMING DEAD OR DECAYING ORGANIC MATTER. (COMPARE.....DETRITIVORE, CARNIVORE, ETC.)

SCAVENGER. AN ORGANISM WHICH OBTAINS FOOD FROM ALREADY DEAD ORGANISMS AND DOES NOT KILL FOR FOOD. (COMPARE.....CARNIVORE, DETRITIVORE, ETC.)

SCLEROPHYLLOUS. CHARACTERIZED BY TOUGH, THICK LEAVES AND TWIGS, AS OF EVERGREEN SHRUBS AND SOMETIMES TREES TYPICALLY FOUND IN DRY (XERIC) CONDITIONS, SUCH AS CHAPARRAL (HUCKLEBERRY OAK, CEONOTHUS SPP.).

SEA. SHORT-PERIOD, STEEP WAVES GENERATED BY LOCAL WINDS AND STORMS. (COMPARE.....SWELL.)

SECONDARY CONSUMER. ORGANISM THAT FEEDS ON PRIMARY CONSUMERS (GRAZERS); CARNIVORE.

SECONDARY MINERAL. A MINERAL FORMED AT OR NEAR THE SURFACE OF THE EARTH DURING THE PROCESS OF WEATHERING. (COMPARE.....PRIMARY MINERAL.)

SECONDARY PRODUCTIVITY. (1) THE MEASURE OF RATE OF BIOMASS ACCRETION PER UNIT AREA PER UNIT TIME BY CONSUMERS OF PLANT MATERIALS (I.E., PRIMARY CONSUMERS). (2) THE MEASURE OF RATE OF BIOMASS ACCRETION BY ALL CONSUMERS.

SECONDARY REGULATING FACTOR. A CONDITION, STATE, OR PROCESS THAT CONTROLS OR REGULATES A PRIMARY REGULATING PROCESS; A PHYSICAL, CHEMICAL, BIOLOGICAL, OR HUMAN FACTOR THAT AFFECTS A REGULATING PROCESS IN AN ECOLOGICAL MODEL. SEE GLOSSARY OF SYMBOLS. (COMPARE.....PRIMARY REGULATING PROCESS.)

SEDIMENT. (1) ANY MATERIAL CARRIED IN SUSPENSION BY WATER, WHICH WILL ULTIMATELY SETTLE TO THE BOTTOM. (2) SOME WATER-BORNE MATTER DEPOSITED OR ACCUMULATED IN BEDS (NOTE: INCLUDES MATERIAL THAT MAY HAVE BEEN IN A DISSOLVED LOAD BUT PRECIPITATED) (HUNT AND GROVES, 1965). SEDIMENT ORIGINS INCLUDE WEATHERED CONSOLIDATED MATERIAL, AS WELL AS BIOLOGICAL DETRITUS AND MAN-MADE WASTES.

SERAL STAGE. ONE TRANSITORY COMMUNITY IN A SERE. (SEE.....SERE; COMPARE.....CLIMAX COMMUNITY.)

SERE. THE ENTIRE SERIES OR SEQUENCE OF COMMUNITIES SUCCESSIVELY OCCUPYING AN AREA. (SEE.....SUCCESSION.)

SERVICES. THE NON-BASIC COMPONENT OF A HUMAN COMMUNITY SOCIOECONOMIC BASE THAT INCLUDES ALL THOSE ACTIVITIES WHICH SERVE THE LOCAL POPULATION OR SUPPORT LOCAL BASIC INDUSTRIES, AND WHICH RECIRCULATE INCOME DERIVED FROM THE BASIC INDUSTRY WITHIN THE COMMUNITY; NON-BASIC HUMAN ACTIVITY.

SESTON. THE COMPLEX OF DECOMPOSING PLANT MATERIAL AND DECOMPOSERS (BACTERIA, FUNGI, AND PROTOZOANS) IN AQUATIC ENVIRONMENTS, BEING A MAJOR PART OF THE DIET OF FILTER-FEEDING ORGANISMS.

SHORE PROCESS CORRIDOR. THE DYNAMIC SHORE ZONE STRADDLING THE EXTREME SURGE-LIMITS OF THE OCEAN, ESTUARY, OR RIVER, AND INCLUDING THOSE AQUATIC AND TERRESTRIAL OUTER FRINGES ON EACH SIDE THAT CAN AFFECT, OR ARE AFFECTED BY, THE PREVAILING GEO-HYDRAULIC SYSTEM OF THE SHORE (BAUER, 1974A). SEE FIG. 2-27 IN MODEL (VOL. 1).

SHORELINE. THE LINE OF CONTACT BETWEEN WATER AND LAND (BASCOM, 1964). THIS TERM IS IMPRECISE AND IS USED IN A VARIETY OF WAYS. THE LINE OF CONTACT VARIES WITH TIDES OR WATER LEVELS. THE ARBITRARY LINES CHOSEN ON MAPS AND CHARTS VARY, DEPENDING ON USAGE AND RATIONALE BEHIND WATER LEVEL CONSIDERATION. (COMPARE.....COAST, SHORE PROCESS CORRIDOR.)

SIGNIFICANT WAVE HEIGHT. THE AVERAGE HEIGHT OF THE 1/3 HIGHEST WAVES OF A GIVEN WAVE GROUP (HUNT AND GROVES, 1965).

SIGNIFICANT WAVE PERIOD. AN ARBITRARY PERIOD GENERALLY TAKEN AS THE PERIOD OF THE 1/3 HIGHEST WAVES WITHIN A GROUP (HUNT AND GROVES, 1965).

SINK, KITCHEN. THE ULTIMATE ITEM IN AN INCLUSIVE LIST. TERM USED TO INDICATE THAT A THOROUGH AND USUALLY UNSELECTIVE JOB HAS BEEN DONE.

SOCIOECONOMIC. PERTAINING TO HUMAN ACTIVITIES, BOTH SOCIAL/CULTURAL AND ECONOMIC.

SOIL. (1) A NATURAL, THREE-DIMENSIONAL BODY ON THE SURFACE OF THE EARTH THAT SUPPORTS PLANTS AND THAT HAS PROPERTIES RESULTING FROM THE INTEGRATED EFFECT OF CLIMATE AND LIVING MATTER ACTING ON EARTH PARENT MATERIAL, AS CONDITIONED BY RELIEF OVER PERIODS OF TIME (U.S.D.A., 1975A). (2) MATERIAL THAT HAS WEATHERED IN THE PLACE WHERE IT IS NOW FOUND AND IS MIXED WITH ORGANIC MATTER NEAR THE SURFACE (GILLULY ET AL., 1959).

SOIL HORIZON. A LAYER OF SOIL, APPROXIMATELY PARALLEL TO THE SURFACE, THAT HAS DISTINCT CHARACTERISTICS PRODUCED BY SOIL-FORMING PROCESSES (U.S.D.A., 1975A). MAJOR SOIL HORIZONS ARE IDENTIFIED AND DESCRIBED IN SECTION 2.2.5 OF MODEL (VOL. 1).

SPRING TIDE. THE DAILY TIDAL CYCLE OF GREATEST VERTICAL RANGE. (COMPARE.....NEAP TIDE.)

STABILIZED DUNE. A DUNE PROTECTED BY VEGETATION FROM FURTHER MOVEMENT OR MODIFICATION BY WIND OR STORMS. (COMPARE.....DUNE, PRIMARY DUNE.)

STANDING CROP. AMOUNT OF LIVING TISSUE EXISTING AT ANY GIVEN TIME.

STEELHEAD. A RAINBOW TROUT, SALMO GAIRDNERI, THAT MIGRATES TO THE SEA, AT WHICH TIME IT TAKES ON A SILVERY ASPECT.

STREAM SECTOR. A LENGTH OR REACH OF RIVERINE SHORE THAT EXHIBITS AN INTEGRATED GEO-HYDRAULIC PROCESS SYSTEM CONTAINING A MATERIAL SOURCE, A TRANSPORT WAY, AND AN ACCRETION TERMINUS (BAUER, 1975).

STREAMWAY SECTOR. THAT LOWER PORTION OF A LOW GRADIENT STREAM WHERE THERE IS A TIDAL REVERSAL OF FLOW AND SALT WATER INTRUSION (BAUER, 1975). SEE FIG. 2-23 AND SECTION 2.6.1 IN MODEL (VOL. 1). (COMPARE.....MARINEWAY SECTOR, OPEN-WATER SECTOR.)

SUBMERSIBLE. BETWEEN MEAN LOW WATER AND MEAN HIGH WATER; INTERTIDAL.

SUBSTRATE. (1) THE SURFACE ON WHICH A PLANT OR ANIMAL GROWS OR IS ATTACHED. (2) THE VOLUME, SURFACES, AND MATERIALS THAT PROVIDE LIVING SPACE, PHYSICAL SUPPORT, AND NOURISHMENT FOR ORGANISMS.

SUCCESSION. THE REPLACEMENT OF ONE KIND OF COMMUNITY BY ANOTHER KIND; THE PROGRESSIVE CHANGES IN VEGETATION AND ANIMAL LIFE WHICH OCCUR IN ONE PLACE OVER TIME, CULMINATING IN THE CLIMAX COMMUNITY FOR THAT LOCATION. (SEE.....SERE.)

SURF ZONE. A REGION ALONG AN UNPROTECTED OCEAN BEACH EXTENDING FROM THE SHORELINE TO THE OUTER LINE OF BREAKERS, OR EXTENDING ALONG THE BOTTOM TO BREAKER DEPTH; THE EXTENT VARIES WITH THE STAGE OF THE TIDE, THE CHARACTER OF THE INCOMING WAVES, AND THE SLOPE OF THE BOTTOM.

SURFACE RUNOFF. RUNOFF OF WATER OVER THE LAND SURFACE TO STREAMS AND RIVERS WITHOUT FORMING, OR FLOWING IN, DEFINABLE CHANNELS; A TYPE OF NON-CHANNELIZED FLOW, ALSO CALLED SURFACE FLOW. (COMPARE.....NON-CHANNELIZED FLOW, CHANNELIZED FLOW, RUNOFF.)

SURGE PLAIN. THAT LAND WHICH IS OVERRUN (FLOODED) BY TIDAL REVERSAL UNDER BANK FULL RIVER AND HIGHER HIGH TIDE CONDITIONS; THE UPPERMOST AREA OF LAND/WATER INTERACTION BORDERING THE STREAMWAY SECTOR OF AN ESTUARY, CONTAINING MOSTLY FRESHWATER ORGANISMS (BAUER, 1975).

SUSPENDED LOAD. THE AMOUNT OF SEDIMENT PER UNIT VOLUME OF WATER BEING TRANSPORTED IN SUSPENSION IN A RIVER, STREAM, LAKE, ESTUARY, OR OCEAN. (COMPARE.....DISSOLVED LOAD, BED LOAD.)

SWAMP. A WETLAND CHARACTERIZED BY PREDOMINANTLY WOODY VEGETATION. (COMPARE.....MARSH.)

SWELL. LONG-PERIOD WAVES GENERATED BY OCEANIC STORMS UP TO THOUSANDS OF MILES AWAY. (COMPARE.....SEA.)

THALWEG. THE MAIN CHANNEL OF A RIVER OR STREAM.

THREATENED. LIKELY TO BECOME ENDANGERED WITHIN THE FORESEEABLE FUTURE THROUGH ALL OR A SIGNIFICANT PORTION OF A SPECIES RANGE; A CLASSIFICATION CATEGORY OF THE ENDANGERED SPECIES ACT OF 1973. (COMPARE.....ENDANGERED.)

TIDAL PRISM. THE TOTAL AMOUNT OF WATER THAT FLOWS INTO OR OUT OF AN ESTUARY, BAY, OR HARBOR WITH THE MOVEMENT OF THE TIDE. THIS VOLUME IS A FUNCTION OF THE TIDAL RANGE AND THE SURFACE AREA OF THE ESTUARY, BAY, OR HARBOR INTEGRATED OVER THE RANGE OF THE TIDE.

TIDAL SIGNATURE. TIME-HEIGHT HISTORY OF THE SEA LEVEL PORTRAYED GRAPHICALLY, WITH EFFECTS OF WAVES AND SWELL FILTERED OUT.

TIDE. THE PERIODIC RISE AND FALL OF SEA LEVEL PRODUCED BY GRAVITATIONAL FORCES OF THE MOON AND SUN ACTING UPON THE ROTATING EARTH. SEE FIG. 2-25 IN MODEL (VOL. 1) FOR TIDE LEVEL TERMINOLOGY. (COMPARE.....SPRING TIDE, NEAP TIDE, TIDAL PRISM, TIDAL SIGNATURE.)

TOMBOLO. AN AREA OF UNCONSOLIDATED MATERIAL, DEPOSITED BY WAVE ACTION OR CURRENTS, THAT CONNECTS A ROCK OR ISLAND, ETC., TO THE MAINLAND OR TO ANOTHER ISLAND (HUNT AND GROVES, 1965).

TOPOGRAPHY. THE PHYSICAL FEATURES OF THE SURFACE OF A REGION. (COMPARE.....BATHYMETRY.)

TRANSPIRATION. THE PLANT PROCESS OF GIVING OFF WATER VAPOR (AND WASTE PRODUCTS) THROUGH THE STOMATA OF LEAF TISSUE. (COMPARE.....EVAPOTRANSPIRATION.)

TRIBUTARY. A STREAM OR RIVER FLOWING INTO A LARGER STREAM OR RIVER (MORRIS, 1976). (COMPARE.....DISTRIBUTARY.)

TROPHIC LEVEL. A STRATUM IN THE HIERARCHY OF PRODUCERS (FIRST TROPHIC LEVEL) AND CONVERTERS, AS MODELED IN A PYRAMID OF RELATIVE BIOMASS OR ENERGY; HERBIVOROUS CONSUMERS (GRAZERS) ARE AT THE SECOND-TROPHIC LEVEL; CARNIVOROUS CONSUMERS MAY BE AT THE THIRD OR A HIGHER TROPHIC LEVEL.

TSUNAMI. A SEISMIC SEA WAVE OF HIGH VELOCITY AND LONG PERIOD, GENERATED AT SEA BY LARGE SHOCK OR IMPULSE, SUCH AS AN UNDERSEA EARTHQUAKE; ALSO CALLED TIDAL WAVE, ALTHOUGH IT HAS NOTHING TO DO WITH TIDES.

TURBIDITY. THE STATE OR CONDITION OF HAVING THE TRANSPARENCE OR TRANSLUCENCE DISTURBED, AS WHEN SEDIMENT IN WATER IS STIRRED UP, OR WHEN DUST, HAZE, CLOUDS, ETC., APPEAR IN THE ATMOSPHERE BECAUSE OF WIND OR VERTICAL CURRENTS (HUNT AND GROVES, 1965).

ULTRAPLANKTON. PLANKTON ORGANISMS BELOW ABOUT 5 MICRONS (0.005 MM) WHICH ARE NOT RETAINED BY FINE-MESHED PLANKTON NETS OR OBTAINED BY NORMAL CENTRIFUGATION OF WATER SAMPLES (SVERDRUP ET AL., 1942). THEY CAN BE COLLECTED BY SPECIAL ULTRA-CENTRIFUGATION PROCEDURES. (COMPARE.....NANNOPLANKTON, MICROPLANKTON, MACROPLANKTON.)

UPPER SUBTIDAL ZONE. THE SUBTIDAL AREA OF THE NEARSHORE BOTTOM WHICH IS BETWEEN THE LOWEST MEASURED TIDE AND THE BREAKER DEPTH.

UPTAKE. THE COMBINATION OF PROCESSES IN WHICH VARIOUS SUBSTANCES SUCH AS WATER, NUTRIENT IONS, AND DISSOLVED GASES ARE REMOVED FROM LIQUID SUBSTANCES SUCH AS SEA WATER AND SOIL MOISTURE, AND ARE INCORPORATED INTO ORGANISMS. (COMPARE.....FIXATION.)

UPWELLING. THE RISING OF WATER TOWARD THE SURFACE FROM SUBSURFACE LAYERS OF A BODY OF WATER; MOST PROMINENT WHERE PERSISTENT WIND BLOWS PARALLEL TO A COASTLINE SO THAT THE RESULTANT WIND-DRIVEN CURRENT SETS AWAY FROM THE COAST. IT CONSTITUTES A DISTINCT CLIMATOGENETIC INFLUENCE BY BRINGING COLDER WATER TO THE SURFACE WHICH IS RICHER IN PLANT NUTRIENTS, SO THAT REGIONS OF UPWELLING ARE GENERALLY ALSO AREAS OF RICH FISHERIES (HUNT AND GROVES, 1965).

WATER COLUMN. THE SPACE BETWEEN THE SURFACE AND BOTTOM OF A BODY OF WATER, ESPECIALLY A VOLUME HAVING A LIMITED HORIZONTAL EXTENT AROUND AND INCLUDING A SAMPLING STATION OR STUDY AREA.

WATER TABLE. THE UPPER SURFACE OR EXPRESSION OF THE LEVEL OF GROUND WATER IN PERMEABLE ROCK OR SOIL.

WATERSHED UNIT. GROUP OF WATERSHEDS HAVING ROUGH SIMILARITIES WITH RESPECT TO LATITUDE, CLIMATE, GEOLOGIC STRUCTURE, HYDROLOGY, AND EXTENT OF PENETRATION INLAND FROM THE COAST.

WAVE FRONT. AN EXPRESSION WHICH IS APPLIED TO A PROGRESSIVE WAVE IN SPACE AT ANY GIVEN INSTANT, AND IS THE LINE OR SURFACE OVER WHICH THE PHASE IS EVERYWHERE THE SAME AT THE GIVEN INSTANT. ALL POINTS LYING ON THE CREST OF A SURFACE WATER WAVE ARE IN THE SAME PHASE AND MAY DEFINE A WAVE FRONT (HUNT AND GROVES, 1965).

WAVE HEIGHT. THE VERTICAL DISTANCE BETWEEN A WAVE CREST AND THE FOLLOWING WAVE TROUGH. (DIFFERENT THAN THE WAVE AMPLITUDE, WHICH IS THE VERTICAL MEASURE BETWEEN THE WAVE CREST AND STILL WATER LEVEL).

WAVE LENGTH. THE HORIZONTAL DISTANCE BETWEEN SUCCESSIVE OCEAN WAVE CRESTS OR THE DISTANCE TRAVELED BY A WAVE DURING THE TIME INTERVAL OF ONE COMPLETE CYCLE. IT IS EQUAL TO THE VELOCITY DIVIDED BY THE FREQUENCY (HUNT AND GROVES, 1965).

WAVE PERIOD. THE TIME ELAPSED BETWEEN THE PASSAGE OF A GIVEN PHASE ON ONE WAVE AND THE ARRIVAL OF THE SAME PHASE ON THE NEXT SUCCEEDING WAVE, AS OBSERVED FROM A FIXED LOCATION (HUNT AND GROVES, 1965).

WAVE STEEPNESS. THE RATIO OF WAVE HEIGHT TO WAVE LENGTH (HUNT AND GROVES, 1965).

WEATHER. THE STATE OF THE ATMOSPHERE AT A GIVEN TIME AND PLACE, DESCRIBED BY SPECIFICATION OF VARIABLES SUCH AS TEMPERATURE, MOISTURE, WIND, VELOCITY, AND PRESSURE (MORRIS, 1976).

WEATHERING. ANY OF THE CHEMICAL OR MECHANICAL PROCESSES BY WHICH ROCKS EXPOSED TO THE WEATHER ARE BROKEN DOWN INTO SMALLER PARTICLES OR COMPONENT MATERIALS (MORRIS, 1976). (COMPARE.....EROSION.)

WETLAND. (1) LAND WHERE AN EXCESS OF WATER IS THE DOMINANT FACTOR DETERMINING THE NATURE OF SOIL DEVELOPMENT AND THE TYPES OF PLANT AND ANIMAL COMMUNITIES LIVING AT THE SOIL SURFACE (COWARDIN ET AL., 1977). (2) LAND WHERE THE WATER TABLE IS AT, NEAR, OR ABOVE THE LAND SURFACE LONG ENOUGH TO PROMOTE THE FORMATION OF HYDRIC SOILS OR TO SUPPORT THE GROWTH OF HYDROPHYTES (COWARDIN ET AL., 1977).

WRACK. A TANGLED MASS OF SEAWEED OR OTHER MARINE VEGETATION CAST ASHORE OR FLOATING.

XERIC. DRY; PERTAINING TO AN ARID CONDITION, AS IN A XERIC HABITAT SUCH AS A DESERT. (COMPARE.....HYDRIC, MESIC.)

ZONE. (1) AN AREA CHARACTERIZED BY DISTINCT PHYSICAL CONDITIONS AND POPULATED BY COMMUNITIES OF CERTAIN KINDS OF ORGANISMS (MORRIS, 1976). (2) A DISTINCT ASSEMBLAGE OF ORGANISMS, ENVIRONMENTAL CONDITIONS, AND ECOLOGICAL PROCESSES COMPOSED OF RELATED HABITATS (OFTEN BY SUCCESSION).

ZONE OF COMPATIBILITY. THE MIDDLE SECTOR BETWEEN ENVIRONMENTAL EXTREMES FOR A GIVEN FACTOR AND A GIVEN ORGANISM.

ZOOPLANKTON. AQUATIC ANIMALS OR PROTISTS WHICH CANNOT ACTIVELY SWIM AGAINST THE CURRENT AND WHICH CANNOT MAKE THEIR OWN FOOD BY PHOTOSYNTHESIS; INCLUDES MANY LARVAL FORMS OF OTHERWISE NON-PLANKTONIC ORGANISMS. (COMPARE.....PHYTOPLANKTON; SEE.....PLANKTON.)

LIST OF MEASUREMENT ABBREVIATIONS AND SYMBOLS

The following symbols and abbreviations appear in the Ecological Characterization documents for measurements, units, or regulating factors. Short forms for many of these items (e.g. ft for feet, m for meter) are symbols, not abbreviations, and are not followed by a period. Exponents (2 and 3) are frequently used with linear measurement units to indicate areas and volumes, e.g. in^2 = square inch or sq in, m^3 = cubic meter.

A. MEASUREMENT UNITS AND SYMBOLS:

a = acre (area)
a ft = acre foot (volume)
atm = atmosphere (pressure)
b = bar (pressure)
BOD = biological oxygen demand
C = Celsius (temperature)
cc = cubic centimeter (volume)
cm = centimeter (length)
dbh = diameter at breast height (length)
DO = dissolved oxygen
F = Farenheit (temperature)
f = fathom (length)
ft = foot (length)
g = gram (weight)
gal = gallon (volume)
ha = hectare (area)
hr = hour (time)
hz = hertz (periodicity)
in = inch (length)
JTU = Jackson turbidity unit
k = Kelvin (temperature)
kg = kilogram (length)
km = kilometer (length)
kt = knot (velocity)
kph = kilometer per hour (velocity)
l = liter (volume)
lb = pound (weight)
ly = langley (energy)
M = mole (concentration)
m = meter (length)
mb = millibar (pressure)
mbf = million board feet (timber volume)
mgd = million gallons per day (flow)
mi = statute mile (length)
min = minute (time)
ml = milliliter (volume)
mm = millimeter (length)
mph = mile per hour (velocity)
nm = nautical mile (length)
oz = ounce (volume or weight)
ppm = parts per million (concentration)
pt = pint (volume)
qt = quart (volume)
sec = second (time)
t = ton, long, short, or metric (weight)
T = temperature
Ta = air temperature
Tw = water temperature
yd = yard (length)
% = percent (parts per hundred)
o/oo = permille (parts per thousand)
μ- = micro- (fraction = 10^{-6})
m- = milli- (fraction = 10^{-3})
c- = centi- (fraction = 10^{-2})
d- = deci- (fraction = 10^{-1})

B. SECONDARY REGULATING FACTORS IN MODELS:

ACC = access
A/D = area to depth ratio
BATH = bathymetry
CAPIL = capillary action
CHCAP = channel capacity
CLIM = climate
COND = condensation
CUR = current velocity
DIKE = diking
DIS = discharge
DREDG = dredging
DRIFT = littoral drift
EFTR = effluent treatment
EROD = erodability (chemical and structural make-up of rock)
FWIN = fresh water in
GEO = geology
GMAN = game management
GRAD = gradient
HEAD = hydraulic head
INSOL = insolation
MIX = mixing
NUTS = nutrients
PERM = permeability
PERT = perturbations (fire, vegetation removal, etc.)
PHOT = photosynthesis
POROS = porosity of soil or rock
PRECIP = precipitation
PROD = net productivity
REG = regulation
RO = runoff
SAL = salinity
SEN = annual senescence
SIZE = particle size and density
SOC = socioeconomic decision
STR = man made structures
SUCC = natural succession
T = temperature
Ta = air temperature
TIDE = tides (energy, cycle, etc.)
TOPO = topography
TOX = toxins (man made pollutants)
TURB = turbulence
Tw = water temperature
VEG = vegetation
VEGAN = vegetative anchoring
WIND = wind (speed, direction)
WAVE = wave (energy, direction)
? = not well known

ENGLISH-METRIC MEASUREMENT UNIT CONVERSIONS

Many, perhaps most, of the measurements used in this series of volumes of the Ecological Characterization are approximations or typical values. For example the depth at the edge of the Continental Shelf in the Pacific Northwest is variously given as 100 fathoms, 200 meters, or 600 feet. Obviously 600 feet is exactly 182.88 meters but, since 100 fathoms (600 feet) is an approximation of the shelf depth, the nearest round metric number will be an equally good approximation. Therefore 200 meters is equivalent to 600 feet or 100 fathoms in this instance. Similarly, a 300 foot Douglas fir tree is 90 meters tall, not 91.44 meters tall!

We have tried to make all conversions consistent with the observed or implied accuracy of the original data. Some conversions are carried to several significant figures. Mt. Olympus, for example, is 7,965 feet high; the metric equivalent is 2,427.7 meters, but the heights of peaks in the Olympic and Cascade mountain ranges are only given to the nearest foot on the U.S.G.S. maps. This degree of precision is indicated by the first metric conversion using only one decimal place. Greater precision in the measurement of elevations in this region is not warranted for most purposes nor is greater precision in the conversion justified due to the degree of accuracy of the U.S.G.S. measurement.

The units (metric or English) used by the author in the source of the data are reported first in the text, figures, and tables throughout the Ecological Characterization volumes, followed by the equivalent in parentheses. Both units are given. The result is often a mixture of primary (non-parenthetical) units in a discussion or table, but the reader is thus aware of which units are the original data and which are the conversions.

The following are some basic conversions used in this report.

LENGTH

1 cm (centimeter)	=	0.3937 in (inch)				
0.3048 m (meter)	=	12 in	=	1 ft (foot)		
1 m	=	39.37 in	=	3.28 ft	=	0.547 f (fathom)
1.83 m	=	72 in	=	6 ft	=	1 f
1 km (kilometer)			=	3,280 ft	=	0.621 mi (mile)
1.609 km			=	5,280 ft	=	1 mi
1.852 km			=	6,076 ft	=	1 nm (nautical mile)

AREA

1 cm^2			=	0.155 in^2		
6.45 cm^2			=	1 in^2		
930 cm^2	=	0.093 m^2	=	1 ft^2		
10^4 cm^2	=	1 m^2	=	10.76 ft^2	=	1.196 yd^2
4047 m^2	=	0.405 ha (hectare)	=	1 a (acre)	=	4,840 yd^2
10^4 m^2	=	1 ha	=	2.47 a	=	11,960 yd^2
1 km^2	=	100 ha	=	247 a	=	0.386 mi^2
2.59 km^2	=	259 ha	=	540 a	=	1 mi^2

MASS

1 g (gram)	=	0.035 oz (ounce)		
28.3 g	=	1 oz		
0.454 kg (kilogram)	=	1 lb (pound)		
1 kg	=	2.2 lb		
0.907 t (metric tonne)	=	1 t (short ton)	=	0.905 t (long ton)
1 t	=	1.102 t	=	0.984 t
1.016 t	=	1.12 t	=	1 t

TEMPERATURE

0^oK (Kelvin)	=	-273.2^oC (Celsius)	=	-459.7^oF (Farenheit)
255.4^oK	=	-17.78^oC	=	0^oF
273.2^oK	=	0^oC	=	32^oF
293.2^oK	=	20^oC	=	68^oF
310.2^oK	=	37^oC	=	98.6^oF
323.2^oK	=	50^oC	=	122^oF
373.2^oK	=	100^oC	=	212^oF

$^oC = 0.55\ (^oF-32)$ $\qquad$ $^oF = 1.8(^oC) + 32$

VOLUME

1 cm^3 (or cc)	=	1 ml (milliliter)	=	0.0338 oz (ounce)		
		29.6 ml	=	1 oz		
		0.946 l (liter)	=	1 qt (quart)		
0.001 m^3	=	1 l	=	1.057 qt	=	0.264 gal (gallon)
		3.79 l	=	4 qt	=	1 gal
0.0283 m^3			=	1 ft^3	=	7.48 gal
0.765 m^3	=	765 l	=	1 yd^3	=	202 gal
1 m^3	=	999.973 l	=	1.308 yd^3	=	264 gal
1234 m^3			=	1 a ft (acre foot)	=	324,851 gal
1 km^3	=	$10^9 m^3$	=	8.1×10^4 a ft	=	0.0237 mi^3
42.2 km^3			=	3.42×10^6 a ft	=	1 mi^3

ATMOSPHERIC PRESSURE

27 in	=	686 mm	=	914 mb (millibar)				
28 in	=	711 mm	=	948 mb				
29 in	=	737 mm	=	982 mb				
29.54 in	=	750 mm	=	1000 mb	=	1 bar		
29.92 in	=	760 mm	=	1013.2 mb	=	1 atm (standard atmosphere)		
31 in	=	787 mm	=	1050 mb				
32 in	=	813 mm	=	1084 mb				
32.8 ft	=	10.0 m (sea water)			=	1 atm		
33.9 ft	=	10.3 m (fresh water)			=	1 atm	=	14.7 lb/in^2

(in and mm both refer to the height of a mercury barometer and are, therefore, in-Hg and mm-Hg respectively. Ft and m refer to the height of a water column.)

VELOCITY

1 cm/min			=	0.033 ft/min	=	1 furlong/fortnight		
0.51 cm/sec			=	1 ft/min	=	0.011 mph (mile/hour)		
1 cm/sec			=	1.97 ft/min	=	0.022 mph		
0.28 m/sec	=	1 kph (kilometer/hour)	=	55 ft/min	=	0.62 mph	=	0.54 kt (knot, nm/hr)
0.48 m/sec	=	1.6 kph	=	88 ft/min	=	1 mph	=	0.87 kt
0.51 m/sec	=	1.85 kph	=	101 ft/min	=	1.15 mph	=	1 kt
1 m/sec	=	3.6 kph			=	2.24 mph	=	1.94 kt

FLOW

0.063 l/sec	=	0.000063 m^3/sec	=	0.0022 ft^3/sec	=	1 gpm (gallons per minute)
1.0 l/sec	=	0.001 m^3/sec	=	0.0353 ft^3/sec	=	15.85 gpm
28.32 l/sec	=	0.0283 m^3/sec	=	1.0 ft^3/sec	=	450 gpm
43.8 l/sec	=	0.0438 m^3/sec	=	1.55 ft^3sec	=	1 mgd (million gal per day)
1000 l/sec	=	1.0 m^3/sec	=	35.314 ft^3/sec	=	15,850 gpm
		20.6 m^3/sec	=	1 acre ft/min	=	325,851 gpm

DENSITY OF SPECIFIC SUBSTANCES

(From Lange, 1956, except as noted)

Carbohydrates, (cellulose, starch, sugar)	=	1.47-1.61 g/cc	=	92-100 lb/ft^3		
Fats and oils	=	0.90-0.97	=	56-60		
Protein (silk)	=	1.56	=	97.2		
Tar	=	1.02	=	63.6		
Basalt	=	2.7-3.2	=	168-200		
Clay	=	1.8-2.6	=	112-162		
Concrete	=	1.8-2.45	=	112-145		
Gravel	=	1.8-2.0	=	112-125		
Granite	=	2.51-3.05	=	156-190		
Ice, pure	=	0.917	=	57.1 (Sverdrup et al., 1942)		
Ice, sea	=	0.86-0.92	=	54-57 (Sverdrup et al., 1942)		
Limestone	=	2.46-2.84	=	153-177		
Sand, coarse, dry	=	1.4-1.5	=	87-94		
Sand, fine, dry	=	1.40-1.56	=	87-103		
Sand, fine, moist	=	1.90-2.05	=	118-128		
Sandstone	=	2.2-2.5	=	137-156		
Soil, loamy, dry	=	1.6-1.9	=	100-118		
Soil, loamy, pressed	=	2.0	=	125		
Snow, loose	=	0.125	=	7.8		
Water, fresh	=	1.00	=	62.3	=	1.042 lb/pt
Water, normal sea	=	1.0026	=	62.5	=	1.039

MISCELLANEOUS UNITS DEFINED

LIGHT:

Langley (LY) = 1 g cal/cm^2 = unit of irradiance energy

Foot candle = 1 lumen/ft^2
Lux = 1 lumen/m^3 = unit of illumination (visible spectrum only)

(Note: although not readily convertible because of brightness variations, 1 langley per minute of sunlight x 6700 gives approximate illumination in foot candles (E.P. Odum, 1971).)

TURBIDITY:

Jackson Turbidity Unit (JTU) = measure of turbidity referenced to amount of light scattered by 1 milligram of silicon dioxide dissolved in 1 liter of water, which is defined as 1 JTU.

CHEMICAL CONCENTRATIONS:

Mole (M) = 1 gram atoms/liter (g-at/l) = concentration of 1 gram atomic weight of element or compound per liter; often used in micro (μ-) or milli (m-) fractions.

Equivalent (eq) = the quantity of a chemical substance that could hypothetically react with, or take the place of, one gram-atomic weight of hydrogen ion. Thus, the equivalent weight of hydrogen is 1.008 grams, of oxygen is 8 grams, and of sodium chloride (NaCl) is 58.45 grams.

Part(s) per million (ppm) = part or parts (individuals, units of mass or volume) of solute substance in million parts (individuals, units of mass or volume) of total solute-solvent solution, as of chemicals in air (gas) or water (liquid) or soil (solid).

$\mu g/m^3$ (microgram(s) per cubic meter) = mass of solute (in micrograms) per unit (cubic meter) volume of solution, as of chemicals in air, etc.

(Note: for sulfur dioxide in air, at N.T.P. (0^oC and 1 bar), 1 ppm = 2860 $\mu g/m^3$; at 20^oC, 1 ppm(SO_2) = 2660 $\mu g/m^3$ (Ferry et al., 1973).)

LIST OF REFERENCES

The following list of cited references has been prepared using the Annotated Bibliography system developed for this study based on the FAMULUS program of the U.S. Forest Service. This open-ended program allows for multiple searching by authors, dates, key words, etc., and enables printing of reference lists by volume or Watershed Unit as cited.

Multiple authors are listed uniformly, i.e. initials (for given names) following the surname in all cases. This is a departure from the Council of Biological Editors and the FWS style manuals, but facilitates computer searching and printing of author lists, provides uniformity of name listing, and makes for easier editing.

This list of references cited in Volume 2 contains only the author, date, title, and publication fields for each reference. The descriptor (key word), annotation, location, and other fields of the full entry have been suppressed for this printout.

See Part 1 of Volume 5, the Data Source Appendix, for more information on the Annotated Bibliography.

ACOE--SEE.....U.S. ARMY CORPS OF ENGINEERS.

ADAMS, J.R. 1975. THE INFLUENCE OF THERMAL DISCHARGES ON THE DISTRIBUTION OF MACROFLORA AND FAUNA AT HUMBOLDT BAY NUCLEAR POWER PLANT, CALIFORNIA. PH.D. THESIS. UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 364 PP.

AHLGREN, C.E. 1966. SMALL MAMMALS AND REFORESTATION FOLLOWING PRESCRIBED BURNING. J. FORESTRY 64:614-618.

AHO, P.E., SEIDLER, R.J., EVANS, H.J., AND NELSON, A.D. 1976. ASSOCIATION OF NITROGEN-FIXING BACTERIA WITH DECAY IN WHITE FIR. IN: PROCEEDINGS OF THE FIRST INTERNATIONAL SYMPOSIUM ON NITROGEN FIXATION (NEWTON, W.E., AND NYMAN, C.J., EDS.), PP. 629-636. WASHINGTON STATE UNIVERSITY PRESS, PULLMAN, WASHINGTON.

AKERS, E., AND HANSEN, R. 1973. MATURE DOUGLAS-FIR FOREST. AUDUBON FIELD-NOTES 27:1001.

AKINS, G.J., AND JEFFERSON, C.A. 1973. COASTAL WETLANDS OF OREGON. OREGON COASTAL CONSERVATION AND DEVELOPMENT COMMISSION, FLORENCE, OREGON. 190 PP.

ALBRECHT, W.A. 1941. SOIL ORGANIC MATTER AND IONIC AVAILABILITY FOR PLANTS. SOIL SCIENCE 51:487-494.

ALBRECHT, W.A. 1971. PHYSICAL, CHEMICAL AND BIOLOGICAL CHANGES IN THE SOIL COMMUNITY. IN: MANS IMPACT ON ENVIRONMENT (DETWYLER, T.R., ED.), PP. 395-418. MCGRAW-HILL BOOK CO., NEW YORK.

ALBRIGHT, R., AND RAMMER, A.D. 1976. THE EFFECT OF INTERTIDAL DREDGED MATERIAL DISPOSAL ON BENTHIC INVERTEBRATES IN GRAYS HARBOR, WASHINGTON. IN: MAINTENANCE DREDGING AND THE ENVIRONMENT OF GRAYS HARBOR, WASHINGTON (ACOE, 1976-1977), APPENDIX E, 244 PP. U.S. ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT.

ALCORN, G.D. 1972. BIBLIOGRAPHY. BIRDS OF THE STATE OF WASHINGTON. OCCASIONAL PAPERS, NO. 44, PP. 538-630, UNIVERSITY OF PUGET SOUND, TACOMA, WASHINGTON.

ALDRICH, J.W. 1970. REVIEW OF THE PROBLEM OF BIRDS CONTAMINATED BY OIL AND THEIR REHABILITATION. U.S. DEPARTMENT OF THE INTERIOR BUREAU OF SPORT FISHERIES AND WILDLIFE, RESOURCE PUBLICATION NO. 37. WASHINGTON, D.C. 10 PP.

ALLEE, W.C. 1923. STUDIES IN MARINE ECOLOGY: I. THE DISTRIBUTION OF COMMON LITTORAL INVERTEBRATES OF THE WOODS HOLE REGION. BIOL. BULL. 44(4):167-191.

ALLEE, W.C. 1934. CONCERNING THE ORGANIZATION OF MARINE COASTAL COMMUNITIES. ECOL. MONOGR. 14(4):541-554.

ALVERSON, D.L. 1972. BIOENVIRONMENTAL FEATURES: AN OVERVIEW. IN: THE COLUMBIA RIVER ESTUARY AND ADJACENT OCEAN WATERS: BIOENVIRONMENTAL STUDIES (PRUTER, A.T., AND ALVERSON, D.L., EDS.), PP. 845-857. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON.

ALVERSON, D.L., PRUTER, A.T., AND RONHOLT, L.L. 1964. A STUDY OF DEMERSAL FISHES AND FISHERIES OF THE NORTHEASTERN PACIFIC OCEAN. INSTITUTE OF FISHERIES, UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, B.C. 190 PP.

ANDERSEN, H.E. 1956. CLEARCUTTING AS A SILVICULTURAL SYSTEM IN CONVERTING OLD FORESTS TO NEW IN SOUTHEAST ALASKA. PROC. SOC. AMER. FORESTERS 1955:171-172.

ANDERSON, G.C. 1964. THE SEASONAL AND GEOGRAPHIC DISTRIBUTION OF PRIMARY PRODUCTIVITY OFF THE WASHINGTON AND OREGON COASTS. LIMNOL. OCEANOG. 9:284-302.

ANDERSON, G.C. 1972. ASPECTS OF MARINE PHYTOPLANKTON STUDIES NEAR THE COLUMBIA RIVER, WITH SPECIAL REFERENCE TO A SUBSURFACE CHLOROPHYLL MAXIMUM,, IN: THE COLUMBIA RIVER ESTUARY AND ADJACENT OCEAN WATERS, BIOENVIRONMENTAL STUDIES (PRUTER, A.T., AND ALVERSON, D.L., EDS.), PP. 219-240. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON. 868 PP.

ANDERSON, H.W. 1972. EVALUATING SEDIMENTATION AND STREAMFLOW TURBIDITY HAZARDS IN WILDLAND USE. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE. PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, BERKELEY, CALIFORNIA. 45 PP.

ANDERSON, S.H. 1970. ECOLOGICAL RELATIONSHIPS OF BIRDS IN FORESTS OF WESTERN OREGON. PH.D. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 124 PP.

ANDERSON, S.H. 1972. SEASONAL VARIATIONS IN FOREST BIRDS OF WESTERN OREGON. NORTHWEST SCIENCE 46:194-206.

ANDREWS, R.S. 1965. MODERN SEDIMENTS OF WILLAPA BAY, WASHINGTON. A COASTAL PLAIN ESTUARY. UNIVERSITY OF WASHINGTON DEPARTMENT OF OCEANOGRAPHY TECHNICAL REPORT NO. 118. REFERENCE M65-8, 43 PP.

ANON. 1977. THE MISSING LINK - LITTLE MAMMALS BOOST LITTLE TREES. PACIFIC SEARCH 11(7):23(ONLY).

ARASAKI, M. 1950A. THE ECOLOGY OF AMAMO (ZOSTERA MARINA) AND KOAMAMO (ZOSTERA NANA). BULL. JAP. SOC. SCI. FISH. 15(10):567-572.

ARASAKI, M. 1950B. STUDIES ON THE ECOLOGY OF ZOSTERA MARINA AND ZOSTERA NANA, II. BULL. JAP. SOC. SCI. FISH. 16:70-76.

ARNO, S.F., AND HAMMERLY, R.P. 1977. NORTHWEST TREES. THE MOUNTAINEERS, SEATTLE, WASHINGTON. 222 PP.

AVOLIO, G.W. 1973. GRANULOMETRIC ANALYSIS OF RECENT SEDIMENTS OF TILLAMOOK BAY, OREGON. M.S. THESIS. DEPARTMENT OF EARTH SCIENCES, PORTLAND STATE UNIVERSITY, PORTLAND, OREGON. 67 PP.

BAAS-BECKING, L.G.M., AND WOOD, E.J.F. 1955. BIOLOGICAL PROCESSES IN THE ESTUARINE ENVIRONMENT: I. AND II. ECOLOGY OF THE SULFUR CYCLE. ACAD. SCI. AMST. B. PROC. 58:160-181.

BACKMAN, T.W., AND BARILOTTI, D.C. 1976. IRRADIANCE REDUCTION: EFFECTS ON STANDING CROPS OF THE EELGRASS, ZOSTERA MARINA, IN A COASTAL LAGOON. MAR. BIOL. (BERLIN) 34:33-40.

BAERG, H.J. 1973. HOW TO KNOW THE WESTERN TREES. 2ND ED., WM. C. BROWN COMPANY, DUBUQUE, IOWA. 174 PP.

BAILY, V. 1936. MAMMALS OF FISH ZONES OF OREGON. U.S. DEPARTMENT OF AGRICULTURE, BUR. BIOL. SURV., NORTH AMERICAN FAUNA NO. 55. 416 PP.

BAKER, F.S. 1949. A REVISED TOLERANCE TABLE. J. FORESTRY 47:179-181.

BALANDREAU, J.P., RINAUDO, G., AND DUMAROU, M.M. 1976. ASYMBIOTIC N2 FIXATION IN PADDY SOILS. IN: PROCEEDINGS OF THE FIRST INTERNATIONAL SYMPOSIUM ON NITROGEN FIXATION (NEWTON, W.E., AND NYMAN, C.F., EDS.), VOL. 2, PP. 611-622. WASHINGTON STATE UNIVERSITY PRESS, PULLMAN, WASHINGTON.

BALDA, R.P. 1975. VEGETATION STRUCTURE AND BREEDING BIRD DIVERSITY. U.S. DEPARTMENT OF AGRICULTURE, GENERAL TECHNICAL REPORT WO-1 (SMITH, R.D., ED.). PP. 959-980. PRESENTED AT THE SYMPOSIUM ON MANAGEMENT OF FOREST AND RANGE HABITATS, TUCSON, ARIZONA, MAY, 1975.

BALDWIN, M., KELLOGG, C.E., AND THORP, J. 1938. SOIL CLASSIFICATION. U.S. DEPARTMENT OF AGRICULTURE YEARBOOK 1938, PP. 919-1001, USDA, WASHINGTON, D.C.

BALLARD, R.L. 1964. DISTRIBUTION OF BEACH SEDIMENT NEAR THE COLUMBIA RIVER. TECHNICAL REPORT NO. 98. DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 82 PP.

BARBE, D., AND SNOW, G.F. N.D. AGRICULTURE IN THE COASTAL ZONE. CALIFORNIA STATE DEPARTMENT OF NAVIGATION AND OCEAN DELOPMNT, SACRAMENTO, CALIFORNIA. 299 PP.

BARBOUR, M.G., AND MAJOR, J. 1977. TERRESTRIAL VEGETATION OF CALIFORNIA. WILEY AND SONS, NEW YORK.

BARNES, C.A., DUXBURY, A.C., AND MORSE, B. A. 1972. CIRCULATION AND SELECTED PROPERTIES OF THE COLUMBIA RIVER EFFLUENT AT SEA. IN: THE COLUMBIA RIVER ESTUARY AND ADJACENT OCEAN WATERS, BIOENVIRONMENTAL STUDIES (PRUTER, A.T., AND ALVERSON, D.L., EDS.), PP. 41-80, UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON.

BARNES, G.H. 1962. YIELD OF EVEN-AGED STANDS OF WESTERN HEMLOCK. U.S. DEPARTMENT OF AGRICULTURE TECHNICAL BULLETIN 1273. 52 PP.

BARSS, W.H., DEMORY, R.L., AND TEN EYCK, N. 1977. MARINE RESOURCE SURVEYS ON THE CONTINENTAL SHELF AND UPPER SLOPE OFF WASHINGTON, 1975-76. NATIONAL MARINE FISHERIES SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE, WASHINGTON, D.C. 34 PP.

BASCOM, W. 1964. WAVES AND BEACHES, THE DYNAMICS OF THE OCEAN SURFACE. ANCHOR BOOKS, DOUBLEDAY AND COMPANY, INC., GARDEN CITY, NEW YORK. 267 PP.

BASCOM, W.N., AND MCADAM, D. 1947. BEACH AND SURF CONDITIONS ON THE BEACHES OF THE OREGON AND WASHINGTON COASTS BETWEEN OCTOBER 9, 1946 AND NOVEMBER 18, 1946. UNIVERSITY OF CALIFORNIA, BERKELEY, DEPARTMENT OF ENGINEERING TECHNICAL MEMORANDUM HE-116-247, APRIL 16, 1947 (WATER RESOURCES CENTER ARCHIVES).

BASSETT, P.M. 1977. TIMBER RESOURCES OF SOUTHWEST OREGON. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE BULLETIN, PNW-72. PACIFIC NORTHWEST RANGE AND EXPERIMENT STATION, PORTLAND, OREGON. 29 PP.

BASSETT, P.M., AND CHOATE, G.A. 1974A. TIMBER RESOURCE STATISTICS FOR OREGON, JANUARY 1, 1973. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE BULLETIN PNW-56. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 32 PP.

BASSETT, P.M., AND CHOATE, G.A. 1974B. TIMBER RESOURCE STATISTICS FOR WASHINGTON, JANUARY 1, 1973. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE BULLETIN PNW-53. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON.

BATTELLE PACIFIC NORTHWEST LABORATORIES. 1973. AN INVENTORY AND EVALUATION OF AREAS OF ENVIRONMENTAL CONCERN IN OREGON FOR THE STATE OF OREGON EXECUTIVE DEPARTMENT AND NATURAL RESOURCE AGENCIES. BATTELLE PACIFIC NORTHWEST LABORATORIES, RICHLAND, WASHINGTON. 104 PP.

BATTELLE--SEE.....BATTELLE PACIFIC NORTHWEST LABORATORIES.

BAUER, W. 1974A. THE SHORE-PROCESS CORRIDOR. ITS ANATOMY, FUNCTION, AND BASIS FOR SHORELAND PLANNING AND MANAGEMENT. FOR OREGON COASTAL CONSERVATION AND DEVELOPMENT COMMISSION, PORTLAND, OREGON. 34 PP.

BAUER, W. 1975. ESTUARINE PHYSIOGRAPHY. UNPUBLISHED MANUSCRIPT.

BCDLS--SEE.....BRITISH COLUMBIA DEPARTMENTS OF LAND AND FORESTS.

BEAK CONSULTANTS, INC. 1975. OIL POLLUTION AND THE SIGNIFICANT BIOLOGICAL RESOURCES OF PUGET SOUND: A REVIEW AND ANALYSIS OF AVAILABLE INFORMATION. VOL. 1. TEXT, 216 PP., VOL. 2, BIBLIOGRAPHY, 468 PP. STATE OF WASHINGTON, DEPT. OF ECOLOGY, BASELINE STUDY PROGRAM, NORTH PUGET SOUND (PREPARED BY BEAK CONSULTANTS, PORTLAND, OREGON).

BEAULIEU, J.D., AND HUGHES, P.W. 1975. ENVIRONMENTAL GEOLOGY OF WESTERN COOS AND DOUGLAS COUNTIES, OREGON. OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES BULL. 87, PORTLAND, OREGON. 148 PAGES.

BELL, E.F. 1977. ESTIMATING EFFECT OF TIMBER HARVESTING LEVELS ON EMPLOYMENT IN WESTERN U.S. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESEARCH NOTE INT-237. INTERMOUNTAIN AND RANGE EXPERIMENT STATION, OGDEN, UTAH. 11 PP.

BELLA, D.A., RAMM, A.E., AND PETERSON, P.E. 1972. EFFECT OF TIDAL FLATS ON ESTUARINE WATER QUALITY. J. WATER POLLUTION CONTROL FEDERATION. 44(4):541-556.

BELLA, D.A., AND WILLIAMSON, K.J. 1977. THE SULFUR CYCLE IN ESTUARINE BENTHIC DEPOSITS. IN: ENVIRONMENTAL IMPACTS OF DREDGING IN ESTUARIES, SECTION VA, PP. 337-368. DEO, OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

BENT, A.C. 1919-1968. LIFE HISTORIES OF NORTH AMERICAN BIRDS. U.S. NATIONAL MUSEUM BULLETIN NOS. 107, 113, 121, 126, 130, 135, 142, 146, 162, 167, 170, 174, 191, 195, 196, 197, 203, 211, 237, SMITHSONIAN INSTITUTE. WASHINGTON, D.C.

BERGVALL, J.A., BULLINGTON, D.C., AND GEE, L. 1977. 1976 WASHINGTON MILL SURVEY, WOOD CONSUMPTION AND MILL CHARACTERISTICS. WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES, WASHINGTON MILL SURVEY SERIES REPORT NO. 5, OLYMPIA, WASHINGTON. 135 PP.

BERNTSEN, C.M. 1961. GROWTH DEVELOPMENT OF RED ALDER COMPARED WITH CONIFERS IN 30-YEAR-OLD STAND. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION RESEARCH PAPER NO. 38. PORTLAND, OREGON. 20 PP.

BEUTER, J.H., JOHNSON, K.N., AND SCHEURMAN, H.L. 1976. TIMBER FOR OREGONS TOMORROW, AN ANALYSIS OF REASONABLY POSSIBLE OCCURRENCES. FOREST RESEARCH LABORATORY, SCHOOL OF FORESTRY, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 111 PP.

BIEBL, R., AND MC ROY, C.P. 1971. PLASMATIC RESISTANCE AND RATE OF RESPIRATION AND PHOTOSYNTHESIS OF ZOSTERA MARINA AT DIFFERENT SALINITIES AND TEMPERATURE. MAR. BIOL. 8(1):48-56.

BLACK, H.C. 1974. WILDLIFE AND FOREST MANAGEMENT IN THE PACIFIC NORTHWEST. PROCEEDINGS OF A SYMPOSIUM HELD SEPT. 1-12, 1973. FOREST RESOURCES LABORATORY, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 236 PP.

BLACK, H.C., AND HOOVEN, E.H. 1974. RESPONSE OF SMALL-MAMMAL COMMUNITIES TO HABITAT CHANGES IN WESTERN OREGON. IN: WILDLIFE AND FOREST MANAGEMENT IN THE PACIFIC NORTHWEST (BLACK, H.C., ED.), PP. 177 ET SEQ. OREGON STATE UNIVERSITY SCHOOL OF FORESTRY, CORVALLIS, OREGON.

BLOOM, A.L. 1969. THE SURFACE OF THE EARTH. FOUNDATIONS OF EARTH SCIENCE SERIES, PRENTICE-HALL, INC., ENGLEWOOD CLIFFS, NEW JERSEY. 152 PP.

BOE, K.N. 1960. RESEARCH AT THE REDWOOD EXPERIMENTAL FOREST. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, BERKELEY, CALIFORNIA. 12 PP.

BOE, K.N. 1961. REDWOOD SEED DISPERSION IN OLD-GROWTH CUT-OVERS. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RES. NOTE 177. SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, BERKELEY, CALIFORNIA. 7 PP.

BOE, K.N. 1963. TRACTOR-LOGGING COSTS AND PRODUCTION IN OLD GROWTH REDWOOD. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESEARCH PAPER PSW-8. PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, BERKELEY, CALIFORNIA. 16 PP.

BOGGS, S., JR., AND JONES, C.A. 1976. SEASONAL REVERSAL OF FLOOD-TIDE DOMINANT SEDIMENT TRANSPORT IN A SMALL OREGON ESTUARY. GEOL. SOC. AMER. 87:419-426.

BOLSINGER, C.L. 1973. CHANGES IN COMMERCIAL FOREST AREA IN OREGON AND WASHINGTON, 1945-70. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE BULLETIN PNW-46. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 16 PP.

BOLT, B.A., LOMNITZ, C., AND MCEVILLY, T.V. 1968. SEISMOLOGICAL EVIDENCE ON THE TECTONICS OF CENTRAL AND NORTHERN CALIFORNIA AND THE MENDOCINO ESCARPMENT. SEISMOLOGICAL SOCIETY OF AMERICA BULLETIN. VOL. 58, PP. 1725-1767.

BORROR, D.J., DE LONG, D.M., AND TRIPPLEHORN, C. 1976. AN INTRODUCTION TO THE STUDY OF INSECTS. 4TH ED. HOLT, RINEHART AND WINSTON, NEW YORK.

BOURKE, R.H., GLENNE, B., AND ADAMS, B.W. 1971. THE NEARSHORE PHYSICAL OCEANOGRAPHIC ENVIRONMENT OF THE PACIFIC NORTHWEST COAST. DEPARTMENT OF OCEANOGRAPHY, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 127 PP.

BOYSEN-JENSEN, P. 1914. STUDIES CONCERNING THE ORGANIC MATTER OF THE SEA BOTTOM. REP. DANISH BIOL. STA. 22:1-39.

BRADLY, W. 1977. PERSONAL COMMUNICATION.

BRAY, J.R. 1964. PRIMARY CONSUMPTION IN THREE FOREST CANOPIES. ECOLOGY 45:165-167.

BRITISH COLUMBIA DEPARTMENTS OF LAND AND FORESTS. 1957. CONTINUOUS FOREST INVENTORY OF BRITISH COLUMBIA. BRITISH COLUMBIA DEPARTMENT OF LANDS AND FORESTS, VANCOUVER, BRITISH COLUMBIA. 223 PP.

BRITTELL, J.D., BROWN, J.M., AND EATON, R.L. 1976. MARINE SHORELINE FAUNA OF WASHINGTON, VOL. II. WASHINGTON STATE DEPARTMENTS OF GAME AND ECOLOGY, OLYMPIA, WASHINGTON. 341 PP.

BROEKHUYSEN, G.J. 1935. THE EXTREMES IN PERCENTAGES OF DISSOLVED OXYGEN TO WHICH THE FAUNA OF A ZOSTERA FIELD IN THE TIDE ZONE AT NIEUWEDIEP CAN BE EXPOSED. ARCH. NEERL. ZOOL. 1(3):339-346.

BROIDA, T.R., LARMAR, E.L., LESLIE, J.D., MULCAUGHEY, T., AND WILLIAMS, H.W. 1975. DEL NORTE COUNTY ECONOMIC DEVELOPMENT ACTION PLAN. WINZLER AND KELLEY CONSULTING ENGINEERS, EUREKA, CALIFORNIA, FOR THE TRIAGENCY ECONOMIC DEVELOPMENT AUTHORITY, CRESCENT CITY, CALIFORNIA. 80 PP.

BROWN, D. 1977. OREGON WILDERNESS HANDBOOK. B.A. THESIS (INDEPENDENT STUDY). UNIVERSITY OF OREGON, EUGENE, OREGON. 140 PP.

BROWN, E.R. 1961. THE BLACK-TAILED DEER OF WESTERN WASHINGTON. WASHINGTON STATE GAME DEPARTMENT, OLYMPIA, WASHINGTON. 124 PP.

BROWN, G.W. 1970. WATER TEMPERATURE IN SMALL STREAMS AS INFLUENCED BY ENVIRONMENTAL FACTORS AND LOGGING. IN: PROCEEDINGS OF A SYMPOSIUM ON FOREST LAND USES AND STREAM ENVIRONMENT, OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

BROWN, G.W., AND KRYGIEIR, J.T. 1970. EFFECT OF CLEARCUTTING ON STREAM TEMPERATURE. WATER RESOURCES RES. 6:1113-1139.

BROWN, G.W., GAHLER, A., AND MARSTON, R. 1973. NUTRIENT LOSSES AFTER CLEARCUT LOGGING AND SLASH BURNING IN THE OREGON COAST RANGE. WATER RESOURCES RES. 9(5):1450-1453.

BROWN, G.W., SWANK, G.W., AND ROTHACHER, J. 1971. WATER TEMPERATURE IN THE STEAMBOAT DRAINAGE. U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE RES. PAPER PNW-119. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 17 PP.

BROWNE, J.H. 1914. THE REDWOOD OF CALIFORNIA. AMER. FORESTRY 20(11):795-802.

BROWNELL, R.L. JR. 1971. WHALES, DOLPHINS AND OIL POLLUTION. IN: BIOLOGICAL AND OCEANOGRAPHICAL SURVEY OF THE SANTA BARBARA CHANNEL OIL SPILL, 1969-1970, VOLUME I. BIOLOGY AND BACTERIOLOGY (STRAUGHEN, D, ED.), PP. 255-276. ALLAN HANCOCK FOUNDATION, UNIVERSITY OF SOUTHERN CALIFORNIA, LOS ANGELES, CALIFORNIA.

BROWNELL, R.L., JR., AND LEBOEUF, B.J. 1971. CALIFORNIA SEA LION MORTALITY: NATURAL OR ARTIFACT (QUESTION). IN: BIOLOGICAL AND OCEANOGRAPHICAL SURVEY OF THE SANTA BARBARA CHANNEL OIL SPILL, 1969-1970, VOLUME I. BIOLOGY AND BACTERIOLOGY (STRAUGHEN, D., ED.) PP. 287-306. ALLAN HANCOCK FOUNDATION, UNIVERSITY OF SOUTHERN CALIFORNIA, LOS ANGELES, CALIFORNIA.

BROWNING, M.R., AND ENGLISH, W.W. 1972. BREEDING BIRDS OF SELECTED OREGON COASTAL ISLANDS. MURRELET 53:1-7.

BUCKLAND, D.C. 1946. INVESTIGATION OF DECAY ON WESTERN RED CEDAR. CANAD. J. RES. C24:158-181.

BUDINGER, T.F., COACHMAN, L.K., AND BARNES, C.A. 1964. COLUMBIA RIVER EFFLUENT IN THE NORTHEAST PACIFIC OCEAN, 1961, 1962: SELECTED ASPECTS OF PHYSICAL OCEANOGRAPHY. TECHNICAL REPORT NO. 99. DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 78PP.

BUREAU OF BUSINESS RESEARCH, UNIVERSITY OF OREGON. 1974 AND 1977. OREGON ECONOMIC STATISTICS, 1974. OREGON ECONOMIC STATISTICS, 1977. UNIVERSITY OF OREGON, EUGENE, OREGON. 97 AND 99 PP.

BUREAU OF NATIONAL AFFAIRS, INC. 1978. STATE WATER LAWS. ENVIRONMENTAL REPORTER, S-396, APRIL 28, 1978, PP. 151-152, WASHINGTON, D.C.

BURG, M.W., ROSENBERG, E.S., AND TRIPP, D.R. 1975. VEGETATION ASSOCIATIONS AND PRIMARY PRODUCTIVITY OF THE NISQUALLY SALT MARSH ON SOUTHERN PUGET SOUND, WASHINGTON IN: CONTRIBUTIONS TO THE NATURAL HISTORY OF THE SOUTHERN PUGET SOUND REGION, WASHINGTON (HERMAN, S.G., AND WIEDEMANN, A.M., EDS.) PP. 109-144. EVERGREEN STATE COLLEGE, OLYMPIA, WASHINGTON.

BURKHOLDER, P.R., AND DOHENY, T.E. 1968. THE BIOLOGY OF EELGRASS, WITH SPECIAL REFERENCE TO HEMPSTEAD AND SOUTH OYSTER BAYS, NASSAU COUNTY, LONG ISLAND, NEW YORK. CONTR. NO. 3, DEPARTMENT OF CONSERVATION AND WATERWAYS, TOWN OF HEMPSTEAD, LONG ISLAND (ALSO, CONTR. 1227, LAMONT GEOLOGICAL OBSERVATORY, PALISADES, NEW YORK). 120 PP.

BURNS, J.W. 1971. THE CARRYING CAPACITY FOR JUVENILE SALMONIDS IN SOME NORTHERN CALIFORNIA STREAMS. CALIF. FISH GAME 57(1):44-57.

BURROUGHS E.R., JR., CHALFANT, G.R., AND TOWNSEND, M.A. 1976. SLOPE STABILITY IN ROAD CONSTRUCTION. BUREAU OF LAND MANAGEMENT, OREGON STATE OFFICE, PORTLAND, OREGON.

BYRNE, J.V., AND KULM, L.D. 1967. NATURAL INDICATORS OF ESTUARINE SEDIMENT MOVEMENT. J. WATERWAYS HARBORS DIV. PROCEEDINGS, AMERICAN SOCIETY OF CIVIL ENGINEERS, PP. 181-194.

BYRNE, J.V., AND PANSHIN, D.A. 1968. CONTINENTAL SHELF SEDIMENTS OFF OREGON. OREGON STATE UNIVERSITY SEA GRANT NO. 8. 2 PP.

CALIFORNIA COASTAL ZONE CONSERVATION COMMISSION. 1975. PRELIMINARY COASTAL PLAN. HEARING DRAFT, MARCH 1975. CALIFORNIA COASTAL ZONE CONSERVATION COMMISSION, SAN FRANCISCO, CALIFORNIA. 385 PP.

CALIFORNIA NATIVE PLANT SOCIETY. 1974. INVENTORY OF RARE AND ENDANGERED PLANTS OF CALIFORNIA. CALIFORNIA NATIVE PLANT SOCIETY.

CALIFORNIA REGION FRAMEWORK STUDY COMMITTEE. 1971. COMPREHENSIVE FRAMEWORK STUDY CALIFORNIA REGION APPENDIX IX. PREPARED FOR PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE WATER RESOURCES COUNCIL.

CALIFORNIA STATE DEPARTMENT OF FINANCE, POPULATION RESEARCH UNIT. 1977 AND VARIOUS YEARS. POPULATION ESTIMATES OF CALIFORNIA CITIES AND COUNTIES, JANUARY 1976, AND JANUARY 1977. CALIFORNIA STATE DEPARTMENT OF FINANCE, SACRAMENTO, CALIFORNIA.

CALIFORNIA STATE DEPARTMENT OF FISH AND GAME. 1969-1970. CALIFORNIA SEA BIRD BREEDING GROUND SURVEY. CALIFORNIA STATE DEPARTMENT OF FISH AND GAME, SACRAMENTO, CALIFORNIA.

CALIFORNIA STATE DEPARTMENT OF FISH AND GAME. 1978. PERSONAL COMMUNICATION.

CALIFORNIA STATE DEPARTMENT OF FISHERIES. 1974,1975. MONTHLY FISHERIES PRELIMINARY STATISTICAL REPORTS. CALIFORNIA STATE DEPARTMENT OF FISHERIES, SACRAMENTO, CALIFORNIA.

CALIFORNIA STATE EMPLOYMENT DEVELOPMENT DEPARTMENT. 1976. AREA MANPOWER REVIEW, HUMBOLDT COUNTY, FISCAL YEAR. 1976-1977. STATE OF CALIFORNIA HEALTH AND WELFARE AGENCY, EMPLOYMENT DEVELOPMENT DEPARTMENT, NORTHERN CALIFORNIA EMPLOYMENT DATA AND RESEARCH, SAN FRANCISCO, CALIFORNIA. 47 PP.

CALIFORNIA STATE EMPLOYMENT DEVELOPMENT DEPARTMENT. 1977. ANNUAL PLANNING REPORT, HUMBOLDT COUNTY, 1977-1978. STATE OF CALIFORNIA HEALTH AND WELFARE AGENCY, EMPLOYMENT DEVELOPMENT DEPARTMENT, EMPLOYMENT AND DATA RESEARCH, SACRAMENTO, CALIFORNIA. 40 PP.

CALIFORNIA STATE FISH AND GAME COMMISSION. 1965A. CALIFORNIA FISH AND WILDLIFE PLAN, VOL. III, PART A, SUPPORTING DATA. INVENTORY OF WILDLIFE AND INLAND FISH. STATE OF CALIFORNIA, RESOURCES AGENCY, SACRAMENTO, CALIFORNIA, 322 PP.

CALIFORNIA STATE FISH AND GAME COMMISSION. 1965C. CALIFORNIA FISH AND WILDLIFE PLAN, VOL. III, SUPPORTING DATA, PART C, LAND AND WATER USE, HABITAT AND RESOURCE, 1980. HUMAN USE. STATE OF CALIFORNIA, RESOURCES AGENCY, SACRAMENTO, CALIFORNIA. 105 PP.

CALIFORNIA STATE FISH AND GAME COMMISSION. 1973. LISTING OF CALIFORNIAS ENDANGERED AND RARE FISH AND WILDLIFE. CALIFORNIA FISH GAME COMMISSION, SACRAMENTO, CALIFORNIA.

CALIFORNIA STATE OFFICE OF PLANNING AND RESEARCH. 1973. SUMMARY REPORT. ENVIRONMENTAL GOALS AND POLICY. STATE OF CALIFORNIA, OFFICE OF PLANNING AND RESEARCH, SACRAMENTO, CALIFORNIA. 13 PP.

CALIFORNIA STATE. 1976 (AND VARIOUS YEARS). STATISTICAL ABSTRACT (ANNUAL). STATE OF CALIFORNIA DOCUMENTS CENTER, SACRAMENTO, CALIFORNIA.

CAMERON, F.K. 1914. KELP GROVES OF THE PACIFIC COAST AND ISLANDS OF THE UNITED STATES AND LOWER CALIFORNIA. BUREAU OF SOILS, U.S. DEPARTMENT OF AGRICULTURE, OFFICE OF THE SECRETARY, REPORT NO. 100. GPO, WASHINGTON, D.C.

CAMERON, G.N. 1972. ANALYSIS OF INSECT TROPHIC DIVERSITY IN TWO SALT MARSH COMMUNITIES. ECOLOGY 53(1):58-73.

CAMERON, W.M., AND PRITCHARD, D.W. 1963. ESTUARIES. IN: THE SEA (HILL, M.N., ED.), VOL. 2, PP. 306-324. WILEY-INTERSCIENCE, NEW YORK, NEW YORK.

CAMPBELL, R.W. 1976. SEA-BIRDS BREEDING ON THE CANADIAN WEST COAST. CANADIAN NATURE FEDERATION, SPECIAL PUBLICATION NO. 5. VICTORIA, BRITISH COLUMBIA, CANADA. 65 PP.

CAREY, A.G., JR., PEARCY, W.G., AND OSTERBERG, C.L. 1966. ARTIFICIAL RADIONUCLIDES IN MARINE ORGANISMS IN THE NORTHEAST PACIFIC OCEAN OFF OREGON. IN: DISPOSAL OF RADIOACTIVE WASTES INTO SEAS, OCEANS, AND SURFACE WATERS, PP. 303-319. INTERNATIONAL ATOMIC ENERGY AGENCY, GENEVA, SWITZERLAND.

CARLISLE, A. 1976. THE UTILIZATION OF FOREST BIOMASS AND FOREST INDUSTRY WASTES FOR THE PRODUCTION AND CONSERVATION OF ENERGY. CANADIAN FOREST SERVICE, OTTOWA, CANADA. 54 PP.

CASSIE, M.R., AND CASSIE, V. 1960. PRIMARY PRODUCTION IN A NEW ZEALAND WEST COAST PHYTOPLANKTON BLOOM. NEW Z. J. SCI. 3:173-179.

CCZCC--SEE.....CALIFORNIA COASTAL ZONE CONSERVATION COMMISSION.

CENTER FOR POPULATION RESEARCH AND CENSUS. 1976. POPULATION PROJECTION FOR STATE OF OREGON AND ITS COUNTIES: 1975 - 2000. PORTLAND STATE UNIVERSITY, PORTLAND, OREGON. 50 PP.

CHENG, L. (ED.). 1976. MARINE INSECTS. AMERICAN ELSEVIER, NEW YORK. 581 PP.

CHOATE, G.A. 1972. FLOWS OF MILL RESIDUES TO PULP AND BOARD MANUFACTURERS, WASHINGTON, OREGON AND CALIFORNIA, 1968. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 49 PP.

CLEAVER, F.C. 1944. LIFE HISTORY AND HABITS OF THE COMMERCIAL CRAB, CANCER MAGISTER. BIOLOGICAL CIRCULAR NO. 1. WASHINGTON STATE DEPARTMENT OF FISHERIES, OLYMPIA, WASHINGTON.

CLEAVER, F.C. 1949. PRELIMINARY RESULTS OF THE COASTAL CRAB (CANCER MAGISTER) INVESTIGATION. BIOL. REPT. 49A:47-82. STATE OF WASHINGTON DEPARTMENT OF FISHERIES, OLYMPIA, WASHINGTON.

CNPS--SEE.....CALIFORNIA NATIVE PLANT SOCIETY.

COATS, R.N. 1978. THE ROAD TO EROSION. A CAUTIONARY TALE. ENVIRONMENT VOL. 20, JANUARY/FEBRUARY. PP. 16-20, AND 37-39.

COLE, D.W., CRANE, W.J., AND GRIER, C.C. 1975. THE EFFECT OF FOREST MANAGEMENT PRACTICES ON WATER QUALITY IN A SECOND GROWTH DOUGLAS-FIR ECOSYSTEM. IN: FOREST SOILS AND FOREST LAND MANAGEMENT, PROC. 4TH N. AMERICAN FOREST SOILS CONF., AUG., 1973 (BERNIER, B., AND WINGET, C.H., EDS.), PP. 195-207.

COLINVAUX, P.A. 1973. INTRODUCTION TO ECOLOGY. JOHN WILEY AND SONS, NEW YORK. 621 PP.

COLLIN, T., YOUMANS, R., AND STOEVENER. 1973. IMPACT OF A MAJOR ECONOMIC CHANGE ON A RURAL COASTAL ECONOMY: A LARGE ALUMINUM PLANT IN CLATSOP COUNTY, OREGON. OREGON STATE UNIVERSITY, AGRICULTURAL EXPERIMENT STATION, STATION BULLETIN 614. 30 PP.

CONIFEROUS FOREST BIOME MODELING GROUP. 1977. CONIFER: A MODEL OF CARBON AND WATER FLOW THROUGH A CONIFEROUS FOREST. DOCUMENTATION. BULLETIN NO. 8, CONIFEROUS FOREST BIOME ECOSYSTEM ANALYSIS STUDIES, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON, AND OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 160 PP. MAPS, ILLUSTRATIONS.

CONOVER, J.T. 1958. SEASONAL GROWTH OF BENTHIC MARINE PLANTS AS RELATED TO ENVIRONMENTAAL FACTORS IN AN ESTUARY CONTR. INST. MAR. SCI. UNIV. TEX. 5:97-147.

COOS, CURRY, DOUGLAS ECONOMIC IMPROVEMENT ASSOCIATION (EIA). 1977. OVERALL ECONOMIC DEVELOPMENT PLAN, 1977-78. ACTION PROBLEM FOR THE COOS-CURRY-DOUGLAS ECONOMIC DEVELOPMENT DISTRICT. COOS, CURRY, DOUGLAS ECONOMIC IMPROVEMENT ASSOCIATION, ROSEBURG, OREGON. APPROX. 242 PP.

CORY, E.N., AND CROSTHWAIT, S.L. 1939. SOME CONSERVATION AND ECOLOGICAL IMPLICATIONS OF MOSQUITO CONTROL. J. ECON. ENTOMOL. 32(2):213-215.

COTTAM, C., AND MUNRO, D.A. 1954. EELGRASS STATUS AND ENVIRONMENTAL RELATIONSHIPS. J. WILDL. MANAG. 18(4):449-460.

COTTAM, C., BOURN, W.S., BISHOP, F.C., WILLIAMS, L.L., AND VOGT, V. 1938. WHATS WRONG WITH MOSQUITO CONTROL (QUESTION). TRANS. N. AM. WILDLIFE CONF. 3:81-107.

COUCH, R., VICTOR, L., AND KEELING, K. 1974. COASTAL AND OFFSHORE EARTHQUAKES OF THE PACIFIC NORTHWEST BETWEEN 39 DEGREES AND 49 DEGREES 10 MINUTES NORTH LATITUDE AND 123 DEGREES AND 131 DEGREES WEST LONGITUDE. STATE OF OREGON DEPARTMENT OF GEOLOGY AND MINERAL RESOURCES. 67 PP.

COUNCIL OF STATE GOVERNMENTS. 1974. LAND USE POLICY AND PROGRAM ANALYSIS NO. 4: STATE OF THE ART FOR DESIGNATION OF AREAS OF CRITICAL ENVIRONMENTAL CONCERN. COUNCIL OF STATE GOVERNMENTS, LEXINGTON, KENTUCKY. 52 PP.

COUNCIL OF STATE GOVERNMENTS. 1975. LAND USE POLICY AND PROGRAM ANALYSIS NO. 5: ISSUES AND RECOMMENDATIONS - STATE CRITICAL AREAS PROGRAMS. COUNCIL OF STATE GOVERNMENTS, LEXINGTON, KENTUCKY. 45 PP.

COWAN, I. McT. 1956. LIFE AND TIMES OF THE COAST BLACK-TAILED. IN W. P. TAYLOR, ED., THE DEER OF NORTH AMERICA, THE WHITE-TAILED, MULE AND BLACK-TAILED DEER, GENUS ODOCOILEUS, THEIR HISTORY AND MANAGEMENT. STACKPOLE COMPANY, HARRISBURG. XVII + 668 PP.

COWARDIN, L.M., CARTER, V., GOLET, F.C., AND LAROE, E.T. 1977. CLASSIFICATION OF WETLANDS AND DEEP WATER HABITATS OF THE UNITED STATES (SATHER, J.H., ED.). (AN OPERATIONAL DRAFT, OCTOBER, 1977.) U.S. FISH AND WILDLIFE SERVICE, OFFICE OF BIOLOGICAL SERVICES, WASHINGTON, D.C.

COX, J.L. 1976. SAMPLING VARIATION IN SANDY BEACH LITTORAL AND NEARSHORE MEIOFAUNA AND MACROFAUNA. U.S. ARMY CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, TECHNICAL PAPER NO. 76-14, FORT BELVOIR, VIRGINIA. 72 PP. [PREPARED BY HOPKINS MARINE STATION, STANFORD UNIVERSITY, PACIFIC GROVE, CALIFORNIA.]

CRAMER, O.P. (ED.). 1974. ENVIRONMENTAL EFFECTS OF FOREST RESIDUES MANAGEMENT IN THE PACIFIC NORTHWEST, A STATE-OF-KNOWLEDGE COMPENDIUM. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 418 PP.

CREECH, C. 1973. WAVE CLIMATOLOGY OF THE CENTRAL OREGON COAST, JULY 1971 - JUNE 1973. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION SEA GRANT PROJECT NO. 04-3-158-4. MARINE SCIENCE CENTER, OREGON STATE UNIVERSITY, NEWPORT, OREGON. 19 PP.

CRFSC--SEE.....CALIFORNIA REGION FRAMEWORK STUDY COMMITTEE.

CROSS, F.A., AND SMALL, L.F. 1967. COPEPOD INDICATORS OF SURFACE WATER MOVEMENTS OFF THE OREGON COAST. LIMNOL. OCEANOGR. 12(1):60-72.

CROUCH, G.L. 1974. INTERACTION OF DEER AND FOREST SUCCESSION ON CLEARCUTTING IN THE COAST RANGE OF OREGON. IN: WILDLIFE AND FOREST MANAGEMENT IN THE PACIFIC NORTHWEST (BLACK, H.C., ED.), PP. 133-138.

CROW, M.E., RAJAGOPAL, AND G.F. SCHREUDER. 1976. MODELS OF A FOREST ECOSYSTEM. VIII.--SOME EFFECTS OF MODIFICATION OF STREAM ENVIRONMENT. FOREST RESOURCES MONOGRAPH, CONTRIBUTION NO. 22, INSTITUTE OF FOREST PRODUCTS. COLLEGE OF FOREST RESOURCES, U. OF WASHINGTON, SEATTLE, WASHINGTON.

CZEMERTS, J. 1977. PERSONAL COMMUNICATION.

DAIBER, F.C. 1974. SALT MARSH PLANTS AND FUTURE COASTAL SALT MARSHES IN RELATION TO ANIMALS. IN: ECOLOGY OF HALOPHYTES (REIMOLD, R.L.J., AND QUEEN, W.H., EDS.) PP. 475-508.

DAILY, M.D., HILL, R.H., AND LANSING, N. (EDS.) 1974. A SUMMARY OF KNOWLEDGE OF THE SOUTHERN CALIFORNIA COASTAL ZONE AND OFFSHORE AREAS. VOLUME II. BIOLOGICAL ENVIRONMENT. U.S. DEPARTMENT OF INTERIOR, BUREAU OF LAND MANAGEMENT, CONTRACT 08550-CT4-1. [SOUTHERN CALIFORNIA OCEAN STUDIES CONSORTIUM]. 807 PP.

DARLING, K. 1971. BISHOP PINE FOREST AND MATURE DOUGLAS-FIR FOREST. AUDUBON FIELD-NOTES 27:981.

DARNELL, R.M., PEQUEGNOT, W.E., JAMES, B.M., BENSON, F.J., AND DEFENBAUGH, R.A. 1976. IMPACTS OF CONSTRUCTION ACTIVITIES IN WETLANDS OF THE UNITED STATES. U.S. ENVIRONMENTAL PROTECTION AGENCY CONTRACT NO. 68-01-2452. CORVALLIS ENVIRONMENTAL RESEARCH LABORATORY, CORVALLIS, OREGON. (TERECO CORPORATION.)

DARR, D.R. 1975. SOFTWOOD LOG EXPORTS AND THE VALUE AND EMPLOYMENT ISSUES. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE PAPER PNW-200. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 13 PP.

DARR, D.R., AND FIGHT, R.D. 1974. DOUGLAS COUNTY, OREGON: POTENTIAL ECONOMIC IMPACTS OF A CHANGING TIMBER RESOURCE BASE. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE PAPER PNW-179. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 41PP.

DASMANN, R.F. 1956. DETERMINING STRUCTURE IN COLUMBIAN BLACK-TAILED DEER POPULATIONS. J. WILDL. MANAG. 20:78-83.

DASMANN, R.F. 1964. WILDLIFE BIOLOGY. JOHN WILEY AND SONS, INC., NEW YORK. 231 PP.

DAVIS, B.S. 1977. THE SOUTHERN SEA OTTER REVISITED. PACIFIC DISCOVERY 30(2):1-13.

DAVIS, D., AND WILHOUR, R.G. 1976. SUSCEPTIBILITY OF WOODY PLANTS TO SULFUR DIOXIDE AND PHOTOCHEMICAL OXIDANTS. ENVIRONMENTAL PROTECTION AGENCY, WASHINGTON, D.C. 72 PP.

DAY, J.W. JR., SMITH, W.G., WAGNER, P.R., AND STOWE, W.C. 1973. COMMUNITY STRUCTURE AND CARBON BUDGET OF A SALT MARSH AND SHALLOW BAY ESTUARINE SYSTEM IN LOUISIANA. CENTER FOR WETLAND RESOURCES, LOUISIANA STATE UNIVERSITY, BATON ROUGE, LOUISIANA. LSU-SG-72-04.

DE LA CRUZ, A. 1965. A STUDY OF PARTICULATE ORGANIC DETRITUS IN A GEORGIA ESTUARINE SALT MARSH ECOSYSTEM. PH.D. THESIS. UNIVERSITY OF GEORGIA, ATLANTA, GEORGIA.

DE LA CRUZ, A.A. 1976. SUGGESTED METHODS FOR THE MONETARY EVALUATION OF TIDAL MARSHLANDS IN MISSISSIPPI. J. MISSISSIPPI ACAD. SCI. 29:171-180.

DE LA CRUZ, A.A., AND COURTNEY, T.H. 1977. ENERGY VALUE, ELEMENTAL COMPOSITION AND PRODUCTIVITY OF BELOW GROUND BIOMASS OF A JUNCUS TIDAL MARSH. ECOLOGY 58:1165-1170.

DE LA CRUZ, A.A., AND GABRIEL, B.C. 1974. CALORIC, ELEMENTAL, AND NUTRITIVE CHANGES IN DECOMPOSING JUNCUS ROEMERIANUS LEAVES. ECOLOGY 55:882-886.

DEHLINGER, P., COUCH, R.W., MCMANUS, D.A., AND GEMPERLE, M. 1970. NORTHEAST PACIFIC STRUCTURE. IN: THE SEA (MAXWELL, A.E., ED.), VOL. 4, PP. 133-169. WILEY-INTERSCIENCE, NEW YORK.

DEMORY, R.L., AND ROBINSON, J.G. 1973. RESOURCE SURVEYS ON THE CONTINENTAL SHELF OFF OREGON, ANNUAL REPORT, JULY 1, 1972 TO JUNE 30, 1973, NATIONAL MARINE FISHERIES SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE, AND FISH COMMISSION OF OREGON, PORTLAND, OREGON.

DEMORY, R.L., HOSIE, M.J., TEN EYCK, N., AND FORSBERG, B.O. 1976. RESOURCE SURVEY ON THE OREGON COAST. COMMISSION ON FISHERIES RESOURCES AND DEVELOPMENT ACTS, COMPLETION REPORT. OREGON DEPARTMENT OF FISH AND WILDLIFE PROCEEDINGS REPORT. 49 PP.

DENISON, R.F., CALDWELL, B., BORMAN, B., ELDRED, L., SWANBERG, C., AND ANDERSON, S. 1976. EFFECTS OF ACID RAIN ON NITROGEN-FIXATION IN WASHINGTON CONIFEROUS FORESTS. IN: PROCEEDINGS OF THE FIRST INTERNATIONAL SYMPOSIUM ON ACID PRECIPITATION AND THE FOREST ECOSYSTEM (DOCHINGER, L.S., AND SELIGA, T.A., EDS.), PP. 933-949, U.S. DEPARTMENT OF AGRICULTURE GEN. TECH. REP. NE-23, WASHINGTON, D.C.

DENISON, W.C. 1977. PERSONAL COMMUNICATION.

DENISON, W.C., AND CARPENTER, S.M. 1973. A GUIDE TO AIR QUALITY MONITORING WITH LICHENS. LICHEN TECHNOLOGY, INC., CORVALLIS, OREGON. 39 PP.

DENTON, M., GOLDMAN, B., HITCHCOCK, C.L., KRUCKEBERG, A.R., AND MUELLER, M. 1977. A WORKING LIST OF RARE, ENDANGERED, OR THREATENED VASCULAR PLANT TAXA FOR WASHINGTON. DEPARTMENT OF BOTANY, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 6 PP. (MIMEOGRAPHED).

DETWYLER, T.R. 1971. MANS IMPACTS ON ENVIRONMENT. MCGRAW-HILL BOOK CO., NEW YORK. 731 PP.

DEUEL, D.G. 1973. SALTWATER ANGLING SURVEY - 1970. U.S. DEPARTMENT OF COMMERCE, NATIONAL MARINE FISHERIES SERVICE, CURRENT FISHERY STATISTICS NO. 6200. NOAA, WASHINGTON, D.C.

DEYRUP, M.A. 1975. THE INSECT COMMUNITY OF DEAD AND DYING DOUGLAS-FIR. I. THE HYMENOPTERA. CONIFEROUS FOREST BIOME, BULLETIN NO. 6. UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 104 PP.

DOUGLAS, P.A., AND STROUD, R.H. (EDS.). 1971. SYMPOSIUM ON THE BIOLOGICAL SIGNIFICANCE OF ESTUARIES. SPORT FISHERIES INSTITUTE, WASHINGTON, D.C. 111 PP.

DUXBURY, A.C., MORSE, B.A., AND MCGARY, N. 1966. THE COLUMBIA RIVER EFFLUENT AND ITS DISTRIBUTION AT SEA. DEPARTMENT OF OCEANOGRAPHY, TECHNICAL REPORT NO. 156. UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON.

DYRNESS, C.T., FRANKLIN, J.F., AND MASER, C. 1973. WHEELER CREEK RESEARCH NATURAL AREA. SUPPLEMENT NO. 1: FEDERAL RESEARCH NATURAL AREAS IN OREGON AND WASHINGTON, 1972, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C. 16 PP.

DYRNESS, C.T., FRANKLIN, J.F., MASER, C., COOK, S.A., AND HALL, J.D. 1974. RESEARCH NATURAL AREA NEEDS IN THE PACIFIC NORTHWEST--A CONTRIBUTION TO LAND-USE PLANNING, REVIEW DRAFT. REPORT ON NATURAL AREA NEEDS WORKSHOP, NOVEMBER 29 - DECEMBER 1, 1973, WEEME, OREGON. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION. PORTLAND, OREGON. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, 349 PP.

DYRNESS, C.T., FRANKLIN, J.F., MASER, C., COOK, S.A., HALL, J.D., AND FAXON, G. 1975. RESEARCH NATURAL AREA NEEDS IN THE PACIFIC NORTHWEST, A CONTRIBUTION TO LAND-USE PLANNING. U.S. DEPARTMENT OF AGRICULTURE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PNW-38, PORTLAND, OREGON. 231 PP.

EATON, R.L., BRITTELL, J.D., AND BROWN, J.M. 1975. COASTAL ZONE ENVIRONMENTAL STUDIES REPORT NO. 2. MARINE SHORELINE FAUNA OF WASHINGTON: A STATUS SURVEY. DEPARTMENT OF GAME AND DEPARTMENT OF ECOLOGY, OLYMPIA, WASHINGTON. 594 PP.

EDMONDS, R.L. 1974. AN INITIAL SYNTHESIS OF RESULTS IN THE CONIFEROUS FOREST BIOME, 1970-1973. BULLETIN NO. 7, CONIFEROUS FOREST BIOME. UNIVERSITY OF WASHINGTON, COLLEGE OF FOREST RESOURCES, SEATTLE, WASHINGTON. 248 PP.

EDMONDS, R.L. 1975. CONIFEROUS FOREST BIOME, PROGRESS REPORT, JULY 1974 - AUGUST 1975. INTERNAL REPORT NO. 162. COLLEGE OF FOREST RESOURCES, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 97 PP.

EDMONDS, R.L. (ED.). 1977. CONIFEROUS FOREST BIOME ECOSYSTEM ANALYSIS STUDIES. SUMMARY OF RESEARCH AND SYNTHESIS, ACTIVITIES, JULY 1975-AUGUST 1976. INTERNAL REPORT 1649, CONIFEROUS FOREST BIOME, COLLEGE OF FOREST RESOURCES, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 99 PP.

EFFORD, I.E., AND HALL, K.J. 1975. MARION LAKE - AN ANALYSIS OF A LAKE ECOSYSTEM IN ENERGY FLOW - BIOLOGICAL DIMENSIONS. IN: A SUMMARY OF THE IBP IN CANADA 1954-1974, PP. 199-219. ROYAL SOCIETY OF CANADA, OTTAWA.

EILERS, H.P., III. 1975. PLANTS, PLANT COMMUNITIES, NET PRODUCTION AND TIDE LEVELS: THE ECOLOGICAL BIOGEOGRAPHY OF THE NEHALEM SALT MARSHES, TILLAMOOK COUNTY, OREGON. PH.D. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 368 PP.

EISENHOWER CONSORTIUM FOR WESTERN ENVIRONMENTAL FORESTRY RESEARCH. 1975. MAN, LEISURE, AND WILDLANDS: A COMPLEX INTERACTION. PROCEEDINGS OF THE FIRST EISENHOWER CONSORTIUM RESEARCH SYMPOSIUM, SEPTEMBER, 1975, VAIL, COLORADO. EISENHOWER CONSORTIUM BULLETIN 1, 286 PP.

ELDER, J.A. 1976. EELGRASS PRODUCTION IN LONG ISLAND WATERS. TETRATECH, INC. REPORT FOR NASSAU-SUFFOLK REGIONAL PLANNING BOARD. HAUPPAGE, NEW YORK. 23 PP.

ELLINGER, E., AND SNYDER, G. 1975. AN ANNOTATED BILIOGRAPHY OF THE EFFECTS OF DREDGING AND DREDGE DISPOSAL ON AQUATIC ORGANISMS IN THE PACIFIC NORTHWEST WITH SELECTED REFERENCES ON BIOLOGICAL STUDIES OF THE LOWER COLUMBIA RIVER AND ON RELATED DREDGE AND DISPOSAL STUDIES. U.S. ARMY CORPS OF ENGINEERS CONTRACT WESRF 75-88. U.S. NATIONAL MARINE FISHERIES SERVICE, SEATTLE, WASHINGTON. 51 PP.

ELLIOTT, W.P., EGAMI, R., AND ROSSKNECHT, G. 1971. RAINFALL AT SEA. NATURE 229:108-109.

EMMINGHAM, W.H., AND WARING, R.H. 1977. AN INDEX OF PHOTOSYNTHESIS FOR COMPARING FOREST SITES IN WESTERN OREGON. CANADIAN JOURNAL OF FOREST RESEARCH. 7(1)165-174.

ENGLERTH, G.H. 1947. DECAY OF THE SITKA SPRUCE IN SOUTHEAST ALASKA. J. FORESTRY 45:894-900.

EPA--SEE.....U.S. ENVIRONMENTAL PROTECTION AGENCY.

ESTES, J.A., AND PALMISANO, J.F. 1974. SEA OTTERS: THEIR ROLE IN STRUCTURING NEARSHORE COMMUNITIES. SCIENCE 185:1058-1060.

FABER, R.A., RISEBROUGH, R.W., AND PRATT, H.M. 1972. ORGANOCHLORINES AND MERCURY IN COMMON EGRETS AND GREAT BLUE HERONS. ENVIR. POLL. 3:111-122.

FAVORITE, F., DODIMEAD, A.J., AND NASU, K. 1974. OCEANOGRAPHY OF THE SUBARCTIC PACIFIC REGION 1960-71. 370 PP. MIMEOGRAPH. NATIONAL MARINE FISHERIES SERVICE, NOAA, SEATTLE, WASHINGTON.

FERRY, B.W., BADDELEY, M.S., AND HAWKSWORTH, D.L. (EDS.). 1973. AIR POLLUTION AND LICHENS. UNIVERSITY OF TORONTO PRESS, TORONTO, CANADA. 389 PP.

FEDERAL COMMITTEE ON ECOLOGICAL RESERVES. 1977. A DIRECTORY OF RESEARCH NATURAL AREAS ON FEDERAL LANDS OF THE UNITED STATES. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, WASHINGTON, D.C. 280 PP.

FIKSDAL, A.J. 1974. A LANDSLIDE SURVEY OF STEQUALEHO CREEK WATERSHED, SUPPLEMENTAL REPORT. FISHERIES RESEARCH INSTITUTE, COLLEGE OF FISHERIES, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTONN. 8 PP.

FOGEL, R., AND TRAPPE, J.M. 1978. FUNGUS CONSUMPTION (MYCOPHAGY) BY SMALL ANIMALS. NORTHWEST SCIENCE 52(1):1-131.

FORBES, R.B., PAQUET, P.J., PERRY, C.R., AND WILLIS, R. 1976. REVETMENT CLEARING: ITS INFLUENCE ON RIPARIAN WILDLIFE COMMUNITIES. DEPARTMENT OF BIOLOGY, PORTLAND STATE UNIVERSITY, PORTLAND, OREGON. 77 PP.

FORBIS, L.W. 1975. A HABITAT MANAGEMENT PLAN FOR THE BALD EAGLE (HALIAEETUS LEUCOCEPHALUS) ON THE KLAMATH NATIONAL FOREST, SISKIYOU COUNTY, CALIFORNIA. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, KLAMATH NATIONAL FOREST, VOL. 76, P. 3.

FOREST SOILS COMMITTEE OF THE DOUGLAS-FIR REGION. 1957. AN INTRODUCTION TO FOREST SOILS OF THE DOUGLAS-FIR REGION OF THE PACIFIC NORTHWEST. WESTERN FORESTRY AND CONSERVATION ASSOCIATION, PORTLAND, OREGON. 217 PP.

FORSMAN, E. 1976. A PRELIMINARY INVESTIGATION OF THE SPOTTED OWL IN OREGON. M.S. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 125 PP.

FOSTER, W.A. 1968. STUDIES ON THE DISTRIBUTION AND GROWTH OF JUNCUS ROEMERIANUS IN SOUTHEASTERN BRUNSWICK COUNTY, NORTH CAROLINA. M.S. THESIS. NORTH CAROLINA STATE UNIVERSITY, RALEIGH, NORTH CAROLINA. 167 PP.

FOWELLS, H.A. (COMP). 1965. SILVICS OF FOREST TREES OF THE UNITED STATES. U.S. DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C. 762 PP.

FOX, W.T., AND DAVIS, R.A. JR. 1974. BEACH PROCESSES ON THE OREGON COAST JULY, 1973. WILLIAMS COLLEGE, WILLIAMSTOWN, MASSACHUSETTS. 85 PP.

FRANKLIN, J.F., AND DYRNESS, C.T. 1973. NATURAL VEGETATION OF OREGON AND WASHINGTON. U.S. DEPARTMENT OF AGRICULTURE GENERAL TECHNICAL REPORT PNW-8, WASHINGTON, D.C. 417 PP.

FRANKLIN, J.F., HALL, F.C., DYRNESS, C.T., AND MASER, C. 1972. FEDERAL RESEARCH NATURAL AREAS IN OREGON AND WASHINGTON: A GUIDEBOOK FOR SCIENTISTS AND EDUCATORS. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE, PORTLAND, OREGON. 498 PP.

FRAZER, D.A., LESCHNER, L.L., AND MANUWAL, D.A. 1973. SURVEY OF SEABIRD COLONIES OF WASHINGTONS SAN JUAN, STRAIT OF JUAN DE FUCA, AND OCEANIC ISLANDS. UNPUBLISHED MANUSCRIPT, COLLEGE OF FOREST RESOURCES UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 50 PP.

FREDERICK, L.C. 1967. DISPERSION OF THE COLUMBIA RIVER PLUME BASED ON RADIOACTIVITY MEASUREMENTS. PH.D. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 109 PP.

FREDRIKSEN, R.L. 1971. COMPARATIVE CHEMICAL WATER QUALITY - NATURAL AND DISTURBED STREAMS FOLLOWING LOGGING AND SLASH BURNING. FOREST LAND USES AND STREAM ENVIRONMENT SYMPOSIUM PROCEEDINGS, OCTOBER 19-21, PP. 125-137. OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

FREDRIKSEN, R.L. 1972. IMPACT OF FOREST MANAGEMENT ON STREAM WATER QUALITY IN WESTERN OREGON. IN: PROC. OF A SYMPOSIUM--WATER POLLUTION AND ABATEMENT. FOREST PROD. RES. SOCIETY.

FREDRIKSEN, R.L., MOORE, D.G., AND NORRIS, L.A. 1973. THE IMPACT OF TIMBER HARVEST, FERTILIZATION, AND HERBICIDE TREATMENT ON STREAMWATER QUALITY IN WESTERN OREGON AND WASHINGTON. FOREST SOILS AND FOREST LAND MANAGEMENT, FOURTH NORTH AMERICAN FOREST SOILS CONFERENCE PROCEEDINGS, AUGUST 1972, PP. 283-313. LAVAL UNIVERSITY, QUEBEC.

FRENCH, N.R., GRANT, W.E., GRODZINSKI, W., AND SWIFT, D.M. 1976. SMALL MAMMAL ENERGETICS IN GRASSLAND ECOSYSTEMS. ECOLOG. MONOGR. 46:201-220.

FREY, H.W. 1971. CALIFORNIAS LIVING MARINE RESOURCES AND THEIR UTILIZATION. STATE OF CALIFORNIA RESOURCES AGENCY, DEPARTMENT OF FISH AND GAME, SACRAMENTO, CALIFORNIA. 148 PP.

FRITZ, E. 1929. REDWOOD THE EXTRAORDINARY. TIMBERMAN 30(7):38-39,77.

FRITZ, E. 1930. LUMBER FOR TWENTY HOMES IN A SINGLE TREE. AMER. FORESTS FOREST LIFE 36(11):711.

FRITZ, E. 1934. THE STORY TOLD BY A FALLEN REDWOOD. SAVE-THE-REDWOODS LEAGUE. 7 PP.

FRITZ, E. 1940. REDWOOD FOREST MANAGEMENT FOR UTILIZATION. MECHANICAL ENGINEERING (NEW YORK). PP. 859-863.

FRITZ, E. 1951A. BEAR AND SQUIRREL DAMAGE TO YOUNG REDWOOD. J. FORESTRY 49:651-652.

FRITZ, E. 1951B. SOME PRINCIPLES GOVERNING THE GROWING OF REDWOOD CROPS. J. FORESTRY 49:263-266.

FRITZ, E. 1957. THE LIFE HABITS OF REDWOOD THE EXTRAORDINARY. WEST. CONSERV. J. 14(3):4-7, 38.

FRITZ, E. 1958. SILVICULTURE OF COAST REDWOODS. TIMBER 2:10,46,53,59,60. (SCHOOL OF FORESTRY, UNIVERSITY OF CALIFORNIA, BERKELEY).

FRY, D.H. 1977. INFORMATION ON CALIFORNIA SALMON FISHERIES AND STOCKS. INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION BULLETIN NO. 36, PP. 15-23.

FUJIMORI, T. 1971. PRIMARY PRODUCTIVITY OF A YOUNG TSUGA HETEROPHYLLA STAND AND SOME SPECULATIONS ABOUT BIOMASS OF FOREST COMMUNITIES ON THE OREGON COAST. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE PAPER PNW-123. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 11 PP.

FULTON, L.A. 1968. SPAWNING AREAS AND ABUNDANCE OF CHINOOK SALMON (ONCORNYNCHUS TSHAWYTSCHA) IN THE COLUMBIA RIVER BASIN - PAST AND PRESENT. U.S. FISH AND WILDLIFE SERVICE, SPECIAL SCIENTIFIC REPORT NO. 571, WASHINGTON, D.C. 26 PP.

FULTON, L.A. 1970. SPAWNING AREAS AND ABUNDANCE OF STEELHEAD TROUT AND COHO, SOCKEYE, AND CHUM SALMON IN THE COLUMBIA RIVER BASIN - PAST AND PRESENT. U.S. DEPARTMENT OF COMMERCE, NATIONAL MARINE FISHERIES SERVICE, SPECIAL SCIENTIFIC REPORT NO. 618, WASHINGTON, D.C. 37 PP.

FURNISS, R.L. 1941. FIRE AND INSECTS IN THE DOUGLAS-FIR REGION. FIRE CONTROL NOTES 5(4):211-213.

FURNISS, R.L., AND CAROLIN, V.M. 1977. WESTERN FOREST INSECTS. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE MISC. PUBL. 1339. 654 PP.

FWS--SEE.....U.S. FISH AND WILDLIFE SERVICE.

GARCIA, J.C. 1974. THE INCLUSION OF WILDLIFE CONSIDERATIONS IN REGIONAL PLANNING. PUGET SOUND GOVERNMENTAL CONFERENCE (UNPUBLISHED).

GARCIA, J.C., SCHREUDER, G.F., AND TABER, R.D. 1976. VII. RESOURCE LIMITING MODEL WITH DEVELOPMENT FOR BLACK-TAILED DEER. IN: MODELS OF A FOREST ECOSYSTEM, INSTITUTE OF FOREST PRODUCTS, CONTRIBUTION NO. 21, COLLEGE OF FOREST RESOURCES, U. WASHINGTON, SEATTLE, WASHINGTON. 53 PP.

GASHWILER, J.S. 1959. SMALL MAMMAL STUDY IN WEST-CENTRAL OREGON. J. MAMMOL. 40(1):128-139.

GASHWILER, J.S. 1970. PLANT AND MAMMAL CHANGES ON A CLEARCUT IN WEST-CENTRAL OREGON. ECOLOGY 51:1018-1026.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973A. 1971 COOS BAY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 28 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973B. 1971 UMPQUA RIVER ESTUARY RESOURCE USE STUDY. FISH COMMISSION OF OREGON, PORTLAND, OREGON. 27 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973D. 1971 COLUMBIA RIVER ESTUARY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 16 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973E. 1971 TILLAMOOK BAY RESOURCE USE STUDY. TILLAMOOK BAY RESOURCE COMMISSION, PORTLAND, OREGON. 28 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973F. 1971 SILETZ RIVER ESTUARY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 26 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973G. 1971 ALSEA RIVER ESTUARY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 28 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973H. 1971 COQUILLE RIVER ESTUARY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 27 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973I. 1971 NEHALEM RIVER ESTUARY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 27 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973J. 1971 NESTUCCA RIVER ESTUARY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 24 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973K. 1971 SALMON RIVER ESTUARY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 24 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1973L. 1971 SAND LAKE ESTUARY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 24 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1974A. 1971 NETARTS BAY ESTUARY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 28 PP.

GAUMER, T., DEMORY, D., AND OSIS, L. 1974B. SIUSLAW RIVER ESTUARY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 28 PP.

GAUMER, T., DEMORY, D., OSIS, L., AND WALTERS, C. 1974C. 1970-71 YAQUINA BAY RESOURCE USE STUDY. OREGON FISH COMMISSION, PORTLAND, OREGON. 32 PP.

GEDNEY, D.R., OSWALD, D.D., AND FIGHT, R.D. 1975. TWO PROJECTIONS OF TIMBER SUPPLY IN THE PACIFIC COAST STATES. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE BULL. PNW-60. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION. PORTLAND, OREGON. 40 PP.

GEHM, H. 1973. STATE-OF-THE-ART REVIEW OF PULP AND PAPER WASTE TREATMENT. U.S. ENVIRONMENTAL PROTECTION AGENCY. WASHINGTON, D.C. 252 PP.

GEIGER, C.W. 1926. PROPAGATION OF REDWOOD SEEDLINGS. TIMBERMAN 27(7):176. (SCHOOL OF FORESTRY, UNIVERSITY OF CALIFORNIA, BERKELEY).

GENTRY, R., AND MCALISTER, B. 1976. PHYSIOLOGICAL IMPACT OF OIL ON PINNIPEDS. SEPTEMBER QUARTERLY REPORT, NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION, NORTHWEST FISHERIES CENTER, MARINE MAMMAL DIVISION, SEATTLE, WASHINGTON. 5PP.

GEOMET, INC. 1978. IMPACT OF FOREST BURNING UPON AIR QUALITY, DRAFT FINAL REPORT. U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION X, SEATTLE, WASHINGTON. 253 PP.

GESSEL, S.P., COLE, D.W., AND TURNER, J. 1973. ELEMENTAL CYCLING AND EVEN-AGE FOREST MANAGEMENT. IN: EVEN-AGE MANAGEMENT, PROCEEDINGS OF A SYMPOSIUM (HERMANN, R.K., AND LAVENDER, D.P., EDS.), PP. 179-198. OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

GESSEL, S.P., STOATE, T.N., AND TURNBULL, K.J. 1969. THE GROWTH BEHAVIOR OF DOUGLAS-FIR WITH NITROGENOUS FERTILIZER IN WESTERN WASHINGTON. INSTITUTE OF FORESTRY PRODUCTION CONTRIBUTION NO. 7. COLLEGE OF FOREST RESOURCES, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 119 PP.

GIBBONS, D.R., AND SALO, E.O. 1973. AN ANNOTATED BIBLIOGRAPHY OF THE EFFECTS OF LOGGING ON FISH OF THE WESTERN UNITED STATES AND CANADA. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, GENERAL TECHNICAL REPORT PNW-10. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 145 PP.

GILLULY, J., WATERS, A.C., AND WOODFORD, A.O. 1959. PRINCIPLES OF GEOLOGY. 2ND ED. W. H. FREEMAN AND COMPANY, SAN FRANCISCO, CALIFORNIA. 534 PP.

GNAT, M., HOFFNAGLE, J., VANDERZANDEN, K., AND VAN NESS, R. 1976. DETRITAL PRODUCTION IN COOS BAY SALT MARSHES. IN: COMPARATIVE STUDY OF SALT MARSHES OF THE COOS BAY ESTUARY (HOFFNAGLE, J., ED.), PP. 106-127. OREGON INSTITUTE OF MARINE BIOLOGY, CHARLESTON, OREGON.

GOODMAN, R.M. 1949. UNTITLED. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, NORTHERN FOREST EXPERIMENTAL STATION TECHNICAL NOTE NO. 2. 1 P.

GOODWINN, C.R., EMMETT, C.R., AND GLENNE, B. 1970. TIDAL STUDY OF THREE OREGON ESTUARIES. BULL. NO. 45, ENGINEERING EXPERIMENT STATION, OREGON STATE UNIVERSITY. VAR. PP.

GOSSELINK, J.G., AND KIRBY, C.J. 1974. DECOMPOSITION OF SALT MARSH GRASS, SPARTINA ALTERNIFLORA LOISES. LIMNOL. OCEANOG. 19(5):825-832.

GOSSELINK, J.G., ODUM, E.P., AND POPE, R.M. 1973. THE VALUE OF THE TIDAL MARSH. CENTER FOR WETLANDS RESEARCH, LOUSIANA STATE UNIVERSITY, BATON ROUGE, LOUISIANA.

GOTSHALL, D.W. 1977. STOMACH CONTENTS OF NORTHERN CALIFORNIA DUNGENESS CRABS, CANCER MAGISTER. CALIF. FISH GAME 63(1):43-51.

GOTSHALL, D.W. 1978. RELATIVE ABUNDANCE STUDIES OF DUNGENESS CRABS <u>CANCER MAGISTER</u>, IN NORTHERN CALIFORNIA. CALIF. FISH GAME. 64(1):24-37.

GRAHAM, JOHN CO. 1976. THE ENVIRONMENT OF ALASKA: ANALYSIS OF THE IMPACT POTENTIAL OF DEVELOPMENT. UNPUBLISHED REPORT TO THE JOINT FEDERAL-STATE LAND USE PLANNING COMMISSION FOR ALASKA, ANCHORAGE, ALASKA. APPROX. 300 PP.

GRATOWSKI, H. 1961. BRUSH PROBLEMS IN SOUTHWESTERN OREGON. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE BULLETIN PNW-156. PACIFIC NORTHWEST RANGE AND EXPERIMENT STATION, PORTLAND, OREGON. 10 PP.

GRATOWSKI, H. 1967. ECOLOGICAL CONSIDERATIONS IN BRUSH CONTROL. IN: HERBICIDES AND VEGETATION MANAGEMENT IN FORESTS, RANGES, AND NONCROP LANDS. PROCEEDINGS, OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

GREENACRES CONSULTING CORPORATION. 1976. FORESTS TRIBUTARY TO THE PORT OF COOS BAY - THEIR IMPACT ON WATERBORNE COMMERCE, 1980-2030. PORT OF COOS BAY COMMISSION, COOS BAY, OREGON. 166 PP.

GRIER, C.C., AND COLE, D.W. 1972. ELEMENTAL TRANSPORT CHANGES OCCURRING DURING DEVELOPMENT OF A SECOND-GROWTH DOUGLAS-FIR ECOSYSTEM. IN: PROCEEDINGS - RESEARCH ON CONIFEROUS FOREST ECOSYSTEMS - A SYMPOSIUM (FRANKLIN, J.F., DEMPSTER, L.J., AND WARING, R.H., EDS.), PP. 103-114. U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE, PORTLAND, OREGON.

GRIER, C.C., COLE, D.W., DYRNESS, C.T. AND FREDRIKSEN, R.L. 1974. NUTRIENT CYCLING IN 37 AND 450-YEAR-OLD DOUGLAS-FIR ECOSYSTEMS. CONIFEROUS FOREST INTERNATIONAL BIOME PROGRAM BULL. 5:21-34.

GRIFFEN, J.R., AND CRITCHFIELD, W.B. 1972. DISTRIBUTION OF FOREST TREEES IN CALIFORNIA. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESEARCH PAPER PSW 82. 111 PP.

GROSS, M.G. 1972. OCEANOGRAPHY. A VIEW OF THE EARTH. PRENTICE-HALL, INC., ENGLEWOOD CLIFFS, NEW JERSEY. 581 PP.

GUIGUET, C.J. 1954-1971. THE BIRDS OF BRITISH COLUMBIA. HANDBOOK SERIES, NOS. 1-9, 8 VOLS. BRITISH COLUMBIA PROVINCIAL MUSEUM, VICTORIA, BRITISH COLUMBIA, CANADA.

GUILCHER, A. 1963. ESTUARIES, DELTAS, SHELF, SLOPE. IN: THE SEA (HILL, M.N., ED.), VOL. 3, PP. 620-654. JOHN WILEY AND SONS, NEW YORK.

GUNSOLUS, R.T. (ED.). 1977. COLUMBIA RIVER FISHRUNS AND FISHERIES. OREGON DEPARTMENT OF FISH AND WILDLIFE, AND WASHINGTON DEPARTMENT OF FISHERIES, OLYMPIA, WASHINGTON.

HADDOCK, P.G. 1948. A PROBLEM CHILD REFORMS. UNIVERSITY OF WASHINGTON FOREST CLUB QUARTERLY 22(2):9-15.

HAGAR, D.C. 1960. THE INTERRELATIONSHIPS OF LOGGING, BIRDS, AND TIMBER REGENERATION IN THE DOUGLAS-FIR REGION OF NORTHWESTERN CALIFORNIA. ECOLOGY 41:116-125.

HAIG, J.T., DAVIS, K.P., AND WEIDMAN, R.H. 1941. NATURAL REGENERATION IN THE WESTERN WHITE PINE TYPE. U.S. DEPARTMENT OF AGRICULTURE TECHNICAL BULLETIN 767. WASHINGTON, D.C. 99 PP.

HAINES, E., CHALMERS, A., HANSON, R., AND SHER, B. 1976. NITROGEN POOLS AND FLUXES IN A GEORGIA SALT MARSH. IN: ESTUARINE PROCESS, VOL. 2, CIRCULATION, SEDIMENTS AND TRANSFER OF MATERIAL IN THE ESTUARY (WILEY, M., ED.), PP. 241-254. ACADEMIC PRESS, NEW YORK, SAN FRANCISCO, LONDON.

HALL, R. 1976. THE NUTRITIVE VALUE OF SALT MARSH DETRITUS FOR ESTUARINE INVERTEBRATES. IN: COMPARATIVE STUDY OF SALT MARSHES OF THE COOS BAY ESTUARY (HOFFNAGLE, J., ED.), PP. 138-154. OREGON INSTITUTE OF MARINE BIOLOGY, CHARLESTON, OREGON.

HALPERN, D. 1974. VARIATIONS IN THE DENSITY FIELD DURING COASTAL UPWELLING. TETHYS 6:363-364.

HAMILTON, P.E. 1973. OREGON ESTUARIES. DIVISION OF STATE LANDS, SALEM, OREGON. 40 PP.

HAMILTON, P.E. 1977. THEORY OF COASTAL CURRENTS AND UPWELLING. IN: CURRENT RESEARCH ACTIVITIES OF THE DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON, REFERENCE A77-3, PP. 25-27.

HAMMOND, E.H. 1954. ANALYSIS OF PROPERTIES IN LAND FORM GEOGRAPHY: AN APPLICATION TO BROAD-SCALE LAND FORM MAPPING. MAP SUPPL. NO. 4, CLASSES OF LAND-SURFACE FORM IN THE FORTY-EIGHT STATES, U.S.A. ANN. ASSOC. AM. GEOG. 54:11-19.

HANSEN, R.A., AND LAWRENCE, W.H. 1970. THE IMPACT OF INTENSIVE FOREST MANAGEMENT ON BLACK-TAILED DEER POPULATION IN THE DOUGLAS-FIR REGION. PROCEEDINGS OF ANNUAL CONFERENCE, WESTERN ASSOCIATION OF STATE GAME AND FISH COMMISSIONS 50:420-429.

HARDING, L.W. JR., COX, J.L., AND PEQUEGNAT, J.E. 1978. SPRING - SUMMER PHYTOPLANKTON PRODUCTION IN HUMBOLT BAY, CALIFORNIA. CALIF. FISH GAME 64(1):53-59.

HARDY, A. 1956. THE OPEN SEA - THE WORLD OF PLANKTON. HOUGHTON MIFFLIN COMPANY, BOSTON, MASSACHUSETTS. 335 PP.

HARLETT, J.C., AND KULM, L.D. 1973. SUSPENDED SEDIMENT TRANSPORT ON THE NORTHERN OREGON CONTINENTAL SHELF. GEOL. SOC. AMER. BULL. 84:3815-3826.

HARPER, R.M. 1918. SOME DYNAMIC STUDIES OF LONG ISLAND VEGETATION. PLANT WORLD 21:38-46.

HARRIS, A.S., AND RUTH, R.H. 1970. SITKA SPRUCE - A BIBLIOGRAPHY WITH ABSTRACTS. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RES. PAPER PNW-105. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 251 PP.

HARRISON, P.G. 1977. DECOMPOSITION OF MACROPHYTE DETRITUS IN SEA WATER: EFFECTS OF GRAZING BY AMPHIPODS. OIKOS 28(2/3):165-169.

HARRISON, P.G., AND MANN, K.H. 1975. DETRITUS FORMATION FROM EELGRASS (ZOSTERA MARINA L.) THE RELATIVE EFFECTS OF FRAGMENTATION, LEACHING AND DECAY. LIMNOL. OCEANOGR. 20:924-934.

HART, J.L. 1973. PACIFIC FISHES OF CANADA. FISHERIES RESEARCH BOARD OF CANADA BULLETIN 180, OTTAWA, CANADA. 740 PP.

HATCH, M.H. 1971. THE BEETLES OF THE PACIFIC NORTHWEST. PART V. U. WASHINGTON PUBL. BIOL. 16:1-662.

HAY, C.J. 1977. BIBLIOGRAPHY ON ARTHROPODA AND AIR POLLUTION. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE GENERAL TECHNICAL REPORT NE-34. UPPER DARBY. 16PP.

HAYES, G.L. 1958. SILVICAL CHARACTERISTICS OF PORT-ORFORD-CEDAR. U.S. FOREST SERVICE, PNW SILVICAL SERIES NO. 7. 11 PP.

HEALD, E.J. 1969. THE PRODUCTION OF ORGANIC DETRITUS IN A SOUTH FLORIDA ESTUARY. PH.D. THESIS. UNIVERSITY OF MIAMI, CORAL GABLES, FLORIDA. 205 PP.

HEALD, R.J. 1969. THE PRODUCTION OF ORGANIC DETRITUS IN A GEORGIA SALT MARSH ECOSYSTEM. PH.D. THESIS. UNIVERSITY OF MIAMI, CORAL GABLES, FLORIDA. 110 PP.

HEDGPETH, J.W. 1957. ESTUARIES AND LAGOONS. II. BIOLOGICAL ASPECTS. IN: TREATISE ON MARINE ECOLOGY AND PALEOECOLOGY, VOLUME I, ECOLOGY (HEDGPETH, J.W., ED.), PP. 693-724. MEMOIR 67, GEOLOGICAL SOCIETY OF AMERICA, WASHINGTON, D.C.

HEDGPETH, J.W. 1976. ECOLOGICAL STUDIES OF WILLAPA BAY: A RESEARCH PROPOSAL. U.S. FISH AND WILDLIFE SERVICE, PORTLAND, OREGON. (CONTRACT NO. 14-16-0001-6042-RBS). 68 PP.

HEDGPETH, J.W. 1977. PERSONAL COMMUNICATION.

HEINLE, D.R., FLEMER, D.A., AND USTACH, J.F. 1976. CONTRIBUTION OF TIDAL MARSHLANDS TO MID-ATLANTIC ESTUARINE FOOD CHAINS. IN: ESTUARINE PROCESSES, VOL. 2, CIRCULATION, SEDIMENTS, AND TRANSFER OF MATERIAL IN THE ESTUARY (WILEY, M., ED.), PP. 309-320. ACADEMIC PRESS, NEW YORK, SAN FRANCISCO, LONDON.

HERRMAN, R.R. 1975. CONTINUOUS FLOW BIOASSAY STUDIES IN UPPER GRAYS HARBOR, 1974. IN: GRAYS HARBOR FISH TOXICITY STUDIES, PP. 14-92. WASHINGTON DEPARTMENT OF ECOLOGY, OLYMPIA, WASHINGTON.

HIBBERT, A.R. 1967. FOREST TREATMENT EFFECTS ON WATER YIELD. IN: INTERNATIONAL SYMPOSIUM OF FOREST HYDROLOGY (SOPPER, W.E., AND LULL, H.W., EDS.), PP. 527-543. PERGAMON PRESS, NEW YORK, NEW YORK.

HICKEY, J.J., AND ANDERSON, D.W. 1968. CHLORINATED HYDROCARBONS AND EGGSHELL CHANGES IN RAPTORIAL AND FISH-EATING BIRDS. SCIENCE 162:271-273.

HIRSCH, F. 1970. SPECIAL FOREST PRODUCTS - 1969 HARVESTING REPORT, OREGON AND WASHINGTON. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST REGION. 39 PP.

HITCHCOCK, C.L., AND CRONQUIST, A. 1973. FLORA OF THE PACIFIC NORTHWEST. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON. 730 PP.

HITCHCOCK, C.L., CRONQUIST, A., OWNBEY, M., AND THOMSPSON, J.W. 1955-1969. VASCULAR PLANTS OF THE PACIFIC NORTHWEST. 5 VOLUMES. UNIVERSITY OF WASINGTON PRESS, SEATTLE, WASHINGTON.

HOBSON, L.A. 1966. SOME INFLUENCES OF THE COLUMBIA RIVER ON MARINE PHYTOPLANKTON DURING JANUARY 1961. LIMNOL. OCEANOGR. 12:642-649.

HOFFNAGLE, J. (ED.), 1976. A COMPARATIVE STUDY OF SALT MARSHES IN THE COOS BAY ESTUARY. NAT. SCI. FOUND. STUDY, OREGON INSTITUTE OF MARINE BIOLOGY, CHARLESTON, OREGON. 334 PP.

HOFFNAGLE, J., AND OLSON, R. 1974. THE SALT MARSHES OF THE COOS BAY ESTUARY. OREGON INSTITUTE OF MARINE BIOLOGY, CHARLESTON, OREGON. 86 PP.

HOLDGATE, M.W., AND WACE, N.M. 1971. THE INFLUENCE OF MAN ON THE FLORAS AND FAUNAS OF SOUTHERN ISLANDS. IN: MAN'S IMPACT ON THE ENVIRONMENT (DETWYLER, T.R., ED.), PP. 476-492. MC GRAW - HILL BOOK CO., NEW YORK.

HOLLAND, G.A. 1977. INFORMATION ON COHO AND CHINOOK SALMON STOCKS ORIGINATING IN PUGET SOUND AND WASHINGTON COASTAL STREAMS NORTH OF THE COLUMBIA RIVER. INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION, BULLETIN NO. 36, PP. 25-35.

HOOD, L. 1977. INVENTORY OF CALIFORNIA NATURAL AREAS, VOL. I. CALIFORNIA NATURAL AREAS COORDINATING COUNCIL. 1505 SOBRE VISTA DRIVE, SONOMA, CALIFORNIA, 95426. UNPAGED.

HOOVEN, E.F. 1977. THE MOUNTAIN BEAVER IN OREGON, ITS LIFE HISTORY AND CONTROL. OREGON STATE UNIVERSITY, FOREST RESEARCH LABORATORY, RESEARCH PAPER 30, CORVALLIS, OREGON. 20 PP.

HOOVEN, E.F., AND BLACK, H.C. 1976. EFFECTS OF SOME CLEARCUTTING PRACTICES ON SMALL-MAMMAL POPULATIONS IN WESTERN OREGON. NORTHWEST SCIENCE 50:189-208.

HOPKINS, T.S. 1971. VELOCITY, TEMPERATURE, AND PRESSURE OBSERVATIONS FROM MOORED METERS ON THE SHELF NEAR THE COLUMBIA RIVER MOUTH, 1967-69. SPECIAL REPORT NO. 45, DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 143 PP.

HOWARD, J. 1974. CALIFORNIA FOREST INDUSTRY WOOD CONSUMPTION AND CHARACTERISTICS, 1972. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE BULL. PNW-52. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 91 PP.

HUBBELL, D.W., GLENN, J.L., AND STEVENS, H.H., JR. 1971. STUDIES OF SEDIMENT TRANSPORT IN THE COLUMBIA RIVER ESTUARY. PROCEEDINGS 1971 TECHNICAL CONFERENCE ON ESTUARIES OF THE PACIFIC NORTHWEST. CIRCULAR NO. 42, PP. 190-224. ENGINEERING EXPERIMENT STATION, OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

HUNT, J. AND DIMCOCK, E.J. 1957. PORT-ORFORD-CEDAR. A POOR RISK FOR REFORESTATION. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION RESEARCH NOTE NO. 139. PORTLAND, OREGON. 3 PP.

HUNT, L.M., AND GROVES, D.G. 1965. A GLOSSARY OF OCEAN SCIENCE AND UNDERSEA TECHNOLOGY TERMS. COMPASS PUBLICATIONS, INC., ARLINGTON, VIRGINIA. 173 PP.

HUYER, A. 1974. DISTRIBUTION OF THE COASTAL UPWELLING REGION OFF OREGON DURING 1972. PH.D. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 149 PP.

HUYER, A., HICKEY, B.M., SMITH, J.D., SMITH, R.L., AND PILLSBURY, R.D. 1975. ALONGSHORE COHERENCE AT LOW FREQUENCIES IN CURRENTS OBSERVED OVER THE CONTINENTAL SHELF OFF OREGON AND WASHINGTON. J. GEOPHYS. RES. 80(24):3495-3505.

IACOPI, R. 1964. EARTHQUAKE COUNTRY. LANE BOOKS, MENLO PARK, CALIFORNIA. 192 PP.

INCE, P.J. 1977. ESTIMATING EFFECTIVE HEATING VALUE OF WOOD OR BARK FUELS AT VARIOUS MOISTURE CONTENTS. U.S. FOREST SERVICE, FOREST PRODUCTS LABORATORY, GENERAL TECHNICAL REPORT. 8 PP.

INGLES, L.G. 1965. MAMMALS OF THE PACIFIC STATES. STANFORD UNIVERSITY PRESS, STANFORD, CALIFORNIA. 506 PP.

INGRAHAM, W.J. 1967. THE GEOSTROPHIC CIRCULATION AND DISTRIBUTION OF WATER PROPERTIES OF THE COASTS OF VANCOUVER ISLAND AND WASHINGTON, SPRING AND FALL 1963. FISHERY BULL. 66(2):223-250.

INMAN, D.L., AND BAGNOLD, R.A. 1963. BEACH AND NEARSHORE PROCESSES PART II. LITTORAL PROCESSES. IN: THE SEA, (HILL, M.N., ED.), VOL 3, PP. 529-553. INTERSCIENCE PUBLISHERS, A DIVISION OF JOHN WILEY AND SONS, NEW YORK, NEW YORK.

INMAN, D.L., AND QUINN, W.H. 1952. CURRENTS IN THE SURF ZONE. IN: PROCEEDINGS OF THE SECOND CONFERENCE ON COASTAL ENGINEERING, PP. 24-36. COUNCIL ON WAVE RESEARCH, UNIVERSITY OF CALIFORNIA, BERKELEY, CALIFORNIA.

INMAN, R.E. 1977. SILVICULTURAL BIOMASS FARMS. VOL 1. SUMMARY. MITRE CORPORATION AND GEORGIA PACIFIC CORPORATION, PORTLAND, OREGON. 62 P.

INTERNATIONAL PACIFIC HALIBUT COMMISSION. 1976. ANNUAL REPORT. INTERNATIONAL PACIFIC HALIBUT COMMISSION, SEATTLE, WASHINGTON. 40 PP.

INTERNATIONAL PACIFIC HALIBUT COMMISSION. 1978. THE PACIFIC HALIBUT: BIOLOGY, FISHERY AND MANAGEMENT. INTERNATIONAL PACIFIC HALIBUT COMMISSION, TECHNICAL REPORT 16, SEATTLE, WASHINGTON. 51 PP.

ISAAC, L.A. 1930. SEED FLIGHT IN THE DOUGLAS-FIR REGION. J. FORESTRY 28:492-499.

ISAKSON, J.S. 1976A. CRITICAL AREA STUDY, VOL. 2. MAMMALS, FINAL DRAFT REPORT. FOR STATE OF WASHINGTON, DEPARTMENT OF ECOLOGY BY MATHEMATICAL SCIENCES NORTHWEST, INC., BELLEVUE, WASHINGTON.

ISAKSON, J.S. 1976B. CRITICAL AREA STUDY, VOL. 4. FISH, FINAL DRAFT REPORT. FOR STATE OF WASHINGTON, DEPARTMENT OF ECOLOGY, BY MATHEMATICAL SCIENCES NORTHWEST, INC., BELLEVUE, WASHINGTON.

ISAKSON, J.S. 1976C. CRITICAL AREA STUDY, VOL. 5, INVERTEBRATES, FINAL DRAFT REPORT. FOR STATE OF WASHINGTON, DEPARTMENT OF ECOLOGY, BY MATHEMATICAL SCIENCES NORTHWEST, INC., BELLEVUE, WASHINGTON.

ISAKSON, J.S., AND REICHARD, T.A. 1976B. CRITICAL AREA STUDY. [6 VOLUMES]. MATHEMATICAL SCIENCES NORTHWEST - WASHINGTON DEPARTMENT OF ECOLOGY BASELINE STUDIES CONTRACT 76-099, VOLS. 1-6. BELLEVUE, WASHINGTON.

ISAAC, L.A. 1943. REPRODUCTIVE HABITS OF DOUGLAS FIR. CHARLES LATHRUP PACK FOUNDATION, WASHINGTON, D.C. 107 PP.

JACKMAN, S.M., AND SCOTT, J.M. 1975. LITERATURE REVIEW OF THE TWENTY-THREE SELECTED FOREST BIRDS OF THE PACIFIC NORTHWEST. COOPERATIVE WILDLIFE RESEARCH UNIT, LE GRANDE, OREGON. 382 PP.

JAHN, L.R., AND TREFETHEN, J.B. 1973. THE WATERSHED AS AN ECOSYSTEM. NATIONAL WATERSHED CONFERENCE, JUNE 30, 1973, WICHITA, KANSAS.

JAMES, G.A. 1958. PORT-ORFORD-CEDAR PLANTATIONS IN THE PACIFIC NORTHWEST. U.S. FOREST SERVICE, PNW RES. NOTE 164.

JAMES, W. 1970. A PHOTOGRAPHIC ANALYSIS OF OREGON ESTUARIES. ON FILE AT DEPARTMENT OF CIVIL ENGINEERING, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 112 PP.

JARVIS, R.A. 1964. PRIMARY PRODUCTION IN A FRESHWATER MARSH ECOSYSTEM. PH.D. THESIS. RUTGERS UNIVERSITY, NEW BRUNSWICK, NEW JERSEY.

JAWED, M. 1973A. AMMONIA EXCRETION BY ZOOPLANKTON AND ITS SIGNIFICANCE TO PRIMARY PRODUCTION DURING SUMMER. MAR. BIOL. 23:115-120.

JEFFERSON, C.A. 1974. PLANT COMMUNITIES AND SUCCESSION IN OREGON COASTAL SALT MARSHES. PH.D. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 192 PP.

JENKIN, P.M. 1937. OXYGEN PRODUCTION BY THE DIATOM COSCINODISCUS EXCENTRICUS EWR. IN RELATION TO SUBMARINE ILLUMINATION IN THE ENGLISH CHANNEL. J. MAR. BIOL. ASSOC. (U.K.) 22:301-343.

JEPSON, W.L. 1910. THE SILVA OF CALIFORNIA. VOL. 2. 480 PP.

JEPSON, W.L. 1923. TREES OF CALIFORNIA. 2ND ED. SATHER GATE BOOK SHOP, BERKELEY, CALIFORNIA. 240 PP.

JOHANNESSEN, C.L. 1964. MARSHES PROGRADING IN OREGON: AERIAL PHOTOGRAPHS. SCIENCE 146:1575-1578.

JOHNSON, H. 1917. ALNUS OREGONA: ITS VALUE AS A FOREST TYPE ON THE SIUSLAW NATIONAL FOREST. J. FORESTRY 15:981-987.

JOHNSON, H., HANZLIK, E.J., AND GIBBONS, W.H. 1926. RED ALDER OF THE PACIFIC NORTHWEST. ITS UTILIZATION, WITH NOTES ON GROWTH AND MANAGEMENT. U.S. DEPARTMENT OF AGRICULTURE BULLETIN 1437. WASHINGTON, D.C. 46 PP.

JOHNSON, J.W., MOORE, J.T., AND ORRETT, F.B. 1971. SUMMARY OF THE ANNUAL WAVE POWER FOR TEN DEEP WATER STATIONS ALONG THE CALIFORNIA, OREGON AND WASHINGTON COASTS. UNIVERSITY OF CALIFORNIA HYDRAULIC ENGINEERING LABORATORY TECHNICAL REPORT HEL-24-9, BERKELEY, CALIFORNIA. 241 PP.

JOHNSON, R., AND JONES, D. (TECHNICAL COORDINATORS). 1977. IMPORTANCE, PRESERVATION AND MANAGEMENT OF RIPARIAN HABITAT: A SYMPOSIUM. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, GENERAL TECHNICAL REPORT RM-43, FORT COLLINS, COLORADO. 217 PP.

KEEFE, C.W. 1972. MARSH PRODUCTION: A SUMMARY OF THE LITERATURE. CONTR. MAR. SCI. 16:163-180.

KELLER, M. 1963. GROWTH AND DISTRIBUTION OF EELGRASS (Z. MARINA L.) IN HUMBOLDT BAY, CALIFORNIA. M.S. THESIS. HUMBOLDT STATE COLLEGE, ARCATA, CALIFORNIA. 53 PP.

KENYON, K.W. 1969. THE SEA OTTER IN THE EASTERN PACIFIC OCEAN. NORTH AMERICAN FAUNA. NO. 68, BUREAU OF SPORT FISHERIES AND WILDLIFE, WASHINGTON, D.C. 352 PP.

KENYON, K.W. 1971. THE EFFECTS OF OIL POLLUTION ON MARINE MAMMALS. BUREAU OF SPORT FISHERIES AND WILDLIFE, MARINE MAMMAL SUBSTATION, SEATTLE, WASHINGTON. 9 PP.

KIMMINS, J.P., AND KRUMLIK, G.J. 1976. ON THE QUESTION OF NUTRIENT LOSSES ACCOMPANYING WHOLE TREE LOGGING IN OSLO BIOMASS STUDIES. IUFRO BIOMASS STUDIES, PP. 42-53, UNIVERSITY OF MAINE, ORONO, MAINE.

KING, J., AND SANGER, G. 1977. AN OIL VULNERABILITY INDEX FOR MARINE ORIENTED BIRDS (DRAFT). U.S. FISH AND WILDLIFE SERVICE, JUNEAU, ALASKA. (UNPUBLISHED). 22 PP.

KING, R. 1977. PERSONAL COMMUNICATION.

KIRBY, C.J. 1972. THE ANNUAL NET PRIMARY PRODUCTION AND DECOMPOSITION OF THE SALT MARSH GRASS, SPARTINA ALTERNIFLORA LOISEL, IN BARATARIA BAY ESTUARY OF LOUISIANA. PH.D. THESIS. LOUISIANA STATE UNIVERSITY, BATON ROUGE, LOUISIANA.

KLINGEMAN, P.C., ET AL. 1969. COASTAL PROCESSES - OREGON COASTAL LITTORAL DRIFT, MARINE GEOTECHNIQUE, PRELIMINARY STUDY, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. MIMEOGRAPH (CLASS PAPERS FOR CE572).

KNAPP, J.B., AND JACKSON, A.G. 1914. WESTERN RED CEDAR IN THE PACIFIC NORTHWEST. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, WASHINGTON, D.C.

KOEBIG AND KOEBIG, INC. 1975. HUMBOLDT BAY MASTER PLAN. HUMBOLDT BAY HARBOR, RECREATION AND CONSERVATION DISTRICT.

KOHLER, M.A., NORDENSON, T.S., AND BAKER, D.R. 1959. EVAPORATION MAPS FOR THE UNITED STATES. U.S. WEATHER BUREAU TECHNICAL PAPER NO. 37. DEPARTMENT OF COMMERCE, WASHINGTON, D.C. 137 PP.

KOMAR, P.D. 1971. NEARSHORE CELL CIRCULATION AND THE FORMATION OF GIANT CUSPS. GEOL. SOC. AMER. BULL. 82:2643-2650.

KOMAR, P.D. 1977. BEACH PROFILES OBTAINED WITH AN AMPHIBIOUS DUCK ON THE OREGON AND WASHINGTON COASTS. THE ORE BIN 39:169-180.

KOMAR, P.D., AND REA, C. 1976. BEACH EROSION ON SILETZ SPIT, OREGON. ORE BIN 38(8):119-134.

KOMAR, P.D., LIZARRAGA-ARCINIEGA, J.R., AND TERICH, T.A. 1976A. OREGON COAST SHORELINE CHANGES DUE TO JETTIES. J. WATERWAYS HARBORS COASTAL ENGINEER. DIV. 102 (NO. WW1), PP. 13-30.

KOMAR, P.D., NEUDECK, R.H., AND KULM, L.D. 1972. OBSERVATIONS AND SIGNIFICANCE OF DEEP-WATER OSCILLATORY RIPPLE MARKS ON THE OREGON CONTINENTAL SHELF. IN: SHELF SEDIMENT TRANSPORT (SWIFT, D.J.P., DUANE, D.B., AND PILKEY, O.H., EDS.), PP. 601-619. DOWDEN, HUTCHINSON AND ROSS, INC., STROUDSBURG, PA.

KOMAR, P.D., QUINN, W., CREECH, C., REA, C.C., AND LIZARRAGA-ARCINIEGA, J.R. 1976B. WAVE CONDITIONS AND BEACH EROSION ON THE OREGON COAST. ORE BIN 38(7):103-112.

KOPLIN, J. 1978. PERSONAL COMMUNICATION.

KORN, L. 1977. INFORMATION ON COLUMBIA RIVER SALMON RUNS AND FISHERIES. INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION, BULLETIN NO. 36, PP. 1-14.

KOZLOFF, E.N, 1973. SEASHORE LIFE OF PUGET SOUND, THE STRAIT OF GEORGIA, AND THE SAN JUAN ARCHIPELAGO. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON. 282 PP. + PLATES.

KRANTZ, G.W., WERNZ, J.W., JENSEN, H.I., AND SHIMABUKARO, R. 1973. ACARI, INSECTA, AND NEMATODA OF WATERSHED 10. H.J. ANDREWS EXPERIMENTAL FOREST, INTERNAL REPORT NO. 108, 1972 ANNUAL REPORT. PP.

KRENKEL, P.A., HARRISON, J., AND BURDICK, J.C. 1976. DREDGING AND ITS ENVIRONMENTAL EFFECTS. AMERICAN SOCIETY OF CIVIL ENGINEERS, NEW YORK. 1037 PP.

KRYGIER, E.E., AND HORTON, H.F. 1975. DISTRIBUTION, REPRODUCTION, AND GROWTH OF CRANGON NIGRICAUDA AND CRANGON FRANCISCORUM IN YAQUINA BAY, OREGON. NORTHWEST SCIENCE 49:216-1409

KÜCHLER, A.W. 1946. THE BROADLEAF DECIDUOUS FORESTS OF THE PACIFIC NORTHWEST. ANN. ASSOC. AM. GEOGR. 36:122-147.

KUHN, G.A., LEHR, R.D., BRICKLET, J.A., ZELENKA, J.E., SULLIVAN, A.M., YORK, M.K., AND OGBORN, D.R. (SPECIAL ECONOMIC STUDY TEAM OF THE OREGON COASTAL CONSERVATION AND DEVELOPMENT COMMISSION. 1974. ECONOMIC ANALYSIS AND PROFILE OF THE OREGON COASTAL ZONE. PACIFIC NORTHWEST REGIONAL COMMISSION, VANCOUVER, WASHINGTON, AND STATE OF OREGON, DEPARTMENT OF ECONOMIC DEVELOPMENT, SALEM, OREGON. PP. A1-J20.

KULM, L.D., AND BYRNE, J.V. 1966. SEDIMENTARY RESPONSE TO HYDROGRAPHY IN AN OREGON ESTUARY. MARINE GEOL. 4:85-118.

KULM, L.D., HEINRICHS, D.F., BUEHRIG, R.M., AND CHAMBERS, D.M. 1968. EVIDENCE FOR POSSIBLE PLACER ACCUMULATIONS ON THE SOUTHERN OREGON CONTINENTAL SHELF. ORE BIN 30(5):81-104.

KULM, L.D., ROUSH, R.C., HARLETT, J.C., NEUDECK, R.H., CHAMBERS, D.M., AND RUNGE, E.J. 1975. OREGON CONTINENTAL SHELF SEDIMENTATION: INTERRELATIONSHIPS OF FACIES DISTRIBUTION AND SEDIMENTARY PROCESSES. J. GEOL. 83:145-175.

LANE, R.K. 1965. CLIMATE AND HEAT EXCHANGE IN THE OCEANIC REGION ADJACENT TO OREGON. PH.D. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 115 PP.

LANGE, N.A. (ED.). 1956. HANDBOOK OF CHEMISTRY, 9TH ED. HANDBOOK PUBLISHERS, INC., SANDUSKY, OHIO. 1969 PP.

LARRISON, E.J. 1976. MAMMALS OF THE NORTHWEST. WASHINGTON, OREGON, IDAHO, AND BRITISH COLUMBIA. SEATTLE AUDUBON SOCIETY, SEATTLE, WASHINGTON. 256 PP.

LARSEN, L.H., AND FENTON, D.R. 1974. OBSERVATIONS OF WAVES IN THE NORTH PACIFIC. CONTRIBUTION NO. 770. DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY OF WASHINGTON, SEATTLE, WA. 18 PP.

LAUMAN, J.E. 1972. FISH AND WILDLIFE RESOURCES OF THE ROGUE BASIN, OREGON, AND THEIR WATER REQUIREMENTS. SUPPLEMENT, NOVEMBER, 1970. OREGON STATE GAME COMMISSION, PORTLAND, OREGON. 26 PP.

LAUMAN, J.E., SMITH, A.K., AND THOMPSON, K.E. 1972A. THE FISH AND WILDLIFE RESOURCES OF THE NORTH COAST BASIN, OREGON AND THEIR WATER REQUIREMENTS. SUPPLEMENT, APRIL, 1968. OREGON STATE GAME COMMISSION, PORTLAND, OREGON. 52 PP.

LAUMAN, J.E., THOMPSON, K.E., AND FORTUNE, J.D., JR. 1972B. FISH AND WILDLIFE RESOURCES OF THE UMPQUA BASIN, OREGON, AND THEIR WATER REQUIREMENTS. OREGON STATE GAME COMMISSION, PORTLAND, OREGON. 127 PP.

LAYCOCK, G. 1974. BALD EAGLES AT BAY. NATIONAL WILDLIFE 12:34-37.

LEAF, A.L., DAVEY, C.B., AND VOIGT, G.K. 1973. FOREST SOIL ORGANIC MATTER AND NUTRIENT ELEMENT DYNAMICS. IN: PROCEEDINGS OF THE FIRST SOIL MICROCOMMUNITIES CONFERENCE (DINDALL, D.L., ED.), PP. 33-46. U.S. ATOMIC ENERGY COMMISSION OFFICE OF INFORMATIONAL SERVICES, SPRINGFIELD, VIRGINIA. 285 PP.

LEBOEUF, B.J. 1971. OIL CONTAMINATION AND ELEPHANT SEAL MORTALITY: A NEGATIVE FINDING. IN: BIOLOGICAL AND OCEANOGRAPHICAL SURVEY OF THE SANTA BARBARA CHANNEL OIL SPILL, 1969-1970, VOLUME I, BIOLOGY AND BACTERIOLOGY (STRAUGHEN, D., EDITOR), PP. 277-285. ALLAN HANCOCK FOUNDATION, UNIVERSITY OF SOUTHERN CALIFORNIA, LOS ANGELES, CALIFORNIA.

LEEDY, D.L. 1975. HIGHWAY - WILDLIFE RELATIONSHIPS. VOL. 1. A STATE-OF-THE-ART REPORT. U.S. DEPARTMENT OF COMMERCE, WASHINGTON, D.C. 183 PP.

LEITH, H., AND BOX, E. 1972. EVAPOTRANSPIRATION AND PRIMARY PRODUCTIVITY: C.W. THORNTHWAITE MEMORIAL VOLUME. PAPER PRESENTED AT THORNTHWAITE MEMORIAL SYMPOSIUM, INTERNATIONAL GEOPHYSICAL CONGRESS, 1972, MONTREAL, CANADA.

LEWIN, J. 1978. THE WORLD OF THE RAZOR-CLAM BEACH. PACIFIC SEARCH 12(6):12-13.

LEWIN, J., AND NORRIS, R.E. 1970. SURF ZONE DIATOMS OF THE COASTS OF WASHINGTON AND NEW ZEALAND (CHAETOCEROS ARMATUM T. WEST AND ASTERIONELLA SPP.). PHYCOLOGIA 9(2):143-149.

LEWIN, J., AND RAO, V.N.R. 1975. BLOOMS OF SURF ZONE DIATOMS ALONG THE COAST OF THE OLYMPIC PENINSULA, WASHINGTON: VI. DAILY PERIODICITY PHENOMENA ASSOCIATED WITH CHAETOCEROS ARMATUM IN ITS NATURAL HABITAT. J. PHYCOL. 11(3):330-338.

LEWIS, G.B. 1977. OCCURRENCE OF CHAETOCEROS ARMATUM ON THE PACIFIC NORTHWEST COAST AND ITS ASSOCIATION WITH SILIQUA PATULA. PERSONAL COMMUNICATION OF UNPUBLISHED DATA AND OBSERVATIONS. REPORT OF OCTOBER 28, 1977, BY GARY B. LEWIS.

LINDEMAN, R.L. 1942. THE TROPHIC-DYNAMIC ASPECT OF ECOLOGY. ECOLOGY 23:399-418.

LINDQUIST, J.L., AND PALLEY, M.N. 1961. LIFE CURVES FOR YOUNG-GROWTH COASTAL REDWOOD. UNIVERSITY OF CALIFORNIA SCHOOL OF FORESTRY, CALIFORNIA FORESTRY AND FOREST PRODUCTS NOTE 29. UNIVERSITY OF CALIFORNIA, BERKELEY, CALIFORNIA. 4 PP.

LINDZEY, F.G., AND MESLOW, E.C. 1977. HOME RANGE AND HABITAT USE BY BLACK BEARS IN SOUTHWESTERN WASHINGTON. J. WILDLIFE MANAG. 41(3):413-425.

LITTLE, E.L., JR. 1975. RARE AND LOCAL CONIFERS OF THE UNITED STATES. CONSERVATION RESEARCH REPORT NO. 19. U.S. DEPARTMENT OF AGRICULTURE FORESTSERVICE, WASHINGTON, D.C. 25 PP.

LOEHR, L.C., AND ELLINGER, E. 1974. A DESCRIPTION OF THE OCEANOGRAPHIC ENVIRONMENT OF THE WASHINGTON COAST AND THE STRAIT OF JUAN DE FUCA. UNIVERSITY OF WASHINGTON, DEPARTMENT OF OCEANOGRAPHY, AND WASHINGTON STATE SEA GRANT, PREPARED FOR THE OCEANOGRAPHIC INSTITUTE OF WASHINGTON. 146 PP. WITH APPENDIX.

LONGHURST, W.M., STARKER, L.A., AND DASMANN, R.F. 1952. A SURVEY OF CALIFORNIA DEER HERDS. THEIR RANGES AND MANAGEMENT PROBLEMS. CALIF. DEPART. FISH GAME BULL. 6. 136 PP.

LOTT, H.C. 1923. THE PRODUCTIVITY AND VIABILITY OF REDWOOD (SEQUOIA SEMPERVIRENS) SEED. M.S. THESIS, UNIVERSITY OF CALIFORNIA, BERKELEY, CALIFORNIA.

LOUGH, R.G. 1974. DYNAMICS OF CRAB LARVAE (ANOMURA, BRACHYURA) OFF THE CENTRAL OREGON COAST, 1969-1970. PH.D. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 318 PP. [ABSTRACTED IN: (1) SEA GRANT PUBL. ORESU-XI-74-003, (2) DISSERT. ABSTR. INT. SEC. B, 35/7:3478.]

LOY, W., ALLAN, S., PATTON, C.P., AND PLANK, R.D. 1976. ATLAS OF OREGON. UNIVERSITY OF OREGON, EUGENE, OREGON. 215 PP.

LYSONS, H.H., AND WELLBURN, G.V. 1976. PLANNING MOUNTAIN LOGGING ON THE NORTH AMERICAN WEST COAST. PROCEEDINGS XVI, TUFRO WORLD CONGRESS, PP. 100-117.

MACDONALD, K.B. 1969. QUANTITATIVE STUDIES OF SALT MARSH MOLLUSC FAUNAS FROM THE NORTH AMERICAN PACIFIC COAST. ECOLOGICAL MONOGR. 39:33-60.

MACGINITIE, G.W. 1935. ECOLOGICAL ASPECTS OF A CALIFORNIA MARINE ESTUARY. AMER. MIDL. NAT. 16:629-765.

MACKAY, D.G.C. 1942. THE PACIFIC EDIBLE CRAB, CANCER MAGISTER. J. FISH. RES. BOARD, CANADA 6?:1-32.

MACKERRAS, I.M. (ED.) 1970. THE INSECTS OF AUSTRALIA. MELBOURNE UNIVERSITY PRESS, MELBOURNE, AUSTRALIA. 1029 PP.

MACNAE, W. 1966. MANGROVES IN EASTERN AND SOUTHERN AUSTRALIA. AUSTRALIAN J. BOTANY 14:67-104.

MAGWIRE, C. 1976A. SURVEY OF BIRD SPECIES IN AND AROUND THE SALT MARSHES OF THE COOS BAY ESTUARY. IN: COMPARATIVE STUDY OF SALT MARSHES OF THE COOS BAY ESTUARY (HOFFNAGLE, J., ED.), PP. 177-189. OREGON INSTITUTE OF MARINE BIOLOGY, CHARLESTON, OREGON.

MAGWIRE, C. 1976B. MAMMAL POPULATIONS OF THE COOS BAY SALT MARSHES. IN: COMPARATIVE STUDY OF SALT MARSHES OF THE COOS BAY ESTUARY (HOFFNAGLE, J., ED.), PP. 191-200. OREGON INSTITUTE OF MARINE BIOLOGY, CHARLESTON, OREGON.

MAHNKEN, C., AND JOYNER, T. 1973. PART III: DEVELOPING A COASTAL FISHERY FOR PACIFIC SALMON. MARINE FISH. REV. 35, NO. 10.

MANN, K.H. 1973. SEAWEEDS: THEIR PRODUCTIVITY AND STRATEGY FOR GROWTH. SCIENCE 182:975-981.

MARSHALL, D.B. 1969. ENDANGERED PLANTS AND ANIMALS OF OREGON - III. BIRDS. AGRICULTURE EXPERIMENT STATION, SPECIAL REPORT NO. 278. OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

MARTIN, A.C., ZIM, H.S., AND NELSON, A.L. 1961. AMERICAN WILDLIFE AND PLANTS--A GUIDE TO WILDLIFE FOOD HABITS. DOVER PUBLICATIONS, INC., NEW YORK, NEW YORK. 500 PP.

MARTIN, R.M. 1976. A THEORETICAL BASIS FOR MEASURING THE SOCIAL VALUE OF SALT MARSH. IN: COMPARATIVE STUDY OF SALT MARSHES OF THE COOS BAY ESTUARY (HOFFNAGLE, J., ED.), PP. 305-330, OREGON INSTITUTE OF MARINE BIOLOGY, CHARLESTON, OREGON.

MARTS, M. 1976. COASTAL ZONE HAZARD PROJECT DRAFTS, WASHINGTON AND OREGON. IN: COASTAL ZONE HAZARDS HANDBOOK (WHITE, ED.), BASIC DRAFTS. 8 PP. (UNPUBLISHED).

MARX, D.H. 1969. THE INFLUENCE OF ECTOTROPHIC MYCORRHIZAL FUNGI ON THE RESISTANCE OF PINE ROOTS TO PATHOGENIC INFECTIONS. PHYTOPATHOLOGY 59:411-417.

MARX, D.H., BRYAN, W.C., AND DAVEY, C.B. 1970. INFLUENCE OF TEMPERATURE ON ASEPTIC SYMBIOSIS OF ECTOMYCORRHIZAE BY THELEPHRA TENESTRIS AND PISOLITHUS TINTORIUS ON LOBLOLLY PINE. FOREST SCIENCE 16:424-431.

MASER, C., MATE, B.R., FRANKLIN, J.F., AND DYRNESS, C.T. 1977. NATURAL HISTORY OF OREGON COAST MAMMALS. UNPUBLISHED DRAFT MS. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON.

MASON, M.A. 1953. SURFACE WATER WAVE THEORIES. TRANS. AM. SOC. CIVIL ENG. 18:569.

MASSOGLIA, M.F. 1977. RECOMMENDATIONS FOR BASELINE RESEARCH IN WASHINGTON AND OREGON RELATIVE TO OFFSHORE RESOURCE DEVELOPMENT--CONFERENCE/WORKSHOP PROCEEDINGS, DECEMBER, 1976, PORTLAND, OREGON. THE RESEARCH TRIANGLE INSTITUTE, P.O. BOX 12194, RESEARCH TRIANGLE PARK, NORTH CAROLINA 27709. CONTRACT NO. AA550-CT6-54, FOR THE BUREAU OF LAND MANAGEMENT, U.S. DEPARTMENT OF THE INTERIOR. WASHINGTON, D.C. 308 PP.

MCARDLE, R.E., AND MEYER, W.H. 1930. THE YIELD OF DOUGLAS-FIR IN THE PACIFIC NORTHWEST. U.S. DEPARTMENT OF AGRICULTURE TECHNICAL BULL. NO. 201. WASHINGTON, D.C. 64 PP.

MCCONNAUGHEY, E.A. 1973. COOS BAY STUDY: AN INTERDISIPLINARY STUDY OF MAN AND THE ESTUARY. THESIS. NSF STUDENT-ORIGINATED PROJECT. UNIVERSITY OF OREGON, EUGENE, OREGON. 205 PP.

MCGARY, N.B. 1971. AN ATLAS OF THE COLUMBIA RIVER EFFLUENT AND ITS DISTRIBUTION AT SEA. SPECIAL REPORT NO. 47, U.S. ATOMIC ENERGY COMMISSION CONTRACT (AT945-1)-2225. DEPARTMENT OF OCEANOGRAPHY. UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 57 PP.

MCHARG, I.L. 1969. DESIGN WITH NATURE. DOUBLEDAY/NATURAL HISTORY PRESS, DOUBLEDAY AND CO., INC., GARDEN CITY, NEW YORK. 198 PP.

MCMANUS, D.A. 1964. MAJOR BATHYMETRIC FEATURES NEAR THE COAST OF OREGON, WASHINGTON, AND VANCOUVER ISLAND. NORTHWEST SCIENCE 38:65-82.

MCMINN, R.G. 1960. WATER RELATION AND FOREST DISTRIBUTION IN DOUGLAS-FIR REGION ON VANCOUVER ISLAND. FOREST BIOLOGICAL DIVISION, CANADA DEPARTMENT OF AGRICULTURE PUBLICATION 1091. OTTAWA, CANADA. 71 PP.

MCROY, C.P. 1966. THE STANDING STOCK AND ECOLOGY OF EELGRASS, ZOSTERA MARINA, IZEMBEK LAGOON, ALASKA. M.S. THESIS. UNIV. WASHINGTON, SEATTLE. 138 PP.

MCROY, C.P. 1974. SEAGRASS PRODUCTIVITY: CARBON UPTAKE EXPERIMENTS IN EELGRASS, ZOSTERA MARINA. AQUACULTURE 4(2):131-137.

MCROY, C.P. AND PHILLIPS, R.C. 1968. SUPPLEMENTARY BIBLIOGRAPHY ON EELGRASS, ZOSTERA MARINA. U.S. FISH WILDL. SERV. SPEC. SCI. REP., WILDL. NO. 114. 14 PP.

MCROY, C.P., AND GOERING, J.J. 1974. NUTRIENT TRANSFER BETWEEN SEAGRASS ZOSTERA MARINA AND ITS EPIPHYTES. NATURE (LONDON) 248:173-174.

MCROY, C.P., GOERING, J.J., AND CHANEY, B. 1973. NITROGEN FIXATION ASSOCIATED WITH SEAGRASSES. LIMNOL. OCEANOGR. 18:998-1002.

MEADE, E. 1971. INDIAN ROCK CARVINGS OF THE PACIFIC NORTHWEST. GRAYS PUBLISHING LTD., SYDNEY, B.C., CANADA. 96 PP.

MENARD, H.W. 1964. MARINE GEOLOGY OF THE PACIFIC. MCGRAW-HILL BOOK COMPANY, SAN FRANCISCO, CALIFORNIA. 271 PP.

MERRIL, A.H. 1953. THAR SHE GROWS. REDWOOD LOG 6(5):1-2. (HAMMOND LUMBER CO., SAMOA, CALIFORNIA).

MESLOW, E.C., AND WIGHT, H.M. 1975. AVIFAUNA AND SUCCESSION IN DOUGLAS-FIR FORESTS OF THE PACIFIC NORTHWEST. U.S. DEPARTMENT OF AGRICULTURE, GENERAL TECHNICAL REPORT WO-1 (SMITH, R.D., ED.). PRESENTED AT THE SYMPOSIUM ON MANAGEMENT OF FOREST AND RANGE HABITATS, TUCSON, ARIZONA, MAY, 1975. PP. 266-270.

METCALF, W. 1924. ARTIFICIAL REPRODUCTION OF REDWOOD (SEQUOIA SEMPERVIRENS). J. FORESTRY 22:873-893.

MEURISSE, R.T. 1972. THE QUALITY OF WESTERN HEMLOCK AND CHEMICAL CHARACTERISTICS OF SOME WESTERN OREGON ANDIC SOILS. PH.D. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

MEURISSE, R.T., AND YOUNGBERG, C.T. 1971. SOIL - VEGETATION SURVEY AND SITE CLASSIFICATION REPORT FOR TILLAMOOK AND MUNSON FALLS TREE FARMS. OREGON STATE UNIVERSITY DEPARTMENT OF SOILS, REPORT TO PUBLISHERS PAPER CO. (CORVALLIS, OREGON), 116 PP.

MILNE, L.J., AND MILNE, M.J. 1951. THE EELGRASS CATASTROPHY. SCI. AMER. 184 (1):52-55.

MILTON, B., AND MURRAY, S. 1972. MATURE DOUGLAS-FIR FOREST. AUDUBON FIELD-NOTES 26:987-988.

MOEN, A.N. 1973. WILDLIFE ECOLOGY, AN ANALYTICAL APPROACH. W.H. FREEMAN AND COMPANY, SAN FRANCISCO, CALIFORNIA. 458 PP.

MONROE, G.M. 1973. THE NATURAL RESOURCES OF HUMBOLDT BAY. COASTAL WETLAND SERIES NO. 6, CALIFORNIA STATE FISH AND GAME COMMISSION, STATE OF CALIFORNIA, SACRAMENTO, CALIFORNIA. 160 PP.

MONTGOMERY, JAMES M., CONSULTING ENGINEERS, INC. 1976. FOREST HARVEST, RESIDUE TREATMENT, REFORESTATION AND PROTECTION OF WATER QUALITY. U.S. ENVIRONMENTAL PROTECTION AGENCY, SEATTLE, WASHINGTON. 273 PP.

MOOERS, C.N.K., BOGERT, L.M., SMITH, R.L., AND PATTULLO, J.G. 1968. A COMPILATION OF OBSERVATIONS FROM MOORED CURRENT METERS AND THERMOGRAPHS (AND OF COMPLEMENTARY OCEANOGRAPHIC AND ATMOSPHERIC DATA). VOL. II., AUG-SEPT., 1966. OREGON STATE UNIVERSITY, DEPARTMENT OF OCEANOGRAPHY DATA REPORT 30, REF. 68-5. 98 PP.

MOORE, A.W. 1949. FOREST TREE-SEED-EATERS AND METHODS USED TO MEASURE THEIR POPULATIONS IN THE PACIFIC NORTHWEST DOUGLAS-FIR REGION. UNIVERSITY OF WASHINGTON FOREST CLUB QUARTERLY 23(1):7-11,25.

MOORE, S.F., GARY, R., CHIRLIN, C., AND BRADLY, P. 1974. POTENTIAL BIOLOGICAL EFFECTS OF HYPOTHETICAL OIL DISCHARGES IN THE ATLANTIC COAST AND GULF OF ALASKA. REPORT TO COUNCIL ON ENVIRONMENTAL QUALITY. MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASSACHUSETTS. 121PP.

MORELAND/UNRUH/SMITH, ARCHITECTS AND PLANNERS. 1975. RESOURCE ANALYSIS OF OREGONS COASTAL UPLANDS. OREGON COASTAL CONSERVATION AND DEVELOPMENT COMMISSION, SALEM, OREGON. 204 PP.

MORGAN, A.R., AND GERLACH, A.R. 1950. STRIPED BASS STUDIES ON COOS BAY, OREGON, IN 1949 AND 1950. OREGON FISH COMMISSION CONTRIBUTION NO. 14. 31 PP.

MORGAN, J.B., AND HOLTON, R.L. 1977. A BIBLIOGRAPHY OF ESTUARINE RESEARCH IN OREGON. OREGON ESTUARINE RESEARCH COUNCIL PUBLICATION NO. 1. 141 PP.

MORGAN, M.H. 1961. ANNUAL ANGIOSPERM PRODUCTION ON A SALT MARSH. M.S. THESIS. UNIVERSITY OF DELAWARE, NEWARK, DELAWARE. 205 PP.

MORING, J. 1975. THE ALSEA WATERSHED STUDY: EFFECT OF LOGGING ON THE AQUATIC RESOURCES OF THREE HEADWATER STREAMS OF THE ALSEA RIVER, OREGON. FISHERY RES. REP. NO. 9. OREGON DEPARTMENT OF FISH AND WILDLIFE, CORVALLIS, OREGON,

MORRIS, W. (ED.). 1976. THE AMERICAN HERITAGE DICTIONARY OF THE ENGLISH LANGUAGE. HOUGHTON MIFFLIN CO., BOSTON, MASSACHUSETTS. 1550 PP.

MORSE, B.A., GROSS, M.G., AND BARNES, C.A. 1968. MOVEMENT OF SEABED DRIFTERS NEAR THE COLUMBIA RIVER. PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS, JOURNAL OF THE WATERWAYS AND HARBORS DIVISION, VOL. 94(WWI):93-103.

MOYLE, P.B. 1976 . INLAND FISHES OF CALIFORNIA. UNIVERSITY OF CALIFORNIA PRESS, BERKELEY AND LOS ANGELES, CALIFORNIA. 405 PP.

MUDD, D.R., AND SMITH, J.L. 1976. IMPACT OF DREDGING ON THE MAMMALIAN FAUNA IN GRAYS HARBOR. IN: MAINTENANCE DREDGING AND THE ENVIRONMENT OF GRAYS HARBOR, WASHINGTON (ACOE, 1976-1977), APPENDIX I, 47 PP. U.S. ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT.

NAGLE, J.S. 1965. DISTRIBUTIONAL ASPECTS OF THE CAPE COD EELGRASS EPIBIOTA. BIOL. BULL. 129:417-418.

NATIONAL MARINE CONSULTANTS. 1960. WAVE STATISTICS FOR SEVEN DEEP WATER STATIONS ALONG THE CALIFORNIA COAST. PREPARED FOR THE U.S. ARMY CORPS OF ENGINEERS, LOS ANGELES AND SAN FRANCISCO DISTRICTS. CONTRACT NO. DA-04-353-CIVENG-39-160. SANTA BARBARA, CALIFORNIA. 118 PP.

NATIONAL MARINE CONSULTANTS. 1961A. WAVE STATISTICS FOR TWELVE MOST SEVERE STORMS AFFECTING THREE SELECTED STATIONS OFF THE COAST OF WASHINGTON AND OREGON, DURING THE PERIOD OF 1950-1960. PREPARED FOR THE U.S. ARMY CORPS OF ENGINEERS, SEATTLE AND PORTLAND DISTRICTS. SANTA BARBARA, CALIFORNIA. 20 PP.

NATIONAL MARINE CONSULTANTS. 1961B. WAVE STATISTICS FOR THREE DEEP WATER STATIONS ALONG THE OREGON-WASHINGTON COAST. PREPARED FOR THE U.S. ARMY CORPS OF ENGINEERS, SEATTLE AND PORTLAND DISTRICTS. CONTRACT NO. DA-35-026-CIVENG-61-33. SANTA BARBARA, CALIFORNIA. 59 PP.

NATURE CONSERVANCY, THE. 1977. WESTERN OREGON DATA SUMMARIES - NATURAL HERITAGE PROGRAM. OREGON STATE NATURAL HERITAGE PROGRAM, PORTLAND, OREGON. UNPAGED.

NATURE CONSERVANCY--SEE.....NATURE CONSERVANCY, THE.

NEAL, V.T. 1972. PHYSICAL ASPECTS OF THE COLUMBIA RIVER AND ITS ESTUARY. IN: THE COLUMBIA RIVER ESTUARY AND ADJACENT OCEAN WATERS: BIOENVIRONMENTAL STUDIES (PRUTER, A.T., AND ALVERSON, D.L., EDS.), PP. 19-40. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON.

NEAL, V.T. 1977. RECOMMENDATIONS ESTUARIES SUBGROUP. IN: CONFERENCE/WORKSHOP PROCEEDINGS, RECOMMENDATIONS FOR BASELINE RESEARCH IN WASHINGTON AND OREGON RELATIVE TO OFFSHORE DEVELOPMENT, PP. 165-171. RESEARCH TRIANGLE INSTITUTE, RESEARCH TRIANGLE PARK, NORTH CAROLINA.

NEELY, W.W. 1962. SALINE SOILS AND BRACKISH WATER IN MANAGEMENT OF WILDLIFE, SHRIMP AND FISH. TRANS. N. AM. WILDLIFE CONF. 27:321-334.

NEHLS, H.B., MCQUEEN, L.B., AND SCHULTZ, Z. 1975. FAMILIAR BIRDS OF NORTHWEST SHORES AND WATERS, COVERING BIRDS FOUND WEST OF THE CASCADE MOUNTAINS IN NORTHERN CALIFORNIA, OREGON, WASHINGTON, AND SOUTHWESTERN BRITISH COLUMBIA. PORTLAND AUDOBON SOCIETY, PORTLAND, OREGON. 96 PP.

NEIL, P.H., HOFFMAN, R.W., AND GILL, R.B. 1975. EFFECTS OF HARASSMENT ON WILD ANIMALS - AN ANNOTATED BIBLIOGRAPHY OF SELECTED REFERENCES. COLORADO DIVISION OF WILDLIFE, BOULDER, COLORADO. 21 PP.

NEWELL, R. 1964. THE ROLE OF DETRITUS IN THE NUTRITION OF TWO MARINE DEPOSIT FEEDERS, THE PROSOBRANCH HYDROBIA ULVAE AND THE BIVALVE MACOMA BALTHICA. PROC. ZOOL. SOC. 144:25-46.

NEWTON, M., ELHASSEN, B.A., AND ZAVITKOUSKY, J. 1968. ROLE OF RED ALDER IN WESTERN OREGON FOREST SUCCESSION. P. 73-84 IN: BIOLOGY OF ALDER (TRAPP, J.M., ET AL., EDS.). U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON.

NEWTON, M., AND NORGREN, J.A. 1977. SILVICULTURAL CHEMICALS AND PROTECTION OF WATER QUALITY. U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION 10, SEATTLE, WASHINGTON. 224 PP.

NIXON, S.W., AND OVIATT, C.A. 1973. ECOLOGY OF A NEW ENGLAND SALT MARSH. ECOL. MONOGR. 43:463-498.

NOAA--SEE.....U.S. DEPARTMENT OF COMMERCE. NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION.)

NORTH PACIFIC FUR SEAL COMMISSION. 1975. NORTH PACIFIC FUR SEAL COMMISSION REPORT ON INVESTIGATIONS FROM 1967 THROUGH 1972. NORTH PACIFIC FUR SEAL COMMISSION, WASHINGTON, D.C. 212 PP.

NORTHWEST ENVIRONMENTAL CONSULTANTS. 1974. ENVIRONMENTAL EVALUATION OF THE WILLAPA RIVER AND HARBOR NAVIGATION PROJECT, PACIFIC COUNTY, WASHINGTON. U.S. ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT, CONTRACT NO. DACW67-74-C-0156. SEATTLE, WASHINGTON. 126 PP + APPENDICES.

NORTHWEST ENVIRONMENTAL CONSULTANTS. 1975. THE TIDAL MARSHES OF JEFFERSON COUNTY, WASHINGTON. JEFFERSON COUNTY PLANNING DEPARTMENT, PORT TOWNSEND, WASHINGTON. 94 PP.

NOWAK, R.M. 1976. THE COUGAR IN THE UNITED STATES AND CANADA. U.S. FISH AND WILDLIFE SERVICE, WASHINGTON, D.C. 190 PP.

NYE, P.H., AND GREENLAND, D.J. 1960. THE SOIL UNDER SHIFTING CULTIVATION. COMM. BUREAU SOILS TECHNICAL COMMUNICATION NO. 51.

OCCDC--SEE.....OREGON COASTAL CONSERVATION AND DEVELOPMENT COMMISSION.

OCEANOGRAPHIC INSTITUTE OF WASHINGTON. 1974. OFFSHORE PETROLEUM TRANSFER SYSTEMS FOR WASHINGTON STATE. SUBMITTED TO THE 44TH LEGISLATURE BY THE OCEANOGRAPHIC COMMISSION OF WASHINGTON, SEATTLE, WASHINGTON. 458 PP.

OCEANOGRAPHIC INSTITUTE OF WASHINGTON. 1977. A SUMMARY OF KNOWLEDGE OF THE OREGON AND WASHINGTON COASTAL ZONE AND OFFSHORE AREAS. VOLS. I, II, AND III. OCEANOGRAPHIC INSTITUTE OF WASHINGTON FOR THE BUREAU OF LAND MANAGEMENT, U.S. DEPARTMENT OF THE INTERIOR. VAR. PP.

ODUM, E.P. 1959. FUNDAMENTALS OF ECOLOGY. 2ND ED. SAUNDERS, PHILADELPHIA, PENNSYLVANIA. 546 PP.

ODUM, E.P. 1961. THE ROLE OF TIDAL MARSHES IN ESTUARINE PRODUCTION. CONSERVATIONIST 15:12-13.

ODUM, E.P. 1971. FUNDAMENTALS OF ECOLOGY. THIRD ED. W.B. SAUNDERS CO., PHILADELPHIA, LONDON, TORONTO. 574 PP.

ODUM, E.P. 1974. HALOPHYTES, ENERGETICS, AND ECOSYSTEMS. IN: ECOLOGY OF HALOPHYTES (REIMOLD, R.J., AND QUEEN, W.H., EDS.), PP. 599-602. ACADEMIC PRESS, NEW YORK, NEW YORK.

ODUM, E.P., CONNELL, C.E., AND DAVENPORT, L.B. 1962. POPULATION ENERGY FLOW OF THREE PRIMARY CONSUMER COMPONENTS OF OLD-FIELD ECOSYSTEMS. ECOLOGY 43:88-96.

ODUM, E.P., AND DE LA CRUZ, A. 1967. PARTICULATE ORGANIC DETRITUS IN A GEORGIA SALT MARSH-ESTUARINE ECOSYSTEM. IN: CONFERENCE ON ESTUARIES, JEKYLL ISLAND, 1964 (LAUFF, G., ED.), PP. 383-388. AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, PUBLICATION NO. 83. WASHINGTON, D.C.

ODUM, E.P., AND SMALLEY, A.E. 1959. COMPARISON OF POPULATION ENERGY FLOW OF A HERBIVOROUS AND A DEPOSIT FEEDING INVERTEBRATE IN A SALT MARSH ECOSYSTEM. PROC. NAT. ACAD. SCI. (U.S.)45:617-622.

ODUM, H.T. 1971. ENVIRONMENT, POWER, AND SOCIETY. JOHN WILEY AND SONS, INC., NEW YORK. 331 PP.

ODUM, H.T. 1972. AN ENERGY CIRCUIT LANGUAGE FOR ECOLOGICAL AND SOCIAL SYSTEMS: ITS PHYSICAL BASIS. IN: SYSTEMS ANALYSIS AND SIMULATION IN ECOLOGY (PATEN, B.C., ED.), PP. ACADEMIC PRESS, NEW YORK, NEW YORK.

ODUM, H.T., SILER, W., BEYERS, R.J., AND ARMSTRONG, N. 1963. EXPERIMENTS WITH ENGINEERS OF MARINE ECOSYSTEMS. U. TEXAS INST. MAR. SCI. PUBL. 9:343-403.

ODUM, W.E. 1970. INSIDIOUS ALTERATION OF THE ESTUARINE ENVIRONMENT. TRANS. AMER. FISH. SOC. NO. 4. WASHINGTON, D.C.

OFFICER, C.B. 1976. PHYSICAL OCEANOGRAPHY OF ESTUARIES. OCEANUS 19:3-9.

OHLENDORF, H.M., KLASS, E.E., AND KAISER, T.E. 1974. ENVIRONMENTAL POLLUTION IN RELATION TO ESTUARINE BIRDS. IN: SURVIVAL IN TOXIC ENVIRONMENTS (KHAN, M.A.Q., AND BEDERKA, J.P., JR., EDS.), PP. 53-81. ACADEMIC PRESS, NEW YORK, NEW YORK. 553 PP.

OIW--SEE.....OCEANOGRAPHIC INSTITUTE OF WASHINGTON.

O'NEAL, G., AND SCEVA, J. 1971. EFFECTS OF DREDGING ON WATER QUALITY IN THE NORTHWEST. U.S. ENVIRONMENTAL PROTECTION AGENCY. OFFICE OF WATER PROGRAMS, REGION X, SEATTLE, WA. (A-25). 158 PP.

OREGON COASTAL CONSERVATION, AND DEVELOPMENT COMMISSION. 1975. FINAL REPORT OF THE OREGON COASTAL CONSERVATION AND DEVELOPMENT COMMISSION. OREGON COASTAL CONSERVATION AND DEVELOPMENT COMMISSION, FLORENCE, OREGON. 438 PP. AND APPENDICES.

OREGON COOPERATIVE WILDLIFE RESEARCH UNIT. 1976. INVENTORY OF RIPARIAN HABITATS AND ASSOCIATED WILDLIFE ALONG THE COLUMBIA RIVER. U.S. ARMY CORPS OF ENGINEERS, WALLA WALLA DISTRICT, WALLA WALLA WASHINGTON. 4 VOLS., VAR. PP.

OREGON LCDC--SEE.....OREGON STATE LAND CONSERVATION AND DEVELOPMENT COMMISSION.

OREGON STATE DEPARTMENT OF FISH AND WILDLIFE. 1975. 1975 ANNUAL REPORT, WILDLIFE DIVISION. PORTLAND, OREGON. 178 PP.

OREGON STATE DEPARTMENT OF FISH AND WILDLIFE. 1976A. RESEARCH ON ANADROMOUS FISH IN COASTAL WATERSHEDS OF OREGON. FEDERAL AID PROGRESS REPORTS FISHERIES. 27 PP.

OREGON STATE DEPARTMENT OF FISH AND WILDLIFE. 1976B. 1975-1976 BIENNIAL REPORT. OREGON FISH AND WILDLIFE COMMISSION, PORTLAND, OREGON. 56 PP.

OREGON STATE DEPARTMENT OF FISH AND WILDLIFE. 1977. OREGON'S THEATENED OR ENDANGERED WILDLIFE. OREGON FISH AND WILDLIFE COMMISSION, PORTLAND, OREGON.

OREGON STATE DEPARTMENT OF FISHERIES. 1978. PERSONAL COMMUNICATION.

OREGON STATE DEPARTMENT OF LAND CONSERVATION AND DEVELOPMENT. 1974. A PROPOSAL FOR AN ESTUARINE SANCTUARY GRANT, SOUTH SLOUGH OF COOS BAY OREGON. OREGON STATE DEPARTMENT OF LAND CONSERVATION AND DEVELOPMENT, SALEM, OREGON. 46 PP.

OREGON STATE EMPLOYMENT DIVISION. 1974. RESIDENT LABOR FORCE, UNEMPLOYMENT AND NON-AGRICULTURAL WAGE AND SALARY EMPLOYMENT BY SECTOR. OREGON DEPARTMENT OF HUMAN RESOURCES, EMPLOYMENT DIVISION, RESEARCH AND STATISTICS, SALEM, OREGON.

OREGON STATE EMPLOYMENT DIVISION. 1977. RESIDENT LABOR FORCE, UNEMPLOYMENT AND NON-AGRICULTURAL WAGE AND SALARY EMPLOYMENT BY SECTOR. (VARIOUS YEARS, BY COUNTY.) OREGON STATE DEPARTMENT OF HUMAN RESOURCES, EMPLOYMENT DIVISION, RESEARCH AND STATISTICS, SALEM, OREGON.

OREGON STATE FISH COMMISSION. 1973-1974. RESOURCE USE INVENTORIES OF OREGON ESTUARIES. OREGON FISH COMMISSION, PORTLAND, OREGON.

OREGON STATE LAND CONSERVATION AND DEVELOPMENT COMMISSION. 1976. OREGON COASTAL MANAGEMENT PROGRAM (DRAFT). OREGON STATE LAND CONSERVATION AND DEVELOPMENT COMMISSION, 22 PP. WITH APPENDICES. SALEM, OREGON.

OREGON STATE UNIVERSITY. 1971. OCEANOGRAPHY OF THE NEARSHORE COASTAL WATERS OF THE PACIFIC NORTHWEST RELATING TO POSSIBLE POLLUTION. PREPARED FOR THE U.S. ENVIRONMENTAL PROTECTION AGENCY, WATER QUALITY OFFICE. GRANT NO. 16080 EOK. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. VOL. 1, 615 PP., VOL. 2, 744 PP.

OREGON STATE UNIVERSITY. 1977A. ENVIRONMENTAL IMPACTS OF DREDGING IN ESTUARIES. 675 PP. SCHOOLS OF ENGINEERING AND OCEANOGRAPHY, OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

OREGON STATE UNIVERSITY. 1977B. DREDGING IN ESTUARIES, GUIDES MANUAL. A GUIDE FOR REVIEW OF ENVIRONMENTAL IMPACT STATEMENTS. NATIONAL SCIENCE FOUNDATION GRANT NO. ENV71-01908 A03, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 89 PP.

OREGON STATE UNIVERSITY. 1977C. DREDGING IN ESTUARIES, TECHNICAL MANUAL. A GUIDE FOR REVIEW OF ENVIRONMENTAL IMPACT STATEMENTS. NATONAL SCIENCE FOUNDATION GRANT NO. ENV71-01908 A03, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 313 PP.

OREGON STATE UNIVERSITY. 1977D. SEE NEWTON AND NORGREN, 1977.

OREGON STATE WILDLIFE COMMISSION. 1973. ANNUAL REPORT, GAME DIVISION. OREGON WILDLIFE COMMISSION, PORTLAND, OREGON. 173 PP.

OREGON STATE WILDLIFE COMMISSION. 1974. ANNUAL REPORT, GAME DIVISION, OREGON WILDLIFE COMMISSION, PORTLAND, OREGON. 168 PP.

ORNDUFF, R. 1974. AN INTRODUCTION TO CALIFORNIA PLANT LIFE. UNIVERSITY OF CALIFORNIA PRESS, BERKELEY, CALIFORNIA. 152 PP.

OSBORNE, T. 1972. ECOLOGY AND AVIAN USE OF THE COASTAL ROCKS OF NORTHERN CALIFORNIA. M.A. THESIS. HUMBOLT STATE UNIVERSITY, ARCATA, CALIFORNIA. 215 PP.

OSTERBERG, C.L., CATSHALL, N., JOHNSON, V., CRONIN, J., JENNINGS, D., AND FREDERICK, L. 1966. SOME NON-BIOLOGICAL ASPECTS OF COLUMBIA RIVER RADIOACTIVITY. IN: DISPOSAL OF RADIOACTIVE WASTES INTO SEAS, OCEANS, AND SURFACE WATERS, PP. 321-335. INTERNATIONAL ATOMIC ENERGY AGENCY, GENEVA, SWITZERLAND.

OSU--SEE.....OREGON STATE UNIVERSITY.

OSWALD, D.D. 1968. THE TIMBER RESOURCES OF HUMBOLDT COUNTY. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE BULLETIN PNW-26. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 42 PP.

OSWALD, D.D. 1978. PROSPECTS FOR SAWTIMBER OUTPUT IN CALIFORNIA'S NORTH COAST, 1975-2000. U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE RESOURCE BULLETIN PNW-74. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 20PP.

OSWALD, D.D., AND WALTON, G.S. 1966. FOREST STATISTICS FOR DEL NORTE COUNTY, CALIFORNIA, 1965. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESOURCE BULLETIN PSW-5. PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, BERKELEY, CALIFORNIA, 12 PP.

OTT, W.R. 1978. WATER QUALITY INDICES: A SURVEY OF INDICES USED IN THE UNITED STATES. U.S. ENVIRONMENTAL PROTECTION AGENCY, OFFICE OF MONITORING AND TECHNICAL SUPPORT, AND OFFICE OF RESEARCH AND DEVELOPMENT, WASHINGTON, D.C. EPA-600/4-78-005. 127 PP.

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION. 1977. THE FORESTERS ALMANAC. U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE, PORTLAND, OREGON. 220 PP.

PACIFIC NORTHWEST RIVER BASINS COMMISSION. 1969-1972. COLUMBIA-NORTH PACIFIC REGION COMPREHENSIVE FRAMEWORK STUDY. MAIN REPORT WITH APPENDICES I - XVI. PACIFIC NORTHWEST RIVER BASINS COMMISSION, VANCOUVER, WASHINGTON.

PACIFIC PLANNING ASSOCIATES. 1975. DEVELOPMENT PRESSURES IN THE COASTAL ZONE. OREGON COASTAL CONSERVATION AND DEVELOPMENT COMMISSION.

PAETH, R.C., HARWARD, M.E., KNOX, E.G., AND DYRNESS, C.T. 1971. FACTORS AFFECTING MASS MOVEMENT OF FOUR SOILS IN THE WESTERN CASCADES OF OREGON. SOIL SCIENCE SOCIETY OF AMERICA, PROCEEDINGS 35(6):943-947.

PAGE, D. 1977. BOTTOMING OUT OLD MAN RIVER. SEATTLE POST-INTELLIGENCER, OCTOBER 27, 1977, P. C-10 (ONLY).

PAK, H., BEARDSLEY, G.F. JR., AND PARK, P.K. 1970. THE COLUMBIA RIVER AS A SOURCE OF MARINE LIGHT-SCATTERING PARTICLES. J. GEOPHYS. RES. 75:4570-4578.

PALMER, E. 1941. MARSHES AND THEIR ENVIRONS. NATURE MAGAZINE 34:205-212.

PALMISANO, J.F. 1975. SEA OTTER PREDATION: ITS ROLE IN ROCKY INTERTIDAL COMMUNITY STRUCTURE AT AMCHITKA AND OTHER ALEUTIAN ISLANDS. PH. D. THESIS. UNIVERSITY WASHINGTON, SEATTLE, WASHINGTON. 222PP.

PARDO, R. 1978. NATIONAL REGISTER OF BIG TREES. AMERICAN FORESTS 84(4):17-45.

PARHAM, M.R. 1970. A COMPARATIVE STUDY OF THE MINERAL NUTRITION OF SELECTED HALOPHYTES AND GLYCOPHYTES. PH.D. THESIS. UNIVERSITY OF EAST ANGLIA, UNITED KINGDOM.

PARK, K. 1966. COLUMBIA RIVER PLUME IDENTIFICATION BY SPECIFIC ALKALINITY. LIMNOL. OCEANOGR. 11(1):118-120.

PARK, K., OSTERBERG, C.L., AND FORSTER, W.O. 1972. CHEMICAL BUDGET OF THE COLUMBIA RIVER. IN: THE COLUMBIA RIVER ESTUARY AND ADJACENT OCEAN WATERS: BIOENVIRONMENTAL STUDIES (PRUTER, A.T., AND ALVERSON, D.L., EDS.), PP. 123-134. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON.

PARK, K., PATTULO, J.G., AND WYATT, B. 1962. CHEMICAL PROPERTIES AS INDICATORS OF UPWELLING ALONG THE OREGON COAST. LIMNOL. OCEANOGR. 7:443-450.

PARKER, R. 1975. WATERFOWL HABITAT INVENTORY, EELGRASS SURVEY. WASHINGTON STATE GAME DEPARTMENT, GAME MANAGEMENT DIVISION, PROJECT NO. W-27-R-27. OLYMPIA, WASHINGTON.

PAULEN, D. 1978. PERSONAL COMMUNICATION.

PEARCY, W.G. 1972. DISTRIBUTION AND ECOLOGY OF OCEANIC ANIMALS OFF OREGON. IN: THE COLUMBIA RIVER ESTUARY AND ADJACENT OCEAN WATERS: BIOENVIRONMENTAL STUDIES (PRUTER, A.T., AND ALVERSON, D.L., EDS.), CHAPTER 17, PP. 351-377. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON.

PENHALE, P.A., AND SMITH, W.O., JR. 1977. EXCRETION OF DISSOLVED ORGANIC CARBON BY EELGRASS (ZOSTERA MARINA) AND ITS EPIPHYTES. LIMNOL. OCEANOGR. 22:400-407.

PENMAN, H.L. 1963. VEGETATION AND HYDROLOGY. COMMONWEALTH AGRICULTURAL BUREAU, FARNHAM ROYAL, BICKS, ENGLAND. 124 PP.

PERCY, K.L., SUTTERLIN, C., BELLA, D.A., AND KLINGEMAN, P.C. 1974. DESCRIPTIONS AND INFORMATION SOURCES FOR OREGON ESTUARIES. SEA GRANT COLLEGE PROGRAM. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 294 PP.

PERSON, H.L. 1937. COMMERCIAL PLANTING ON REDWOOD CUT-OVER LANDS. U.S. DEPARTMENT OF AGRICULTURE CIRCULAR 434, WASHINGTON, D.C. 39PP.

PERSON, H.L., AND HALLIN, W. 1939. POSSIBILITIES IN THE REGENERATION OF REDWOOD CUT-OVER LANDS. UNPUBLISHED REPORT ON FILE, PACIFIC SOUTHWEST RANGE AND FOREST EXPERIMENT STATION, BERKELEY, CALIFORNIA.

PESTRONG, R. 1965. THE DEVELOPMENT OF DRAINAGE PATTERNS ON TIDAL MARSHES. STANFORD U. PUBL. GEOL. SCI. 10:1-87.

PETERS, C.F., RICHTER, K.O., MANUWAL, D.A., AND HERMAN, S.G. 1977. COLONIAL NESTING SEA AND WADING BIRD USE OF ESTUARINE ISLANDS IN THE PACIFIC NORTHWEST. JOHN GRAPHAM COMPANY, SEATTLE, WASHINGTON. 183 PP.

PETERSEN, C.J.G. 1913. OM BAENDELTANGENS (ZOSTERA MARINA) AARSPRODUKTION I DE DANSKE FARVANDE. MINDESKRIFT F. JAP. STEENSTRUP.

PETERSEN, C.J.G. 1918. THE SEA BOTTOM AND ITS PRODUCTION OF FISH FOOD. REP. DANISH BIOL. STA. 25:1-82.

PETERSON, W.K. 1972. DISTRIBUTION OF PELAGIC COPEPODA OFF THE COASTS OF WASHINGTON AND OREGON DURING 1961 and 1962. IN: THE COLUMBIA RIVER ESTUARY AND ADJACENT OCEAN WATERS: BIOENVIRONMENTAL STUDIES (PRUTER, A.T., AND ALVERSON, D.L., EDS.), PP. 313-343, UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON.

PETTIJOHN, F.J. 1957. SEDIMENTARY ROCKS. 2ND ED. HARPER AND ROW, NEW YORK, NEW YORK. 718 PP.

PHILLIPS, E.L., AND DONALDSON, W.R. 1972. WASHINGTON CLIMATE FOR THESE COUNTIES: CLALLAM, GRAYS HARBOR, JEFFERSON, PACIFIC AND WAHKAIKUM. COOPERATIVE EXTENSION SERVICES, COLLEGE OF AGRICULTURE, WASHINGTON STATE UNIVERSITY, PULLMAN, WASHINGTON. 124 PP.

PHILLIPS, R.C. 1974. TEMPERATE GRASS FLATS. IN: COASTAL ECOSYSTEMS OF THE UNITED STATES: A SOURCE BOOK FOR ESTUARINE PLANNING, (ODUM, H.T., COPELAND, B.J., AND MCMAHAN, E.A., EDS.), VOL. 2, PP. 244-249. CONSERVATION FOUNDATION, WASHINGTON, D.C.

PHILLIPS, R.C. 1978. SEAGRASSES AND THE COASTAL MARINE ENVIRONMENT. OCEANUS 21(3):30-40.

PHILLIPS, R.C. 1978. PERSONAL COMMUNICATION.

PHIPPS, J.B., AND SCHEIDEGGER, K.F. 1976. HEAVY MINERALS OF GRAYS HARBOR. IN: MAINTENANCE DREDGING AND THE ENVIRONMENT OF GRAYS HARBOR, WASHINGTON (ACOE, 1976-1977), APPENDIX B, 30 PP. U.S. ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT.

PICKERAL, J.C., AND ODUM, W.E. 1976. BENTHIC DETRITUS IN A SALT MARSH TIDAL CREEK. IN: ESTUARINE PROCESSES, VOL. 2, CIRCULATION, SEDIMENTS AND TRANSFER OF MATERIALS IN THE ESTUARY (WILEY, M., ED.), PP. 280-292. ACADEMIC PRESS, NEW YORK, SAN FRANCISCO, LONDON.

PICKETT, S.T.A., AND THOMPSON, J.N. 1978. PATCH DYNAMICS AND THE DESIGN OF NATURE RESERVES. BIOL. CONSERVATION 13:27-37.

PIKE, C.G., AND MACASKIE, I.B. 1969. MARINE MAMMALS OF BRITISH COLUMBIA. BULL. 171, FISHERIES RESEARCH BOARD OF CANADA, OTTAWA, 54PP.

PIKE, L.H., RYDELL, R.A., AND DENISON, W.C. 1977. A 400-YEAR OLD DOUGLAS FIR TREE AND ITS EPIPHYTES: BIOMASS, SURFACE AREA, AND THEIR DISTRIBUTION. CANADA J. FOREST RESOURCES 7:630-699.

PIKE, L.H., TRACY, D.M., SHERWOOD, M.A., AND NIELSON, D. 1972. ESTIMATES OF BIOMASS AND FIXED NITROGEN OF EPIPHYTES FROM OLD GROWTH DOUGLAS FIR. IN: PROCEEDINGS--RESEARCH ON CONIFEROUS FOREST ECOSYSTEMS--A SYMPOSIUM (FRANKLIN, J.F., DEMPSTER, L.J., AND WARING, R.H., EDS.), PP. 177-187. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON.

PINTO, C., SILOVSKY, E., HENLEY, F., RICH, L., PARCELL, J., AND BOYER, D. 1972. RESOURCE INVENTORY REPORT FOR THE OREGON DUNES NATIONAL RECREATION AREA, SIUSLAW NATIONAL FOREST. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST REGION, PORTLAND, OREGON. 294 PP.

PLANK, R.D. 1975. HUMBOLDT COUNTY, CALIFORNIA, ATLAS. HUMBOLDT COUNTY BOARD OF SUPERVISORS, EUREKA, CALIFORNIA. 105 PP.

PNRBC--SEE.....PACIFIC NORTHWEST RIVER BASINS COMMISSION.

POELKER, R.J., AND HARTWELL, H.D. 1973. BLACK BEAR OF WASHINGTON. BIOLOGICAL BULL. NO. 14, WASHINGTON STATE GAME DEPARTMENT, OLYMPIA, WASHINGTON. 180 PP.

POMEROY, L.E. 1959. ALGAL PRODUCTIVITY IN SALT MARSHES IN GEORGIA. LIMNOL. OCEANOGR. 4:386-395.

POMEROY, L.R., BANCROFT, K., BREED, J., CHRISTIAN, R.R., FRANKENBERG, D., HALL, J.R., MAURER, L.G., WIEBE, W.J., WIEGART, R.G., AND WETZEL, R.L. 1976. FLUX OF ORGANIC MATTER THROUGH A SALT MARSH. IN: ESTUARINE PROCESSES, VOL. 2, CIRCULATION SEDIMENTS, AND TRANSFER OF MATERIAL IN THE ESTUARY (WILEY, M., ED.), PP. 270-279. ACADEMIC PRESS, NEW YORK, SAN FRANCISCO, LONDON.

POWELL, W.R. 1974. INVENTORY OF RARE AND ENDANGERED VASCULAR PLANTS OF CALIFORNIA. SPECIAL PUBLICATION NO. 1, CALIFORNIA NATIVE PLANT SOCIETY.

PRUTER, A.T. 1972. REVIEW OF COMMERCIAL FISHERIES IN THE COLUMBIA RIVER AND IN CONTIGUOUS OCEAN WATERS. IN: THE COLUMBIA RIVER ESTUARY AND ADJACENT OCEAN WATERS: BIOENVIRONMENTAL STUDIES (PRUTER, A.T., AND ALVERSON, D.L., EDS.) PP. 81-120. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON.

PRUTER, A.T., AND ALVERSON, D.L. (EDS.). 1972. THE COLUMBIA RIVER ESTUARY AND ADJACENT OCEAN WATERS, BIOENVIRONMENTAL STUDIES. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON. 868 PP.

PYTKOWICZ, R.M. 1964. OXYGEN EXCHANGE RATES OFF THE OREGON COAST. DEEP SEA RES. 11:381-389.

QRC RESEARCH CORPORATION, WINZLER AND KELLY, NATURAL RESOURCES MANAGEMENT CORPORATION, WILLIAMS-KUEBELBECK AND ASSOCIATES INC. 1978. AN ECONOMIC DEVELOPMENT ACTION PLAN AND STRATEGY FOR HUMBOLDT COUNTY, CALIFORNIA. HUMBOLDT COUNTY BOARD OF SUPERVISORS, EUREKA, CALIFORNIA (EDA TITLE IX PROJECT NO. 07-09-01916). 282PP. AND APPENDICES.

QUAYLE, R.C., AND FULBRIGHT, D.C. 1975. EXTREME WIND AND WAVE RETURN PERIODS FOR THE U.S. COAST. MARINERS WEATHER LOG 19(2):67-70.

RANWELL, D.S. 1972. ECOLOGY OF SALT MARSHES AND SAND DUNES. CHAPMAN AND HALL, LONDON. 258 PP.

RAUW, C.I. 1974. SEASONAL VARIATIONS AND TIDAL DYNAMICS, WATER QUALITY AND SEDIMENTS IN SILETZ ESTUARY. M.S. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 174 PP.

REA, C.C., AND KOMAR, P.D. 1975. THE EROSION OF SILETZ SPIT, OREGON. SCHOOL OF OCEANOGRAPHY, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. REFERENCE 75-4. 105 PP.

REAL ESTATE RESEARCH CORPORATION. 1974. THE COST OF SPRAWL. U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C. 278 PP.

REED, P.H. 1969. STUDIES OF DUNGENESS CRAB, (CANCER MAGISTER DANA) LARVAE: CULTURE METHODS AND THE EFFECT OF TEMPERATURE AND SALINITY ON SURVIVAL AND GROWTH IN THE HABITAT. J. FISH RES. BOARD CANADA, 26:389-397.

REES, G.H. 1963. EDIBLE CRABS OF THE UNITED STATES. FISH LEAFLET 550. U.S. FISH AND WILDLIFE SERVICE, U.S. DEPARTMENT OF THE INTERIOR, WASHINGTON, D.C. 18 PP.

REICHARD, T. 1976. CRITICAL AREA STUDY, VOL. 3. BIRDS. STATE OF WASHINGTON DEPARTMENT OF ECOLOGY. BASELINE STUDY PROGRAM. OLYMPIA, WASHINGTON.

REIFSNYDER, W.E., AND LULL, H.W. 1965. RADIANT ENERGY IN RELATION TO FOREST. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE TECHNICAL BULL. NO. 1344. 111 PP.

RICHTER, K.O. 1976. THE FORAGING ECOLOGY OF THE BANANA SLUG ARIOLIMAX COLUMBIANUS GOULD (ARIONIDAE). PH.D. THESIS. UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 228 PP.

RICHTER, K.O. 1978. (IN PRESS) ASPECTS OF NUTRIENT CYCLING BY ARIOLIMAX COLUMBIANUS G. (MOLLUSCA:ARIONIDAE) IN PACIFIC NORTHWEST CONIFEROUS FORESTS. PEDOBIOLOGIA (IN PRESS).

RICKERT, D.T. 1969. THE MICROBIOLOLOGICAL FORMATION OF IRON SULFIDES. STOCKHOLM CONF. GEOLOGY 20, P. 49.

RICKETTS, E.F., AND CALVIN, J. 1968. BETWEEN PACIFIC TIDES. 4TH REVISED EDITION (BY J.W. HEDGPETH). STANFORD UNIVERSITY PRESS. STANFORD, CALIFORNIA. 614 PP.

ROBERTS, R.W. 1974. MARINE SEDIMENTOLOGICAL DATA OF THE WASHINGTON CONTINENTAL SHELF. SPECIAL REPORT NO. 57. NATIONAL SCIENCE FOUNDATION GRANT GA 28376 A,2. DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 129 PP.

RODEN, G.I. 1967. ON RIVER DISCHARGE INTO THE NORTHEASTERN PACIFIC OCEAN AND THE BERING SEA. J. GEOPHYS. RES. 72(22):5613-5629.

RODGERS, J.B., AND DOUGLAS, J.J. 1974. SHOREBIRDS AND PREDATORS (BIRDS OF THE PACIFIC NORTHWEST, V.1). U. BRITISH COLUMBIA, VANCOUVER, B.C., CANADA. 195 PP.

ROGERS, L.C. 1966. BLUE WATER 2 LIVES UP TO PROMISE. OIL GAS J. AUGUST 15, 1966. PP. 73-75.

ROTHACHER, J. 1970A. REGIMES OF STREAMFLOW AND THEIR MODIFICATION BY LOGGING. IN: PROCEEDINGS OF A SYMPOSIUM ON FOREST LAND USES AND STREAM ENVIRONMENT. OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

ROTHACHER, J. 1970B. INCREASES IN WATER YIELD FOLLOWING CLEARCUT LOGGING IN THE PACIFIC NORTHWEST. WATER RESOUR. RES. 6:653-658.

ROTHACHER, J. 1973. DOES HARVEST IN WEST SLOPE DOUGLAS-FIR INCREASE PEAK FLOWS IN SMALL FOREST STREAMS (QUESTION). U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RESEARCH PAPER PNW-163. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 13 PP.

ROUNSEFELL, G.A. 1975. ECOLOGY, UTILIZATION, AND MANAGEMENT OF MARINE FISHERIES. THE C.V. MOSBY COMPANY, SAINT LOUIS, MISSOURI. 516 PP.

RUDERMAN, F.K. 1977A. PRODUCTION, PRICES, EMPLOYMENT, AND TRADE, IN NORTHWEST FOREST INDUSTRIES, FIRST QUARTER, 1977. U.S. DEPARTMENT OF AGRICULTURE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 53 PP.

RUDERMAN, F.K. 1977B. PRODUCTION, PRICES, EMPLOYMENT, AND TRADE IN NORTHWEST FOREST INDUSTRIES, SECOND QUARTER. U.S. DEPARTMENT OF AGRICULTURE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 69 PP.

RUDERMAN, F.K. 1977C. PRODUCTION, PRICES, EMPLOYMENT, AND TRADE IN NORTHWEST FOREST INDUSTRIES, THIRD QUARTER, 1977. U.S. DEPARTMENT OF AGRICULTURE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 55 PP.

RUSSEL, D.W. 1973. THE LIFE HISTORY OF VINE MAPLE ON THE H.J. ANDREWS EXPERIMENTAL FOREST. M.S. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 167 PP.

RUTH, R.H. 1954. CASCADE HEAD CLIMATOLOGICAL DATA 1936 TO 1952. U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 29 PP.

RUTH, R.H. 1957. TEN-YEAR HISTORY OF AN OREGON COASTAL PLANTATION. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION RESEARCH PAPER 21. PORTLAND, OREGON. 15 PP.

RUTH, R.H., AND YODER, R.A. 1953. REDUCING WIND DAMAGE IN THE FORESTS OF THE OREGON COAST RANGE. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION RESOURCE PAPER 7. PORTLAND, OREGON. 30 PP.

RYAN, J.A., AND MORISON, I.G. 1976. MODELS OF A FOREST ECOSYSTEM. IV. HYDROLOGY, METEOROLOGY AND ATMOSPHERE. FOREST RESOURCES MONOGRAPH CONTRIBUTION NO. 18, COLLEGE OF FOREST RESOURCES, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 46 PP.

RYTHER, J.H. 1969. PHOTOSYNTHESIS AND FISH PRODUCTION IN THE SEA. SCIENCE 130:602-608.

SALO, E.O. 1974. ANADROMOUS FISH. IN: SALMONID MANAGEMENT. TROUT UNLIMITED 15(1):12-21.

SALO, L.J. 1975. A BASELINE SURVEY OF SIGNIFICANT MARINE BIRDS IN WASHINGTON STATE. COASTAL ZONE ENVIRONMENTAL REPORT NO. 1. WASHINGTON STATE DEPARTMENT OF GAME AND DEPARTMENT OF ECOLOGY, OLYMPIA, WASHINGTON. 417 PP.

SAMUELSON, P.A. 1961. ECONOMICS, AN INTRODUCTORY ANALYSIS. MCGRAW-HILL BOOK, CO., INC., NEW YORK.

SANDERS, J. 1978. PERSONAL COMMUNICATION.

SANGER, G.A. 1970. THE SEASONAL DISTRIBUTION OF SOME SEABIRDS OFF WASHINGTON AND OREGON WITH NOTES ON THEIR ECOLOGY AND BEHAVIOR. CONDOR 72:339-357

SANGER, G.A. 1972. PRELIMINARY STANDING STOCK AND BIOMASS ESTIMATES OF SEABIRDS IN THE SUBARCTIC PACIFIC REGION. IN: BIOLOGICAL OCEANOGRAPHY OF THE NORTHERN PACIFIC OCEAN (TAKENOUTI, A.Y., ED.), PP. 584-611. IDEMITSU SHOTEN, TOKYO. 626 PP.

SAYRE, J.A. 1978. NEWS RELEASE: BALD EAGLE THE NATIONAL SYMBOL IS ENDANGERED IN 43 STATES. U.S. FISH AND WILDLIFE SERVICE, PORTLAND, OREGON. 2 PP.

SCHAEFER, M.B. 1939. THE PRESENT STATUS OF THE RAZOR CLAM STOCKS IN THE STATE OF WASHINGTON. WASHINGTON STATE DEPARTMENT OF FISHERIES BIOLOGICAL REPORT NO. 378. OLYMPIA, WASHINGTON.

SCHALLAU, C., MAKI, W., AND BEUTER, J. 1969. ECONOMIC IMPACT PROJECTIONS FOR ALTERNATIVE LEVELS OF TIMBER PRODUCTION IN THE DOUGLAS-FIR REGION. ANN. REG. SCI. 3(1,JUNE):96-106.

SCHALLAU, C.H. 1970. AN ECONOMIC ANALYSIS OF ACCELERATED ROAD CONSTRUCTION ON THE BUREAU OF LAND MANAGEMENTS TILLAMOOK RESOURCE AREA. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RES. PAPER PNW-98. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 29 PP.

SCHEIDEGGER, K.F., KULM, L., AND RUNGE, E.J. 1971. SEDIMENT SOURCES AND DISPERSAL PATTERNS OF OREGON CONTINENTAL SHELF SANDS. J. SEDIMENT. PETROL. 41:1112-1120.

SCHLIEPER, C. (ED.). 1972. RESEARCH METHODS IN MARINE BIOLOGY. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON. 356 PP.

SCHMISSEUR, W.E., AND BOODT, W. 1975. OREGON COASTAL AREA, INCLUDING SOUTH-WESTERN OREGON COUNTIES: ECONOMIC SURVEY AND ANALYSIS. PACIFIC NORTHWEST RIVER BASINS COMMISSION, VANCOUVER, WASHINGTON. 123 PP.

SCHMISSEUR, W.E., YOUMANS, R., AND BOODT, W.E. 1975B. ECONOMIC IMPACT OF PUBLIC INVESTMENTS IN SMALL-BOAT FACILITIES AND COUNTY AND STATE PARKS IN THE LOWER UMPQUA RIVER AREA OF DOUGLAS COUNTY, OREGON. WATER RESOURCES RESEARCH INSTITUTE, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 51 PP.

SCHRAG, J. 1976. DISTRIBUTIONS, TROPHIC RELATIONSHIPS, AND ENERGETICS OF SALT MARSH INSECT POPULATIONS. IN: A COMPARATIVE STUDY OF SALT MARSHES OF THE COOS BAY ESTUARY (HOFFNAGLE, J., ED.), PP. 156-168. OREGON INSTITUTE OF MARINE BIOLOGY, CHARLESTON, OREGON.

SCHUBERT, G.H. 1952. GERMINATION OF VARIOUS CONIFER SEEDS AFTER COLD STORAGE. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RES. NOTE 83. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION PORTLAND, OREGON. 7 PP.

SCHULDT, J.P., AND HOWARD, J.O. 1974. OREGON FOREST INDUSTRIES 1972, WOOD CONSUMPTION AND MILL CHARACTERISTICS. OREGON STATE UNIVERSITY EXTENSION SERVICE, SCHOOL OF FORESTRY, CORVALLIS, OREGON, AND PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 113 PP.

SCHUSTER, E.G. 1976. LOCAL ECONOMIC IMPACT, A DECISION VARIABLE IN FOREST RESOURCES MANAGEMENT. MONTANA FOREST AND CONSERVATION EXPERIMENT STATION, SCHOOL OF FORESTRY, UNIVERSITY OF MONTANA, MISSOULA, MONTANA. 104 PP.

SCOTT, W.B., AND CROSSMAN, E.J. 1973. FRESHWATER FISHES OF CANADA. FISHERIES RESEARCH BOARD OF CANADA, BULL. 184, OTTAWA, CANADA. 966 PP.

SEAMAN, M.H. (ED.). 1977. COLUMBIA RIVER ESTUARY. INVENTORY OF PHYSICAL, BIOLOGICAL AND CULTURAL CHARACTERISTICS. PREPARED FOR THE COLUMBIA RIVER ESTUARY STUDY TASKFORCE (CREST), ASTORIA, OREGON.

SEDELL, J.R., TRISHA, F.J., HALL, J.D., ANDERSON, N.H., AND LYFORD, J.H. 1974. SOURCES AND FATES OF ORGANIC INPUTS IN CONIFEROUS FOREST STREAMS. INTERNATIONAL BIOME PROGRAM BULLETIN. 5:57-69. UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON.

SENATE COMMITTEE ON INTERIOR AND INSULAR AFFAIRS. 1973. REPORT NO. 93-197, JUNE 7. LAND USE POLICY AND PLANNING ASSISTANCE ACT, U.S. SENATE, WASHINGTON, D.C. 29 PP.

SETCHELL, W.A. 1929. MORPHOLOGICAL AND PHENOLOGICAL NOTES ON ZOSTERA MARINA L. UNIV. CALIFORNIA PUBL. BOT. 14:389-452.

SETCHELL, W.A. 1933. A PRELIMINARY SURVEY OF THE SPECIES OF ZOSTERA. PROC. NAT. ACAD. SCI. (U.S.) 19:810-817.

SHARPE, G. 1974. WESTERN RED CEDAR. COLLEGE OF FOREST RESOURCES, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 144 PP.

SHORT, F.T. 1975. EELGRASS PRODUCTION IN CHARLESTOWN POND: AN ECOLOGICAL ANALYSIS AND NUMERICAL SIMULATION MODEL. M.S. THESIS. UNIVERSITY OF RHODE ISLAND, KINGSTON, RHODE ISLAND. 124 PP.

SHOW, S.B. 1932. TIMBER GROWING AND LOGGING PRACTICE IN COAST REDWOOD REGION OF CALIFORNIA. U.S. DEPARTMENT OF AGRICULTURE TECH. BULL. 283. WASHINGTON, D.C. 22 PP.

SIDDALL, J.L. 1977A. FIELD CHECKING PROGRESS REPORT TO FIELD BOTANISTS ON PROVISIONAL LIST OF RARE, THREATENED AND ENDANGERED PLANTS IN OREGON. OREGON RARE AND ENDANGERED PLANT PROJECT, LAKE OSWEGO, OREGON. 23 PP. (MIMEOGRAPHED).

SIDDALL, J.L. 1977B. PROVISIONAL LIST OF THE RARE, THREATENED AND ENDANGERED PLANTS IN OREGON. OREGON COAST PROVINCE. OREGON RARE AND ENDANGERED PLANT PROJECT, LAKE OSWEGO, OREGON. 1 PP. (MIMEOGRAPHED).

SIDHU, S.C., AND CASE, A.B. 1977. A BIBLIOGRAPHY ON THE ENVIRONMENTAL IMPACT OF FOREST RESOURCE ROADS: A LIST. NEWFOUNDLAND FOREST RESEARCH CENTRE, INFORMATION REPORT N-X-149. ST. JOHNS, NEWFOUNDLAND. 28 PP.
CALIFORNIA,,

SIGGINS, H.W. 1933. DISTRIBUTION AND RATE OF FALL OF CONIFER SEEDS. J. AGR. RESOUR. 47:119-128.

SILEN, R.R., AND DOIG, I. 1976. THE CARE AND HANDLING OF THE FOREST GENE POOL. PACIFIC SEARCH 10(8):7-9.

SILOVSKY, G.D., AND PINTO, C. 1974. FOREST WILDLIFE INVENTORIES: IDENTIFICATION OF CONFLICTS AND MANAGEMENT NEEDS. IN: WILDLIFE AND FOREST MANAGEMENT IN THE PACIFIC NORTHWEST, (BLACK, H.C., ED.), P. 53. SCHOOL OF FORESTRY, OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

SILVESTER, R. 1974. COASTAL ENGINEERING, 2, DEVELOPMENTS IN GEOTECHNICAL ENGINEERING. VOL. 4B. ELSEVIER SCIENTIFIC PUBLISHING COMPANY, NEW YORK. 338 PP.

SIMMONS, H.B. 1955. SOME EFFECTS OF UPLAND DISCHARGE ON ESTUARINE HYDRAULICS. PROCEEDINGS, AMERICAN SOCIETY OF CIVIL ENGINEERS, VOL. 81, NO. 792.

SIMMONS, I.G. 1974. THE ECOLOGY OF NATURAL RESOURCES. JOHN WILEY AND SONS, NEW YORK, NEW YORK. 424 PP.

SIMONS, D. 1977. PERSONAL COMMUNICATION.

SKEESICK, D.G. 1963. A STUDY OF SOME PHYSICAL - CHEMICAL CHARACTERISTICS OF HUMBOLDT BAY. M.S. THESIS. HUMBOLDT STATE UNIVERSITY, ARCATA, CALIFORNIA. 148 PP.

SLAYTER, R.O. 1967. PLANT-WATER RELATIONSHIPS. ACADEMIC PRESS, LONDON.

SLOTTA, L.S., BELLA, D.A., HANCOCK, D.R., MCCAULEY, J.E., SOLLIT, C.K., STANDER, J.M., AND WILLIAMSON, K.J. 1974. AN EXAMINATION OF SOME PHYSICAL AND BIOLOGICAL IMPACTS OF DREDGING IN ESTUARIES. INTERIM PROGRESS REPORT SUBMITTED TO THE DIVISION OF ENVIRONMENTAL SYSTEM AND REVIEW, NATIONAL SCIENCE FOUNDATION, SCHOOLS OF ENGINEERING AND OCEANOGRAPHY, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 62 PP.

SMALL, L.F., CURL, H., JR., AND GLOOSCHENKO, W.A. 1972. EFFECTS OF SOLAR RADIATION AND UPWELLING ON DAILY PRIMARY PRODUCTION OFF OREGON. J. FISH. RES. BOARD CANADA 29:1269-1275. ALSO IN COLL. REPR. OSU-OCEANOGRAPHY, 1972, VOL. II, PP. 594-600. OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

SMALLEY, A.E. 1959. THE GROWTH CYCLE OF SPARTINA AND ITS RELATION TO THE INSECT POPULATIONS IN THE MARSH. IN: PROCEEDINGS OF SALT MARSH CONFERENCE, 1958 (RAGOTZKIE, R.A., ED.). UNIVERSITY OF GEORGIA, INSTITUTE OF MARINE SCIENCE.

SMALLEY, A.E. 1960. ENERGY FLOW OF A SALT MARSH GRASSHOPPER POPULATION. ECOL. 41:672-677.

SMITH, A.K., AND LAUMAN, J.E. 1972. FISH AND WILDLIFE RESOURCES OF THE MIDDLE COAST BASIN, OREGON, AND THEIR WATER REQUIREMENTS (REVISED). OREGON STATE GAME COMMISSION, PORTLAND, OREGON. 98 PP.

SMITH, H.G. 1973. BIOMASS OF SOME YOUNG RED ALDER STANDS. IUFRO BIOMASS STUDIES, PP. 399-412. UNIVERSITY OF MAINE, ORONO, MAINE.

SMITH, I.D. 1968. THE EFFECTS OF HUNTING AND SERAL SUCCESSION UPON VANCOUVER ISLAND BLACK-TAILED DEER. M.S. THESIS. UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA. 135 PP.

SMITH, J.D., HICKEY, B., AND BECK, J. 1976. OBSERVATIONS FROM MOORED CURRENT METERS ON THE WASHINGTON CONTINENTAL SHELF FROM FEBRUARY 1971 TO FEBRUARY 1974. UNIVERSITY OF WASHINGTON DEPARTMENT OF OCEANOGRAPHY SPECIAL REPORT NO. 65, REFERENCE M76-44. 383 PP.

SMITH, J.L., AND MUDD, D.R. 1976. IMPACT OF DREDGING ON THE AVIAN FAUNA IN GRAYS HARBOR. IN: MAINTENANCE DREDGING AND THE ENVIRONMENT OF GRAYS HARBOR, WASHINGTON (ACOE, 1976-1977), APPENDIX H, 217 PP. U.S. ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT.

SMITH, J.L., MUDD, D.R., AND MESSMER, L.W. 1976. IMPACT OF DREDGING ON THE VEGETATION IN GRAYS HARBOR. IN: MAINTENANCE DREDGING AND THE ENVIRONMENT OF GRAYS HARBOR, WASHINGTON (ACOE, 1976-1977), APPENDIX F, 121 PP. U.S. ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT.

SMITH, L.L. 1971. INFLUENCE OF HYDROGEN SULFIDE ON FISH AND ARTHROPODS. PRELIMINARY COMPLETION REPORT, EPA PROJECT 18050, PCG. 30 PP.

SMITH, L.L., AND OSEID, D. 1971. TOXIC EFFECTS OF HYDROGEN SULFIDE TO JUVENILE FISH AND FISH EGGS. PROCEEDINGS, 25TH PURDUE INDUSTRIAL WASTE CONFERENCE.

SMITH, R.L., PATTULLO, J.G., AND LANE, R.K. 1966. AN INVESTIGATION OF THE EARLY STATE OF UPWELLING ALONG THE OREGON COAST. J. GEOPHYS. RES. 71:1135-1140.

SMITH, T.G., AND GERACI, J.R. 1975. THE EFFECT OF CONTACT AND INGESTION OF CRUDE OIL ON RINGED SEALS OF THE BEAUFORT SEA. BEAUFORT SEA TECHNICAL REPORT NO. 5. ENVIRONMENT CANADA, VICTORIA, BRITISH COLUMBIA, CANADA.

SMITHSONIAN INSTITUTION. 1975. REPORT ON ENDANGERED AND THREATENED PLANT SPECIES OF THE UNITED STATES. U.S. HOUSE OF REPRESENTATIVES DOCUMENT 94-51 AND U.S. GPO PUBLICATION 94A. WASHINGTON, D.C. 200 PP.

SMOKER, W.A. 1955. THE EFFECTS OF STREAMFLOW ON SILVER SALMON PRODUCTION IN WESTERN WASHINGTON. PH.D. THESIS. U. WASHINGTON. SEATTLE, WASHINGTON.

SNOW, D. 1977. PERSONAL COMMUNICATION.

SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT. 1975. ENVIRONMENTAL EFFECTS OF THE DISPOSAL OF MUNICIPAL WASTEWATERS IN OPEN COASTAL WATERS. PREPARED FOR THE NATIONAL COMMISSION ON WATER QUALITY. NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA. 70 PP.

SPRUNT, A. 1963. BALD EAGLES ARE NOT PRODUCING ENOUGH YOUNG. AUDUBON 65:32-35.

SQUIRE, J.L., JR., AND SMITH, S. 1977. ANGLERS GUIDE TO THE UNITED STATES PACIFIC COAST. NATIONAL MARINE FISHERIES SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE, WASHINGTON, D.C. 139 PP.

STATE OF CALIFORNIA--SEE.....CALIFORNIA STATE.

STAUFFER, R.C. 1937. CHANGES IN THE INVERTEBRATE COMMUNITY OF A LAGOON AFTER DISAPPEARANCE OF THE EELGRASS. ECOLOGY 18:427-431.

STEARNS, L.A., AND MACCREARY, D. 1957. THE CASE OF THE VANISHING BRICK DUST. MOSQUITO NEWS 17:303-304.

STEARNS, L.A., MACCREARY, D., AND DAIGH, F.C. 1940. EFFECT OF DITCHING ON THE MUSKRAT POPULATION OF A DELAWARE TIDEWATER MARSH. U. DELAWARE AGR. EXP. STA. BULL. 225. 55 PP.

STEFANSSON, U., AND RICHARDS, F.A. 1964. DISTRIBUTIONS OF DISSOLVED OXYGEN, DENSITY AND NUTRIENTS OFF THE WASHINGTON AND OREGON COASTS. DEEP-SEA RES. 11:355-380.

STEIN, J.E., DENISON, J.G., AND PETERSEN, R.R. 1966. GRAYS HARBOR WATER VOLUMES. TIDAL EXCURSIONS AND SUGGESTED RE-LOCATION OF DIFFUSER LINE. REPORT NO. G 10:1-4, OLYMPIC RESEARCH DIVISION, ITT-RAYONIER, SHELTON, WASHINGTON. 9 PP.

STEPHENSON, M.D. 1977. SEA OTTER PREDATION ON PISMO CLAMS IN MONTEREY BAY. CAL. FISH. GAME 63:117-120.

STERNBERG, R.W., AND MCMANUS, D.A. 1972. IMPLICATIONS OF SEDIMENT DISPERSAL FROM LONG-TERM, BOTTOM CURRENT MEASUREMENTS ON THE CONTINENTAL SHELF OF WASHINGTON. IN: SHELF SEDIMENT TRANSPORT (SWIFT, D.J.P., DUANE, D.B., AND PILKEY, O.H., EDS.), PP. 181-194. DOWDEN, HUTCHINSON AND ROSS, STROUDSBERG, PENNSYLVANIA.

STERNES, G.L. 1960. CLIMATES OF THE STATES: OREGON. U.S. ENVIRONMENTAL SCIENCES SERVICE ADMINISTRATION, WASHINGTON, 27 PP.

STEVENSON, J.C., HEINLE, D.R., FLEMER, D.A., SMALL, R.J., ROWLAND, R.A., AND USTACH, J.F. 1976. NUTRIENT EXCHANGES BETWEEN BRACKISH WATER MARSHES AND THE ESTUARY. IN: ESTUARINE PROCESSES, VOL. 2, CIRCULATION, SEDIMENTS AND TRANSFER OF MATERIALS IN THE ESTUARY (WILEY, M., ED.), PP. 219-240. ACADEMIC PRESS, INC., NEW YORK, SAN FRANCISCO, LONDON.

STEVENSON, M.R., AND PATTULLO, J.G. 1967. SUBSURFACE CURRENTS OF THE OREGON COAST (ABSTRACT). TRANS. AMER. GEOPHYS. UNION 48:30(ONLY).

STEWART, R.M., AND HIGBEE, J. 1973. BISHOP PINE FOREST. AUDUBON FIELD-NOTES 27:998-999.

STOATE, T.N., COOPER, D.W., GESSEL, S.P., AND MILES, J.G. 1975. FOREST AND RANGE STUDIES ON THE MAD RIVER IN NORTHERN CALIFORNIA. COLLEGE OF FOREST RESOURCES, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON.

STOBER, Q.J., AND SALO, E.O. 1973. ECOLOGICAL STUDIES OF THE PROPOSED KIKET ISLAND NUCLEAR POWER SITE. FISHERIES RESEARCH INSTITUTE, COLLEGE OF FISHERIES, UNIVERSITY OF WASHINGTON. SEATTLE, WASHINGTON. 537 PP.

STOEVENER, H.H., STEVENS, J.B., HORTON, H.F., SOKOLOSKI, A., PARRISH, L.P., AND CASTLE, E.N. 1972. MULTI-DISCIPLINARY STUDY OF WATER QUALITY RELATIONSHIPS: A CASE STUDY OF YAQUINA BAY, OREGON. AGRICULTURAL EXPERIMENT STATION, OREGON STATE UNIVERSITY, CORVALLIS, OREGON. 135 PP.

STORIE, R.E., AND WEIR, W.W. 1953. SOIL SERIES OF CALIFORNIA. UNIVERSITY OF CALIFORNIA, BERKELEY, CALIFORNIA.

STRAND, M.A. 1974. CANOPY FOOD CHAIN IN A CONIFEROUS FOREST WATERSHED. INTERNATIONAL BIOME PROGRAM BULLETIN NO. 5, PP. 41-47. UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON.

STRAND, R.G. 1969. GEOLOGIC MAP OF CALIFORNIA, OLAF P. JENKINS EDITION, REDDING SHEET. 2ND ED. DIVISION OF MINES AND GEOLOGY, STATE OF CALIFORNIA, SACRAMENTO, CALIFORNIA.

STRAND, R.G. 1973. GEOLOGIC MAP OF CALIFORNIA, OLAF P. JENKINS EDITION, WEED SHEET. 2ND ED. DIVISION OF MINES AND GEOLOGY, STATE OF CALIFORNIA.

STROUD, L.M., AND COOPER, A.W. 1969. COLOR-INFRARED AERIAL PHOTOGRAPHIC INTERPRETATION AND NET PRIMARY PRODUCTIVITY OF A REGULARLY-FLOODED NORTH CAROLINA SALT MARSH. RALEIGH RESEARCH INSTITUTE REPORT NO.14. RALEIGH, NORTH CAROLINA.

STUDDARD, G.J. 1974. COMMON ENVIRONMENTAL TERMS. A GLOSSARY. U.S. ENVIRONMENTAL PROTECTION AGENCY, WASHINGTON, D.C. 23 PP.

STUNZ, L. 1976. A COMPARATIVE STUDY OF HETEROTROPHIC MICROBE-MEDIATED DECOMPOSITION RATES AND NUTRITIONAL VALUES OF VARIOUS SALT MARSH PLANTS. IN: COMPARATIVE STUDY OF SALT MARSHES IN THE COOS BAY ESTUARY (HOFFNAGLE, J., ED.), PP. 129-136. OREGON INSTITUTE OF MARINE BIOLOGY, CHARLESTON, OREGON.

SUDA, J. 1974. PRELIMINARY INVESTIGATIONS OF ZOSTERA COMMUNITY METABOLISM AND ITS IMPLICATION IN GREAT SOUTH BAY ECOSYSTEM PRODUCTION. M.S. THESIS. STATE UNIVERSITY OF NEW YORK, STONY BROOK, NEW YORK. 88 PP.

SURING, L.H. 1974. HABITAT USE AND ACTIVITY PATTERNS OF THE COLUMBIAN WHITE-TAILED DEER ALONG THE LOWER COLUMBIA RIVER. M.S. THESIS. OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

SVERDRUP, H.U., JOHNSON, M.W., AND FLEMING, R.H. 1942. THE OCEANS, THEIR PHYSICS, CHEMISTRY, AND BIOLOGY. PRENTICE-HALL, INC., NEW YORK. 1087 PP.

SWANSON, F.J., AND DYRNESS, C.T. 1975. IMPACT OF CLEAR-CUTTING AND ROAD CONSTRUCTION ON SOIL EROSION BY LANDSLIDES IN WESTERN CASCADE RANGE, OREGON. GEOLOGY 3(7):393-396.

SWANSON, R.H., AND HILLMANN, G.R. 1977. PREDICTING INCREASED WATER YIELD AFTER CLEAR-CUTTING VERIFIED IN WEST-CENTRAL ALBERTA. NORTHERN FOREST RESEARCH CENTER, EDMONTON, ALBERTA, INFORMATION REPORT, NOR-X-198. 41 PP.

TABER, R.D. 1956. DEER NUTRITION AND POPULATION DYNAMICS IN NORTH COAST RANGE OF CALIFORNIA. NORTH AMER. WILDLIFE CONF. TRANS. 21:159-172.

TABER, R.D. 1970. THE BIOLOGICAL BASIS OF WILDLIFE DIVERSITY AND ABUNDANCE. UNPUBLISHED FILE, COLLEGE OF FOREST RESOURCES, UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON. 43 PP.

TABER, R.D. 1972. EFFECTS OF EVEN-AGED FOREST MANAGEMENT ON BIG GAME. IN: SYMPOSIUM ON EVEN-AGED FOREST MANAGEMENT (HERMANN, R., ED.), PP. 60-67. CORVALLIS, OREGON.

TABER, R.D. 1973. EFFECTS OF EVEN-AGE MANAGEMENT ON BIG GAME. IN: EVEN-AGE MANAGEMENT - PROCEEDINGS OF A SYMPOSIUM (HERMAN, R.K., AND LAVENDER, D.P., EDS.), PP. 59-84. OREGON STATE UNIVERSITY. CORVALLIS, OREGON.

TABER, R.D., AND DASMANN, R.F. 1957. THE DYNAMICS OF THREE NATURAL POPULATIONS OF THE DEER ODOCOILEUS HEMIONUS COLUMBIANUS. ECOLOGY 38:233-246.

TARRANT, R.F. 1961. STAND DEVELOPMENT AND SOIL FERTILITY IN A DOUGLAS FIR--RED ALDER PLANTATION. FOREST SCI. 7:238-246.

TAYLOR, R.F. 1934. YIELD OF SECOND GROWTH WESTERN HEMLOCK - SITKA SPRUCE STANDS IN SOUTHEAST ALASKA. U.S. DEPARTMENT OF AGRICULTURE TECH. BULL. 412. WASHINGTON, D.C. 299 PP.

TEAL, J.M. 1958. DISTRIBUTION OF FIDDLER CRAB IN GEORGIA SALT MARSHES. ECOLOGY 39:185-193.

TEAL, J.M. 1962. ENERGY FLOW IN THE SALT MARSH ECOSYSTEM OF GEORGIA. ECOLOGY 43:614-624.

TEGELBERG, H. 1970. A NEW PACIFIC RAZOR CLAM SPECIES. STATE OF WASHINGTON, DEPARTMENT OF FISHERIES, MANAGEMENT AND RESEARCH DIVISION, OLYMPIA, WASHINGTON.

TEGELBERG, H., MAGOON, D., LEBOKI, M., AND WESTRY, J. 1971. THE 1969 AND 1970 RAZOR CLAM FISHERIES AND SAMPLING PROGRAMS. PROGRESS REPORT, STATE OF WASHINGTON DEPARTMENT OF FISH MANAGEMENT, RESEARCH DIVISION, OLYMPIA, WASHINGTON.

TENORE, K.R., TEITJEN, J.H., AND LEE, J.J. 1977. EFFECT OF MEIOFAUNA ON INCORPORATION OF EELGRASS, ZOSTERA MARINA, DETRITUS BY THE POLYCHAETE NEPHTYS INCISA. J. FISH. RES. BOARD CANADA 34:563-567.

TERRELL, T.T. 1977. INTERIM HIERARCHIAL REGIONAL CLASSIFICATION SCHEME FOR COASTAL ECOSYSTEMS OF THE UNITED STATES AND ITS TERRITORIES. BIOLOGICAL SERVICES PROGRAM, FWS/OBS-77/48, FISH AND WILDLIFE SERVICE, U.S. DEPARTMENT OF THE INTERIOR. 39 PP.

THAYER, G.W., WOLFE, D.A., AND WILLIAMS, R.B. 1975. THE IMPACT OF MAN ON SEAGRASS SYSTEMS. AMER. SCIENTIST 63:288-296.

THOMAS, J., MASER, C., AND RODIEK, J. 1976. RIPARIAN ZONES - THEIR IMPORTANCE TO WILDLIFE AND THEIR MANAGEMENT. UNPUBLISHED MANUSCRIPT. PACIFIC NORTHWEST EXPERIMENT STATION, LE GRANDE, OREGON. 14 PP.

THOMPSON, K., AND SNOW, D. 1974. FISH AND WILDLIFE RESOURCES, OREGON COASTAL ZONE. OREGON COASTAL CONSERVATION AND DEVELOPMENT COMMISSION, PORTLAND, OREGON. 114 PP + MAPS.

THOMPSON, K.E., SMITH, A.K., AND LAUMAN, J.E. 1972. FISH AND WILDLIFE RESOURCES OF THE SOUTH COAST BASIN, OREGON, AND THEIR WATER REQUIREMENTS (REVISED). (ENVIRONMENTAL INVESTIGATIONS, SOUTH COAST BASIN). A REPORT WITH RECOMMENDATIONS TO THE OREGON STATE WATER RESOURCES BOARD. OREGON STATE GAME COMMISSION. FEDERAL AID TO FISH RESTORATION COMPLETION REPORT, FISHERIES STREAM FLOW REQUIREMENTS. PROJECT F-69-R-7, JOB NO. 11. PORTLAND, OREGON.

THORNTHWAITE, C.W. 1944. REPORT OF THE COMMITTEE ON TRANSPIRATION AND EVAPORATION. TRANS. AM. GEOPHYS. UNION 25:683-693.

TILLMAN, R., ARNER, D.H., AND GILL, J. 1976. PROCEEDINGS OF THE FIRST NATIONAL SYMPOSIUM ON ENVIRONMENTAL CONCERNS IN RIGHT-OF-WAY MANAGEMENT. MISSISSIPPI STATE UNIVERSITY, OXFORD, MISSISSIPPI. 335 PP.

TOBIN, D.G., AND SYKES, L.R. 1968. SEISMICITY AND TECTONICS OF THE NORTHEASTERN PACIFIC OCEAN. J. GEOPHYS. RES. 73:3821-3846.

TOKSOZ, M.N. 1973-74. CONSUMPTION OF THE LITHOSPHERE. OCEANUS 19:14-19.

TRAPPE, J.M., AND STRAND, R.F. 1969. MYCORRHIZAL DEFICIENCY IN A DOUGLAS-FIR REGION NURSERY. FOR. SCI. 15(4):381-389.

TRAPPE, J.M., FRANKLIN, J.F., TERRANT, R.T., AND HANSEN, G.M. (EDS.). 1967. BIOLOGY OF ALDER. PROC. OF SYMPOSIUM: NORTHWEST SCIENTIFIC ASSOC. 40TH ANNUAL MEETING, PULLMAN, WASHINGTON. 292 PP.

TYLER, G. 1971. DISTRIBUTION AND TURNOVER OF ORGANIC MATTER AND MINERALS IN A SHORE MEADOW ECOSYSTEM. OIKOS 22:265-291.

U.S. ARMY CORPS OF ENGINEERS. 1971. NATIONAL SHORELINE STUDY. INVENTORY REPORT, COLUMBIA-NORTH PACIFIC REGION, WASHINGTON AND OREGON. U.S. ARMY CORPS OF ENGINEERS, NORTH PACIFIC DIVISION. 80 PP. + 50 PLATES.

U.S. ARMY CORPS OF ENGINEERS. 1973C. NATIONAL STUDY REGIONAL INVENTORY REPORT. CALIFORNIA REGIONAL INVENTORY. 93RD CONGRESS, FIRST SESSION, HOUSE DOCUMENT NO. 93-121. U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.

U.S. ARMY CORPS OF ENGINEERS. 1974. COLUMBIA AND LOWER WILLAMETTE RIVER MAINTENANCE AND COMPLETION OF THE FORTY FOOT NAVIGATION CHANNEL DOWNSTREAM OF VANCOUVER, WASHINGTON AND PORTLAND, OREGON. DRAFT ENVIRONMENTAL IMPACT STATEMENT. U.S. ARMY CORPS OF ENGINEERS, PORTLAND DISTRICT, PORTLAND, OREGON. 114 PP., APPENDICES, MAPS.

U.S. ARMY CORPS OF ENGINEERS. 1975A. COOS BAY, OREGON, DEEP DRAFT NAVIGATION CHANNEL, ENVIRONMENTAL IMPACT STATEMENT, DRAFT SUPPLEMENT, VOL. I, BACKGROUND INFORMATION. U.S. ARMY CORPS OF ENGINEERS, PORTLAND DISTRICT, PORTLAND, OREGON. APPROX. 248 PP.

U.S. ARMY CORPS OF ENGINEERS. 1975B. COOS BAY, OREGON, DEEP DRAFT NAVIGATION CHANNEL, ENVIRONMENTAL IMPACT STATEMENT, FINAL SUPPLEMENT. U.S. ARMY CORPS OF ENGINEERS, PORTLAND DISTRICT, PORTLAND, OREGON. APPROX. 325 PP. + MAPS.

U.S. ARMY CORPS OF ENGINEERS. 1975C. COOS BAY, OREGON, DEEP DRAFT NAVIGATION CHANNEL, ENVIRONMENTAL IMPACT STATEMENT, DRAFT SUPPLEMENT, VOL. II, BACKGROUND INFORMATION. U.S. ARMY CORPS OF ENGINEERS, PORTLAND DISTRICT, PORTLAND, OREGON. 181 PP.

U.S. ARMY CORPS OF ENGINEERS. 1975D CHETCO, COQUILLE AND ROGUE RIVER ESTUARIES AND PORT ORFORD, OREGON. FINAL ENVIRONMENTAL IMPACT STATEMENT. U.S. ARMY CORPS OF ENGINEERS, PORTLAND DISTRICT, PORTLAND, OREGON. 287 PP.

U.S. ARMY CORPS OF ENGINEERS. 1975E. CORPS OF ENGINEERS ACTIVITIES IN THE CHETCO AND ROGUE RIVER ESTUARIES AND PORT ORFORD, OREGON. TECHNICAL APPENDICES TO DRAFT ENVIRONMENTAL IMPACT STATEMENT. U.S. ARMY CORPS OF ENGINEERS, PORTLAND DISTRICT, PORTLAND, OREGON. 200 PP.

U.S. ARMY CORPS OF ENGINEERS. 1975F. WASHINGTON ENVIRONMENTAL ATLAS. U.S. GOVERNMENT PRINTING OFFICE. WASHINGTON, D.C. 114 PP.

U.S. ARMY CORPS OF ENGINEERS. 1975G. FINAL ENVIRONMENTAL IMPACT STATEMENT. OPERATION AND MAINTENANCE OF THE CHANNELS AND BREAKWATERS IN YAQUINA BAY AND RIVER. U.S. ARMY CORPS OF ENGINEERS, PORTLAND DISTRICT, PORTLAND, OREGON. APPROX. 135 PP.

U.S. ARMY CORPS OF ENGINEERS. 1976-1977. MAINTENANCE DREDGING AND THE ENVIRONMENT OF GRAYS HARBOR, WASHINGTON. SUMMARY REPORT AND APPENDICES A-N. U.S. ARMY CORPS OF ENGINEERS SEATTLE DISTRICT, SEATTLE, WASHINGTON. 1611 PP. IN 5 DOCUMENTS.

U.S. ARMY CORPS OF ENGINEERS. 1976B. NEHALEM WETLANDS REVIEW, SUMMARY REPORT (DRAFT). U.S. ARMY CORPS OF ENGINEERS, PORTLAND DISTRICT, PORTLAND, OREGON. , 132 PP., APPENDICES.

U.S. ARMY CORPS OF ENGINEERS. 1976C. PORT OF GRAYS HARBOR/KAISER STEEL CORPORATION. FINAL ENVIRONMENTAL IMPACT STATEMENT. U.S. ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT, SEATTLE, WASHINGTON. 334 PP.

U.S. ARMY CORPS OF ENGINEERS. 1976G. WETLANDS REVIEW, ALSEA BAY, OREGON. U.S. ARMY CORPS OF ENGINEERS, PORTLAND DISTRICT, PORTLAND, OREGON. 344 PP. WITH APPENDICES.

U.S. ARMY CORPS OF ENGINEERS. 1976H. WILLAPA RIVER AND HARBOR NAVIGATION PROJECT, WASHINGTON. FINAL ENVIRONMENTAL IMPACT STATEMENT. U.S. ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT, SEATTLE, WASHINGTON. 464 PP.

U.S. ARMY CORPS OF ENGINEERS. 1976I. WETLANDS REVIEW, SILETZ BAY, OREGON. U.S. ARMY CORPS OF ENGINEERS, PORTLAND DISTRICT, PORTLAND, OREGON. 273 PP., APPENDICES.

U.S. ARMY CORPS OF ENGINEERS. 1976J. ANNUAL FISH PASSAGE REPORT. COLUMBIA RIVER PROJECTS. U.S. ARMY CORPS OF ENGINEERS, PORTLAND AND WALLA WALLA DISTRICTS. UNPAGED.

U.S. ARMY CORPS OF ENGINEERS. 1977A. MAINTENANCE DREDGING AND THE ENVIRONMENT OF GRAYS HARBOR WASHINGTON. SUMMARY REPORT AND APPENDIX D--SPECIES LISTS. U.S. ARMY CORPS OF ENGINEERS SEATTLE DISTRICT, SEATTLE, WASHINGTON. 105 PP.

U.S. BUREAU OF LAND MANAGEMENT. 1974. THE WESTERN GULF OF ALASKA. A SUMMARY OF AVAILABLE KNOWLEDGE. U.S. DEPARTMENT OF THE INTERIOR. BUREAU OF LAND MANAGEMENT, WASHINGTON, D.C. 599 PP.

U.S. DEPARTMENT OF AGRICULTURE. 1908. REDWOOD. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE SILVICAL LEAFLET 18. WASHINGTON, D.C. 55 PP.

U.S. DEPARTMENT OF AGRICULTURE. 1960 AND 1967 SUPPL. SOIL CLASSIFICATION, A COMPREHENSIVE SYSTEM. U.S. DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C. 265 PP.

U.S. DEPARTMENT OF AGRICULTURE. 1963. ANNUAL REPORT 1962. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION, BERKELEY, CALIFORNIA. 50 PP.

U.S. DEPARTMENT OF AGRICULTURE. 1974B. HABITAT MAPS FOR SPECIES OF CONCERN. UNPUBLISHED. ON FILE, SINSLAW NATIONAL FOREST, OREGON.

U.S. DEPARTMENT OF AGRICULTURE. 1975A. BEACHES AND DUNES OF THE OREGON COAST. U.S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE, PORTLAND, OREGON. 161 PP.

U.S. DEPARTMENT OF AGRICULTURE. 1975B. SOIL SURVEY OF JEFFERSON COUNTY AREA, WASHINGTON. U.S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE, PORTLAND, OREGON. 100 PP. + MAPS.

U.S. DEPARTMENT OF AGRICULTURE. 1976A. ENVIRONMENTAL STATEMENT, LAND USE PLAN FOR THE MT. BUTLER DRY CREEK PLANNING UNIT. U.S. FOREST SERVICE SISKIYOU NATIONAL FOREST, GRANTS PASS, OREGON.

U.S. DEPARTMENT OF AGRICULTURE. 1976B. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE ENVIRONMENTAL STATEMENT, LAND USE PLAN FOR THE ROGUE-ILLINOIS PLANNING UNIT (ROGUE-ILLINOIS PLANNING UNIT). U.S. FOREST SERVICE, SISKIYOU NATIONAL FOREST, GRANTS PASS, OREGON.

U.S. DEPARTMENT OF AGRICULTURE. 1977A. THE NATION'S RENEWABLE RESOURCES - AN ASSESSMENT, 1975. U.S. DEPARTMENT OF AGRICULTURE DEPARTMENT OF AGRICULTURE FOREST SERVICE, FOREST RESOURCE REPORT NO. 21. U.S. DEPARTMENT OF AGRICULTURE GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C. 243 PP.

U.S. DEPARTMENT OF AGRICULTURE. 1978A. RARE II. DRAFT ENVIRONMENTAL STATEMENT. ROADLESS AREA REVIEW AND EVALUATION. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, WASHINGTON, D.C. 112 PP.

U.S. DEPARTMENT OF AGRICULTURE. 1978B. RARE II, WASHINGTON, SUPPLEMENT TO DRAFT ENVIRONMENTAL STATEMENT, ROADLESS AREA REVIEW AND EVALUATION. U.S. FOREST SERVICE, WASHINGTON, D.C. 104 PP.

U.S. DEPARTMENT OF AGRICULTURE. 1978C. RARE II, OREGON, SUPPLEMENT TO DRAFT ENVIRONMENTAL STATEMENT, ROADLESS AREA REVIEW AND EVALUATION. U.S. FOREST SERVICE, WASHINGTON, D.C. 154 PP.

U.S. DEPARTMENT OF AGRICULTURE. 1978D. RARE II, CALIFORNIA, SUPPLEMENT TO DRAFT ENVIRONMENTAL STATEMENT, ROADLESS AREA REVIEW AND EVALUATION. U.S. FOREST SERVICE, WASHINGTON, D.C. 195 PP.

U.S. DEPARTMENT OF AGRICULTURE, STATISTICAL REPORTING SERVICE. 1976 (AND VARIOUS YEARS). AGRICULTURAL STATISTICS. U.S. DEPARTMENT OF AGRICULTURE STATISTICAL REPORTING SERVICE, WASHINGTON, D.C.

U.S. DEPARTMENT OF COMMERCE. 1968. CLIMATIC ATLAS OF THE UNITED STATES. ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION, ENVIRONMENTAL DATA SERVICE, NATIONAL CLIMATIC CENTER, FEDERAL BUILDING, ASHEVILLE, NORTH CAROLINA. 28801.

U.S. DEPARTMENT OF COMMERCE. 1969,1974 (AND VARIOUS YEARS). U.S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS, WASHINGTON, D.C.

U.S. DEPARTMENT OF COMMERCE. 1970 (AND VARIOUS YEARS). CENSUS OF POPULATION (DECENNIAL). U.S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS, WASHINGTON, D.C.

U.S. DEPARTMENT OF COMMERCE. 1974A. CLIMATES OF THE STATES. VOLUME II--WESTERN STATES. WATER INFORMATION CENTER, INC., PORT WASHINGTON, NEW YORK. 2 VOLS., APPROX. 690 PP.

U.S. DEPARTMENT OF COMMERCE. 1974B. RULES AND REGULATIONS PROMULGATED UNDER SECTION 312 OF THE COASTAL ZONE MANAGEMENT ACT OF 1972. ESTUARINE SANCTUARY GUIDELINES. FED. REG. 39(108)19922-19927.

U.S. DEPARTMENT OF COMMERCE. 1976. U.S. COAST PILOT 7. PACIFIC COAST, CALIFORNIA, OREGON, WASHINGTON, AND HAWAII. 12TH ED. U.S. DEPARTMENT OF COMMERCE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION/NATIONAL OCEAN SURVEY. 400 PP.

U.S. DEPARTMENT OF COMMERCE. 1977A. TIDAL CURRENT TABLES, PACIFIC COAST OF NORTH AMERICA AND ASIA. PUBLISHED ANNUALLY BY THE AUTHOR AGENCY. WASHINGTON, D.C.

U.S. DEPARTMENT OF COMMERCE. 1977B. TIDE TABLES, HIGH AND LOW WATER PREDICTIONS, WEST COAST OF NORTH AMERICA, INCLUDING THE HAWAIIAN ISLANDS. PUBLISHED ANNUALLY BY THE AUTHOR AGENCY. WASHINGTON D.C.

U.S. DEPARTMENT OF COMMERCE. 1977C. LOCAL CLIMATOLOGICAL DATA, ANNUAL SUMMARY WITH COMPARATIVE DATA, EUREKA, CALIFORNIA. U.S. DEPARTMENT OF COMMERCE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, ENVIRONMENTAL DATA SERVICE, NATIONAL CLIMATIC CENTER, ASHEVILLE, NORTH CAROLINA. 4 PP.

U.S. DEPARTMENT OF COMMERCE. 1977D. FINAL ENVIRONMENTAL IMPACT STATEMENT, STATE OF OREGON COASTAL MANAGEMENT PROGRAM AND APPENDIX. OFFICE OF COASTAL ZONE MANAGEMENT, NATIONAL OCEANIC AND ATMOSPHERIC ADMINSTRATION, WASHINGTON, D.C. 106 PP.

U.S. DEPARTMEMT OF COMMERCE, BUREAU OF THE CENSUS. 1977E. COUNTY BUSINESS PATTERNS, 1975. U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.

U.S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS. 1974C. CENSUS OF MANUFACTURERS, 1972. U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.

U.S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS. 1977D. COUNTY BUSINESS PATTERNS, 1975. U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C. 1977.

U.S. DEPARTMENT OF THE INTERIOR. 1970. THE NATIONAL ATLAS OF THE UNITED STATES OF AMERICA. U.S. DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY, WASHINGTON , D.C. 417 PP.

U.S. DEPARTMENT OF THE INTERIOR. 1970. NATIONAL ESTUARY STUDY. U.S. GOVERNMENT PRINTING OFFICE. 7 VOLS.

U.S. DEPARTMENT OF THE INTERIOR. 1973. THREATENED WILDLIFE OF THE UNITED STATES. BUREAU OF SPORT FISHERIES AND WILDLIFE RESOURCE PUBLICATION 114. WASHINGTON, D.C.

U.S. DEPARTMENT OF THE INTERIOR. 1978. PERSONAL COMMUNICATION. NATIONAL PARK SERVICE PRESS RELEASE.

U.S. DEPARTMENT OF THE NAVY. 1958. MARINE CLIMATIC ATLAS OF THE WORLD. VOL. 2. NORTH PACIFIC OCEAN. NAVAER 50-1C-529, 1 V. U.S. DEPARTMENT OF THE NAVY, WASHINGTON, D.C.

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1975A. LOGGING ROADS AND PROTECTION OF WATER QUALITY. U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION X WATER DIVISION, SEATTLE, WASHINGTON. 312 PP.

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1976A. FOREST HARVEST, RESIDUE TREATMENT, REFORESTATION, AND PROTECTION OF WATER QQUALITY. U.S. EPA REGION 10, EPA 910/9-76-020. 273 PP.

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1976B. QUALITY CRITERIA FOR WATER. U.S. ENVIRONMENTAL PROTECTION AGENCY, WASHINGTON, D.C., EPA-440/9-76-023. 501 PP.

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1978. WATER QUALITY STANDARDS FOR MARINE WATERS. U.S. ENVIRONMENTAL PROTECTION AGENCY, WASHINGTON, D.C.

U.S. FISH AND WILDLIFE SERVICE. 1976A. BIRDS AND MAMMALS OBSERVED ON OREGON COASTAL ISLANDS. UNPUBLISHED DATA FILE, FISH AND WILDLIFE SERVICE, CORVALLIS, OREGON.

U.S. FISH AND WILDLIFE SERVICE. 1976C. ENDANGERED AND THREATENED WILDLIFE AND PLANTS, REPUBLICATION OF THE LIST OF SPECIES. FEDERAL REGISTER, VOL. 41, NO. 208, PP. 47181-47198.

U.S. FISH AND WILDLIFE SERVICE. 1977A. PROPOSED ENDANGERED STATUS FOR 4 U.S. SPECIES OF FAUNA. FEDERAL REGISTER, VOL. 42, NO. 8, PP. 2507-2515.

U.S. FISH AND WILDLIFE SERVICE. 1977B. STATUS OF 10 SPECIES OF AMPHIBIANS. U.S. FEDERAL REGISTER VOL 42, NO. 148.

U.S. FISH AND WILDLIFE SERVICE. 1977C. BALD EAGLE MANAGEMENT GUIDELINES, OREGON - WASHINGTON. U.S. DEPARTMENT OF THE INTERIOR, FISH AND WILDLIFE SERVICE, PORTLAND, OREGON. 7 PP.

U.S. FISH AND WILDLIFE SERVICE. 1978. CHECKLIST OF ENDANGERED AND THREATENED SPECIES: UNITED STATES FISH AND WILDLIFE SERVICE REGION ONE, BY STATES. U.S. FISH AND WILDLIFE SERVICE, PORTLAND, OREGON. 15 PP.

U.S. NATIONAL COMMITTEE FOR THE INTERNATIONAL BIOLOGICAL PROGRAM. 1974. U.S. PARTICIPATION IN THE INTERNATIONAL BIOLOGICAL PROGRAM. U.S. NATIONAL COMMITTEE FOR THE INTERNATIONAL BIOLOGICAL PROGRAM, BULL. NO. 6, NATIONAL ACADEMY OF SCIENCES, WASHINGTON, D.C. 166 PP.

U.S. NATIONAL MARINE FISHERIES SERVICE. 1977A. FINAL ENVIRONMENTAL IMPACT STATEMENT/PRELIMINARY FISHERY MANAGEMENT PLAN, TROLL SALMON FISHERY OF THE PACIFIC COAST. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE, WASHINGTON, D.C. 128 PP.

U.S. NATIONAL MARINE FISHERIES SERVICE. 1977B. FINAL ENVIRONMENTAL IMPACT STATEMENT/PRELIMINARY FISHERY MANAGEMENT PLAN, TRAWL FISHERY OF THE WASHINGTON, OREGON AND CALIFORNIA REGION. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE, WASHINGTON, D.C. 115 PP.

U.S. NAVY--SEE.....U.S. DEPARTMENT OF THE NAVY.

U.W.--SEE.....UNIVERSITY OF WASHINGTON.

UDVARDY, M.D. 1963. BIRD FAUNAS OF NORTH AMERICA. INTERN. ORNITHOL. CONGR. PROC. 13:1147-1167.

UDVARDY, M.D. 1975. A CLASSIFICATION OF THE BIOGEOGRAPHICAL PROVINCES OF THE WORLD. INTERNATIONAL UNION FOR CONSERVATION OF NATURE AND NATURAL RESOURCES SWITZERLAND, IUCN, OCCAS. PAPER 18, 49 PP.

UDVARDY, M.D. 1977. THE AUDUBON SOCIETY FIELD GUIDE TO NORTH AMERICAN BIRDS, WESTERN REGION. ALFRED A. KNOPF, NEW YORK. 855 PP.

UNIVERSITY OF OREGON, BUREAU OF BUSINESS RESEARCH--SEE.....BUREAU OF BUSINESS RESEARCH. UNIVERSITY OF OREGON.

UNIVERSITY OF WASHINGTON DEPARTMENT OF OCEANOGRAPHY. 1955B. HUMBOLDT BAY, CALIFORNIA. A LITERATURE SURVEY. UNIVERSITY OF WASHINGTON, DEPARTMENT OF OCEANOGRAPHY, SEATTLE, WASHINGTON. 144 PP.

UNIVERSITY OF WASHINGTON. 1974. LEADBETTER POINT ENVIRONMENTAL ASSESSMENT. UNIVERSITY OF WASHINGTON COLLEGE OF FOREST RESOURCES, SEATTLE, WASHINGTON. 155 PP.

USDA--SEE.....U.S. DEPARTMENT OF AGRICULTURE.

USDC--SEE.....U.S. DEPARTMENT OF COMMERCE.

USDI--SEE.....U.S. DEPARTMENT OF THE INTERIOR.

VAN RAALTE, C.D. 1977. NITROGEN FIXATION IN SALT MARSHES--A BUILT-IN PLANT FERTILIZER. OCEANUS 20(3):58-63.

VANDERZANDEN, K.J. 1976. SALT MARSH PLANTS AND MARSH ZONATION. IN: COMPARATIVE STUDY OF SALT MARSHES IN COOS BAY ESTUARY (HOFFNAGLE, J., ED.) PP. 26-62. OREGON INSTITUTE OF MARINE BIOLOGY, CHARLESTON, OREGON.

VANDERZANDEN, K.J., VAN NESS, B., GNAT, M., AND HOFFNAGLE, J. 1976. NET PRIMARY PRODUCTION IN COOS BAY SALT MARSH. IN: COMPARATIVE STUDY OF SALT MARSHES IN THE COOS BAY ESTUARY (HOFFNAGLE, J., ED.), PP. 64-104. OREGON INSTITUTE OF BIOLOGY, CHARLESTON, OREGON.

VERNER, J. 1975. AVIAN BEHAVIOR AND HABITAT MANAGEMENT. IN: THE SYMPOSIUM ON MANAGEMENT OF FOREST AND RANGE HABITAT (SMITH. G.D., ED.), PP. 39-58. U.S. DEPARTMENT OF AGRICULTURE, GENERAL TECHNICAL REPORT WO-1. WASHINGTON, D.C.

VIDA. G. 1977. GENETIC DIVERSITY AND THE ENVIRONMENTAL FUTURE. ENVIRON. CONSERV. 4:231-232.

VOIGHT, G.K. 1965. BIOLOGICAL MOBILIZATION OF POTASSIUM FROM PRIMARY MINERALS. IN: FOREST-SOIL RELATIONSHIPS IN NORTH AMERICA (YOUNGBIRD, C.T., ED.), PP. 33-46. OREGON STATE UNIVERSITY, CORVALLIS, OREGON.

WADDELL, J.E. 1964. THE EFFECT OF OYSTER CULTURE ON EELGRASS (ZOSTERA MARINA L.) GROWTH. M.S. THESIS. HUMBOLDT STATE COLLEGE. 48 P.

WAHL, T.R. 1975. SEABIRDS IN WASHINGTONS OFFSHORE ZONE. WESTERN BIRDS 6:117-134.

WAHL, T.R., AND PAULSON, D. 1971. A GUIDE TO BIRD-FINDING IN WASHINGTON. UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON.

WAITS, E.D. 1967. NET PRIMARY PRODUCTIVITY OF AN IRREGULARLY-FLOODED NORTH CAROLINA SALT MARSH. PH.D. THESIS. NORTH CAROLINA STATE UNIVERSITY, RALEIGH, NORTH CAROLINA. 215 PP.

WALL, B.R. 1973. EMPLOYMENT IMPLICATIONS OF PROJECTED TIMBER OUTPUT IN THE DOUGLAS-FIR REGION, 1970-2000. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 11 PP.

WALL, B.R., AND OSWALD, D.D. 1975. A TECHNIQUE AND RELATIONSHIPS FOR PROJECTIONS OF EMPLOYMENT IN THE PACIFIC COAST FOREST PRODUCTS INDUSTRIES. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE RES. PAPER PNW-189. PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION, PORTLAND, OREGON. 49 PP.

WARING, R.H. 1969. FOREST PLANTS OF THE EASTERN SISKIYOUS: THEIR ENVIRONMENTAL AND VEGETATIONAL DISTRIBUTION. NORTHWEST SCIENCE 43:2-17.

WARREN, C.E. 1971. BIOLOGY AND WATER POLLUTION CONTROL. W.B. SAUNDERS CO., PHILADELPHIA, PENNSYLVANIA. 434 PP., ILLUSTRATIONS, BIBLIOGRAPHY.

WASHINGTON CROP AND LIVESTOCK REPORTING SERVICE. 1976 AND VARIOUS YEARS. WASHINGTON AGRICULTURAL STATISTICS, 1976 (AND ALSO 1973 AND 1975). WASHINGTON CROP AND LIVESTOCK REPORTING SERVICE, SEATTLE, WASHINGTON, IN COOPERATION WITH WASHINGTON DEPARTMENT OF AGRICULTURE AND U.S. DEPARTMENT OF AGRICULTURE STATISTICAL REPORTING SERVICE.

WASHINGTON STATE DCED--SEE.....WASHINGTON STATE DEPARTMENT OF COMMERCE AND ECONOMIC DEVELOPMENT.

WASHINGTON FOREST PRACTICE BOARD. 1976. WASHINGTON FOREST PRACTICE RULES AND REGULATIONS. WASHINGTON FOREST PRACTICE BOARD. 68 PP.

WASHINGTON STATE DEPARTMENT OF COMMERCE AND ECONOMIC DEVELOPMENT. 1977A. AN ECONOMIC ASSESSMENT OF AREA I: CLALLAM AND JEFFERSON COUNTIES. ECONOMIC POLICY ANALYSIS DIVISION, WASHINGTON STATE DEPARTMENT OF COMMERCE AND ECONOMIC DEVELOPMENT, OLYMPIA, WASHINGTON. 70 PP.

WASHINGTON STATE DEPARTMENT OF COMMERCE AND ECONOMIC DEVELOPMENT. 1977B. AN ECONOMIC ASSESSMENT OF AREA II: GRAYS HARBOR, LEWIS, MASON, PACIFIC, AND THURSTON COUNTIES. E ONOMIC POLICY ANALYSIS DIVISION, WASHINGTON STATE DEPARTMENT OF COMMERCE AND ECONOMIC DEVELOPMENT, OLYMPIA, WASHINGTON. 86 PP.

WASHINGTON STATE DEPARTMENT OF COMMERCE AND ECONOMIC DEVELOPMENT. 1977C. AN ECONOMIC ASSESSMENT OF AREA III: CLARK, COWLITZ, KLICKITAT, SKAMANIA, AND WAHKIAKUM COUNTIES. ECONOMIC POLICY ANALYSIS DIVISION, WASHINGTON STATE DEPARTMENT OF COMMERCE AND ECONOMIC DEVELOPMENT, OLYMPIA, WASHINGTON. 99 PP.

WASHINGTON STATE DEPARTMENT OF ECOLOGY. 1975. WATER QUALITY ASSESSMENT REPORT. REPORT NO. 75-8. WASHINGTON STATE DEPARTMENT OF ECOLOGY, OLYMPIA, WASHINGTON. 2 VOLS.

WASHINGTON STATE DEPARTMENT OF ECOLOGY. 1976. WASHINGTON STATE COASTAL ZONE MANAGEMENT PROGRAM. WASHINGTON STATE DEPARTMENT OF ECOLOGY, OLYMPIA, WASHINGTON. 143 PP., APPENDICES.

WASHINGTON STATE DEPARTMENT OF FISHERIES. 1973. FISHERIES RESOURCES IN SOUTHWEST WASHINGTON. WASHINGTON STATE DEPARTMENT OF ECOLOGY, REVIEW DRAFT, 1973, OLYMPIA, WASHINGTON. 154 PP.

WASHINGTON STATE DEPARTMENT OF FISHERIES. 1976. 1975 FISHERIES STATISTICAL REPORT (WARD, D., AND ROBISON, R.S., EDS.). DEPARTMENT OF FISHERIES, STATE OF WASHINGTON, OLYMPIA, WASHINGTON. 115 PP.

WASHINGTON STATE DEPARTMENT OF FISHERIES. 1978. PERSONAL COMMUNICATION.

WASHINGTON STATE DEPARTMENT OF GAME. 1974. WASHINGTON'S WILDLIFE, 1973-1974, SMALL GAME REPORT. OLYMPIA, WASHINGTON. 236 PP.

WASHINGTON STATE EMPLOYMENT SECURITY DEPARTMENT, RESEARCH AND STATISTICS BRANCH. 1976. LABOR MARKET INFORMATION FOR OLYMPIC PENINSULA AND SOUTHWEST WASHINGTON. WASHINGTON STATE EMPLOYMENT SECURITY DEPARTMENT, OLYMPIA, WASHINGTON. PP. 22,28.

WASHINGTON STATE GAME DEPARTMENT. 1977. ANNUAL REPORT. WASHINGTON GAME DEPARTMENT, OLYMPIA, WASHINGTON. 133 PP.

WASHINGTON STATE OFFICE OF PROGRAM PLANNING AND FISCAL MANAGEMENT. 1975. STATE OF WASHINGTON POCKET DATA BOOK, 1974. WASHINGTON STATE OFFICE OF PROGRAM PLANNING AND FISCAL MANAGEMENT, OLYMPIA, WASHINGTON.

WATTS, J.S., AND FAULKNER, R.E. 1968. DESIGNING A DRILLING RIG FOR SEVERE SEAS. OCEAN INDUST. 3:28-37.

WEED, S.B., DAVEY, C.B., AND COOK, M.G. 1969. WEATHERING OF MICA BY FUNGI. SOIL SCIENCE SOCIETY OF AMERICA, PROCEEDINGS 33:702-706.

WEINS, J.A. 1975. AVIAN COMMUNITIES, ENERGETICS, AND FUNCTIONS IN CONIFEROUS FOREST HABITATS. U.S. DEPARTMENT OF AGRICULTURE, GENERAL TECHNICAL REPORT WO-1 (SMITH, R.D., ED.), PP. 226-265. PRESENTED AT THE SYMPOSIUM ON MANAGEMENT OF FOREST AND RANGE HABITATS, TUCSON, ARIZONA, MAY, 1975.

WEINS, J.A., AND NUSSBAUM, R.A. 1975. MODEL ESTIMATION OF ENERGY FLOW IN NORTHWESTERN CONIFEROUS FOREST BIRD COMMUNITIES. ECOLOGY 56:

WEIR, J.R. 1916. KEITHIA THUJINA, THE CAUSE OF A SERIOUS LEAF DISEASE OF THE WESTERN RED CEDAR. PHYTOPATHOLOGY 6:360-363.

WELTY, J.C. 1962. THE LIFE OF BIRDS. PHILADELPHIA AND LONDON. 546 PP.

WESTERN LAND GRANT UNIVERSITIES AND COLLEGES AND U.S. SOIL CONSERVATION SERVICE. 1964. SOILS OF THE WESTERN UNITED STATES (EXCLUSIVE OF HAWAII AND ALASKA). WASHINGTON STATE UNIVERSITY, PULLMAN, WASHINGTON. 69 PP.

WESTERN WOOD PRODUCTS ASSOCIATION. 1976. 1975 STATISTICAL YEARBOOK. WESTERN WOOD PRODUCTS ASSOCIATION, STATISTICAL DEPARTMENT, PORTLAND, OREGON. 32 PP.

WESTMAN, W.E. 1977. HOW MUCH ARE NATURES SERVICES WORTH (QUESTION). SCIENCE 197:960-964.

WEYMOUTH, F.W., MCMILLIN, H.C., AND HOLMES, H.B. 1925. GROWTH AND AGE AT MATURITY OF THE PACIFIC RAZOR CLAM, SILIQUA PATULA (DIXON). BULL. U.S. BUR. FISH. 41:201-236.

WHITAKER, J.O., JR., AND MASER, C. 1976. FOOD HABITS OF FIVE WESTERN OREGON SHREWS. NORTHWEST SCIENCE 50:102-107.

WHITTAKER, R.H. 1954. THE ECOLOGY OF SERPENTINE SOILS. NO. IV. THE VEGETATIONAL RESPONSE TO SERPENTINE SOILS. ECOLOGY 35:258-288.

WHITTAKER, R.H. 1960. VEGETATION OF THE SISKIYOU MOUNTAINS, OREGON AND CALIFORNIA. ECOL. MONOGR. 30:279-338.

WHITTAKER, R.H. 1961. VEGETATION HISTORY OF THE PACIFIC COAST STATES AND THE CENTRAL SIGNIFICANCE OF THE KLAMATH REGION. MADRONO 16:5-22.

WIGHT, H.M. 1974. NONGAME WILDLIFE AND FOREST MANAGEMENT. IN: WILDLIFE AND FOREST MANAGEMENT IN THE PACIFIC NORTHWEST (BLACK, H.C., ED.), P. 27. OREGON STATE UNIVERSITY SCHOOL OF FORESTRY, CORVALLIS, OREGON.

WILLIAMS, R.B., AND MURDOCK, M.B. 1966. ANNUAL PRODUCTION OF SPARTINA ALTERNIFLORA AND JUNCUS ROEMIANUS IN SALT MARSHES NEAR BEAUFORT, NORTH CAROLINA. ASSOC. SOUTHEAST. BIOL. BULL. 13:49.

WILLIAMS, R.W., LARAMIE, R.M., AND AMES, J.J. 1975. A CATALOG OF WASHINGTON STREAMS AND SALMON UTILIZATION. VOL. 1. PUGET SOUND REGION. WASHINGTON STATE DEPARTMENT OF FISHERIES, OLYMPIA, WASHINGTON. APPROX. 500 PP.

WILSEY AND HAM INC. 1974. ESTUARINE RESOURCES OF THE OREGON COAST. A NATURAL RESOURCE INVENTORY REPORT TO THE OREGON COASTAL CONSERVATION AND DEVELOPMENT COMMISSION. WILSEY HAM, INC., PORTLAND, OREGON. 233 PP.

WILSON, B.W., AND TORUM, A. 1968. THE TSUNAMI OF THE ALASKA EARTHQUAKE, 1964: ENGINEERING EVALUATION. TECHNICAL MEMORANDUM NO. 25. U.S. ARMY CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, FORT BELVOIR, VIRGINIA.

WINZLER AND KELLY CONSULTING ENGINEERS. 1977. A SUMMARY OF KNOWLEDGE OF THE CENTRAL AND NORTHERN CALIFORNIA COASTAL ZONE AND OFFSHORE AREAS. VOL. 1. PHYSICAL CONDITIONS. WINZLER AND KELLY CONSULTING ENGINEERS, EUREKA, CALIFORNIA, FOR THE BUREAU OF LAND MANAGEMENT.

WISE, J.P., AND THOMPSON, B.G. 1977. FISHERY STATISTICS OF THE UNITED STATES, 1974. STATISTICAL DIGEST NO. 68, DATA MANAGEMENT AND STATISTICS DIVISION, NATIONAL MARINE FISHERIES SERVICE, NOAA, SEATTLE, WASHINGTON. 424 PP.

WOOD, A.J., COWAN, I., AND NORDAN, H.C. 1962. PERIODICITY OF GROWTH IN UNGULATES AS SHOWN BY DEER OF THE GENUS ODOCOILEUS. CAN. J. ZOOL. 40:593-603.

WOODWELL, G.M., WURSTER, C.F., AND ISAACSON, P.A. 1967. DDT RESIDUES IN AN EAST COAST ESTUARY: A CASE OF BIOLOGICAL CONCENTRATION OF A PERSISTENT INSECTICIDE. SCIENCE 156:821-824.

WORTHINGTON, N.P. 1955. A COMPARISON OF CONIFERS PLANTED ON THE HEMLOCK EXPERIMENTAL FOREST. U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE, PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION RESOURCE NOTE III, PORTLAND, OREGON. 5 PP.

WRIGHT, E., AND ISAAC, L.A. 1956. DECAY FOLLOWING LOGGING INJURY TO WESTERN HEMLOCK, SITKA SPRUCE AND TRUE FIRS. U.S. DEPARTMENT OF AGRICULTURE TECHNICAL BULLETIN 1148. 34 P.

WROBLEWSKI, J.S. 1977. A MODEL OF PHYTOPLANKTON PLUME FORMATION DURING VARIABLE OREGON UPWELLING. J. MAR. RES. 35(2):357-394.

WURSTER, C.F., JR. 1971. CHLORINATED HYDROCARBON INSECTICIDES AND THE WORLD ECOSYSTEM. IN: MANS IMPACT ON ENVIRONMENT (DETWILER, T.R., ED.), PP. 555-564. MCGRAW-HILL BOOK CO., NEW YORK.

WYATT, B., BURT, W.V., AND PATTULLO, J.G. 1972. SURFACE CURRENTS OFF OREGON AS DETERMINED FROM DRIFT BOTTLE RETURNS. J. PHYS. OCEANOGR. 2(3):286-293.

WYDOWSKI, R.S., AND WHITNEY, R.R. 1979 (IN PRESS). INLAND FISHES OF WASHINGTON. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON. 400 PP.

WYGODZINSKY, P. 1961. ON A SURVIVING REPRESENTATIVE OF THE LEPIDOTRICHIDAE (THYSANURA). ANN. ENT. SOC. AMER. 54(5):621-627.

YOCUM, C.F. 1951. WATERFOWL AND THEIR FOOD PLANTS IN WASHINGTON. UNIVERSITY OF WASHINGTON PRESS, SEATTLE, WASHINGTON. 272 PP.

YOCUM, C.F., AND BROWN, V. 1971. WILDLIFE AND PLANTS OF THE CASCADES. NATUREGRAPH PUBLISHERS, HEALDSBURGH, CALIFORNIA. 286 PP.

YOCUM, C.F., AND KELLER, M. 1961. CORRELATION OF FOOD HABITS AND ABUNDANCE OF WATERFOWL, HUMBOLDT BAY, CALIFORNIA. CALIF. FISH GAME 47(1):41-53.

YOUMANS, R., ROMPA, W., AND IVES, E. 1977. THE TILLAMOOK COUNTY ECONOMY: A WORKING MODEL FOR EVALUATING ECONOMIC CHANGE. OREGON STATE UNIVERSITY EXTENSION SERVICE SPECIAL REPORT 478. CORVALLIS OREGON. 17 PP.

ZAK, B. 1975. MYCORRHIZAE AND CONTAINER SEEDLINGS. PROC. 23RD ANNUAL WESTERN INTERNATIONAL DISEASE WORK CONFERENCE, PP. 21-23.

ZAK, B. 1976. PURE CULTURE SYNTHESIS OF BEARBERRY MYCORRHIZAE. CAN. J. BOT. 54(12):1297-1305.

ZOBELL, C.E. 1946. MARINE MICROBIOLOGY. CHRONICA BOTANICA CO., WALTHAM, MASSACHUSETTS. 240 PP.

ZOPF, D.O., CREECH, C., AND QUINN, W.H. 1976. THE WAVEMETER: A LAND BASED SYSTEM FOR MEASURING NEARSHORE OCEAN WAVES. MARINE TECHNOL. SOC. BULL. 10:19-25.

DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE