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COMPREHENSIVE REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FOLLOWING DISTURBANCES: MARINE INVERTEBRATE COMMUNITIES

by

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EXECUTIVE SUMMARY

This paper is a comprehensive review and critical synthesis of the readily available literature on recovery of marine benthic invertebrate communities following disturbances. It was commissioned by the staff of the Oil Spill Restoration Planning Office to assist them in their management of Alaska's Prince William Sound area following the oil spill of the *Exxon Valdez*.

Benthic invertebrate communities are very productive, rich in species and support food webs that include commercially and ecologically important species. These communities are vulnerable to disturbances, including storm damage, sewage pollution and oil pollution. Many scientific studies have described the recovery of these communities after a disturbance.

This document summarises 79 of these recovery studies. In particular, it addresses the following issues: (a) recovery time; (b) abiotic factors that affect recovery; (c) management practices; and (d) recommended approach to determine when recovery has occurred.

(a) Recovery time. The general conclusions were :

1. Most studies reported that recovery did not occur in the time allowed by the investigators. [Most studies were conducted for less than three years.] This makes discussion of recovery times difficult and forces one to examine trends in the recovery times found in the studies.
2. Recovery was more likely after a small disturbance than after a large disturbance.
3. Recovery was equally as likely in intertidal and subtidal habitats.
4. Recovery was more likely after a non-oiling disturbance than after an oiling disturbance.
5. Recovery was more likely after oiling of hard substrates than after oiling of soft substrates.
6. Recovery times of invertebrate communities after an oiling event are estimated to be 10 - 20 years for communities on hard substrates and 10 - 25 years for communities on soft substrates.

(b) Abiotic factors that affect recovery. Recovery is generally slower (a) after a large oil spill than after a small oil spill, (b) in soft sediments than on hard sediments, (c) in the high intertidal zone than in the low intertidal zone, and (d) at high latitudes than at temperate latitudes.

(c) Management practices. Many management practices may influence recovery. In particular, I point out the problems associated with clean-up and bioremediation, and suggest that transplantation of some species should be considered.

(d) Recommended approach to determine when recovery has occurred. I believe that the following six points are crucial to conducting a successful study.

1. A definition of recovery is necessary. I suggest: "Complete recovery of an invertebrate community after an oil spill occurs when (a) all the species that were present before the oil spill are again present; (b) each of these species has reached their original abundances and biomasses, (c) each of these species has reached their original age distributions, and (d) all individuals are as healthy (as measured by growth rates) and productive (as measured by reproductive condition) as the individuals that were present at the time of the oil spill." In the absence of pre-spill data, original conditions (i.e.,

abundances, biomasses, age distributions, growth rates and productivities) should be estimated from several unoiled communities in similar physical/chemical environments.

2. The hypotheses being tested should be clearly stated. The following hypotheses are appropriate: that there are no significant differences in (a) the species that are present in oiled and unoiled areas; (b) the abundances and biomasses of the species in oiled and unoiled areas; (c) the age distributions of the species in oiled and unoiled areas; and (d) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

3. None of the 79 studies provides a good example of how to conduct a recovery study (defined as testing the hypotheses cited in #2 above). It is clear that if a study is to stand up to scrutiny it will have to be a careful and thorough study planned by competant statisticians and biologists familiar with the Alaskan ecosystem.

4. Natural communities are spatially and temporally heterogenous. This means (a) that it is necessary to study many unoiled and many oiled sites so that the range of natural variability can be determined, (b) that a large area should be sampled at each site, and (c) that many samples are required for reliable estimates of population densities.

5. All the results that are necessary and sufficient to test the hypotheses should be presented in the research report.

6. Details about "important species" (e.g., those that are numerically dominant, provide much of the structure to the community, or play an important role in the dynamics of the system) should also be presented. An analysis of the recovery of the community therefore requires a detailed knowledge of the community.

1.0 INTRODUCTION

1.1 Background

On 24 March 1989 the tanker *Exxon Valdez* ran aground in Alaska's Prince William Sound causing the largest oil spill in U.S. history. Approximately 11 million gallons of North Slope crude was lost at sea. The oil spread over an area of >900 square miles and oiled 1, 244 miles of the shorelines in the Prince William Sound, and on the Kenai Peninsula, Alaska Peninsula and Kodiak Island (Alaska Department of Environmental Conservation, 1989).

A tremendous clean-up and restoration effort has followed the spill and the managers of this effort would like to know what to expect in the recovery of these habitats. In particular, they would like answers to questions such as: How long will recovery take? What factors are likely to affect recovery? What indicators of recovery should the biologists be measuring? In an attempt to answer these questions for benthic marine invertebrate communities I have reviewed the literature on recovery of invertebrate communities after various disturbances, including oil spills.

Benthic invertebrate communities in the intertidal and shallow subtidal zones are particularly vulnerable to oil spills because much of the oil is deposited and concentrated in these habitats (National Research Council 1985) and, because most invertebrates are relatively immobile, they are unable to escape the toxic and smothering effects of oiling. The recovery of these communities is relatively slow, i.e., several years, and the damage caused by an oil spill can often still be detected several years after a major spill (e.g., Southward and Southward 1978).

Benthic invertebrate communities are very productive, rich in species and support complex food webs that frequently include commercially and ecologically important species. For instance, the benthic invertebrates in Alaska support many species of bottom feeding fish (e.g., black rockfish), birds (e.g., oystercatchers), and mammals (e.g., gray whale, sea otter, brown bear, black bear, even man -- subsistence harvesting of mussels and clams). Also many benthic invertebrates have planktonic larvae and these become important components of planktonic food webs which include pelagic fishes (e.g., salmon, herring), birds (e.g., puffins, kittiwakes, murres, bald eagles), and mammals (e.g., harbor seals). Damages to the benthic invertebrate communities can therefore have wide-spread effects.

The effects of disturbances on benthic invertebrate communities have been well studied, particularly during the past 20 years (e.g., Kvitek et al. in press, see Connell and Keough 1985, and Sousa 1985, for reviews). However, long-term studies of recovery in these communities are rare -- I have found only 79 studies that deal with recovery and most of these (62%) followed recovery for a rather short time -- three years or less. My review of these recovery studies expands upon earlier reviews by Mann and Clark (1978), Thistle (1981), and Ganning et al. (1984), and provides a different perspective to the review by Baker et al. (1990).

1.2 Objectives

There are two objectives to this paper:

1. To review the readily available literature on recovery of marine invertebrate communities after a disturbance. I will focus on the rate of recovery and factors that may affect recovery.
2. To extrapolate the information obtained in the review to the injured Alaskan ecosystem. In particular, to identify the most practical indicators of recovery to measure, and to recommend an approach to determine when recovery has occurred.

2.0 TECHNICAL APPROACH

2.1 Information Retrieval and Sources of Data

I searched in many places for papers dealing with the recovery of marine invertebrate communities. These included:

GENERAL REFERENCES

1. Aquatic Sciences and Fisheries Abstracts -- 1982 to 1990. Using the key words: oil-spills-benthic; intertidal-recruitment; intertidal-succession; subtidal-succession; disturbance-recovery-invertebrates; disturbance-recovery-marine; and oil-invertebrates.

2. The reference lists in: Vesco and Gillard 1980; Sousa 1984; Foster et al. 1988.

OIL POLLUTION REFERENCES

3. Oil Spill Public Information Center's Collection List (1366 entries) -- June 1991.

4. Proceedings of the American Petroleum Institute Oil Spill Conferences from 1975 through 1991 (e.g., American Petroleum Institute 1991).

5. The reference lists in: National Research Council 1975, 1985; Wolfe 1976; Stevenson 1978; Cox 1980; Cairns and Buikema 1984; Boesch and Rabalais 1987; Mielke 1990; Houghton et al. 1991a.

6. Marine Pollution Bulletin for the years 1985 through 1990.

DREDGING and DRILLING MUD REFERENCES

7. The reference lists in: Kester et al. 1982; National Research Council 1983; Ketchum et al. 1985; Cullinane et al. 1990.

EARTHQUAKES, LANDLEVEL CHANGES and NUCLEAR TESTING REFERENCES

8. The reference lists in: Kirkwood 1971; National Research Council 1971, 1973; Merritt and Fuller 1977.

9. Citation Index for recent citations of: Hubbard 1971; Baxter 1971; Haven 1971; O'Clair 1977; Lebednik and Palmisano 1977.

2.2 Analysis and Synthesis

Papers were excluded from the review if: (1) they dealt with the effect of a disturbance and not recovery after the disturbance (e.g., Maki 1991, see Teal and Howarth 1984, and National Research Council 1985 for reviews of effects); (2) they dealt with only the effect of oil on the physiology, biochemistry or behavior of species (e.g., Percy 1977, see National Research Council 1985 for review); and (3) they were not in English (e.g., NOAA-CNEXO 1982). Thus the papers that are included in this review deal with the population and community level recovery after many kinds of disturbances (from whale feeding excavations to oil and sewage spills), in several different habitats (from subtidal soft sediments to rocky shores), and from many parts of the world (from the Straits of Magellan to Norway).

I grouped the papers according to the nature of the habitat (soft substrates and hard substrates, intertidal and subtidal), the size of the disturbance (small, if less than square meters; medium if square meters; and large if square kilometers), and the type of disturbance (non-organic, organic, and oil pollution).

3.0 REVIEW OF READILY AVAILABLE INFORMATION ON RECOVERY

3.1 Benthic Invertebrates

3.1.1 Rate, Duration, and Degree of Recovery Following Disturbance

It is important to define what is meant by the terms disturbance and recovery. Disturbance is "a discrete, punctuated killing, displacement, or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established" (Sousa 1984). Typical disturbances in benthic invertebrate communities are oil pollution, sewage pollution, the shearing force of large waves, and the foraging activities of animals, such as whales.

The majority of the papers discussed below do not define recovery, however their implied definition was usually "the return of all population densities to pre-disturbance levels or to undisturbed levels". For the purposes of this section I have chosen to keep to this definition. However, in Section 4.2.1 I discuss further the definition of recovery.

Here I review many different types of disturbances and deal with soft and hard sediments separately because there are some differences in the recovery of their benthic invertebrate communities.

SOFT SUBSTRATES

A) Succession model

The effects of organic pollution on infaunal invertebrate communities have been studied for many years and a general model has emerged of the succession that occurs in these communities during recovery (Pearson and Rosenberg 1978, Rhoads and Germano 1982). Figure 1A describes part of this model. In general, a heavy input of organic material (e.g., sewage, pulp-mill effluent) onto the sediment reduces the oxygen content of

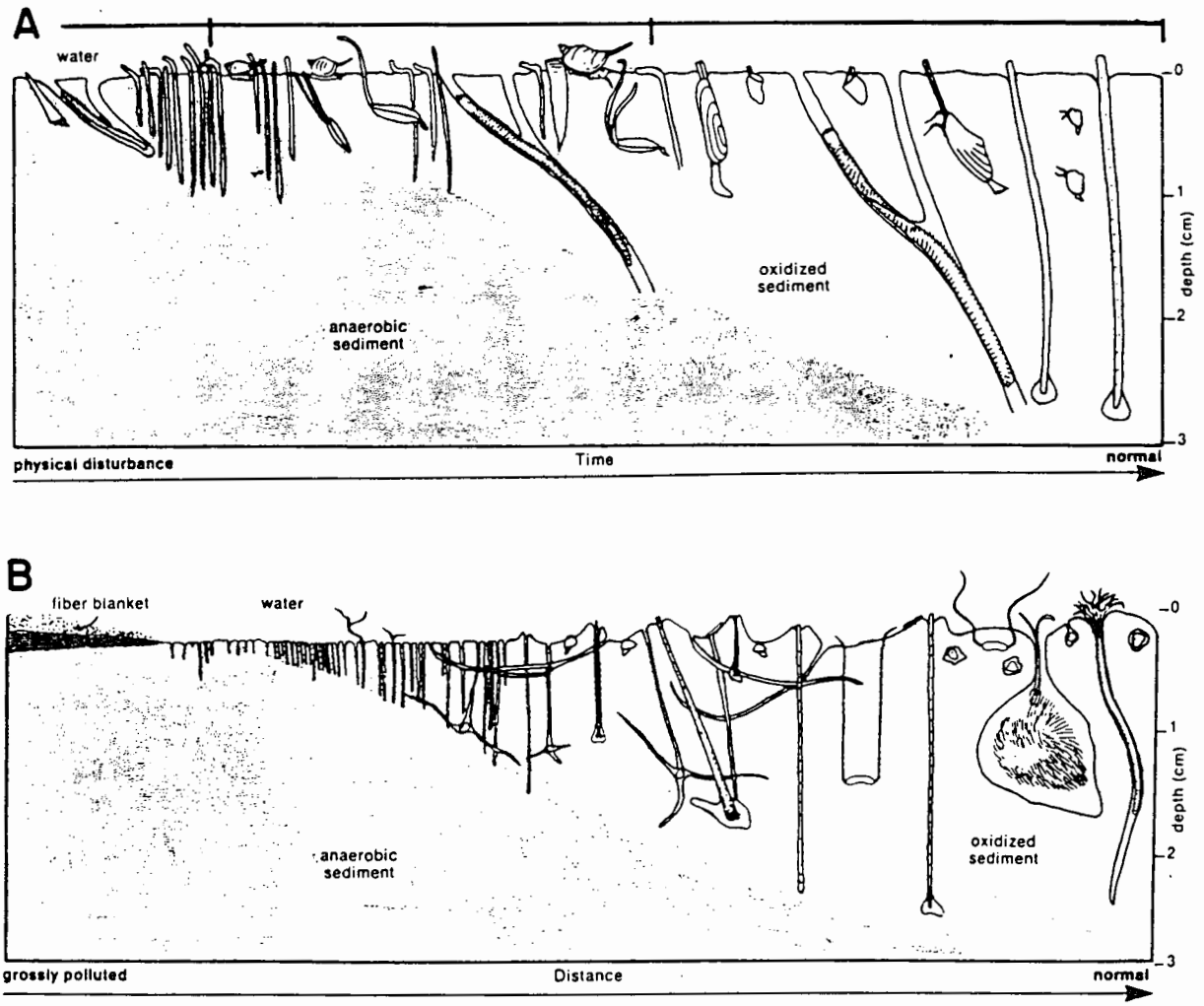

Figure 1. A diagram showing the variations in a typical benthic infauna community. The changes that occur in time during recovery from a disturbance (A) and the changes that occur in space around a source of pollution (B). From Rhoads and Germano (1982); used without permission.

the sediment and a black anaerobic layer rises to the sediment surface. The combination of high sulphide, low pH, and low oxygen concentrations in anaerobic sediment may cause complete defaunation. With no further input of organic material, currents carry away some of the organic material, conditions improve and a few macroinvertebrate species invade. These opportunistic, or "pioneer", species are usually epibenthic or surface-dwelling species (e.g., small tubiculous polychaetes) that are able to tolerate the conditions and take advantage of the rich organic material available. As conditions improve further and oxygen penetrates farther into the sediment, other species invade. These species, called "equilibrium" species or late succession species, include sub-surface deposit feeders whose burrowing activities result in further aeration of the sediment. Finally, these late succession species grow large, other late succession species invade, some (or all) of the opportunists drop out, and the community is indistinguishable from an undisturbed community.

Notice that the succession began when the area was invaded by relatively small, abundant, surface dwelling polychaete opportunists and ended when the area was inhabited by a suite of relatively large, rare, deep dwelling late succession species that include polychaetes, mollucs, crustaceans and echinoderms. Not only does the diversity of phyla increase but the number of foraging modes also increases, from non-selective sub-surface deposit feeders (e.g., *Capitella*) and carnivores, to suspension-feeders, omnivores, carnivores, and selective surface deposit feeders (Pearson and Rosenberg 1978).

The second part of the model describes how three important community characteristics (total number of species, total number of individuals, and total biomass) change during recovery of the community following an organic pollution event (Pearson and Rosenberg 1978; Figure 2). The total number of species increases steadily but then declines slightly because the opportunistic species tend to drop out. The total number of individuals rises very rapidly because the opportunists can be very dense but as the opportunists are replaced by late succession species the number of individuals drops quickly and eventually levels off at a relatively low number. The total biomass tends to increase steadily to a plateau usually with two peaks -- one early in the succession when opportunists are abundant and the other in the middle of succession when the greatest number of species are present in the community.

The end point of the succession is termed the "climax." This climax may only exist as an average condition on a relatively large spatial scale because frequent disturbances will prevent all parts of the habitat from reaching the climax state at the same time (Sousa 1984). The habitat will appear spatially heterogenous, i.e., many small patches at different stages of succession will be scattered in the large climax community.

The successional patterns described here also occur in space (Figure 1B). As one proceeds from a point source of organic pollution one will find in turn: an afaunal area, an area dominated by surface dwelling polychaetes, an area where there is a mixture of opportunistic and late succession species (transitional), and finally an area dominated by late succession species. This spatial pattern has been studied more than the temporal pattern (e.g., Pearson 1975, Swartz et al. 1986).

An important aspect of this model is that the composition of the early and late communities are quite predictable. The opportunistic species that invade during the initial stages of recovery from enrichment are distributed world-wide and the composition of the community they form is usually very similar from place to place (Pearson and Rosenberg 1978). It is therefore predictable. The late succession species that form the community during the final stage of recovery are more locally distributed and the "normal" communities they form differ from site to site depending on the habitat and the faunal region. However, the composition of these "normal" communities is predictable from

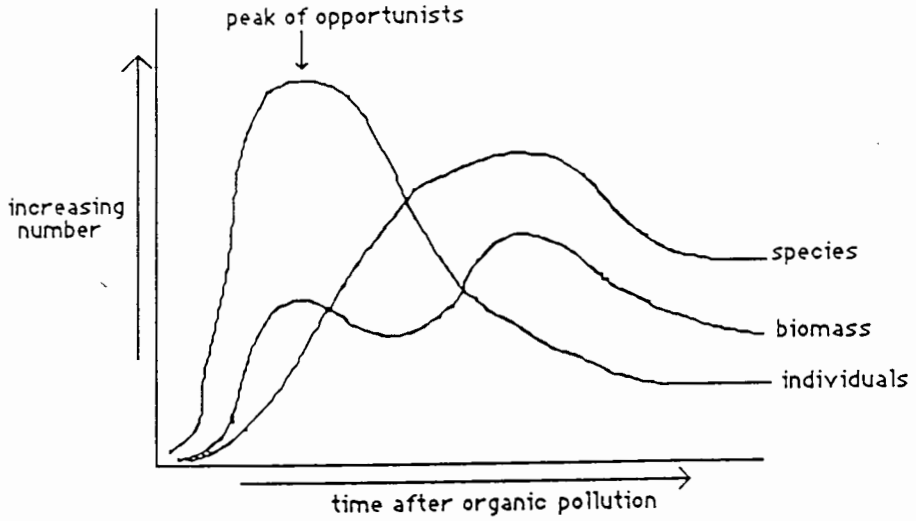

Figure 2. The fluctuations that occur in the number of species, number of individuals, and total biomass during the recovery of a typical benthic infauna community. From Pearson and Rosenberg (1978).

undisturbed areas nearby. Only the transitional community is unpredictable. This is because both the recruitment of the late succession species and the elimination of the opportunistic species is unpredictable.

Another important aspect of this succession is that a large number of species at a site does not necessarily indicate a fully recovered community. Actually a fully recovered site has fewer species, fewer individuals and less biomass than a partially recovered site. It will probably have the following characteristics: the anaerobic layer will be deep, several phyla will be present and several feeding modes will be present. However, a site can be considered to have fully recovered only when it is structurally and functionally indistinguishable from undisturbed reference sites.

B) Recovery times

Fifty-three studies dealt with the recovery of invertebrate communities in soft bottom habitats (Table 1). In deciding whether an area had recovered or not, I adopted the decision of each author, i.e., if the author determined that the area had recovered then I entered it as a "Yes", and if the author determined that it had not recovered then I entered it as a "No". The words "yes" and "no" could be replaced with "recovered" and "recovering".

a. Non-organic disturbances

A few studies dealt with the recovery of invertebrate communities after they were disturbed by animals, e.g., crabs, rays and walruses. These disturbances tended to be on a relatively small scale -- even the excavations made by the gray whales are usually less than $50m^2$ in size (Oliver and Slattery 1985). Recovery of these communities was relatively rapid -- some recovery had occurred in just a few days and in most cases full recovery was expected to occur within one year. Recovery occurred relatively quickly in other small scale disturbances as well, e.g., experimental pits made to mimic the effects of animal foraging activities (e.g., Savidge and Taghon 1988) and experimentally defaunated areas (e.g., Zajac and Whitlatch 1982a, b). Most authors attributed this to the rapid invasion of small areas by animals from the water column and the surrounding areas.

Recovery from more extensive disturbances, such as following dredging, a red tide, an earthquake or a hurricane, were slower -- recovery had not been completed in any of these cases and most of the studies had lasted for more than one year. One study found that recovery had not occurred in an area of mine tailings after 12 years (Ellis and Hoover 1990a, b).

b. Anthropogenic pollution

Organic pollution and oil pollution have been described as similar -- both forms of pollution are frequently extensive and affect the sediment and its inhabitants in similar ways (Glémarec 1986). Several studies dealt with the recovery of invertebrate communities following an organic pollution event (Table 1). Most commonly the authors reported that recovery was not complete, but recovery did occur in one case (Rosenberg 1976).

Rosenberg (1976) monitored the subtidal benthic community in the Saltkallefjord before and after a paper mill stopped dumping organic material. He found that recovery of the community was slowest in the most polluted sites; after approximately six years these sites had partially recovered -- they had the same number of species as the less polluted sites but the species compositions were not similar. After eight years, however, the

Table 1. A summary of the papers dealing with the recovery of marine invertebrate communities after a disturbance. For each paper the type of disturbance (dist.) and its size (Sm. = small, M = medium, L = large) are given. The time is either the recovery time (if recovery occurred) or the time between the disturbance and the last visit to the site (if recovery did not occur). The community is determined to have recovered if the authors said it had recovered or if the disturbed site was indistinguishable from a reference site. Quotes from the papers are included to amplify the answers. "REF" refers to the type of reference site(s) used (S = space, i.e., undisturbed site(s), T = time, i.e., the same site(s) prior to disturbance); "exp." = experimental; and "defaun." = defaunation. In addition, an * indicates that pollution was the source of the disturbance and, although it was substantially reduced, it was not completely eliminated. The Bibliography contains the full citation and abstract of each of these papers.

DIST. and SIZE	HABITAT	SITE	TIME	RECOVERY OF COMMUNITY ?	REF.	SOURCE
Soft Substrates						
Non-organic disturbance						
exp. pits, Sm.	intertidal	Oregon	24 days	**Yes**, "harpacticoids, juvenile spionids, cumaceans, and tanaids returned rapidly to ambient densities"	S	Savidge & Taghon 1988
crabs, Sm.	subtidal	Scotland	1 mo.	**Yes**, "the community returned to its original state within 25 to 30 days"	S	Hall et al. 1991
rays, Sm.	subtidal	S. California	1-1.5 mo	**Yes**, "the third phase of colonization is the gradual return of several numerically dominant species to predisturbance densities on a scale of 4-6 weeks"	S	Van Blaricom 1982
walruses, Sm.	subtidal	Bering Sea	2.5 mo.	**No**, "the infauna had not recovered by this time"	S	Oliver et al. 1985
exp. mounds, Sm.	intertidal	Scotland	4.5 mo.	**No**, "numbers remained low throughout the recovery period, being only 50% of the control population"	S	McLusky et al. 1983
exp. pits, Sm.	intertidal	Scotland	4.5 mo.	**Yes**, "the basins had populations equal to the controls"	S	McLusky et al. 1983
whales, Sm.	subtidal	Bering Sea & Brit. Columbia	7 mo.	**Yes**, "community patterns probably were re-established within the experimental excavations"	S	Oliver & Slattery 1985

Table 1 (cont.)
Soft Substrates Non-organic disturbance (cont.)

DIST. and SIZE	HABITAT	SITE	TIME	RECOVERY OF COMMUNITY ?	REF.	SOURCE
exp. defaun., Sm.	subtidal	Connecticut	1.08 yr.	**Yes**, "recovery to ambient conditions occurred rapidly in the lower reach, while successional changes in the middle and upper basins continued at least until the end of the winter"	S	Zajac & Whitlatch 1982a, b
exp. defaun., Sm.	subtidal	Lake Erie	2.17 yrs.	**No**, "late colonizers ... reached natural abundances only after several months if at all"	S	Soster & McCall 1990
dredging, M.	subtidal	Italy	6 mo.	**No**, "the 6-month post-dredging communities still showed a noticeable qualitative dissimilarity with respect to the predredging period and neighbouring non-dredged areas"	T & S	Pagliai et al. 1985
dredging, M.	subtidal	New York	11 mo.	**No**, "the bay sediments exhibited an overall reduction in epi- and infaunal populations, which did not approach recovery levels 11 mo. after dredging"	T	Kaplan et al. 1974
drill cuttings, M.	subtidal	New Jersey	6 mo.	**No**, "although polychaete species composition was unaffected by the drilling, polychaete densities were significantly lowered"	T & S	Maurer et al. 1981
drill cuttings, M.	subtidal	North Sea	1.33 yrs.	**No**, "results ... indicate partial recovery of macrofaunal communities"	T & S	Mair et al. 1987
red tide, M.	intertidal	Florida	2 yrs.	**No**, "although species composition was fairly constant, the distribution of individuals among species changed greatly"	T	Dauer & Simon 1976
mine tailings, M.	subtidal	West Canada	12 yrs.	**No**, "biological differences between tailing and non-tailing areas remain after 12 years"	S	Ellis & Hoover 1990a, b
earthquake, L.	intertidal	Alaska	1 yr.	**No?**, "some species have apparently experienced little reproduction since the earthquake"	T	Hubbard 1971

Table 1 (cont.)
Soft Substrates Non-organic disturbance (cont.)

earthquake, L.	intertidal	Alaska	1 yr.	**No**, post-earthquake clam abundances were 64% the (estimated) pre-earthquake abundances	T	Baxter 1971
hurricane, L.	subtidal	Chesapeake Bay	2.5 yrs.	**No**, "the deep mud bottom community ... had not recovered 2.5 years after the storm"	T	Boesch et al. 1976
Anthropogenic pollution						
organic, L.	subtidal	L.A. Harbor	1 yr.	**No**, but there was an "upgrading of species composition from a polluted to a semi-healthy species composition in the immediate area"*	None	Reish et al. 1980
organic, L.	subtidal	Sweden	4 yrs.	**No**, but "the echinoderms, which were the dominating animal group ... began to be re-established"*	T	Rosenberg 1972
organic, L.	subtidal	England	7 yrs.	**No**, "in the middle reaches a fauna tolerant of organic pollution is very abundant"*	S	Shillabeer & Tapp 1989
organic, L.	subtidal	Sweden	8 yrs.	**Yes**, "the basic recovery ... took five years, and ... after eight years it was not possible to distinguish between a normal and a recovery -influenced succession"*	T & S	Rosenberg 1976
organic, L.	subtidal	Texas	12 yrs.	**No**, but "it was evident that the Neches river estuary had been greatly improved"*	None	Harrel & Hall 1991
Oil pollution						
exp. oiling, Sm.	salt marsh	Georgia	5 mo.	**Yes**, "increased periwinkle density in the oiled area was due to recolonization of the area by juvenile forms"	T & S	Lee et al. 1981

Table 1 (cont.)
Soft Substrates Oil pollution (cont.)

exp oiled mud, Sm.	intertidal	Wales	10 mo.	No, "total faunal density and abundance of certain species remain depressed for the duration of the experiment"	S	Dixon 1987
exp oiling, Sm.	intertidal	Virginia	10 mo.	No, oligochaetes, polychaetes and amphipods more abundant in control even after 39 wks.	S	Bender et al. 1977
exp oiling, Sm.	intertidal	Washington	1.25 yrs.	No, "for individual species densities as well as overall abundance ... oiled substrates had recovered only about one-half"	S	Vanderhorst et al. 1980
oil spill, M.	subtidal	L.A. Harbor	11 mo.	No, "population levels appeared normal ... although total numbers have not equalled the (pre-oiling) levels"*	T & S	Reish et al. 1980
oil spill, L.	subtidal	Sweden	10 mo.	No, "the soft bottom community did not show even the beginning of a recovery"	T	Linden et al. 1979
oil spill, L.	eelgrass	France	1 yr.	No, but "recovery took place relatively rapidly... all numbers were at the same level as the year before, the filter feeding amphipoda being the only exception"	T	Jacobs 1980
oil spill, L.	subtidal	France	1 yr.	No, "one year later, several species eliminated from the polluted area, had still not yet begun to recover"	T	Cabioch 1980
oil spill, L.	intertidal	Alaska	1.25 yrs.	No, "shoreline treatment and oil contamination each caused major negetive impacts ... but the effects of the treatment predominated"	S	Houghton et al. 1991a, b
oil spill, L.	coral & mangroves	Panama Canal	1.5 yrs.	No, "after 1.5 years only some organisms in areas exposed to the open sea have recovered"	T & S	Jackson et al. 1989

Table 1 (cont.)
Soft Substrates Oil pollution (cont.)

oil spill, L.	intertidal	Washington	2.5 yrs.	**No**, bivalve biomass and infaunal species number still higher in unoiled site *	S	Blaylock & Houghton 1989
oil spill, L.	intertidal	Arctic	2 yrs.	**No**, "neither in 1979 or 1980 were living macrobenthic organisms recorded"	S	Gulliksen & Taasen 1982
oil spill, L.	intertidal	France	2 yrs.	**No**, "the original community has been replaced by a new community containing a very small number of tolerant species"	T & S	Laubier 1980
oil spill, L.	subtidal	France	2 yrs.	**No**, "there is no question that on a quantitative basis the stricken communities have not yet recovered to their previous richness and diversity"	T & S	Laubier 1980
oil spill, L.	subtidal	Nova Scotia	2.25 yrs.	**No**, "longer term effects involved extensive mortalities of *Mya arenaria* and *Spartina alterniflora*."	None	Thomas 1973
oil spill, L.	saltmarsh	S. Chile	2.33 yrs.	**No**, "observations ... at the east inlet of Puerto Espora demonstrated that the benthic macrobiota is still very scarce"	S	Guzman & Campodonico 1981
oil pollution, L.	subtidal	Finland	3 yrs.	**No**, "3 or 4 years is not long enough for monitoring the final stages of a postabatement succession"	S	Leppäkoski & Lindström 1978
oil spill, L.	intertidal	France	3 yrs.	**No**, "the biological environment has not returned to its pristine condition "	T & S	Conan 1982
oil spill, L.	salt marsh	Massachusetts	3 yrs.	**No**, "the interstitial fauna ... showed an extremely reduced number of individuals and species"	S	Hampson & Moul 1978
oil spill, L.	subtidal	Baltic	3.4 yrs.	**No**, "full recovery is likely to require more than 5 years and may take a decade or more"	T & S	Elmgren et al. 1983

Table 1 (cont.)
Soft Substrates Oil pollution (cont.)

oil spill, L.	intertidal	California	5 yrs.	**No**, "the present densities (of *Emerita analoga* and *Nepthys californiensis*) have not approached the pre-oil status for this area"	T	Chan 1977
oil spill, L.	intertidal	Massachusetts	5 yrs.	**No**, "after more than five years the fauna had only slightly recovered"	S	Michael et al. 1975, Sanders 1978, Sanders et al. 1980
oil spill, L.	subtidal	Massachusetts	5 yrs.	**No**, "recovery had begun but it was not very far advanced"	S	Michael et al. 1975 Sanders 1978, Sanders et al. 1980,
oil spill, L.	salt marsh	Nova Scotia	5 yrs.	**No**, "soft-shell clams ... have shown persistent mortalities proportional to oil content of the sediment"	None	Thomas 1977
oil spill, L.	subtidal	France	5.5 yrs.	**Yes**, recovery of the fauna took between 66 mo. (# individuals and species) and 84 mo. (biomass)	None?	Glémarec 1986
oil spill, L.	intertidal	Massachusetts	7 yrs.	**No**, "the persistent reduction in fiddler crab populations observed at Wild Harbor at least 7 years after the original oil spill"	S	Krebs & Burns 1977
oil spill, L.	intertidal	Nova Scotia	7 yrs.	**No**, "species diversity was uniformly higher at control than oiled stations. Analysis of abundance and biomass data ... showed a significant overall difference between oiled and control stations"	S	Thomas 1978
oil spill, L.	subtidal	France	8 yrs.	**No**, "the amphipod populations ... have not yet fully recovered 8 years after the pollution"	T	Dauvin 1987
oil spill, L.	intertidal	France	10 yrs.	**No**, "the amphipod populations ...were in the least advanced state of recovery"	T	Dauvin & Gentil 1990
oil spill, L.	subtidal	France	10 yrs.	**Yes**, "the population structure tended towards a return to the inital situation"	T	Ibanez & Dauvin 1988

Table 1 (cont.)

Hard Substrates

Non-organic disturbances

exp. removal, Sm.	intertidal	Oregon	1.75-. 3.17 yrs.	**Yes**, "the timing and magnitude of successful barnacle recruitment appeared to cause much of the variation in the rate of succession"	S	Farrell 1991
exp. removal, Sm.	intertidal	Washington	3 yrs.	**No**, "when members of a sparse, isolated group of mussels were lost, no recovery was seen within periods ranging up to 3 yr."	T & S	Dethier 1984
exp. removal, Sm.	intertidal	California	3 yrs.	**No**, "*Mytilus californianus* did not recruit to the patches from the plankton during the 3 years"	T & S	Sousa 1984
exp. removal, Sm.	intertidal	California	4 yrs	**Yes**, "leads to development of ... the equivalent late successional stage in a minimum of 4 years"	T & S	Sousa 1979(a & b), 1980
exp. removal, Sm.	intertidal	Washington	5.5 yrs.	**Yes**, "recovery should occur in roughly 40 mo."	T & S	Paine & Levin 1981
nuclear test, M.	intertidal	Alaska	3.5 yrs.	**No**, "significant changes were still observed in some plots 3.5 years after the test"	T & S?	Lebednik & Palmisano 1977
nuclear test, M.	intertidal	Alaska	3.75 yrs.	**No**, "plot 1 is the only plot ... to show signs of recolonization by intertidal organisms after 33 months post-event"	T & S	O'Clair 1977
earthquake, L.	intertidal	Alaska	1.25 yrs.	**No**, "the inferred climax community had not yet become established in the post-earthquake intertidal zone"	S	Haven 1971
earthquake, L.	intertidal	Chile	4 yrs.	**No**, "rapid invasion by barnacles" but "no settlement of the competitively dominant intertidal mussel"	S	Castilla 1988, Castilla & Oliva 1990
earthquake, L.	intertidal	Alaska	5 yrs.	**Yes**, "with some exceptions these communities have returned to essentially their pre-earthquake condition"	S	Haven 1971

Table 1 (cont.)

Hard Substrates

Oil pollution

exp. oiling, Sm.	mesocosms	Norway	1 yr.	**No**, "most responses were back to normal, and population regeneration of mussels and amphipods had started, but some physiological dysfunctions were still detected"	T & S	Bakke 1986
exp. oiling, Sm. + dispersants	subtidal	Panama	1.7 yrs.	**No**, "recovery of sea urchins was complete after 1 year but the recovery of corals and other encrusting organisms will probably take several years"	T & S	Ballou et al. 1989
oil spill, M. + dispersants	intertidal	Ireland	2 yrs	**Yes**, "the rocky-shore littoral community ... had largely recovered from the effects of the oil spill"	S	Flower 1983
oil spill, M.	intertidal	Washington	2.5 yrs.	**Yes**, "the area affected has returned to an apparently normal state as determined by our level of investigation"*	S	Clark et al. 1975
oil spill, M.	intertidal	Wahington	5 yrs.	**Yes**, "the community balance in this rocky intertidal ecosystem does not appear to be markedly altered"*	S	Clark et al. 1978
oil spill, L.	intertidal	Sweden	1 yr.	**No**, "the recovery of the littoral fauna was well under way one year after the spill but was not yet complete"	T	Linden et al. 1979
oil spill, L.	intertidal	sub-Antarctic	1 yr.	**No**, "densities of marine invertebrates appeared to have been markedly reduced in the lower littoral and sublittoral zones"	S	Pople et al. 1990
oil spill, L.	intertidal	Alaska	1.25 yr.	**No**, "lower densities of limpets and littorines" and *Nucella lamellosa* in oiled sites	S	Houghton et al. 1991a, b
oil spill, L.	intertidal	France	2 yrs.	**Yes**, "the recovery of areas exposed to waves, currents and winds is almost complete"	T & S	Laubier 1980

Table 1 (cont.)

Hard Substrates	Oil pollution (cont.)					
oil spill, L.	intertidal	Nova Scotia	2.25 yrs.	**No**, "longer term effects involved extensive mortalities of *Fucus spiralis*"	None	Thomas 1973
oil spill, L.	intertidal	Baltic	4 yrs.	**Yes**, "no significant evidence of lasting detrimental effects can be found when natural annual variations ... are taken into account"	S	Notini 1978
oil spill, L.	intertidal	Nova Scotia	5 yrs.	**No**, "sporelings of fucoid algae have repeatedly settled in this zone but have never survived to a size where they could be identified"	None	Thomas 1977
oil spill, L.	intertidal	California	5 yrs.	**No**, "crab numbers are only half the pre-spill numbers"	T	Chan 1977
oil spill, L.	intertidal	Nova Scotia	7 yrs.	**No**, "species diversity was uniformly higher at control than oiled stations. Analysis of abundance and biomass data ... showed a significant overall difference between oiled and control stations"	S	Thomas 1978
oil spill, L.	intertidal	Shetland Is.	9 yrs.	**No**, "the biological communities at the sites that were cleaned mechanically were obliterated and still have not recovered"	T & S	Rolan & Gallagher 1991
oil spill, L. + dispersants	intertidal	England	10 yrs.	**No**, "lightly oiled, wave-beaten rocks that received light dispersant treatment showed the most complete return to normal, taking about 5-8 yr; heavily oiled places that received repeated application of dispersants have taken 9-10 yr and may not be completely normal yet"	T	Southward & Southward 1978

compositions of the most polluted and least polluted sites were similar, and they were similar to that recorded prior to the establishment of the paper mill, forty years earlier.

c. Oil pollution

Many studies dealt with the recovery of benthic infaunal communities after being oiled (Table 1). The scale of the oil pollution ranged from small experimental oilings to major oil spills.

The recovery of invertebrates after a small scale oiling was slow. Above, I pointed out that recovery in small areas is usually fast, but when oil is applied to the sediment the recovery is slower. For example, in the study by Vanderhorst et al. (1980), recovery was not complete after 16 months. Although the species lists were similar in the control and oiled sites, the abundances of the species were significantly lower in the oiled sites.

Only two of the 25 studies describing the recovery of soft bottom invertebrate communities after a large-scale oiling found full recovery (Glémarec 1986, Ibanez and Dauvin 1988; Table 1). The recovery times for these studies were 5.5 years, and 10 years, respectively. More typically the researchers return to a site three to ten years after an oil spill, and determine that recovery still has not occurred (e.g., Thomas 1977).

I suspect that insufficient time has been allowed for full recovery to occur at most of these study sites. I conclude that the recovery of soft sediment invertebrate communities after an oil spill can take longer than ten years, but how much longer one cannot say.

HARD SUBSTRATES

A) Succession

Succession on rocky shores has been well studied in temperate zones (e.g., Dayton 1971, Lubchenco 1983, Sousa 1984, Farrell 1991) and a general view of the process has emerged (Paine and Levin 1981). In the absence of disturbance, the competitive dominant species spreads out and occupies nearly 100% of the primary space. For example, mussels are the competitive dominant on exposed Washington shores and they can form beds that cover 100% of the rock surface (Dayton 1971). Disturbance by waves, logs or starfish predation opens gaps in the beds of the competitive dominant. These gaps are relatively small, usually less than $1m^2$ (Paine and Levin 1981). Small gaps are filled by the growth or movement of animals from the surrounding area. Large gaps are invaded by these means and by the settlement of species out of the plankton. The first settlers are usually small algal species, followed by barnacles and worms, and finally by the dominant large algae and/or mussels. Thus a succession generally occurs, but this succession is not particularly predictable -- the rates at which species invade depend upon the presence of their larvae in the water column and inhibition of one species by another can occur. Frequently a shoreline looks like a mozaic where the matrix of the competitive dominant is interrupted by scattered patches of other species at different stages of succession.

An important principle has come out of these studies -- the intermediate disturbance principle: the highest number of species is found in a system with an intermediate degree of disturbance (Paine 1966, Connell 1978). If the combined disturbance from all sources (e.g., predation, wave action) is low, then the system becomes dominated by the competitive dominant and its attendant species (i.e., a relatively low number of species). If the combined disturbance is high, then few opportunities arise for most species to recruit successfully -- therefore the total number of species is again low. Only when the combined disturbance is intermediate do conditions favour a large number of species. This pattern is

usually studied in space, i.e., at several places at the same time, but it is also observed at one place over time, i.e., during the recovery of invertebrate communities after a disturbance (Connell 1978). In this respect recovery on hard sediments is similar to that in soft sediments -- the greatest number of species occur before full recovery. Therefore, again, the presence of a large number of species does not necessarily indicate that a site has recovered.

An important feature of the studies that have led to these generalizations about succession on rocky shores is that the disturbances examined are unlike oil pollution -- the bare spaces, or gaps, are relatively small and organic enrichment is rarely involved. However, Southward and Southward (1978) stated that the general sequence of recolonization after the Torrey Canyon oil spill was similar to that described above for small-scale experiments where the rocks were scraped clean.

B) Recovery times

I reviewed 26 studies that dealt with the recovery of invertebrate communities on hard substrates (Table 1). In this section, as above, in deciding whether an area had recovered or not, I adopted the decision of each author, i.e., if the author determined that the area had recovered then I entered it as a "Yes", and if the author determined that it had not recovered then I entered it as a "No". The words "yes" and "no" could be replaced with "recovered" and "recovering".

a. Non-organic disturbances

Several studies in Table 1 deal with the recovery of rocky shore invertebrate communities after non-organic disturbances. Recovery was relatively common and rapid -- between 1.75 years (Farrell 1991) and 5.5 years (Paine and Levin 1981); however, some sites had not recovered after more than three years (e.g., O'Clair 1977, Castilla 1988).

Boulder beaches are common in Alaska and the recovery of the communities on boulder beaches is therefore of special interest. Sousa (1979a, 1979b, 1980) showed that the recovery of early successional assemblages on boulder beaches takes approximately 5 months, middle successional assemblages 2.5 years, and late successional assemblages a minimum of 4 years.

Landslides and elevation changes resulting from earthquakes and nuclear testing are examples of extreme physical disturbances. Uplifting from the 1964 Alaska earthquake and the 1971 "Cannikin" nuclear test caused a die-off of most species whose elevation was raised. These species were being replaced by others that generally occur higher up the shore (e.g., O'Clair 1977, Haven 1971).

It must be remembered that these disturbances are not necessarily similar to oil spills because several were relatively small and none involved the addition of toxic organic material.

b. Oil pollution

Many studies have dealt with the recovery of rocky shore invertebrate communities after oiling (Table 1). In general, recovery was common and occurred relatively quickly (five years or less) after small and medium sized oil spills, but recovery was less common and occurred relatively slowly after large spills (even after ten years a site may not be fully recovered).

Southward and Southward (1978) noted that "heavily oiled places that received repeated application of dispersants have taken nine to ten years and may not be completely normal yet." Thomas (1978) found that, seven years after an oil spill, the oiled communities still did not resemble the unoiled communities. The fucoid algae (e.g., *Fucus*), in particular, were slow to recover.

CONCLUSIONS

Whereas Table 1 contains the details of recovery of invertebrate communities Table 2 shows an overview of Table 1. The general trends are:

1. Most of the studies report that recovery did not occur in the time allowed by the investigators. Recovery occurred in only 24% of the studies (Table 2). This means that either: recovery was going to occur in all cases but the assessment of recovery was conducted too early, i.e. prior to recovery (Teal 1990, Harding 1990); or recovery was not going to occur in all cases because the systems were irreparably damaged and will never recover to their pre-disturbance conditions.

2. Recovery was more likely after a small disturbance than after a large disturbance. Recovery was reported in 50% of the studies following a small disturbance, 25% of the studies following a medium disturbance, and in only 13% of the studies following a large disturbance (Table 2). This suggests that recovery times are relatively fast after a small disturbance but slow after a large disturbance.

3. Recovery was equally as likely in intertidal and subtidal habitats. Recovery was reported in 25% of the intertidal studies and 19% of the subtidal studies (Table 2).

4. Recovery was more likely after a non-oiling disturbance than after an oiling disturbance. Recovery was reported in 33% of the stuidies following a non-oiling disturbance and in only 17% of the studies following an oiling disturbance (Table 2). This suggests that recovery times are relatively fast after a non-oiling disturbance but slow after an oiling disturbance. A reason for these trends is that oil persists longer than other disturbances (e.g., sewage); Ganning et al. (1984) estimated that the minimum residence time of oil on mud flats was 10 years..

5. Recovery was more likely after oiling of hard substrates than after oiling of soft substrates. Recovery was reported in 31% of the studies of oiling of hard substrates and in only 10% of the studies of oiling of soft substrates (Table 2). Again, this suggests that recovery times are relatively fast on hard substrates but slow in soft substrates. One reason for these trends is that oil persists longer in soft sediments than on hard substrates (Vandermeulen 1977; see Section 3.1.2 for further discussion).

6. Recovery times of invertebrate communities after an oiling event are estimated to be 10 - 20 years for communities on hard substrates and 10 - 25 years for communities on soft substrates. Recovery occurred in only 17% of the oiling studies thus making calculations of mean recovery times impossible (Table 2). However, with what data we have at present, it appears that these estimates of 10 - 20 years and 10 - 25 years are reasonable.

Table 2. The number of studies that recorded full recovery (yes) and incomplete recovery (no) of invertebrate communities. They are grouped according to the size of the disturbance, nature of the habitat, nature of the disturbance, and oiling in different habitats. The studies are from Table 1.

INVERTEBRATE COMMUNITY RECOVERY				
	YES	NO	TOTAL	% YES
total	19	60	79	24 %
size of disturbance				
small	10	10	20	50 %
medium	3	9	12	25 %
large	6	41	47	13 %
nature of habitat				
intertidal	12	36	48	25 %
subtidal	6	25	31	19 %
nature of disturbance				
not oiled	11	22	33	33 %
oiled	8	38	46	17 %
oiling in different habitats				
oiling of soft substrates	3	27	30	10 %
oiling of hard substrates	5	11	16	31 %

These recovery time estimates are similar to those estimated by most others (e.g., Vandermeulen 1978 -- 5 to 15 years). Only the Exxon Corporation biologists who reviewed the literature on recovery of cold water marine environments after oil spills suggest much faster recovery time estimates (Baker et al. 1990). They concluded that "rocky shores usually recover in 2 to 3 years. Other shorelines show substantial recovery in 1 to 5 years with the exception of sheltered, highly productive shores (e.g., salt marshes), which may take 10 years or more to recover." Their lower estimated recovery times can be partly attributed to their definition of recovery (see Section 4.2.1).

However, the Exxon Corporation biologists tended to use references selectively. Their paper covers the same topics as mine -- it includes a section on the benthic environment and a table (their Table 7) which is much like my Table 1. When a comparison is made of the two tables it is obvious that theirs omits some important references -- the relatively long-term studies of soft sediments that found the recovery to be incomplete (e.g., Elmgren et al. 1983, Sanders 1978, Sanders et al. 1980, Thomas 1977, Dauvin 1987). In addition, in some cases, they chose to present the rosiest picture. For example, Southward and Southward (1978) state that "lightly oiled, wave-beaten rocks that received light dispersant treatment showed the most complete return to normal, taking about 5-8 years; heavily oiled places that received repeated application of dispersants have taken 9-10 years and may not be completely normal yet." Baker et al. (1990) describe these results in their table as "good recovery after 2 years." It is clear that the paper by Baker and her colleagues must be read with some skeptism.

3.1.2 Effects of Abiotic Factors on Recovery

Because recovery occurred in so few of the studies cited in Table 1, it is extremely difficult to make correlations between abiotic factors and recovery times. However, drawing on the data and observations presented in the papers, I conclude that four abiotic factors influence recovery.

NATURE OF THE OIL SPILL

It has been noted that each spill is unique because numerous variables affect spill impact. These include type of spill, duration of exposure, volume and type of oil, oil state and age (degree of weathering), weather, season, use of dispersants, etc. (Straughan 1972). However, the severity of the oil spill and its areal extent appear to affect the recovery time most (Southward and Southward 1978, Sanders et al. 1980); high concentrations of oil will kill more of the resident species, making recovery slower, and large areas killed by oiling take longer for invertebrates to recolonize, partly because large areas are recolonized primarily by larvae and partly because sources of new individuals are far away (Sousa 1984).

HABITAT

Recovery is slower in soft sediments than on rocky shores (Vandermeulen 1977, Table 2). The main reason for this appears to be the lingering effects of oil in soft sediments. The time taken for oil to weather and disperse after an oil spill depends on the water flow in the habitat (National Research Council 1985). Ganning et al. (1984) reported that the estimated minimum residence time of oil spilled in the following habitats was: 6 months on rocky shores, 4 years on sandy shores, and 10 years on mud flats. Factors that promote oil retention are weak tidal action, weak currents and fine sediments

(Vandermeulen 1977, Gundlach 1987). Although recovery starts as soon as organisms can tolerate the conditions, which is well before all the oil has dissappeared, it appears that the residual hydrocarbons retard recovery of the invertebrate communities by taking up space, by killing individuals, and by reducing their reproductive output (Southward and Southward 1978).

Also lingering oil may cause "delayed effects". The effects of an oil spill may be delayed up to three years after the spill; however the cause-and-effect relationship is often difficult to demonstrate. Conan (1982) gives two examples: was the death of all the intertidal individuals of the species *Tellina fabula* (a clam) several months after an oil spill due to oil? Also, was the poor recruitment of *Tellina fabula* and *Donax vittatus* for the two years following a spill due to oil?

The disturbance level in the habitat will also influence the recovery time because a frequently disturbed habitat will have younger adults than an infrequently disturbed habitat. For instance, intertidal boulders are frequently disturbed by large waves that cause the boulders to roll over and thereby crush or smother the organisms growing on them (Sousa 1979a, b); stable rocky shores are also affected by the large waves but less so (Dayton 1971). Thus, stands of old organisms are rare on boulder beaches but common on stable rocky shores. One would therefore predict that recovery would be faster on boulders than on stable rocky shores.

TIDAL HEIGHT

Position in the intertidal zone is important to the recovery of the community after a disturbance -- low- and mid-tidal communities recover more quickly than high-tidal communities (e.g., Farrell 1991). This appears to be related to the amount of time underwater and its influence on growth rates and larval survivorship.

Position in the intertidal zone is also important to the natural self-cleaning of stranded oil -- oil stranded half-way up the shore is removed more quickly than oil stranded at the top of the shore (Vandermeulen 1977, Thomas 1977, 1978). This appears to be due to the amount of time underwater and the differing forces of waves in the low and high intertidal.

The recovery of the high intertidal species is likely to take a long time partly because recovery is naturally slower than that of the mid-tidal species and partly because oil stranded in the high intertidal zone slows the process still further. Describing the recovery of the intertidal communities five years after the Arrow oil spill, Thomas (1977) stated that "recolonization has proceeded from lower to higher levels but has not yet occurred in the high tide zone."

TEMPERATURE

Cool temperatures slow biological processes. Cold water organisms are longer lived, have longer generation times, lower fecundity and slower growth rates than their warm water counterparts (Southward and Southward 1978, Roberts 1989). Recovery of invertebrate communities is therefore expected to proceed more slowly at high latitudes (Dunbar 1968, Southward and Southward 1978, Clarke 1979). The only study that I found that tested this idea was by Oliver and Slattery (1981) -- unfortunately it is an abstract from the proceedings of a meeting and it is therefore sadly incomplete (no time

scales are given). However, they report on the recovery of benthic infauna to defaunated soft-bottom habitats in and around Monterey Bay and in Antarctica. They state that the rate of succession "was dramatically extended at the cold polar latitude."

3.1.3 Dependency of Recovery on Habitat Protection, Changes in Management Practices, and Other Restoration Approaches

Given sufficient time, full recovery after an oil spill is likely to occur naturally. It will probably take a long time in areas (a) that were heavily oiled, (b) that were heavily oiled and destructively cleaned, (c) where the sediments are soft, and (d) where the oiling was extensive (see Section 3.1.2). In order to speed recovery, managers will want to consider restoration options.

One option is to do nothing. Teal (1990) advises against active restoration. He states that it is best to leave the area alone after picking up as much oil as possible. He believes that we know so little about the ecosystems we are trying to restore that we could do more harm than good.

Below I discuss other restoration options -- clean-up, bioremediation, habitat protection and transplantation.

THE CLEAN-UP OF AN OIL SPILL

Stranded oil disperses slowly and so cleaning up as much of the stranded oil as possible is an important first step on the road to recovery of the system. However, many of the methods used to clean-up oil spills appear to be more harmful than the oil itself. For instance, in 1967 after the Torrey Canyon spill off England, 10,000 tons of toxic dispersants (also called detergents) were used in the cleaning operations, and most of the invertebrate mortalities could be attributed to the dispersants rather than the oil (Southward and Southward 1978). More recently, mechanical removal (Rolan and Gallagher 1991) and high pressure hot water (Broman et al. 1983, Houghton et al. 1991a) have been used to clean oiled shores, but both treatments also kill many organisms.

These studies show that the effects of the cleaning are detrimental to the invertebrate communities both in the short-term (Broman et al. 1983, Houghton et al. 1991a) and in the long-term (Rolan and Gallagher 1991). Recovery is likely to be slower in cleaned areas because, in general, very large clearings take longer to recover than patches that have some of the original inhabitants intact (Sousa 1984, Smith and Brumsickle 1989).

Thomas (1978) believes that some clean-up methods on rocky shores do more harm than good, but suggested that clean-up of oil from soft sediments would promote recovery. He stated that "if clean-up methods for lagoons could be improved so that oil could be removed without sediment penetration or disturbance, clean-up should help to minimize oil pollution effects" (Thomas 1978). However, this is easier said than done.

BIOREMEDIATION TO SPEED-UP RECOVERY

In most bioremediation, a nitrogen-phosphorus fertilizer is sprayed onto the stranded oil. This fertilizer provides extra nutrients for naturally occurring micro-

organisms (i.e., bacteria and fungi) that break down oil. This technique, long employed against toxic wastes, can more than double the speed of oil removal (EPA 1990). The micro-organisms feed on the oil, reduce its toxicity, and increase its removal by waves and currents (Lee and Levy 1991). Two problems with this approach are that bacteria may not be active below the top few inches of soft sediments and that micro-organisms are relatively slow to break-down oil in cold marine habitats (Cretney et al. 1978, Atlas et al. 1978). The first large-scale use of bioremediation took place in Prince William Sound during 1989, as a series of experiments. The preliminary results of the experiments look promising (EPA 1990, Chianelli et al. 1991), but the effects on long-term recovery of the communities are not known.

HABITAT PROTECTION DURING RECOVERY

None of the studies described in Table 1 compared the recovery of communities in habitats that were protected from humans to recovery in unprotected habitats. However, there are a few studies on rocky shores that indicate that human interference -- trampling, souvenir collection, handling, and bait collection -- does have a negative effect on the community (Zedler 1978, Beauchamp and Gowling 1982, Ghazanshahi et al. 1983, Addessi 1992). Therefore, limiting human access to a community would likely promote recovery.

TRANSPLANTATION OF SPECIES

Another option is to transplant species into the disturbed sites. Species' recovery rates will depend on life-history characteristics and tolerance of oil. The species that have larvae in the plankton all, or most, of the year will recruit quickly into large disturbed spaces. On the other hand, the species whose larvae are rarely found in the plankton or whose larvae have extremely short-range dispersal, will recruit slowly into the same patches. Species with poor larval recruitment include many asteroids and some echinoids (Simenstad, pers. com.). Examples of species with short-range dispersal are soft corals (Gerrodette 1981), amphipods (Cabioch 1980), some *Octopus* (Hochberg and Fields 1980), many of the snails in the order Neogastropoda (Abbott and Haderlie 1980), and several species of algae (Dayton 1973, Paine 1979, Sousa 1984). Most of these propagules disperse less than 2m from the adult. Recruitment of such species to disturbed patches will correlate with the abundance of propagule-releasing adults in the immediate vicinity of the clearing. Thus the complete recolonization of large bare areas by these types of species will take a very long time. These short-range dispersal species would be the most likely to benefit from transplantation. Short-range dispersal is also more common in the Arctic than in temperate waters (Thorson 1950).

The alga, *Fucus*, is a short-range dispersal species (Brawley 1992) that is an important species on hard substrates in Alaska -- it is common and provides cover and food for many invertebrate species. The recovery of *Fucus* may well determine the pattern of recovery for the community as a whole. To speed the recovery of *Fucus*, particularly in large disturbed areas, managers may consider transplanting plants into the area.

Unfortunately there is little information on how to conduct the restoration of marine communities. The restoration of kelp beds in southern California may provide an example for the restoration of the damaged ecosystems in Alaska. *Macrocystis pyrifera*, the giant kelp, forms the main component of southern California's kelp forests. Although an adult plant produces millions of spores, and although the spores and gametes are planktivorous, colonization of disturbed areas can be slow. Population declines of this species around

sewer outfalls and power plants, and during warm water years, have stimulated many attempts at restoration (see Foster and Schiel 1985 for review). Transplants have been made of three stages in the life-cycle of the plant -- adult sporophytes, juvenile sporophytes and microscopic sporophytes. Most restoration attempts using these methods have not had suitable controls, so their success rates are difficult to determine (Foster and Schiel 1985). However, *Macrocystis* has returned to some of the transplanted areas.

If transplantation of *Fucus* and other organisms is attempted, I recommend that care be taken to not damage the areas from which the transplants are taken. In addition, I recommend that any major restoration project begin with an experimental phase so that the success rates of different methods can be evaluated. This will help rule out techniques that don't work and will help identify promising approaches that can be developed further (see PERL 1990). This research will provide valuable information on restoration techniques (a subject about which little is known) as well as further our knowledge of the Alaskan ecosystems. All major restoration projects should be continually evaluated with a long-term monitoring program that will allow managers to take advantage of unforeseen benefits and to address unexpected problems quickly.

4.0 EXTRAPOLATION TO THE INJURED ALASKAN ECOSYSTEM

4.1 Identification of Most Practical and Cost Effective Indicators of Recovery to Measure

What is needed to determine whether recovery has occurred is an extensive study of the abundances, biomasses, age distributions, growth rates and reproductive condition of all the species influenced by the spill (see Section 4.2). If any of these characteristics goes unmeasured then a conclusion that recovery has occurred may be criticized. However, should insufficient funds be available to conduct a thorough study it is appropriate to consider alternative approaches.

"Indicator species" have been used extensively in pollution studies. Indicator species are those species which, by their presence and abundance, provide some indication of the prevailing environmental conditions. The best indicator species are those that have narrow and specific environmental tolerances, because they will show a marked response to quite small changes in environmental quality (Abel 1989). However, indicator species provide only a general overview of the approximate position of the community in the successional process, i.e., whether the community is generally in the early or the late successional stage.

A viable alternative to examining all the invertebrates is to sample only "target species." These are species that are abundant in certain zones, are key space occupiers, or are consumers known to play an important role in community structure (Dethier 1991). Sampling only target species would have the advantage of reducing costs and allowing increased replication. Dethier (1991) compiled a list of recommended target organisms for the Washington coast and I have repeated it here (Table 3A). I have added a short list of suggested target species for the Alaskan coast from Houghton et al. (1990a; Table 3B).

There are two problems with the target species approach. First, in considering oil effects, "confining sampling to dominant species might miss a significant oil effect, or underestimate the degree of impact" (Dethier 1991). And second, "in considering recovery from oil spills it is important to take into account not only the dominant species, which might recolonize and recover quickly, but also the uncommon ones which may take longer

to return to former abundances (e.g., because of limited dispersal or small 'source' populations)" (Dethier 1991).

However, I suggest that a sound determination of recovery after an oil spill could be based on the study of the abundances, biomasses, age distributions, growth rates and reproductive condition of several target species. The choice of target species will be critical. Houghton et al. (1990a) have begun a target species study of growth rates in Prince William Sound but their study is of four molluscs only. I suggest that target species should come from several different phyla, a few different feeding modes, and mostly from late successional stages.

Table 3. Target species recommended for intensive sampling effort on the Washington coast (Dethier 1991) and on the Alaskan coast (Houghton et al. 1990a).

WASHINGTON COAST

ROCKY SHORES

Wave-exposed

Eudistylia vancouveri
Mytilus californianus
Mytilus edulis
Pollicipes polymerus
Anthopleura elegantissima
Nucella spp.
Pisaster ochraceus
Katharina tunicata
Endocladia muricata
Mastocarpus papillatus
Corallina vancouveriensis
Dilsea californica

Wave-protected

Fucus spp.
Endocladia muricata
Mastocarpus papillatus
Neorhodomela larix
Phaeostrophion irregulare
Lacuna spp.

COBBLE SHORES

Fucus spp.
Gelidium coulteri
Phyllospadix spp.
Odonthalia floccosa
Tegula funebralis
Hemigrapsus spp.
Leptasterias hexactis

SANDY SHORES

Eohaustorius spp.
Excirolana spp.
Euzonus mucronatus
total number of polychaetes

ALASKAN COAST

ROCKY SHORES

Fucus spp.
red algae
Mytilus edulis
Nucella lamellosa
Pagurus spp.

BOULDER/COBBLE SHORES

Fucus spp.
red algae
green algae
Lottiidae

SOFT SUBSTRATES

polychaeta
gastropoda
bivalvia
crustacea

4.2 Recommended Approach to Determine When Recovery has Occurred

4.2.1 Definition of Recovery

It is important that in any study of recovery one state one's objectives clearly and define what one will or will not accept as a fully recovered ecosystem. The objectives will guide the entire project, including the sampling design, statistical tests and conclusions. Without clear objectives, the work will result in a poorly directed sampling design and weak conclusions.

If one's objective is to determine whether an area has fully recovered from an oil spill then one must define what one will accept as recovered. Most of the researchers in Table 1 did not explicitly define recovery but their implicit definition was:

- "the return of all population densities to pre-disturbance levels or undisturbed levels."

However, there are many other possible definitions of recovery.

- American Heritage Dictionary (1973): "return to a normal condition; the getting back of something lost."

- Ganning et al. (1984): "the restoration to original functional and structural conditions with original species present in original numbers."

- Ganning et al. (1984): "returning the ecosystem to within the limits of natural variability."

- Lewis (1982): "complete recovery (has occurred when) there are no discernable after-effects."

- Boesch et al. (1987): "complete recovery is the time required for a disturbed community to exhibit variation that is within the bounds of variation seen in undisturbed, control areas."

- Conan (1982): "a new stable age distribution and equilibrium species assemblages attained".

- National Research Council (1975; page 91): "Complete recovery means that (1) the faunal and floral constituents that were present before the oil spill are again present and (2) they have their full complement of constituent age classes."

- Committee on Restoration of Aquatic Ecosystems, National Research Council (in press) " the return of an ecosytem to a close approximation of its condition prior to disturbance."

None of these definitions is completely satisfactory. They give a general description of the term but few specifics. I suggest the following definition of recovery -- it is a combination of the above definitions:

- Boland (this report): "Complete recovery after an oil spill occurs when (1) all the species that were present before the oil spill are again present; (2) each of these species has reached their original abundances and biomasses, (3) each of these species has reached their original age distributions, and (4) all individuals are as healthy (as measured by growth rates) and productive (as measured by reproductive condition) as the individuals that were present at the time of the oil spill." In the absence of pre-spill data, original conditions should be estimated from several unoiled communities in similar physical/chemical environments.

Prespill data on species abundances, biomasses, age distributions, growth rates and reproductive conditions are necessary for determining when recovery has occurred, however these data are usually unavailable. In these cases, studies of many unoiled sites must be conducted instead. These unoiled sites should be chosen carefully and should include all the habitats that were oiled. All the appropriate data should be collected in the unoiled sites soon after the oil spill and used as the baseline data representing the prespill conditions in the oiled sites.

Therefore, when one is testing for recovery one is testing the hypotheses that there are no significant differences in (1) the species that are present in oiled and unoiled areas; (2) the abundances and biomasses of the species in oiled and unoiled areas; (3) the age distributions of the species in oiled and unoiled areas; and (4) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

Notice that the recovered community does not have to be identical to the undisturbed community, only not statistically different from the undisturbed community, i.e., it is varying within the bounds exhibited by undisturbed systems (see definition by Boesch et al. 1987).

Notice also that my definition, like those above, focuses on the structure of the community rather than on its functioning. Too little is known about the functioning of marine communities to include it in the definition. One hopes that when the structure returns the functioning will return too.

My definition of recovery is based upon that used by many researchers and the dictionary definition. However, the biologists working for The Exxon Corporation have recently proposed a different definition of recovery and this is:

- Baker et al. (1990): "recovery is marked by the re-establishment of a healthy biological community in which the plants and animals characteristic of that community are present and functioning normally. It may not have the same composition or age structure as that which was present before the damage, and will continue to show further change and development." This definition is very different from all the others outlined above in that it will consider a community recovered when it is only on the road to recovery. This is unacceptable. For instance, using this definition one may consider a mussel bed to have recovered if the rocks are completely covered with healthy opportunistic species such as green algae.

The defintion of recovery of Baker et al. (1990) leads them to estimate recovery times that are relatively fast. For instance, they say that "rocky shores usually recover in 2 to 3 years. Other shorelines show substantial recovery in 1 to 5 years with the exception of

sheltered, highly productive shores (e.g., salt marshes), which may take 10 years or more to recover." In subtidal sand and mud systems "recovery times are 1 to 5 years, but they can be 10 years or longer in exceptional cases" (Baker et al. 1990). My literature survey suggests that recovery times are longer than these, and in general, these numbers should be doubled to obtain true estimates of recovery times (Section 3.1.1).

In conclusion, the definition of recovery is an extremely important part of any study of recovery.

4.2.2. Methods to be used in a Recovery Study

The researchers need to test the hypotheses that there are no significant difference in (1) the species that are present in oiled and unoiled areas; (2) the abundances and biomasses of the species in oiled and unoiled areas; (3) the age distributions of the species in oiled and unoiled areas; and (4) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

Notice first, that no mention has been made of summarizing statistics such as species diversity, total number of species, total biomass or total number of individuals -- as we have seen in Section 3.1.1, these numbers cannot be used to show when recovery has occurred. Second, that identifications need to be made to the species level. Some research has shown that little information is lost when identifications are made to the family level, but this applies to only some analyses, e.g., ordinations (Warwick 1988).

In my opinion, none of the papers cited in Table 1 provides a good example of how to conduct a recovery study. Sanders et al. (1980) critized past research on recovery by saying that the researchers have arrived at "conclusions that are, at best, equivocal interpretations of insufficient and ambiguous data. Such inadequacies are usual in many pollution-related studies of benthic ecology, including those in which important decisions are based." It is clear that if a study is to stand up to scrutiny it will have to be a careful and thorough study planned by competant statisticians and biologists familiar with the Alaskan ecosystem. Many books and papers describe appropriate sampling programs and methods to be used for studying marine benthos (e.g., Green 1979, Gauch 1982, Holme and McIntyre 1984, Mead 1988, Underwood 1981, Hurlbert 1984, Stewart-Oaten et al. 1986, Carney 1987, Gray et al. 1988, Krebs 1989, PERL 1990, Dethier 1991), and these sources should be consulted.

Natural communities are spatially and temporally heterogenous. This means:
(1) that it is necessary to study many sites nearby that were not oiled and many sites within the oiled area so that the range of natural variability can be determined (Mann 1978, Ganning et al. 1984);
(2) that a large area should be randomly sampled at each site; because communities change with water depth, a useful design is stratified random sampling in which one blocks with water depth (Gray et al. 1988); and
(3) that a large number of samples are required for reliable estimates of population densities; even to estimate population densities to within 20-40% of their true value may require several hundred samples at each site (Abel 1989). Even well funded studies such as Houghton et al (1990a) often fail in all three respects.

4.2.3. Results and Conclusions of a Recovery Study

All the results that are necessary and sufficient to test the hypotheses should be presented in the research report. Frequently researchers collect a lot of information but report only species diversity. Some also report total biomass and total abundance but rarely do papers go beyond these summarizing statistics and describe the abundances of individual species. This is a weakness because, as we have seen above (Figure 2), "climax" communities do not have the greatest number of species, biomasses, or individuals. Also, these summarizing statistics cannot be used to test the hypotheses.

Details about "important species" (e.g., those that are numerically dominant, provide much of the structure to the community, or play an important role in the dynamics of the system) should also be presented. An analysis of the recovery of the community therefore requires a detailed knowledge of the functioning of the community.

Finally, the conclusions of any recovery study should be clearly presented.

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8.0 ANNOTATED BIBLIOGRAPHY

Here follows a detailed description of each of the recovery papers reviewed in Table 1. It includes the abstracts of each paper taken verbatim from the original papers. Three papers (Flower 1983, Glémarec 1986, Guzman and Campodonico 1981) did not have abstracts and for these I wrote a brief summary of their findings.

Bakke, T. 1986

Experimental Long Term Oil Pollution in a Boreal Rocky Shore Environment

Norwegian Institute for Water Research

Environment Canada. Proceedings of 9th annual Arctic and marine oil spill program technical seminar 17: 167-178.

ABSTRACT

The paper presents the design, experimental range and an overview of the results of a large scale mesocosm experiment performed during 1979 to 1985 at the Marine Research Station Solbergstrand, Eastern Norway. The aim of the experiment was to investigate the effects of continuous sublethal exposure to diesel oil on a cold temperate rocky shore community. The monthly mean temperature range of the mesocosm was 0.6-18.9°C during the six years the experiment lasted. The mesocosm communities were established in 1979 by transplantation of rocks with sessile organisms to four flow-through concrete basins (8x5x1.5 meters) equipped with wave generators and tide simulation. The communities were allowed to develop undisturbed for three years, whereafter two of the basins were exposed continuously to a diesel oil in seawater emulsion at mean levels of 130 and 30 µg/liter respectively (fluorescence analysis). The two remaining basins acted as controls. The oil exposure lasted from September 1982 to September 1984. After that the communities were followed for redcovery for one year. The experiment covered a range of subprojects aimed at studying the effects on general community structure, community recruitment and metabolism, population dynamics and genetics, physiology, cell chemistry, histology and tissure hydrocarbon levels of key species. The effects ranged from population collapse (blue mussel, amphipods), reduced growth (bladder wrack, kelp, mussels) and recruitment (winkles, barnacles), reduced primary production, increased cover of opportunistic green algae, reduced feeding and energy utilization (mussels, winkles), accumulation of hydrocarbons in algae and animals, to cyto- and biochemical stress indications (mussels, winkles). The effects were in most cases dependent on season. Relation to dose was not always found. The population genetics did not indicate any short term selection due to the oil. After one year recovery, most responses were back to normal, and population regeneration of mussels and amphipods had started, but some physiological dysfunctions were still detected.

Ballou, T.G., S.C. Hess, R.E. Dodge, A.H. Knap, and T.D. Sleeter. 1989.

Effects of untreated and chemically dispersed oil on tropical marine communities: a long-term field experiment.

Wibur Smith Associates, P.O. Box 92, Columbia, South Carolina 29201.

Proceedings of 1989 International Oil Spill Conference, American Petroleum Institute, p447-454.

ABSTRACT

A multidisciplinary long-term field experiment was conducted to evaluate the use of chemical dispersants to reduce the adverse environmental effects of oil spills in nearshore, tropical waters. Three study sites, whose intertidal and subtidal components consisted of mangroves, seagrass beds, and coral reefs, were studies in detail before, during and after exposure to untreated crude oil or chemically dispersed oil. This study simulated an unusually high ("worst case") exposure level of dispersed oil and a moderate exposure level of untreated oil. The third site served as an untreated reference site. Assessments were made of the distribution and extent of contamination by hydrocarbons over time, and the short- and long-term effects on survival, abundance, and growth of the dominant flora and fauna of each habitat. The whole, untreated oil had severe, long-term effects on survival of mangroves and associated fauna, and relatively minor effects on seagrasses, corals, and associated organisms. Chemically dispersed oil caused declines in the abundance of corals, sea urchins, and other reef organisms, reduced coral growth rate in one species, and had minor or no effects on seagrasses and mangroves. Conclusions were drawn from these results on decision making for actual spills based on trade-offs between dispersing or not dispersing the oil.

This report deals only with the major results of the study. A large number of parameters were monitored, but in the interest of brevity only the most important aspects of the study are reported here. A detailed description of the methods used and a complete presentation and discussion of results is given in Ballou et al.

Baxter, R.E. 1971.

Earthquake effects on clams of Prince William Sound

Alaska Department of Fish and Game.

In: National Research Council. 1971. The Great Alaska Earthquake of 1964. National Academy of Sciences, Washington, D.C.

ABSTRACT

The changes in land elevations associated with the Alaska earthquake of 1964 affected the intertidal populations of hard-shell clams in the Prince William Sound. Mortality was estimated at 36%. Studies established that 29% of the surviving hard-shell clams were in the optimum habitat zone between mean low water and lowest low water; before the earthquake, 82% of the hard-shell clams were in the optimum zone. No species of hard-shell clam is in danger of disappearing from the fauna of Prine William Sound. Ninety-nine species of pelecypodss were tentatively identified during studies in the Sound.

Bender, M.E., E.A. Shearls, R.P. Ayres, C.H. Hershner, and R.J. Hugget. 1977.

Ecological effects of experimental oil spills on Eastern Coastal Plain estuarine ecosystems.

Virginia Institute of Marine Science, Gloucester Point, Virginia 23062.

Proceedings of 1977 International Oil Spill Conference, American Petroleum Institute, p505-509.

ABSTRACT

Five segments of a mesohaline marsh located off the York River in Virginia were physically isolated from the surrounding area, except for allowing subtidal flow, and dosed with fresh and artificially weathered South Louisiana crude oil. The experimental design and field site utilized in this study are described. The mini-ecosystems each contained about 695 sq. m. of marsh, 100 sq m of open water and 15 sq m of intertidal mud flat. In September 1975, three barrels (570l) of each of the experimental oils were spilled into replicate systems.

Overall, the artificially weathered oil was shown to have as great an ecological impact on the communities as the fresh crude. Phytoplankton and fish populations all showed declines following the spills in the weathered oil systems. Phytoplankton production declined immediately after both spills but had recovered to control values within seven days. Species composition was not affected by the oils, while perihyton biomass, as measured by ATP, increased after both treatments. Marsh grass production was reduced in both spill units. Benthic animals, showing population declines after both oil, included nereid polychaetes, insect larvae and amphipods. Oligochaete populations decreases shortly after the fresh crude spill, returned to normal within 30 days, and then declined again relaive to the control in both treatments 11 weeks after the spill. Mortalities of fish, *Fundulus heteroclitus*, held in live boxes were noted only in the weathered treatment systems.

Blaylock, W.M., and J.P. Houghton. 1989.

Infaunal recovery at Ediz Hook following the *Arco* Anchorage oil spill

Dames & Moore, 500 Market Place Tower, 2025 First Avenue, Seattle, Washington 98121

Proceedings of the 1989 American Petroleum Institute oil spill conference: 421-426.

ABSTRACT

The Arco Anchorage crude oil spill occurred near Ediz Hook, in Port Angeles, Washington, in 1985. Following the spill, replicate infaunal sampling was carried out during five summer and winter seasons at a series of transects that ranged from relatively clean and unaffected by the spill to industrialized sites that had received heavy oiling. Average wet weight biomass, abundance, species diversity, and number of species were calculated for all samples. Analysis of variance was used to test for differences in these parameters over time within a transect. A statistically significant increase in average biomass, density, and species diversity was seen at several heavily oiled stations over time. A similar pattern was not seen at an unoiled reference station. Biomass, density, and number of species had significant negative correlations with sediment hydrocarbon concentration. A widespread settlement of bivalves was observed in October 1986 samples. Several species from this settlement (e.g., *Macoma nasuta* and *Clinocardium nuttallii*) were present in successively larger sized classes in subsequent samplings. The industrialized nature of Ediz Hook and pollution events unrelated to the oil spill probably limited the degree of recovery and recolonization documented at several of the transects.

Boesch, D.F., R.J. Diaz, and R.W. Virnstein. 1976

Effects of Tropical Storm Agnes on Soft-bottom Macrobenthic Communities of the James and York Estuaries and the Lower Chesapeake Bay

Virginia Institute of Marine Science, Gloucester Point, Virginia 23062

Chesapeake Science 17: 246-259

ABSTRACT

Macrobenthos was studied at 58 previously surveyed stations following the drastic salinity reductions caused by Tropical Storm Agnes. Effects were greatest in the lower, polyhaline portions of the James and York estuaries, where many abundant species were eliminated from shallow bottoms due to the usually low salinities and several species were eliminated or reduced in abundance on deeper bottoms due to the somewhat reduced salinity but, more importantly, to low oxygen concentrations resulting to strong density stratification of the water masses. Irruptions of opportunistic species followed these perturbations and the deep mud bottom community in the lower York estuary had not recovered 2 1/2 years after the storm. The primary alteration to usually mesohaline communities was an infusion of species more abundant in oligohaline and/or shallow brackish habitats. Communities in usually oligohaline or tidal freshwater reaches of the James and York estuaries and those at the mouth of the bay were hardly affected by Agnes.

Cabioch, L. 1980.

Pollution of subtidal sediments and disturbance of benthic animal communities.

Station Biologique, 29211 Roskoff, France.

Ambio 9: 294-296

ABSTRACT

In the sublittoral areas, the organisms most affected by *Amoco Cadiz* oil were living in fine sediments on the bottoms of bays and estuaries. A few sensitive species were completely wiped out in the polluted area. The author notes that for some species, repopulation is proving to be difficult.

Castilla, J.C. 1988.

Earthquake-caused coastal uplift and its effects on rocky intertidal communities.

Pontificia Universidad Católica de Chile, Casilla 114-D, Santiago , Chile

Science 242: 440-443

ABSTRACT

The coastal uplift (approximately 40 to 60 centimeters) associated with the Chilean earthquake of 3 March 1985 caused extensive mortality of intertidal organisms at the Estación Costera de Investigaciones Marinas, Las Cruces. The kelp belt of the laminarian *Lessonia nigrescens* was particularly affected. Most of the primary space liberated at the upper border of this belt was invaded by species of barnacles, which showed an opportunistic colonization strategy. Drastic modifications in the environment such as coastal uplift, subsistence, or the effects of the El Niño phenomenon are characteristic of the southern Pacific. Modifications in the marine ecosystem that generate catastrophic and widespread mortalities of intertidal organisms can affect species composition, diversity, or local biogeography.

Castilla, J.C. and D. Oliva. 1990

Ecological consequences of coseismic uplift on the intertidal kelp belts of *Lessonia nigrescens*

Pontificia Universidad Católica de Chile, Casilla 114-D, Santiago, Chile.

Estuarine, Coastal and Shelf Science 31: 45-56.

ABSTRACT

Coseismic uplift from the Chilean earthquake of 3 March 1985 caused changes in the biomass and vertical zonation of rocky intertidal organisms at four sites along 150 Km of the central Chilean coast. The 11-60cm uplift causedwidespread mortality mainly of the dominant intertidal kelp *Lessonia nigrescens*, reducing its biomass in the upper part of its pre-earthquake range and altering the vertical zonation. The *L. nigrescens* belt shrank from the top by about 0.5-1m within 1 year of the shock, then expanded downward by about 1m. An important part of the primary space liberated at the pre-earthquake upper border of *Lessonia* was invaded by the barnacles *Chthamalus scabrosus* and *Jelius cirratus*. None of the foregoing changes occured at the two control sites located outside the shock area. The ecological effects of these recurrent sudden and drastic environmental processes on the rocky intertidal communities include the liberation of the primary space, enhancement of mosaic areas and modification of the vertical zonation of competitively dominant organisms.

Chan, G.L. 1977.

The five-year recruitment of marine life after the 1971 San Francisco oil spill.

College of Marin, Kentfield, California.

Proceedings of 1977 International Oil Spill Conference, American Petroleum Institute, p543-545.

ABSTRACT

On January 18, 1971, two Standard Oil tankers collided underneath the Golden Gate Bridge, releasing about 840,000 gallons of Bunker C fuel. An estimated 4.2 million to7.5 million intertidal invertebrates, chiefly barnacles, were smothered by the oil. Five-year observations of marine life recruitment following the spill indicate that population densities of some marine species have significantly increased in the San Fransisco Bay area intertidal zones at Sausalito and Duxbury Reef. With some fluctuations, the barnacles *Balanus glandula* and *Chthamalus dalli* have increased from July 1971 to May 1976--from 93 to 189 barnacles per dm^2 at Sausalito and from nine to 34 per dm^2 at Duxbury Reef. The large bed of mussels, *Mytilus californianus*, showed a steady rise from 5.9/m^2 in April 1971 to 14.0/dm^2 in July 1976. The desity of mobile organisms, such as limpets, snails, crabs, and starfish, all show cyclical variations; some show an overall increase. The limpets, *Collisella spp.*, which suffered high mortality during the spill have increased threefold over pre-oil counts.

In 1975, some significantly low sample means were recorded for barnacles in Sausalito and for 18 composite species at Duxbury Reef, probably due to natural ecological forces. The five-year recruitment (1971-1976), however, shows no evidence of lasting detrimental effects of Bunker C. oil on the populations of marine life within the transect sites.

Clark, R.C. Jr., J.S. Finley, B.G. Patten and E. DeNike. 1975

Long-term chemical and biological effects of a persistent oil spill following the grounding of the *General M.C. Meigs*

National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington

Proceedings of the 1975 Conference on Prevention and Control of Oil Pollution, API/USCG/EPA, San Francisco, CA, 25-27 March 1975.

ABSTRACT

Petroleum hydrocarbon uptake patterns and observations of plant and animal populations of an intertidal community exposed continually since January 1972 to small quantities of a Navy Special Fuel Oil residue from the grounded unmanned troopship General M.C. Meigs were obtained by an interagency team of oceanographers, biologists, chemists, and engineers. Although the tar-ball-like character of the released oil served to limit its coverage, specific members of the intertidal community showed effects of the persistence of the spill. This report describes the long-term observations and analyses made since the grounding of the 622-foot military transport on a rich and productive intertidal regime.

Clark, R.C., B.G. Patten and E.E. DeNike. 1978.

Observations of a Cold-Water Intertidal Community After 5 Years of a Low Level, Persistent Oil Spill from the *General M.C. Meigs*

Environmental Conservation Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle, Wash. 98112, USA

J. Fish Res. Board Can. 35: 754-765.

ABSTRACT

A rich and productive intertidal community was exposed continually for over 5 yr to small quantities of a Navy Special fuel oil from the unmanned troopship *General M.C. Meigs* that came aground on the Washington coast in January 1972. Observations of animal and plant populations and their petroleum hydrocarbon uptake patterns showed early evidence of contamination and the persistence of the oil spill throughout the study period. Abnormal and dead urchins, and loss of algal fronds and pigment were observed in localized areas near the wreck for at least 1 yr. Within 2 mo of the accident, paraffinic hydrocarbons had been taken up by prominent members of the community and continued to appear in certain species even after 5 yr. Although changes were seen in certain species during the early days of this persistent low-level pollution incident, the community balance in this rocky.intertidal ecosystem does not appear to have been markedly altered.

Conan, G. 1982.

The long-term effects of the *Amoco Cadiz* oil spill

Centre Océanologique de Bretagne (C.N.E.X.O.), B.P. 337, 29273 Brest Cedex, France

Phil. Trans. R. Soc. Lond. B. 297: 323-333

ABSTRACT

The supertanker *Amoco Cadiz* wrecked on the coast of northern Brittany in April 1978. The resulting spill of 223,000 t of crude oil polluted some 360 km of rocky or sandy shores, salt marshes and estuaries.

An immediate mortality impact was observed. Populations of bivalves, periwinkles, limpets, peracarid crustaceans, heart urchins and sea birds were the most severely affected. Populations of polychaete worms, large crustaceans and coastal fishes were less affected. Three to six generations (5-10 years for bivalves but up to 60 years for birds) may be necessary before populations retrieve their stable age distribution.

Delayed effects on mortality, growth and recruitment were still observed up to 3 years after the spill. Estuarine flat fishes and mullets had reduced growth, fecundity and recruitment; they were affected by fin rot disease. Populations of clams and nematodes in the meiofauna declined one year after the spill. Weathered oil is still present in low-energy areas.

Species with short life cycles tend to replace long-lived species. A fauna of cirratulid and capitellid polychaete worms now prevails in sandy to muddy areas. For several clam populations, recruitment remains unstable. Three years after the spill it is still premature to decide how long it will take before populations and ecosystems reach their former or new equilibria.

Dauer, D.M. and J.L. Simon, 1976.

Repopulation of the polychaete fauna of an intertidal habitat following natural defaunation: species equilibrium

Department of Biology, University of South Florida, Tampa, Florida 33620.

Oecologia 22: 99-117

ABSTRACT

During summer, 1971, a massive outbreak of red tide resulted in defaunation of a previously characterized sandy, mtertidal habitat in upper Old Tampa Bay, Tampa, Florida. Repopulation of the polychaete fauna was studied from August 1971, to July 1973. A transect composed of 4 stations running from just below mean high water to just below mean low water was quantitatively sampled each month for species composition, densities of individual populations, biomass, and distribution of age classes.

Analysis of the rates of immigration and extinction, and the resulting colonization curve showed that repopulation conformed to the species equilibrium model of MacArthur and Wilson. Immigration was rapid with an equilibrium number of species becoming established in the 11th month. Although species composition was fairly constant, the distribution of individuals among species changed greatly.

In contrast to the ideas of Thorson, adult dispersal was shown to be a significant factor in the establishment of benthic populations with larval settlement being more significant in maintenance of the populations.

The community is viewed as a system in which species composition is determined primarily by the physical attributes of the area, and the density dominance of any species is dampened by the vagaries of adult dispersal and larval settlement. Such a system could be used to explain the relatively large number of species which belong to the same trophic type and yet occupy the same habitat.

Dauvin, Jean-Claude. 1987.

Evolution a Long Terme (1978-1986) des Populations d'Amphipodes des Sables Fins de la Pierre Noire (Baie de Morlaix, Manche Occidentale) Après la Catastrophe de l'Amoco Cadiz

CNRS-LP 4601 et Université P. et M. Curie (Paris Vl), 29211 Roscoff, France

Marine Environmental Research 21: 247-273

ABSTRACT

Greatly reduced in 1978 by the *Amoco Cadiz* oil spill, the amphipod populations of the fine sand community of Pierre Noire in the Bay of Morlaix, have not yet fully recovered 8 years after the pollution. The sublittoral sandy-mud benthic communities in the western part of the English Channel show a discontinuous distribution, occurring in isolated zones which are localized in estuaries and bays. The amphipods, which are characteristic of these communities and lack a pelagic larva, form insular populations. This insular distribution delays their re-introduction to the fine sand community of Pierre Noire. Moreover, the biological and demographic characteristics of the species entail limited periods of recolonisation and increase in population.

Dauvin, J-C., and F. Gentil. 1990.

Conditions of the Peracarid populations of subtidal communities in northern Brittany ten years after the *Amoco Cadiz* oil spill.

CNRS-LP 4601 et Université P. et M. Curie (Paris VI), 29211 Roscoff, France.

Marine Pollution Bulletin 21: 123-130.

ABSTRACT

Peracarid populations were greatly reduced in 1978 by oil from the *Amoco Cadiz*. Ten years after the spill, a benthic survey was conducted in the soft-bottom infra-littoral communities of the bays of Morlaix and Lannion and the Aber Wrac'h channel to study the rate of recovery of peracarid populations. Living in isolated populations in fine sand and muddy sand communities with low potential for immigration, the recolonization and the reconstitution of these disturbed populations was expected to be slow. The amphipod populations from the subtidal channel of Aber Wrac'h, which were initially the most affected by the oil spill were in the least advanced state of recovery. Some species present in abundance before the oil spill have not rediscovered. Novertheless, ten years after the oil spill, most of the populations had completely recovered.

Dethier, M.N. 1984.

Disturbance and recovery in intertidal pools: maintenance of mosaic patterns

University of Washington, Friday Harbor Laboratories, Friday Harbor, Washington 98250.

Ecological Monographs 54: 99-118.

ABSTRACT

The species composition of pools in the intertidal zone on the coast of Washington State varies greatly from pool to pool and from time to time. While assemblages change somewhat predictably from the low- to the high-intertidal zone (presumably owing to different stress tolerances of the species), the variance among pools at a given tidal height cannot be ascribed to such physical factors. Some pools at each height are dominated by one species that monopolizes space on the rock or in the water column and modifies the pool environment. Each dominant species, once established, can spread rapidly through a pool (either by vegetative growth or by enhanced recruitment of its conspecifics) and is thus potentially self-perpetuating. When abundant, most dominants appear to prevent potential competitors from settling and surviving by monopolization of resources, abrasion of the substratum, and/or collection of sediment. Six such dominants were identified for Washington tidepools: from low to high pools, these are (1) the surfgrass *Phyllospadix scouleri*, (2) articulated coralline algoa, (3) the mussel *Mytilus californianus* (exposed shores), (4) the cloning anemone *Anthopleura elegantissima* (more protected shores), (5) the red alga *Rhodomela larix*, and (6) the green alga *Cladophora* sp. Colonial diatoms also appear capable of cominating low pools in the absence of wave disturbance. However, each dominant monopolizes only 20-50% of the polls at anyh height.

Disturbnces, defined here as a loss of biomass exceeding 10% cover of a sessile species within 6 months and caused by extrinsic forces, were observed frequently in regularly censused tidepools. Disturbance agents included waves, excessive heat, wave-driven logs or rocks, and unusual influxes of predators and herbivores. Severe disturbances (those affecting a large proportion of the organisms in a pool) tended to occur in high pools in the summer (due to heat stress) and low pools in the winter (due to wave damage). Overall, a disturbance occurred in every pool studied an average of every 1.6 years. About half of the 231 observed disturbances affected one of the six dominant species. The frequencies of these disturbances ranged from one every 2-5 years, and recovery of the species to its original level required 3 months to over 2 years. Some species (e.g., *Rhodomela*) were disturbed frequently but recovered quickly because of rapid vegetative growth. However if asexual propagation was not possible, such as when the entire population of a species was removed from a pool, the slowness and irregularity of recruitment of sexual propagules greatly impeded recover. Experimental manipulations involving the total removal of dominant species from pools showed that such large disturbances often require over three years for recovery. The irregularity of planktonic recruitment can be compounded by the presence of herbivores, which can remove most settling organisms from the substratum, or by the absence of other organisms that are necessary for the settlement of a dominant (e.g., seed-attachment sites for *Phyllospadix*).

The combination of high disturbance frequency and slow rates of recovery makes it impossible for any dominant to occupy all the pools in its tidal range at any one time. Disturgbance is viewed in these habitats as the stochastic factor overlying other, more predictabl, community-structuring factors such as tidal height, pool size, wave exposure, and levels of herbivory, predation, and competation. Thus combined deterministic processes and random events operate to produce a complex mosaic of species assemblages in pools in one region. None of the tidepool asemblages is "stable" over many generations; rather, they seem to exist in a dynamic state where disturbances are an integral structuring factor.

Dixon, I.M.T. 1987.

Experimental application of oil-based muds and cuttings to seabed sediments

Oil Pollution Reasearch Unit, Field Studies Council, Orielton Field Centre, Pembroke, Dyfed, U.K.

In: J. Kuiper and W.J. Van den Brink (eds.). Fate and effects of oil in marine ecosystems. Martinus Nijhoff Publishers, Dordrecht, Netherlands.

ABSTRACT

Between September 1984 and July 1985, a field experiment was carried out in Milford Haven to follow the macrofaunal effects and subsequent recovery from a single application of used diesel and 'low-tox' oil based muds (OBM). Six treatments, including two levels of cuttings addition, were investigated and each was replicated three times in a randomised block experimental design. The cuttings' treatments were designed to give surficial sediment hydrocarbon concentrations of about 5000 ppm (high dose) and 400 ppm (low dose). Treatments were applied by divers to marked seabed plots (2m x 2m). Core samples were taken for hydrocarbon, sedimentological and macrofaunal analysis prior to treatment and then subsequently at 2 weeks, 1 month and then 2 monthly intervals for a total period of 10 months.

Prior to treatment no hydrocarbon or biological gradients across the experimental site were discernible. Following treatment, sediment hydrocarbon concentrations tended to fall rapidly within the first month, followed by a period of slower removal. Evidence of OMB contamination had disappeared from the low-dose plots after 4-6 months. In the high-dose plots hydrocarbon levels had all fallen almost to within the background range of values by 10 months, but slight contamination was still evident on all GLC traces.

Faunal disturbance was minor and significant effects were mainly recorded from the high-dose plots where the initial effect of oiled cuttings addition was to depress faunal density, species richness and diversity relative to controls. Population reductions were observed in a number of species but no expansion of opportunists occured. In the high-dose plots, total faunal density and the abundance of certain species remained depressed for the duration of the experiment. Faunal disturbance occurred more rapidly following diesel treatment than with low-tox treatment; reflecting the greater acute toxicity of the former. After 1 or 2 months, however, the longer term effects of low-tox OBM's became indistinguishable from those of the diesel treatment.

Ellis, D.V. and P.M. Hoover. 1990a.

Benthos on tailings beds from an abandoned coastal mine

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Marine Pollution Bulletin 21: 477-480

ABSTRACT

The marine benthos which had recolonized the site of a mine tailing dischage 12 years after mining activiy had ceased was compared to an adjacent area in which no tailings were found. Test (tailings) and Reference (no tailings) sampling stations consistently separated in a series of 6 cluster analyses. They invariably provided the last linkages, thus demonstrating that biological differences between tailing and non-tniling areas remain after 12 years. Tailing station faunas were less diverse than those at non-tailing stations, and each had chnracteristic faunas. Shallow (25 m) and deep (100 m) stntions clustered together for both Test and Reference trnnsects, but were significantly different (P<O.O5). There was a progressive increase in diversity from, shallow to deep stations, and from tailings to no tailings, and there were different highly abundant species at each station. The pattern of clusters and their significance was not affected by reducing taxa for the analyses to only those fully identified to species. Screening specimens from deposits using 2 mm and 0.5 mm mesh sieves, gave paired data sets, which clustered together for each sampling station. Only in one case were these sieve clusters significantly different, suggesting that sieve mesh size in this investigation did not seriously influence results.

Ellis, D.V. and P.M. Hoover. 1990b.

Benthos recolonizing mine tailings in British Columbia fiords

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Marine Mining 9:441-457

ABSTRACT

A comparison of the benthic species occuring in three British Columbia fiords into which mine tailings have been discharged was undertaken to demonstrate colonizing species which may be targeted for reclaimation of fishery feedstock. Data were drawn from three sources: Island Copper MIne, still in operation, and Anaconda Britannia Copper Mine and AMAX Kitsault Molybdenum Mine, both of which have ceased operation. Apparent deposite feeding polychaetes dominated in all areas, with sedentary forms representing the largest numbers of specimens and taxa in recovering sites, while errant (mobile) polychaetes were dominant in the most highly impacted areas. Other taxa, such as crustaceans and molluscs, were found in progressively larger numbers on recovering beds. Predischarge benthic fauna differed from fauna occurring during discharge, which in turn differed from fauna at sites in which discharge activities have ceased (although progressive changes were demonstated). Reclamation studies require knowledge of the dominant colonizing species, their biology, especially feeding habits, and procedures for fertilizing organically poor tailing beds.

Elmgren, R., S. Hansson, U. Larsson, B. Sundelin, and P. Boehm. 1983.

The *Tsesis* oil spill: acute and long-term impact on the benthos

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Marine Biology 73: 51-65

ABSTRACT

The "Tsesis" oil spill in October 1977 resulted in the release of over 1000 tons of medium grade fuel oil in an archipelago in the brackish Baltic Sea. Considerable oil quantities reached the benthos by sedimentation. Within 16 d benthic amphipods of the genus *Pontoporeia*, as well as the polychaete *Harmothoe sarsi* Kinberg, showed reduction to less than 5% of pre-spill biomasses at the most impacted station. The clam *Macoma balthica* (L.) was more resistant, and showed little or no mortality, but was heavily contaminated by oil (about 2000 $\mu g\ g^{-1}$ dry wt total hydrocarbons). The meiofauna was strongly affected, with ostracods, harpacticoids, Turbellaria and kinorhynchs showing clear reductions in abunance, while nematodes, as a group, were more resistant. In the winter following the spill gravid *Pontoporeia affinis* Lindström females showed a statistically significant increase in the frequency of abnormal or undifferentiated eggs. Food-chain transfer of oil to flounder [*Platichthys flesus* (L.)] was indicated. Not until the second summer after the spill were the first signs of recovery noted at the most heavily impacted station: Amphipods, *H. sarsi* and harpacticoids increased and the oil concentrations in *M. balthica* decreased (to about 1000 $\mu g\ g^{-1}$). In the area where amphipods had been virtually eliminated, there was an unusually heavy recruitment of *M. balthica*, reaching 4000 juveniles, of 1.5-2 mm length, per square metre, probably from settling in summer 1978. Three years after the spill *Pontoporeia* spp. biomass was still depressed in the most affected area, while *H. sarsi* showed normal biomass, and *M. balthica* abundance was inflated. Oil concentrations in *M. balthica* (about 250 $\mu g\ g^{-1}$) and flounder were only slightly elevated and the oil could no longer be confidently ascribed to "Tsesis" origin, even using GC/MS-analysis. Recovery was thus underway, but the long lifespan of *M. balthica* implies that the disturbed community composition may persist for many years at this station. Full recovery is likely to require more than 5 yr and may take a decade or more. An effort to evaluate the accumulated monetary loss to fishery from the accident indicates that direct costs of shoreline cleanup and vessel damage were considerably greater.

Farrell, T. 1991.

Models and mechanisms of succession: an example from a rocky intertidal community

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Ecological Monographs. 61: 95-113

ABSTRACT

An investigation of the processes that cause succession was performed in an intertidal community on the central Oregon coast. The community was dominated by barnacles and several species of macroalgae. The sucessional sequence was determined at three different sites by clearing sets of plots in a way that mimicked natural disturbance. Succession at each of these sites followed the same general sequence. A barnacle, *Chthamalus dalli*, first colonized the plots and was later replaced by a second barnacle, *Balanus glandula*. The macroalgae *Pelvetiopsis limitata, Fucus distichus,* and *Endocladia muricata* colonized the plots only after *Balanus* was established. While the order of species arrival and departure was consistent, the rate of succession varied greatly among sites. The sequence of community development that was observed at one site over a 36-mo period occurred in <12 mo in a nearby area. Differences in the rate of succession appeared to result from variation in the timing of successful *Balanus* recruitment.

The mechanisms of succession were investigated in a series of field experiments. An experiment with *Balanus*-removal, *Chthamalus*-removal, and control plots was used to assess the interactions between barnacles. A direct interaction, competition for space with *Balanus*, caused *Chthamalus* to decrease in abundance as succession proceeded. *Chthamalus* did not affect the establishment of *Balanus*. Successful *Balanus* recruitment depended on occasional periods of larval settlement followed by periods of favorable weather. At all three sites, algal colonization was dependent on the presence of barnacles. *Balanus* greatly facilitated algal colonization, while *Chthamalus* only weakly facilitated algal colonization. Facilitation of algal colonization by epoxy-filled barnacle tests indicated that facilitation resulted from barnacle tests altering the substrate, rather than the activities of the living animals. A factorial experiment involving manipulations of barnacle and consumer (limpet) abundances demonstrated that the facilitation of algae by barnacles is an indirect interaction that is mediated by limpets. Barnacles decreased limpet foraging activity and thereby increased algal abundance.

Succession in this community is complicated by several processes that are not included in traditional views of succession. (1) Not all early successional species have the same effect on the establishment of later successional species. This results in spatial variation in the rate of succession. (2) The model of succession is different in each step in the successional sequence. The *Chthamalus-Balanus* interaction is an example of the tolerance model, while the barnacle-algal interaction is an example of the facilitation model. (3) Both direct and indirect interactions between species determine the course of succession.

The results of this study support a general model that predicts the effect of consumers on the rate of succession. Consumers slowed succession in this community in two ways. First, limpets delayed the establishment of *Balanus* and the competitive exclusion of *Chthamalus*. Second, limpets delayed the establishment of macroalgae. Previous studies inmarine and terrestrial habitats have found that consumers may slow, accelerate, or have no effect on the rate of succession and these observations are consistent with the predictions of this general model.

Flower, R.J. 1983

Some effects of a small oil spill on the littoral community at Rathlin Island, Co. Antrim

School of Biological and Environmental Studies, The New University of Ulster, Coleraine.

Irish Naturalists' Journal 21: 117-120

ABSTRACT

(by PERL) The trawler, *Ella Hewitt*, sank in Church Bay, Rathlin Island, during November 1962. Small quantities of bunker oil leaked from the trawler until 21 September 1978 when the Royal Navy destroyed the wreck with controlled explosions. This caused about 170 tons of oil to be washed onto the shores of Church Bay. Attempts were made to remove the stranded oil from the rocky shores (chemical dispersants) and sandy beach (mechanical methods). In order to determine the long-term effects of the oil on the rocky shores, observations were made during May 1979 and November 1980. During May 1979, one transect was run on an oiled shore and one was run on a similar unoiled shore, approximately 120m away. The abundances of invertebrates and algae were similar along the two transects, however the sea anemone, *Actinia equina*, was abundant at the unoiled site and rare at the oiled site. During November 1980 the abundances of the sea anemone were similar along the two transects. Therefore I conclude that the rocky shore organisms had recovered from the effects of the oil spill within two years.

Glémarec, M. 1986.

Ecological impact of an oil spill: utilization of biological indicators

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Water Science and Technology 18: 203-211

ABSTRACT

(By PERL) The ecological effects of the Amoco Cadiz oil spill were gauged by studying the recovery of sand-dwelling macrofauna at two subtidal sites -- lightly oiled and heavily oiled. [Hydrocarbon levels: at lightly oiled site < 700 ug/g for "a few months," and at heavily oiled site > 1000 ug/g for "over one year."]

At the lightly oiled site many macroinvertebrate species survived the disturbance and recovery of the fauna to the "normal" number of species took approximately 30 months. At the heavily oiled site all species were destroyed and recovery of the fauna took between 66 months (number of indivuals and number of species) and 84 months (biomass). At this site the number of species actually overshot the "normal" number of species between 36 and 66 months after the disturbance.

Oil acts like sewage in that it overloads the sediment with organic material and anoxic conditions occur. A succession of species occurs: first opportunistic species, then other tolerant species, and finally sensitive species are added to the community. However, this succession was rough -- sensitive species were present at 14 months although recovery was at approximately 66 months. The total number of sensitive individuals does not appear to be a good indication of the recovery of the ecosystem; the presence of specific sensitive species, on the other hand, may be a good indication that the community has recovered. The sensitive species suggested as indicators of recovery were: *Apseudes latreilli*, *Lanice* (polychaete) and *Ampelisca* (amphipod). [Opportunistic species were: Oligochaetes and the polychaetes *Scolelepis fuliginosa*, *Capitella capitata*, *Capitellides giardi*.]

Gulliksen, B. and J.P. Taasen. 1982.

Effect of an Oil Spill in Spitzbergen in 1978

Department of Marine Biology, Tromso Museum, University of Tromso, P.O. Box 2550, N-9001 Tromso, Norway.

Marine Pollution Bulletin 13: 96-98.

ABSTRACT

The oil content in the sediment and the marine life along the arctic shores of Van Mijenfjord, Spitzbergen, were investigated about two years after a spill from diesel storage tanks. High values of oil were recorded in the sediment along the shore near the tanks. The shore fauna is generally poor in these areas and the only biological effect detected was the disappearance of the amphipod *Gammarus setosus* from the surface layers.

Guzman, L. and I. Campodonico. 1981.

Studies after the *Metula* oil spill in the Straits of Magellan, Chile.

Dept. of Hydrobiology, Instituto de la Patagonia, Punta Arenas, Chile.

Proceedings of the Petromar 1980 conference: 363-376.

ABSTRACT

(by PERL) The *Metula* ran aground during August 1974, releasing approximately 40, 000 tons of oil. Much of the oil was washed ashore and approximately 250km of shoreline was oiled. This paper summarizes many observations made at the oiled sites and many papers published on the oil spill.

Hall, S.J., D.J. Basford, M.R. Robertson, D.G. Raffaelli, and I. Tuck.
1991

Patterns of recolonisation and the importance of pit-digging by the crab *Cancer pagurus* in a subtidal sand habitat

SOAFD Marine Laboratory, PO Box 101, Victoria Road, Aberdeen AB9 8DB, Scotland.

Marine Ecology Progress Series 72: 93-102

ABSTRACT

The nature and level of disturbance to a benthic community caused by the pit-digging activities of the crab *Cancer pagurus* were examined in a shallow sub-tidal sand habitat on the west coast of Scotland. From observations by acoustic tracking we estimate that each individual digs between 6 and 7 pits per day, with a total of 20 pits dug in a 1000 m^2 area each day. Recolonisahon of simulated crab pits suggest that the community returned to its original state within 25 to 30 d. This was achieved initially by erosion from the surrounding sediments followed by the random arrival of adult colonists from the available benthic pool. Feeding or other competitive interactions within disturbed patches were not altered sufficiently to be reflected as changes in the relative abundance of taxa. We estimate that 3.6% of the habitat will be at some stage of recovery from disturbance by pit-digging at this time of year.

Hampson, G.R. and E.T. Moul. 1978.

No 2 fuel oil spill in Bourne, Massachusetts: immediate assessment of the effects on marine invertebrates and a 3-year study of growth and recovery of a salt marsh.

Woods Hole Oceanographic Institution, Woods Hole, Mass. 02543.

J. Fish. Res. Board Can. 35: 731-744.

ABSTRACT

On October 9, 1974 the oil barge *Bouchard 65* loaded with 73,000 barrels of oil spilled what was initially thought by the Coast Guard to be a few barrels and later raised to an undetermined amount of No. 2 fuel oil off the west entrance of the Cape Cod Canal in Buzzards Bay, Massachusetts (anchor site C, Fig. 1). Within the following 2-week period, oil from the barge was found contained along the west side of Bassett's Island and inner Red Brook Harbor, a distance of 5.0 km from the site of the spillage. Qualitative samples of dead and moribund marine invertebrates were collected in tide pools and slight depressions along the beaches. A collection consisting of 4360 invertebrates comprising 105 species, plus 2 species of fish were found in 8 samples. Noticeable effects of the oil on the salt-marsh plant community were also observed. A detailed quantitative examination was begun to determine the effects of the oil on various components of the affected salt-marsh community in Winsor Cove compared to a selected control site. From data collected in September 1977, the marsh grass in the lower intertidal zone in Winsor Cove has shown an inability to reestablish itself by either reseeding or rhizome growth. The associated sediments show a correspondingly high concentration of petroleum hydrocarbons impregnated in the peat substrate. Erosion rates measured in the affected area, as a result of the 3 year period of marsh degeneration, were 24 times greater than the control site. Microscopic algae were collected during the sampling period and those present were considered least sensitive to environmental changes. Examination of the interstitial fauna found in the study area in the summer of 1977 showed an extremely reduced number of individuals and species.

Harrel, R.C. and M.A. Hall. 1991

Macrobenthic community structure before and after pollution abatement in the Neches River estuary (Texas)

Lamar University, Department of Biology P.0. Box 10037, Beaumont, TX 77710, USA

Hydrobiologia 211: 241-252

ABSTRACT

Macrobenthos and physicochemical conditions in the lower 39 km of the Neches River estuary were studied from August, 1984 to May, 1985. The results were compared with data collected in 1971-1972. Between 1972 and 1984 the permitted BOD waste load in the tidal Neches River was reduced from 12325 kg d to 8717 kg d. River discharge and dissolved oxygen concentrations were consistently higher and salinity was lower, during the same seasons, during the 1984-1985 study. A total of 50 taxa of macrobenthos were collected in 1971-1972 and 104 taxa were collected in 1984-1985. The numbers of taxa per collection at each station in 1984-1985 were at least twice those found in 1971-1972. Minimum densities in 1984-1985 were much higher than the maximum densities in 1971-1972 at all stations. Patterns of dominance, Sorenson's similarity index, and diversity *(d)* values indicated improved water quality in 1984-1985. Statistical analysis of macrobenthic diversity indicated significant differences between upper estuary and lower estuary stations in 1971-1972. No significant differences were found in 1984-1985. Significant differences in numbers of taxa, macrobenthos densities, and *d* values between the two studies were found. Reductions of waste loads, increased river discharge, and deepening of the navigation channel were among the factors that probably contributed most to the changes in community structure of the macrobenthos observed.

Haven, S.B. 1971

Effects of land-level changes on intertidal invertebrates, with discussion of postearthquake ecological succession

Simon Fraser University.

In: National Research Council (ed.). The Great Alaska Earthquake of 1964: Biology. National Academy Press, Washington, D.C.

ABSTRACT

Investigations were carried out in summer 1965 on the effects of land-level changes and other factors associated with the March 1964 earthquake on intertidal invertebrate populations in Prince William Sound, Alaska.

Effects of the earthquake varied with type of habitat and organism and with the amount and direction of land-level change. In general, organisms lifted above their normal vertical ranges were killed.

Postearthquake community development (in terms of similarity to inferred preearthquake conditions) had in general proceeded most rapidly in the *Laminaria* zone and less rapidly upward and signifcantly less rapidly on maximally uplifted shores than on the less strongly affected shores elsewhere.

In areas of maximum uplift, the postearthquake intertidal communities had to develop entirely anew. The fauna was greatly reduced-many species were absent, many others rare-compared to the time before the earthquake, except in the *Laminaria* zone, which supported a near-normal fauna.

Evidence for ecological succession was provided by four main aspects of the postearthquake rocky shore communities that were significantly different from inferred preearthquake conditions: the dominance by algal films rather than *Verrucaria* in the uppermost zone; the dominance of *Balanus balanoides* in the midlittoral zone; the attachment of mussels to underlying algae; and, in the maximally uplifted area, the dominance of *Porphyra* rather than *Fucus*, correlated with the scarcity of grazing gastropods. Additional aspects of succession in rocky shore and level bottom habitats are discussed

Houghton, J.P., D.C. Lees, H. Teas, H.L. Cumberland, S. Landing, W.B. Driskell and T.A.Ebert 1991a

Evaluation and condition of intertidal and shallow subtidal biota in Prince William Sound following the *Exxon Valdez* oil spill and subsequent shoreline treatment

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NOAA, WASC Contract No. 50ABNC-0-00121

ABSTRACT

The effect and extent of shoreline treatment in areas affected by the *Exxon Valdez* oil spill will greatly complicate assessment of the long-term impacts of treatment and the oil alone. Because much of the heavily oiled shoreline was washed with high-pressure hot water at least once, and because so little of the oiled shoreline was left untreated, only a limited number of areas remain where comparisons may be made to distinguish between effects of oiling and the effects oiling plus treatment. Lack of specificity in the available treatment information (e.g., equipment, temperature, duration, bioremediation application rates, and repetitions) also complicates separation of effects of individual treatment approaches.

Nevertheless, the results from this study to date provide a strong basis to argue that conditions spanning a broad spectrum of biological properties reflect both the influences of hydrocarbon contamination and the intrusive shoreline treatment. The high number of cases in which the null hypothesis of no impact from oiling and/or treatment was rejected is impressive. It is clear, based on the number of rejections and the high levels of significance observed in many cases, that the data provided by this study strongly support the conclusion that hydrocarbon contamination and high pressure, hot-water treatment each caused major adverse impacts to the intertidal biota of western Prince William Sound, but that the effects of the treatment predominated. Moreover, it appears likely that the treatment, while removing oil from the upper and mid-littoral zones, where its effects were somewhat restricted to relatively tolerant organisms such a barnacles, rockeweed, and mussels, transported the remobilized oil into the lower intertidal and shallow subtidal zones, where the oil was placed into contact with relatively more sensitive and productive organisms such as hardshelled clams and crustaceans.

Houghton, J.P., D.C. Lees, W.B. Driskell and A.J. Mearns. 1991b.

Impacts of the *Exxon Valdez* spill and subsequent cleanup on intertidal biota -- 1year later

Pentec Environmental, Inc., 120 West Dayton, Edmonds, Washington 98020

Proceedings of the 1991 International Oil Spill Conference, American Petroleum Institute, p467-475.

ABSTRACT

A substantial amount of the crude oil which spilled from the tanker *Exxon Valdez* on March 24, 1989, was deposited on beaches in Prince Williams Sound. Major beach cleanup activities began in May and continued throughout the summer of 1989. Additional cleanup activities occured during the summer of 1990. A study was conducted in 1989 to document the short-term impact to biota of hot water wash treatments. Additional field surveys were conducted in the summer of 1990 to evaluate recovery of littoral habitats from the effects of oiling and shoreline treatment. Stratified-random sampling was used to assess epibiota and infauna at 27 sites, representing several habitats and degrees of disturbance.

Preliminary data evaluations indicate that treaatment methodologies applied in 1989 had varied effects on intertidal assemblages. Some treated rocky beaches were stripped of flora and fauna at mid- and upper intertidal elevations and showed relatively little colonization by mid summer 1990. On other oiled rocky beaches that recieved less severe or no treatment, the majority of the community dominants remained in place and significant recolonization was underway. Protected sand and gravel beaches subjected to hydraulic treatments displayed greatly altered beach morphology. Finer sands and gravels were flushed from upper intertidal elevations, often burying the lower beach in several centimeters of sediment, resulting in major reductions in infauna in 1990. Oiled but untreated sand and gravel beaches had a rich and varied infauna. The effects of 1989 shoreline treatment activities on intertidal flora and fauna were significant and widespread and will greatly complicate assessment of the long-term impacts of the oil itself.

Hubbard, J.D. 1971.

Distribution and abundance of intertidal invertibrates at Olsen Bay in Prince William Sound, Alaska, One Year after the 1964 earthquake

University of Wisconsin at Sheboygan

In: National Research Council (ed.). The Great Alaska Earthquake of 1964: Biology. National Academy Press, Washington, D.C.

ABSTRACT

In the summer of 1965, the Bureau of Commercial Fisheries began a study of intertidal invertebrates in the Olsen Bay area of Prince Williams Sound; this included an evaluation of the effect on intertiidal organisms of uplift caused by the 1964 Alaska earthquake. Intensive sampling of four areas representative of the three most common types of habitat in this protected bay revealed a vertical distribution and abundance of invertebrate species strongly influenced by substrate composition and tidal exposure. Mean tide level (+6.2 ft) exhibited particular importance as the upper limit of numerous organisms. It was found that the uplift produced measurable changes in the distributions of certain bivalve mollusks. Amount of uplift, approximately 3.0 to 3.5 ft in Olsen Bay, could be estimated by comparing the positions of some of these organisms before and after the earthquake. The most obvious and reliable quantitative index of the uplift was provided by pre- and postearthquake limits of barnacle populations, whereas supportive evidence was obtained from examination of certain bivalve mollusk distributions. Differential mortality, noted especially between different species of mollusks and between different age-classes of certain species, was apparently attributable to earthquake-related processes. While reproductive success of some species appeared unaffected by the earthquake, other species have apparently experienced little reproduction since the earthquake.

Ibanez, F. and J-C Dauvin. 1988.

Long-term changes (1977 to 1987) in a muddy fine sand Abra alba-Melinna palmata community from the Western English Channel: multivariate time-series analysis

CEROV, Station Zoologique, BP 28, F-06230 Villefranche-sur-Mer, France.

Mar. Ecol. Prog. Ser. 49: 65-81.

ABSTRACT

Long-term monitoring for 10 years (1977 to 1987) of the muddy fine sand community of the Bay of Morlaix (N. France) has allowed us to determine the principal stages of structural succession following pollution by the hydrocarbons of the *Amoco Cadiz* (1978). Abundance of 30 main species and biomasses of 30 categories were investigated. Regular series were obtained by averaging values from each season, resulting in 40 sequential observations. General trends and seasonal variations were extracted by the Eigen-Filtering method which takes into account the shortness of the annual sampling. Principal component analysis of the covariance matrix of the general trends exhibits 7 successive periods of temporal community changes. This succession is a function of changes in direction in gradients within the populations. The community developed through a successional phase following the oil spill, with establishment at first of a community of opportunists, followed by a colonisation of the polychaete *Lanice conchilega* and finally by reestablishment of the original community pre-Amoco Cadiz. An attempt to classify the species according to their seasonal variations is proposed using a semi-quantitative approach. Results show a concentration of maximal abundances in summer and autumn, and of minimal abundances in winter. The dissimilarity correlograms of the densities and the biomasses were used after rearranging the species into 3 trophic groups. The different behaviour of trophic groups is related to recolonization after the oil spill and to organic matter in the sediment.

Jackson, J.B.C. et al. 1989.

Ecological effects of a major oil spill on Panamanian coastal marine communities.

STRI, Apartado 2072, Balboa, Republic of Panama.

Science 243: 37-44.

ABSTRACT

In 1986 more than 8 million liters of crude oil spilled into a complex region of mangroves, seagrasses, and coral reefs just east of the Caribbean entrance to the Panama Canal. This was the largest recorded spill into coastal habitats in the tropical Americas. Many populations of plants and animals in both oiled and unoiled sites had been studied previously, thereby providing an unprecedented measure of ecological variation before the spill. Documentation of the spread of oil and its biological effects begun immediately. Intertidal mangroves, seagrasses, algae, and associated invertebrates were covered by oil and died soon after. More surprisingly, there was also extensive mortality of shallow subtidal reef corals and infauna of seagrass beds. After 1.5 years only some organisms in areas exposed to the open sea have recovered.

Jacobs, R. 1980.

Effects of the *Amoco Cadiz* oil spill on the seagrass community at Roscoff with special reference to the benthic infauna

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Mar. Ecol. Prog. Ser. 2: 207-212

ABSTRACT

The benthic fauna of an eelgrass (*Zostera marina L.*) community has been investigated at Roscoff (France) from October 1977 to April 1979. The impact of the *Amoco Cadiz* oil spill of March 1978 on the community was studied. Direct effects on the eelgrass itself were only local during the first weeks after the spill, when many plants had black, 'burnt' leaves. This was, however, a temporary phenomenon, for the production of new leaf tissue continued normally. Effects on the benthic fauna were observed directly after the arrival of the oil at Roscoff. A sharp decrease in numbers of both individuals and species occurred - mainly caused by an almost total disappearance of the smaller Crustacea and Echinodermata, and a serious numerical decrease in other groups. Recovery took place relatively rapidly. In the beginning of 1979 all numbers were at the same level as the year before, the filter feeding Amphipoda being the only exception: on 1 May 1979 they were still absent.

Kaplan, E.H., J.R. Welker and M.G. Kraus. 1974.

Some effects of dredging on populations of macrobenthic organisms

Biology Dept., Hofstra University, Hempstead, NY 11550.

Fishery Bulletin 72: 445-480.

ABSTRACT

Populations of epi- and infauna were studied from 10 mo before to 11 mo after a navigation channel was dredged through a small, shallow lagoon. A new sampler which penetrated 20-30 cm into the substratum was used.

Current velocities and sedimentation patterns were changed due to an altered distribution of tidal currents, although flushing time was not appreciably altered.

Values of certain particulate and dissolved nutrients changed after dredging, but no correlation was observed between animal populations and fluctuations in nutrients.

Significant reductions in standing crop figures and species and specimen numbers occurred in both the bay and the dredged channel. *Mercenaria mercenaria* populations were reduced, but there was no evidence of mass mortality. Recovery of biomass in the channel was affected by sediment composition, but seasonal and sediment type variations were not significant in the bay as a whole.

Goose Creek had a high predredging epi-and infaunal standing crop estimated at 36.83 g/m^2, but the number of organisms/m^2 was relatively low, indicating a preponderance of large forms.

Productivity of Goose Creek was calculated at 89.87 $g/m^2/yr$ before dredging and 31.18 $g/m^2/yr$ after dredging. Productivity figures for the mixed peripheral marsh were calculated and the annual loss due to replacement of 10.87 ha of marsh by spoil areas was estimated at 49,487 kg. Altered land usage patterns tended to fix this loss on a permanent basis.

The unusually profound effects of dredging reported for Goose Creek are attributed to its small size and shallowness.

Krebs, C.T. and K.A. Burns 1977.

Long-term effects of an oil spill on populations of the salt-marsh crab *Uca pugnax*

Division of Natural Science and Mathematics, St. Mary's College, St. Mary's City, Maryland 20686

Science 197: 484-487

ABSTRACT

A spill of fuel oil at West Falmouth, Massachusetts, in 1969, contaminated contiguous salt marshes with up to 6000 microgramsof oil per gram (ppm) of wet mud and affected local populations of *Uca Pugnax*. Directly related to high-sediment oil content were reduced ratio of females to males, reduced juvenile settlement, heavy overwinter mortality, incorporation of oil into body tissues, behavioral disorders such as locomotion impairment, and abnormal burrow construction. Concentrations of weathered fuel oil greater than 1000 ppm were directly toxic to adults, while those of 100 to 200 ppm were toxic to juveniles. Cumulative effects occured at lower concentrations. Recovery of the marsh from this relatively small oil spill is still incomplete after 7 years.

Laubier, L. 1980.

The *Amoco Cadiz* oil spill: an ecological impact study

Centre National pour l'Exploitation des Oceans, 66, avenue d'lena, 75116-Paris, France.

Ambio 9: 268-276

ABSTRACT

When the *Amoco Cadiz* ran aground off the coast of France in March, 1978, 223,000 tons of oil spilled into the ocean. After two years, major studies show the recovery of areas exposed to waves, currents and winds is almost complete. But oil persists in areas protected from the physical movement of the sea, and there are sublethal long-range effects on the reproduction of marine organisms.

Lebednik, P.A. and J.F. Palmisano. 1977.

Ecology of marine algae

Fisheries Research Institute, University of Washington, Seattle Washington.

In M.L. Merritt and R.G. Fuller (eds.). The environment of Amchitka Island, Alaska. Technical Information Center..

ABSTRACT

The rocky shores of Amchita Island are densely carpeted by marine algal communities, which, beyond the coast exposed by the tides, are characterized by extensive floating kelp beds. An unusual feature of the intertidal area of the southeastern third of the island if the occurance of wide, often extremely flat, rock benches at about mean tide level.

The Milrow nuclear test affected about 4 ha (10acres) of littoral vegetation when an uplift of about 12 cm (5in.) occured on an intertidal rock bench. Mortality was extensive in the upper portions of all zones 6 months after the disturbance, and significant changes were still occuring when last observed, $3\,1/2$ years after Milrow. The Cannikin nuclear test resulted in uplifting to a maximum of 1 m (3ft). Mortality of the littoral vegetation was severe along 1.9 km (1.2 miles) of coast, including areas with 0.5 to 1 m of uplift. Moderate mortality was observed along an additional 1.5 km (1 mile) of coast, and mortality was detectable along a further 2.7 km (1.7 miles) of coast. Significant changes in vegetation were reported to be occuring nearly 3 years after Cannikin. A normal littoral vegetation will eventually return to both the Milrow and the Cannikin disturbed areas. The lifting of some rock benches above the midlittoral area as a result of the Cannikin test has resulted in significant permanent reduction in the area available to most littoral species.

Lee, R. F., B. Dornseif, F. Gonsoulin, K. Tenore and R. Hanson. 1981.

Fate and Effects of a Heavy Fuel Oil Spill on a Georgia Salt Marsh

Skidaway Institute of Oceanography, PO Box 13687, Savannah, Georgia 31406, USA

Marine Environmental Research 5: 125-143

ABSTRACT

Addition of a heavy oil to a Spartina salt marsh in the autumn resulted in high concentrations of polycyclic aromatic hydrocarbons in sediment and benthic animals. The highest concentrations of phenanthrene, chrysene and fluoranthene in the sediment were 112, 105 and 75 ng/g sediment, respectively. These concentrations rapidly decreased during the 20 week period following the spill. The times for these hydrocarbons to decrease to 50% of their highest values, i.e. half-life, were approximately 100, 70 and 30, days in sediment, mussels and oysters, respectively. Benthic macrofauna species showed three responses to oil addition which included no change, an increase, or a decrease in the population. No changes were noted in populations of fiddler crabs (*Uca pugnax*), oysters (*Crassostrea virginica*), and mussels (*Modiolus demissus*). Mud snails (*Nassarius obsoleta*) increased in density after the spill due to immigration of adult snails from untreated areas to scavenge on animals killed by the oil. Many of the adult periwinkles (*Littorina irrorata*) were killed by the oil. In the spring, juvenile periwinkles recolonised to oiled areas as a result of larvae settling.

Leppakoski, E.J. and L.S. Lindstrom. 1978.

Recovery of benthic macrofauna from chronic pollution in the sea area off a refinery plant, southwest Finland.

Institute of Biology, Abo Akademi, SF-20500 Abo, Finland.

J. Fish Res. Board Can. 35: 766-775.

ABSTRACT

Quantitative field studies (density, wet weight biomass, Shannon diversity, species richness, evenness of distribution) on benthic sublittoral macrofauna were made in the vicinity of an oil refinery in southwest Finland before and after the installation of a new wastewater treatment plant that reduced the amount of oil and liquid effluents by ca. 90-95%. The number of species and species diversity increased during the 1st and 2nd year after pollution abatement at the stations close to the former outflows. The amphipods *Pontoporeia affinis, Corophium volutator*, and *C. lacustre*, midge largae of the *Chironomus plumosus*-group, the oligochaete *Tubifex costatus*, the polychaetes *Harmothoe sarsi* and *Polydora redeki*, and the bivalve *Cardium* sp. were the most successful recolonizers of the 23 taxa sampled. The strong lethal effect of oil-contaminated sediments upon *Chironomus plumosus* larvae decreased markedly in laboratory experiments (LT50 was estimated at 7 d in 1973 and at 28 d in 1974; in 1975, 80-90% of the larvae survived for 28 d). Details of postabatement succession are discussed. The results demonstrate not only the recovery from chronic oil pollution but also the degree of ecological damage caused by previous continuous discharge of oil.

Linden, O., R. Elmgren and P. Boehm. 1979.

The *Tsesis* oil spill: its impact on the coastal ecosystem of the Baltic Sea.

Swedish Water and Air Pollution Research Institute (IVL), Studsvik, S-611 82 Nykoping, Sweden.

Ambio 8: 244-253.

ABSTRACT

The Tsesis oil spill was relatively minor by international standards - roughly 1000 tons of medium grade fuel oil. However, severe effects were observed, at least locally, in the pelagic, littoral and benthic ecosystems and the speed of recovery varied greatly. The plankton communities were back to normal after about one month, but it took a year before the littoral communities showed considerable recovery and within that time soft bottom community did not show even the beginning of a recovery.

Mair, J.McD., I. Matheson and J.F. Appelbee. 1987.

Offshore macrobenthic recovery in the Murchison field following the termination of drill-cuttings discharges

Institute of Offshore Engineering, Heriot-Watt University, Research Park, Riccarton, Edinburgh EH14 4AS, UK

Marine Pollution Bulletin 18: 628-634.

ABSTRACT

The effects of discharged drilling cuttings contaminated with oil-based drilling fluids on the macrobenthos surrounding several North Sea oil-production platforms have been well documented. Areas of biological effect ranging from highly modified benthic communities, through transitional zones to undisturbed zones have been identified and characterized. Results are presented from a series of studies at the Murchison oil field which indicate partial recovery of macrofaunal communities around the production platform after cuttings discharges had ceased. Eventual rates of recovery of affected macrobenthic communities around production platforms are discussed in terms of persistence of oil in the drilling cuttings and the rates of degradation of the oil and its toxic components.

McLusky, D.S., F.E. Anderson and S. Wolfe-Murphy. 1983.

Distribution and population recovery of *Arenicola marina* and other benthic fauna after bait digging.

Department of Biology, The University of Stirling, Stirling FK9 4LA, Scotland.

Mar. Ecol. Prog. Ser. 11: 173-179.

ABSTRACT

Effects of bait digging on distribution and population recovery of *Arenicola marina*, *Hydrobia ulvae* and *Macoma balthica* have been investigated on trial plots at Blackness, Forth estuary (Scotland). *A. marina* rapidly recolonised the basins created by digging, but had reduced populations on the dug mounds. Its populations were dislocated for over 3 mo after digging. *H. ulvae* and *M. balthica* showed enhanced populations on the mounds for up to 2 wk, but were otherwise unaffected by digging. Factors influencing the mode of population recovery are discussed; it is suggested that enhanced basin populations of recolonising *A. marina* are due substantially to above-surface migration of worms into areas with increased levels of organic matter.

Maurer, D., W. Leathem and C. Menzie. 1981.

The impact of drilling fluid and well cuttings on polychaete feeding guilds from the US northeastern continental shelf.

College of Marine Studies, University of Delaware, Lewes, Delaware 19958.

Mar. Poll. Bull. 12:342-347

ABSTRACT

The effect of recent drilling operations (fluid and well cuttings) on polychaete feeding guilds from continental shelf off Atlantic City, New Jersey, was examined. Although there were some adverse effects on macrobenthos from 2160 metric tons of cuttings and mud solids discharged into the marine environment, the composition of polchaete feeding guilds remained essentially unchanged. This key trophic relationship between polychaetes and the changing environment due to the drilling operation was apparently uninterupted. This relationship remains to be examined in other natural and perturbed habitats.

Michael, A.D., C.R. Van Raalte, and L.S. Brown. 1975.

Long-term effects of an oil spill at West Falmouth, Massachusetts

Marine Biological Laboratory, Woods Hole, Massachusetts.

Proceedings of 1975 International Oil Spill Conference, American Petroleum Institute, p573-582.

ABSTRACT

A small spill of No. 2 fuel oil occured near Wild Harbor, Massachusetts, in September 1969. The benthic fauna of Wild Harbor Marsh, boat basin, and offshore area was sampled through the fourth and fifth year after the spill (1973, 1974). Sediment sampels were analyzed for the presence of petroleum hydrocarbons. Gas chromatography produced evidence of hydeocarbons typical of weathered fuel oil in the sediments of the marsh, boat basin, and two offshore stations. The numbers of benthic species at the offshore stations and the marsh were slightly, but significantly, lower than those found at control stations but not in the case of the marsh. The boat basin was still heavily affected. Some stations were charaterized by the presence of opportunistic species The recovery process in terms of the total benthos has leveled off, but there was evidence for further recovery during the course of the study.

Notini, M. 1978.

Long-term effects of an oil spill on *Fucus* macrofauna in a small Baltic bay

Swedish Water and Air Pollution Research Institute, IVL Baltic Sea Laboratory, Studsvik, Fack, S-611 01 Nyköping, Sweden.

J. Fish. Res. Board Can. 35: 745-753.

ABSTRACT

On October 6, 1970, the small tanker *Irini* ran aground in the southern part of the Stockholm archipelago, releasing about 1000 t of medium and heavy fuel oil. Approximately 400 t drifted into a small bay, Gästviken, wiping out nearly the entire littoral fauna. Most of the oil was collected mechanically during the winter, and by May 1971 cleanup operations were completed. The recruitment of the bladder wrack (*Fucus vesiculosus*) community in the bay was observed at intervals over a 5-yr period. Significantly increased macrofauna population densities were found for a number of species in the 1974 and 1976 samples compared to those of 1971 and 1972. From June-July 1971 to June 1976, the mean numbers of individuals for all species rose from about 280 to 1000/100 g *Fucus* dry weight (d.w.). The bivalve *Mytilus edulis* increased in number from 0 to about 45, the gastropod *Theodoxus fluviatilis* from 0 to about 160, the amphipod *Gammarus* spp. from about 40 to 580, the isopods *Idotea* spp. from about 5 to 35, and *Iaera* spp. from almost 0 to about 10/100 g *Fucus*. Larvae of Chironomidae were the only group found with a decreased density between the first and sixth summers after the spill, with 240 and 145 individuals, respectively. The data obtained are discussed in relation to conditions in a nearby unpolluted bay and to normally occurring cyclic variations.

O'Clair, C.E. 1977.

Marine Invertebrates in Rocky Intertidal Communities

Fisheries Research Institute, University of Washington, Seattle, Washington.

In: Merritt and Fuller (eds.). 1977. The Environment of Amchitka Island, Alaska. Technical Information Center, Energy and Research and Development Administration.

ABSTRACT

Previous knowledge of Aleutian marine benthic invertebrates was based on few observations and collections, the history of which is summarized. In this study three belt transects (one sampled once and two sampled seven times) and two intertidal arrays (sampled twice each) of 0.25-m^2 quadrats were used for descriptive studies of intertidal communities at Amchitka Island. These communities are dominated by algae at all tidal levels. Three communities are dominated by algae at all tidal levels. Three communities designated according to their dominant macrophytes are the *Laminaria* community, the *Alaria-Hedophyllum* community, and the Halosaccion-Fucus community. Invertebrates in these communities are mostly inconspecious. Despite the large proportion of North American species in the fauna of Amchitka, species that play key roles in structuring intertidal communities elsewhere on the west coast of North America are absent or in low abundance at Amchitka. Invertebrates in subtidal communities are discussed briefly. An annotated list of over 365 littoral and sublittoral invertebrate species is appended.

Seven zoogeographical elements were recognized in the shallow-water marine fauna of Amchitka. The greatest proportion of species are North Pacific or North American in their distribution. Two oceanographic features (the Alaskan Stream and the Kamchatka Current) and one geologic feature (the Aleutian "stepping-stone" islands between Amchitka and the Asian and North American mainlands) increase the immigration rates of North American species over Asiatic species.

The effects of Cannikin were determined with the use of two intertidal arrays of fixed 0.25-m^2 quadrats (totaling 40 plots) examined twice preevent and ten times postevent (over 33 months) and an intertidal grid (control) sampled randomly once preevent and twice (over 9 months) postevent. The rate of die-off and emigration of intertidal species in maximally uplifted (as much as 1 m) areas depended on exposure to open ocean waves. Most preevent intertidal species were replaced by supralittoral fringe species.

Oliver, J.S. and P.N. Slattery. 1985

Destruction and opportunity on the sea floor: effects of gray whale feeding

Moss Landing Marine Laboratories, P.O. Box 223, Moss Landing, California 95039, USA.

Ecology 66: 1965-1975

ABSTRACT

Gray whales (*Eschrichtius robustus*) are highly disruptive bottom feeders that remove infaunal invertebrate prey and sediments by suction. The response of the benthos to gray whale feeding was examined in the primary feeding grounds of the Bering Sea dn in an ecological analog of these prey communities along the west coast of Vancouver Island. Prey communities were dominated by ampeliscid and other amphipod crustaceans that formed dense tube mats. Large feeding excavations (often 2-20m^2) were rapidly colonized by scavenging lysianassid amphipods, especially *Anonyx* spp., that attacked injured and dislodged infauna. Many of the attacked animals were small crustaceans (< 1 cm long) and polychaete worms. *Anonyx* spp. was 20-30 times more abundant inside fresh excavations than in the surrounding tube mat, where they dispersed within hours after the initial feeding disturbance. A smaller species of lysianassid, *Orchomene minuta*, invaded less rapidly and remained much longer in excavations than the larger, *Anonyx* spp. Natural scavenging events outside feeding excavations revealed that lysianassids commonly fed on relatively small crustacean carcasses (< 3 cm long). Within days and weeks, gray whale feeding excavations trapped organic debris. Most invading species were much more abundant in debris patches compared to debris-free areas of the same excavations. The number of some colonists remained elevated in disturbed areas for > 2 mo. Early colonists were characterized by much greater abundances inside excavations relative to the adjacent tube mat. Two numerically dominant groups of tube-dwelling amphipods were not characterized by a large pulse of abundance inside excavations. *Ampelisca* and *Protomedeia* gradually colonized pits. They also swam less frequently than the early colonists, and probably had more infaunal habits. Gray whale feeding clearly has a dramatic impact on the structure of benthic communities, and also may enhance the population size of several secondary prey.

Oliver, J.S., R. Kvitek and P. Slattery. 1985.

Walrus feeding disturbance: scavenging habits and recolonization of the Bering Sea benthos

Moss Landing Marine Laboratories, Moss Landing, CA 95039.

J. Exp. Mar. Biol. Ecol. 91: 233-246.

ABSTRACT

Walruses *(Odobenus rosmarus* Illiger) influenced the structure of macrobenthic assemblages in a variety of ways as they excavated their major bivalve prey from soft sediments. Benthic animals were attracted to discarded bivalve shells and they colonized pits and furrows made during prey excavation. Discarded shells contained soft tissues that were eaten by several invertebrate scavengers. The most abundant and widespread scavenger was the sea star, *Asterias amurensis* Lutken. Sea stars out-competed brittle stars *(Amphiodia craterodmeta* Clark) for fresh scavenging events. They also attacked brittle stars under shells in the laboratory, and thus may have obtained two meals from discarded shells by eating remnant tissue and by consuming animals that used the shell as a habitat. In nature, brittle stars were abundant under discarded shells. In experiments, brittle stars invaded shells with soft tissue in the absence of sea stars, but not in their presence. In other experiments, brittle stars were most abundant under shells with soft tissue, but were also attracted to shells without organic matter. Large brittle stars were more abundant under shells than in the surrounding bottom, and the reverse was true of small individuals. Bottom communities recovered gradually inside experimental feeding excavations, which were not invaded by large numbers of opponunistic infaunal or epifaunal invertebrates. This is in contrast to gray whale feeding excavations, which are colonized by a large number of opportunistic peracarid crustaceans.

Pagliai, A., A. Varriale, R. Crema, M. Galletti, and R. Zunarelli. 1985.

Environmental Impact of Extensive Dredging in a Coastal Marine Area

Institute of Zoology, the University of Modena, 41100 Modena, Italy.

Marine Pollution Bulletin 16: 483-488.

ABSTRACT

An area of the Thyrrenian Sea in the Gulf of Cagliari, Sardinia, Italy, was investigated before, during and after extensive dredging operations to create an access channel for oil tankers to reach a refinery. The observed abiotic parameters were not greatly affected, but the benthic macrofauna was completely eliminated from the dredged area. Recolonization of this area by the macrobenthos was very rapid. Six months after dredging, benthic communities had main structural parameters very similar to those of the predredging period and neighbouring non-dredged areas. However, the six month post dredging communities still showed a noticeable qualitative dissimilarity with respect to the predredging period and neighbouring non-dredged areas. Communities in the neighbouring non-dredged zones were unaffected by the large scale dredging. These results are only in fact in agreement with those reported in previous investigations into the effects of dredging of the benthic biota. They suggest that the environmental impact of this human induced disturbance may be quite variable from case to case, also in dependence of the concomitant action of other pollutants.

Paine, R.T. and S.A. Levin. 1981.

Intertidal landscapes: disturbance and the dynamics of pattern

Department of Zoology, University of Washington, Seattle, Washington 98195.

Ecological Monographs 51: 145-178.

ABSTRACT

The mussel *Mytilus californianus* is a competitive dominant on wave-swept rocky intertidal shores. Mussel beds may exist as extensive monocultures; more often they are an ever-changing mosaic of many species which inhabit wave-generated patches or gaps. This paper describes observations and experiments designed to measure the critical parameters of a model of patch birth and death, and to use the model to predict the spatial structure of mussel beds. Most measurements were made at Tatoosh Island, Washington, USA, from 1970-1979.

Patch size ranged at birth from a single mussel to 38 m^2; the distribution of patch sizes approximates the lognormal. Birth rates varied seasonally and regionally. At Tatoosh the rate of patch formation varied during six winters from 0.4-5.4% of the mussels removed per month. The disturbance regime during the summer and at two mainland sites was 5-10 times less. Annual disturbance patterns tended to be synchronous within 11 sites on one face of Tatoosh over a 10-year interval, and over larger distances (16km) along the coastline. The pattern was asynchronous, however, among four Tatoosh lacalities. Patch birth rate, and mean and maximum size at birth can be used as adequate indices of disturbance.

Patch disappearance (death) occurs by three mechanisms. Very small patches disappear almost immediately due to a leaning response of the border mussels (0.2 cm/d). Intermediate-sized patches (<3.0 m^2) are eventually obliterated by lateral movement of the peripheral mussels: estimates based on 94 experimental patches yield a mean shrinking rate of 0.05 cm/d from each of two principal dimensions. Depth of the adjacent mussel bed accounts for much of the local variation in closing rate. In very large patches, mussels must recruit as larvae from the plankton. Recovery begins at an average patch age of 26 months; rate of space occupation, primarily due to individual growth, is 2.0-2.5%/month.

Winter birth rates suggest a mean turnover time (rotation period) for mussel beds varying from 8.1-34.7 years, depending on the location. The minimal value is in close agreement with both observed and calculated minimal recovery times.

Projections of total patch area, based on the model, are accurate to within 5% of that observed. Using a method for determining the age of patches, based on a growth curve of the barnacle *Balanus cariosus*, the model permits predictions of the age-size structure of the patch population. The model predicts with excellent resolution the distribution of patch area in relation to time since last disturbance. The most detailed models which include size structure within age categories are inconclusive due to small sample size. Predictions are good for large patches, the major determinants of environmental patterns, but cannot deal adequately with smaller patches because of stochastic effects.

Colonization data are given in relation to patch age, size and intertidal position. We suggest that the reproductive season of certian long-lived, patch-dependent species is moulded by the disturbance regime. The necessary and vital connection between disturbance which generates spatial pattern and species richness in communities open to invasion is discussed.

Pople, A., R.D. Simpson, and S.C. Cairns. 1990.

An incident of Southern Ocean oil pollution: effects of a spillage of diesel fuel on the rocky shore of Maquarie Island (sub-Antactic)

Department of Zoology, University of New England, Armidale, N.S.W., 2351, Austalia.

Aust. J. Mar. Freshwater Res. 41: 603-20.

ABSTRACT

On 3 December 1987, the Australian resupply ship *Nella Dan* ran aground at Macquarie Island, releasing approximately 270 000 L of oil, mostly light marine diesel, into the sea. This represented one of the few spills to have occured in southern hemisphere cold waters. Following the spill, thousands of marine invertebrates were washed up dead on beaches along 2 Km of the shore. Twelve months after the spill, a study was conducted to examine the shore community in 5 zones at 2 oil-affected and 2 control locations three sites were examined within each of these locations. Densities of marine invertebrates appeared to have been markedly reduced in the lower littoral and sublittoral zones in the vicinity of the wreck In the upper littoral zones, algal cover and invertebrate abundance were similar at oil-affected and control locations. The significance of the oil spill and its long-term effects are disscussed.

Reish, D.J., D. F. Soule and J. D. Soule. 1980.

The benthic biological conditions of Los Angeles-Long Beach Harbors: results of 28 years of investigations and monitoring.

Dept. of Biology, California State University, Long Beach, Long Beach, California, 90720.

Helgolander Meeresunters 34: 193-205.

ABSTRACT

Los Angeles-Long Beach Harbors were a grossly polluted body of water at the time of the initiation of benthic biological studies in 1951. Industrial, domestic and storm wastes were discharged into these waters with little or no treatment. The inner harbor waters contained little or no dissolved oxygen and much of the benthos was azoic or possessed a stressed community. However, the outer harbor water mass contained adequate dissolved oxygen, and the benthos supported a rich fauna dominated by many species of polychaetes. A pollution abatement program was initiated in 1968 and today many former wastes have been eliminated or are being diverted to treatment plants for processing. The benthic fauna changed markedly and rapidly following this environmental clean-up. Peaks in population were reached throughout the harbor in 1973-1974 which was followed by a slight decline then stability. An oil tanker explosion, pre-treatment of fish-cannery wastes then diversion of these wastes to a sewage treatment plant, and a change from primary to secendary treatment of sewage brought about changes in the benthic fauna. In the latter instance, benthic populations of polychaetes, fish populations and the number of birds feeding within the area decreased significantly.

Rolan, R.G. and R. Gallagher. 1991.

Recovery of intertidal biotic communities at Sullom Voe following the *Esso Bernicia* oil spill of 1978.

British Petroleum America, 200 Public Square, Cleveland, Ohio 44114.

Proceedings of the 1991 International Oil Spill Conference, American Petroleum Institute, p461-465.

ABSTRACT

In December 1978, the *Esso Bernicia* spilled 8,000 barrels of Bunker C oil during a berthing accident near Sullom Voe Oil Terminal. About 100 miles of shoreline were oiled, much of that span heavily. Sullom Voe is a bay of the Shetland Islands, north of Scotland, An area environmentally similar to Prince William Sound. The highly indented, rocky shoreline is inhabited by typical intertidal communties characterized by fucoid algae (rockweed), barnacles, and snails. Biological survey data for the interdidal communties had been collected for three years prior to the spill.

During The cleanup, most of the shores that were accessible to heavy equipment were stripped of oily rock, cobble, and gravel. Other fairly accessible areas were hand-cleaned. Dispersants were tried on a few shores, but were ineffective. Many of the less accessible locations were not cleaned at all.

The oiled shorelines were resurveyed every year from 1979 through 1987, except 1982 and 1983. Except for the mechanically cleaned areas, the biological communities in the rocky intertidal zone returned to very near normal within the first year, and have remained so in spite of the presence of traces of weathered oil. Normal populations of snails and small crustaceans have thrived in intimate contact with ashphaltic residues that still remain in some locations. In contrast, the biological communities at the sites that were cleaned mechanically were obliterated, and still had not fully recovered after almost nine years.

Rosenberg, R. 1972

Benthic faunal recovery in a Swedish fjord following the closure of a sulphite pulp mill

Swedish Water and Air Pollution Research Laboratory, Box 4052, S-400 40 Gothenburg, Sweden.

Oikos 23: 92-108.

ABSTRACT

During 1968-70, the recovery of the benthic macrofauna was investigated at 53 stations in Saltkallefjord, an inner branch of Gullmarsfjord on the west coast of Sweden. Physico-chemical analyses have shown that the water quality in Saltkallefjord improved as a result of reduced waste water discharge subsequent to discontinuance of production of sulphite pulp in 1966.

After 1968, the benthic macrofauna has colonized fjord areas which earlier in the 1960's were azoic, or occupied by a poor fauna only. During May-October, 1969, a successive monthly increase of the number of species appeared in these areas. Classification of some species in the succession is subject to discussion.

Rosenberg, R., 1976

Benthic faunal dynamics during succession following pollution abatement in Swedish estuary

Swedish Water and Air Pollution Research Laboratory, Gothenburg

Oikos 27: 414-427

ABSTRACT

The recovery of benthic communities has been studied continuously since the closure of a sulphite pulp mill in 1966. The previous, increasing organic enrichment in the estuary had deteriorated the marine environment and reduced the fauna over large areas. The succession of the macrobenthic communities to a level where the recovery process was indistinguishable from annual fluctuations to that recorded forty years earlier. The successional changes in number of species, individuals and biomass are illustrated for the total fauna as well as for dominating groups. The sequential changes of some numerically dominant populations showed a bell-shaped curve patter. During the first years after pollution abatement, when polychaetes dominated, these population changes were drastic but evened out in later seral stages. The role of larval recruitment in succession is discussed. Three diversity indices were used to assess the community structure: Shannon's formula, its measurement of evenness, and Sanders rarefaction technique. As tools for assessing pollution or recovery, the two former had to be used with care, as the highest values were recorded at the beginning of the recovery process when the individuals found were few but evenly distributed among the few species present. The rarefaction technique and the measure of species richness were more satisfactory for this kind of assessment.

Sanders, H. L. 1978.

Florida oil spill impact on the Buzzards Bay benthic fauna: West Falmouth

Woods Hole Oceanographic Institution, Woods Hole. Mass. 02543, USA.

J. Fish. Res. Board Can. 35: 717-730.

ABSTRACT

No matter what criterion is used to measure the effects of the *Florida* oil spill, the densities and species composition and the array of statistical methods demonstrate that the same hierarchical pattern emerges. Densities and species composition remain stable over time at the minimally oiled and unoiled stations, but display considerable fluctuations and marked changes at the more heavily oiled stations. With simple presence or absence data, highest fidelity is present at the marginally oiled stations, lower fidelity at the intermediately oiled stations, and lowest fidelity at the severely oiled stations. The discrepancy index measures mean yearly differences in faunal composition at each of the stations. Very large and large differences are documented for the severely and intermediately oiled stations but only small differences are found for the marginally oiled stations. The coefficient of variation is a measure of faunal variability throughout the entire sampling period for each of the stations. Faunal variation remains very high at the severely and intermediately oiled stations but low at the marginally oiled sites. Cluster analysis reveals profound temporal changes in the fauna from samples collected at the severely and intermediately oiled stations but demonstrates a much more homogeneous pattern with only small seasonal changes from samples obtained at the marginally oiled stations.

Sanders, H.L., J.F. Grassle, G. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980.

Anatomy of an oil spill: long-term effects from the grounding of the barge Florida off West Falmouth, Massachusetts.

Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, 02543.

J. Mar. Res. 38: 265-380.

ABSTRACT

To determine carefully the effects on the marine and extuarine benthos of Number 2 fuel oil spilled by the barge FLORIDA off West Falmouth, Massachusetts, we sampled for many months along an onshore-offshore gradient of pollution, and less intensively at unoiled sites. Analyses of hydrocarbons established that pollution was greatest and most persistent in the intertidal and subtidal zones of Wild Harbor River, less severe in degree and duration at stations farthest from shore. A variety of concurrent analyses showed that disturbance of the fauna was most severe and longest lasting at the most heavily oiled sites, and least severe but perceptible at lightly oiled stations. Patterns of disturbance were not related to granulometry of the sediments. Plants, crustaceans, fish, and birds suffered both high mortality immediately after the spill, and physiological and behavioral abnormalities directly related to high concentrations of the fuel oil. Five years after the spill its effects on the biota were still detectable, and partly degraded #2 fuel oil was still present in the sediments in Wild Harbor River and estuary.

Savidge, W.B. and G.L. Taghon. 1988.

Passive and active components of colonization following two types of disturbance on intertidal sandflat

Mark O. Hatfield Marine Science Center, Oregon State University, Newport, Oregon.

J. Exp. Mar. Biol. 115: 137-155

ABSTRACT

Immigration of small benthic invertebrates into two types of disturbed patches, small depressions and patches of azoic sand, was compared. Rates of recolonization differed between patch types, with numerical recovery in depressions occurring more quickly than in defaunated sediments. The results suggest that colonization by most taxa was dominated by passive advection. The effects of both disturbance types on faunal abundances were of short duration.

Shillabeer, N. and J.F. Tapp. 1989.

Improvements in the benthic fauna of the Tees Estuary after a period of reduced pollution loadings.

ICI Brixham Laboratory, Freshwater Quarry, Brixham, Devon TQ5 8BA, UK.

Marine Pollution Bulletin 20: 119-123

ABSTRACT

The Tees Estuary (north east England) has been industrialized since the nineteenth century and used for the disposal of industrial amd domestic waste. Its physical nature has been changed by canalization amd dredging. In 1970 a number of water quality objectives were established by the Northumbrian River Board and local industry, and during the 1970s water quality improved.

Classification analysis identihes three faunal associations within the estuary. The seaward end of the estuary has a typical estuarine fauna, and the middle reaches are dominated by an abundant fauna tolerant of organic pollution. Species diversity and abundance increased between 1979 and 1985 with a penetration of marine fauna into the estuary and increase in abundance in the middle reaches.

Soster, F.M., and P.L. McCall. 1990.

Benthos response to disturbance in western Lake Erie: field experiments

Department of Geology and Geography, DePauw University, Greencastle, IN 46135, USA

Can. J. Fish. Aquat. Sci. 47: 1970-1985

ABSTRACT

Open space (defaunated sediment) was provided on the floor of Lake Erie on 11 occasions during different seasons over a 26-mo period. The benthic community that developed was sampled over time and compared with the nearby undisturbed bottom community. A consistent succession of functional and adaptive types was observed. Early colonizers - the ostracod *Physocypria globula*, the nadid oligochaete *Vejdovskyella intermedia*, and the chironomid, *Chironomus plumosus* - exceeded their natural bottom abundances by 2-7 x within 40 d, but decreased in abundance later. They are small and mobile, live and feed close to the sediment-water interface, and reproduce often. Late colonizers - *Limnodrilus* spp., *Ilyodrilus templetoni*, and pisidiid bivalves - reached natural abundances only after several months if at all. They are large, deep infaunal dwellers that grow slowly and reproduce late in life. An intermediate group - *Arcteonais lomondi, Specaria josinae, Pristina acuminata, Dero digitata, Procladius* sp., and *Coelotanypus* sp. - reached their natural abundances early but did not exceed them. This successional sequence of functional and adaptive types appears to be a general response by both shallow freshwater sublittoral and shallow marine subtidal macrofauna to space-providing disturbances despite radical taxonomic dissimilarity.

Sousa, W.P. 1979a.

Disturbance in marine intertidal boulder fields: the nonequilibrium maintenance of species diversity.

Dept of Zoology, University of California, Berkeley, California 94720.

Ecology 60: 1225-1239.

ABSTRACT

The effects of disturbance on local species diversity were investigated in an algal-dominated intertidal boulder field in southern California. In this habitat, the major form of disturbance occurs when waves, generated by winter storms, overturn boulders. These natural physical disturbances open space, interrupt successional sequences, and determine local levels of species diversity. Because small boulders are more frequently overturned than larger ones,.the plants and sessile animals of boulder fields are distributed in a patchwork of successional stages.

Boulders which are subjected to intermediate disturbance frequencies are usually less dominated than those which are very frequently disturbed, and always less dominated than those which are seldom disturbed. In all seasons most small boulders have fewer species than those of intermediate size. Large boulders also usually have fewer species, except in the spring, when defoliation of the algal canopy during the previous winter has opened space for colonization. Species richness on these boulders declines during summer months, and is less than that on boulders of intermediate size in the fall.

Small boulders, with a shorter disturbance interval, support only sparse early successional communities of the green alga, *Ulva*, and barnacles. Large, infrequently disturbed boulders are dominated by the late successional red alga, *Gigartina canaliculata*. Intermediate-sized boulders support the most diverse communities composed of *Ulva*, barnacles, several middle successional species of red algae, and *Gigartina canaliculata*. Comparison of the pattern of succession on experimentally stabilized boulders with that on unstable ones confirms that differences in the frequency of disturbance are reponsible for the above patterns of species composition.

The frequency of disturbance also determines the degree of between-boulder variation in species composition and diversity. Small boulders which are frequently overturned sample the available pool of spores and larvae more often. As a result, a greater number of different species occur as single dominants on these boulders. Boulders with an intermediate probability of being disturbed are most variable in species diversity. Assemblages on these boulders range from being dominated by a single species to being very diverse while most communities on boulders which are frequently or seldom disturbed are strongly dominated.

Observations on the local densities of three species of middle successional red algae over two year-long periods indicate that most of these are variable in time. More local populations went extinct or became newly established on boulders than remained constant in size. These species persist globally in the boulder field mosaic by colonizing recent openings created by disturbances. These results lend support to a nonequilibrium view of community structure and, along with other studies suggest that disturbances which open space are necessary for the maintenance of diversity in most communities of sessile organisms.

Sousa, W.P. 1979b.

Experimental investigations of disturbance and ecological succession in a rocky intertidal algal community

Dept of Zoology, University of California, Berkeley, California 94720.

Ecological Monographs 49: 227-254.

ABSTRACT

Mechanisms of ecological succession were investigated by field experiments in a rocky intertidal algal community in southern California. The study site was an algal-dominated boulder field in the low intertidal zone. The major form of natural disturbance which clears space in this system is the overturning of boulders by wave action. Algal populations recolonize cleared surfaces either through vegetative regrowth of surviving individuals or by recruitment from spores.

Boulders which are experimentally cleared and concrete blocks are colonized within the first month by a mat of the green alga, *Ulva*. In the fall and winter of the first year after clearing, several species of perennial red algae including *Gelidium coulteri, Gigartina leptorhynchos, Rhodoglossum affine*, and *Gigartina canaliculata* colonize the surface. If there is no intervening disturbance, *Gigartina canaliculata* gradually dominates the community holding 60-90% of the cover after a period of 2 to 3 years. If undisturbed, this monoculture persists through vegetative reproduction, resisting invasion by all other species. During succession diversity increases initially as species colonize a bare surface but declines later as one species monopolizes the space.

Several contemporary theories concerning the mechanisms of ecological succession were tested. The early successional alga, *Ulva*, was found to inhibit the recruitment of perennial red algae. This competition for settling space is an important feature of the successional process. *Ulva* is the best competitor for this space; it reproduces throughout the year and quickly becomes established on newly cleared substrates. As long as these early colonists remain healthy and undamaged, they preempt colonization by perennial red algae which have highly seasonal recruitment and slower growth.

Selective grazing on *Ulva* by the crab, *Pachygrapsus crassipes*, breaks this inhibition and accelerates succession to a community of long-lived red algae. Grazing by small molluscs, expecially limpets, has no long-term effect on the successional sequence. Their grazing temporarily enhances the recruitment of the barnacle, *Chthamalus fissus*, by clearing space in the mat of algal sporelings and diatoms which develops on recently denuded rock surfaces.

Where locally abundant, middle successional red algae also slow the invasion and growth of the late successional dominant, *Gigartina canaliculata*. This alga replaces middle successional species because it is less susceptible to damage by desiccation and overgrowth by epiphytes.

The results of this study do not support either the classical facilitation model or the tolerance (competitive) model of ecological succession. Once early colonists secure the available space/light, they resist rather than facilitate the invasion of subsequent colonists. Early colonists are not killed by direct interference competition with late successional species which grow up through their canopy; rather, early colonists can successfully inhibit the recruitment and growth of these species. Successional sequences occur because species which dominate early in a succession are more susceptible to the rigors of the physical environment and to attacks by natural enemies than late successional species. Late species colonize and grow to maturity when early species are killed and space is opened. Only late in a successional sequence, when large clearings become a mosaic of small openings, does direct competition with surrounding adult plants of late successional species contribute to the decline in cover of the remaining early species. Studies of succession in a number of terrestrial and marine communities lend support to this inhibition model.

Sousa, W.P. 1980.

The responses of a community to disturbance: the importance of successional age and species' life histories.

Dept of Zoology, University of California, Berkeley, California 94720.

Oecologia 45: 72-81.

ABSTRACT

The responses of different successional stages of a temperate intertidal algal community to disturbance were investigated with a field experiment. The experiment was conducted in a low intertidal boulder field in southern California. In this habitat, the top surfaces of boulders are covered with algae. The composition of the assemblage on any particular boulder depends on the length of time since it was last overturned by wave action. When a boulder is overturned, the algae on what was formerly the top surface, are killed in whole or part by a combination of sea urchin grazing, anoxia, light levels below compensation intensity, and mechanical damage caused by crushing or abrasion. The length of time that a boulder remains overturned and the local abundance of sea urchins determines the intensity of the disturbance. When the boulder is righted, recolonization begins either by vegetative regrowth of survivors and/or by spores from outside.

Using a three-factorial design, this natural form of disturbance was experimentally mimicked and the responses of three different successional stages of the algal community monitored. Boulders in each successional category were overturned for periods of 17, 27 and 54 days in areas with and without sea urchins, then righted. Two aspects of community response to perturbation were evaluated. These were (1) the assemblage's ability to resist change and (2) its ability, if altered, to adjust to some semblance of its original state. The resistance of each assemblage and of its component species to change was measured by the percent decrease in algal cover and by the decline in percent similarity of the community to its original composition. The recovery rate of each assemblage and of the cover lost by each species during the first 35 days following a disturbance was measured by the rate of increase in percent similarity to the original composition and the percent reestablishment of lost cover.

The experimental evidence demonstrates that the successional stages of the producer level of an intertidal algal community differ significantly in their responses to distrubance. Early successional communities suffer more damage from a given level of perturbation but recover more quickly that either middle or late successional communities. Damage to any particular assemblage of algae, irrespective of successional age, is more extensive and recovery slower, the longer the boulder is overturned and/or sea urchins are present. Several thresholds in these responses were also identified.

Differences in community responses and non-linearities in these responses were attributable to the life history characteristics of the component species rather than emergent properties of the assemblage. These characteristics have evolved in response to a variety of recurrent natural disturbances. This interpretation is in agreement with recent critical reevaluations of the trends and mechanisms of successional change in natural communities.

Sousa, W.P. 1984.

Intertidal mosaics: patch size, propagule availability, and spatially variable patterns of succession

Dept of Zoology, University of California, Berkeley, California 94720.

Ecology 65: 1918-1935.

ABSTRACT

Localized disturbances transform most assemblages of sessile organisms into mosaics of patches differing in characteristics such as size and age (time since last disturbed). This mosaic nature of natural communities is especially evident on exposed intertidal shores along the northwest coast of North America, where the competitively dominant mussel, *Mytilus californianus*, occupies much of the space at mid-tidal levels. Nearly continuous beds of this species are interrupted by patches of open space generated mainly by the shearing forces of winter storm waves. These patches serve as foci for the recruitment, growth, and reproduction of many competitively inferior, "fugitive" species, including both algae and sessile invertebrates. These species are doomed to local extinction as the lateral encroachment of adult mussels closes the patch and excludes them from the area.

This study examined the dynamics of algal succession within experimental patches cleared in mussel beds. In particular, two potentially important sources of variation in successional dynamics were investigated: (1) the size of the patch when first created, and (2) the location of the patch with respect to potential sources of propagules.

The size of a cleared patch was found to influence strongly the course of algal succession. This effect was largely indirect, resulting from an interaction between patch size and grazing intensity. Small patches support higher densities of grazers, especially limpets, than do large patches. As a consequence the assemblages of algae that develop within small and large patches differ markedly. The assemblage in small patches includes grazer-resistent but apparently competitively inferior species, whereas that in large patches is composed of grazer-vulnerable but competitively superior species. Small patches appear to serve as refuges from competition for grazer-resistent species.

Recruitment was variable among the experimental patches. Percent cover of several species was found to be highly correlated with the cover of epizoic conspecific adults within 1 m of the edge of the patch. This result suggests that a number of the species inhabiting patches within mussel beds may disperse their propagules over relatively short distances. For such species, patch dispersion may influence the regional dynamics of their populations.

Southward, A.J., and E.C. Southward. 1978.

Recolonization of rocky shores in Cornwall after use of toxic dispersants to clean up the *Torrey Canyon* spill.

Marine Biological Association, Citadel Hill, Plymouth, U.K.

J. Fish Res. Board Can. 35: 682-706.

ABSTRACT

Fourteen thousand tons of Kuwait crude oil, reduced from 18,000 tons by weathering at sea, was stranded along 150 km of the coast of West Cornwall, England, in March 1967. The oil was treated with 10,000 tons of toxic dispersants during cleaning operations. By itself the oil was not very toxic, although it killed some limpets and barnacles, and most of the mortalities that followed cleaning were due to the dispersants. There was a graded effect. Most animals and some algae were killed on the shores treated heavily with dispersants, while a few animals and most algae survived in places less heavily treated. However, long stretches of coast were contaminated to some extent by drifting of patches of oil and dispersants along the shore and by indiscriminate dispersant use in remote coves. The general sequence of recolonization was similar to that which has been found after small-scale experiments, where the rocks were scraped clean, or where limpets were removed, but took longer to complete. There was first a rapid "greening" by the alga *Enteromorpha;* then a heavy settlement and growth of perennial brown algae (*Fucus* species), leading to loss of surviving barnacles. A settlement of limpets and other grazing animals followed, with eventual removal or loss of the brown algae. The final phases were a reduction in the limpet population and a resettlement of barnacles. Lightly oiled, wave-beaten rocks that received light dispersant treatment showed the most complete return to normal, taking about 5-8 years; heavily oiled places that received repeated application of dispersants have taken 9-10 years and may not be completely normal yet. Most common species returned within 10 years, but one rare hermit crab is still missing from places directly treated with dispersants. The early recolonization by algae resulted in a raising of the upper limit of *Laminaria digitata* and *Himanthalia elongata* by as much as 2 m in wave-beaten places, demonstrating that grazing pressure by limpets must be one of the factors controlling the zonation of these plants. Later, other species of plants and animals were found higher up the shore than usual, under the shade and shelter provided by the dense canopy of *Fucus*. Fluctuations in the populations of algae and herbivorous animals during the course of the recolonization illustrate the importance of biological interactions in controlling the structure of intertidal communites. Pollution disturbance affects the herbivores more than plants, hence the point of stability of the community is shifted towards the sheltered shore condition of low species richness and greater biomass.

Thomas, M.L.W. 1973.

Effects of Bunker C oil on intertidal and lagoonal biota in Chedabucto Bay, Nova Scotia

Department of Biology, University of New Brunswick, Saint John, N.B.

J. Fish. Res. Board Can. 30: 83-90

ABSTRACT

In February 1970, a large spill of Bunker C oil occurred in Chedabucto Bay, Nova Scotia. The incident was of particular interest since large spills of this type of oil had not previously been studied. Further interest was added by the unusually cold temperatures and by the nonuse of detergents in cleanup. The effects of the oil on intertidal and lagoonal biota have been followed since the accident. Many rocky shores and lagoons were heavily oiled. On exposed shores, oil has decreased steadily since oil stopped coming ashore in mid-1970 and by August 1971 only small amounts remained. In sheltered areas, particularly lagoons, heavy oil contamination remains. The summer remobilisation and subsequent redeposition of oil added a chronic aspect to the pollution. Initial effects of oil involved minor smothering of fauna and tearing loose of algae. Longer term effects involved extensive mortalities of *Fucus spiralis* on rocky shores and *Mya arenaria* and *Spartina alterniflora* in lagoons. Other biota were not visually affected. In all three affected species, mortalities took place either continuously or only in the second year of pollution. Causes of death are unknown. It is recommended that in all intertidal areas very heavy oil deposits should be mechanically removed and the remainder of the oil left to natural degradation.

Thomas, M.L.W. 1977.

Long term biological effects of Bunker C oil in the intertidal zone

Department of Biology, University of New Brunswick, Saint John, New Brunswick, Canada

Proceedings of the Seattle Symposium. 238-246.

ABSTRACT

In February, 1970 a large spill of Bunker C oil occurred in Chedabucto Bay, Nova Scotia, Canada when the tanker "Arrow" grounded. Oil from the tanker has persisted for over six years on rocks and in intertidal sediments on the shores of the bay. During this period mortalities of common species in all major communities on both exposed and sheltered shores have occurred. On rocky shores, the dominant fucoid algae suffered heavy initial mortalities which were more severe at high tidal levels. Recolonization has proceeded from lower to higher levels but has not yet occurred in the high tide zone. Delayed recolonization appears to be related to long term toxicity. In salt-marsh and sheltered lagoonal communities, the dominant grass, salt marsh cord grass, suffered heavy mortality delayed one year from the initial spill, recovery commenced two years later and is proceeding steadily. Soft-shell clams in lagoonal sediments have shown persistent mortalities proportional to oil content of sediments. This pattern appears to be a result of direct toxicity, environmental change caused by oil and sub-lethal metabolic effects.

Thomas, M.L.W. 1978.

Comparison of oiled and unoiled intertidal communities in Chedabucto Bay, Nova Scotia.

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J. Fish Res. Board Can. 35: 707-716.

ABSTRACT

During 1976, detailed surveys of four oiled and four unoiled control stations, each subdivided into seven standardized intertidal levels, were carried out in Chedabucto Bay. Seventy-one species were found, 14 unique to control and 9 to oiled locations. Species diversity was uniformly higher at control than oiled stations. No differences in horizontal zonation of major species were apparent. Analysis of abundance and biomass data for the eight stations and seven tidal levels showed a significant overall difference between oiled and control situations. However, no particular station or tidal level was significantly different from any other. Ten species accounted for most of the variance between oiled and control stations. Six of these were more important at controls and four more important at oiled stations. The flora were particularly affected at oiled stations and species dominant on both sedimentary and rocky shores at all but the lowest tidal levels have been reduced. Length and weight data for the clam *Mya arenaria* showed significantly lower values at oiled stations, but that for the periwinkle *Littorina littorea* showed the opposite. The length-weight relationship for both of these species showed a significantly lower increase in weight per unit of length at oiled than at control stations. Oiled stations showed significantly greater concentrations of oil in biota and sediments than unoiled, where concentrations were essentially at background levels.

VanBlaricom, G.R. 1982.

Experimental analyses of structural regulation in a marine sand community exposed to oceanic swell

Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California 92093.

Ecological Monographs 52: 283-305.

ABSTRACT

The development of general theories concerning the origin and maintenance of community organization in marine sedimentary environments will benefit from studies of similar processes in the widest possible range of habitat types. The roles of predation and disturbance by large epibenthos are thought to be significant in many such habitats, but the bulk of recent experimental confirmation comes from shallow areas protected from oceanic swell. This field experimental study examines relationships among demersal predators, predator-caused local disturbance, infauna, and infaunal food resources in an exposed marine sand habitat at 17 m depth in southern California, USA.

Manipulation of predator densities with exclusion cages, simulation of biological disturbance, and study of dispersal and habitat selection of infauna showed the importance of recurrent local disturbances by the rays *Urolophus halleri* and *Myliobatis californica*, which dig pits to expose prey but clear other infauna in the process. Benthic invertebrate populations show complex but reproducible patterns of reoccupation of disturbed sites. The most striking aspect of these patterns is active selection of recently formed pits by certain species. Ray pits are sites of accumulation for organic material on which most of the infauna feed. Experiments showed that populations which rapidly colonize new ray pits are responding to the concentration of food resources which are otherwise sparsely distributed. Responses of infauna to ray disturbance are correclated with postlarval swimming capability and method of feeding. Early colonists are active nocturnal swimmers that feed on detritus at the sand-water interface. Such features allow efficient exploitation of patchy, ephemeral concentrations of organic matter. Later arrivals are primarily subsurface feeders with limited swimming activity. The relative abundances of infauna are sensitive to seasonal changes in ray disturbance rates. Early pit colonists predominate when disturbance rates are high. The ray disturbance phenomenon produces a persistent mosaic of patches in various stages of infaunal recolonization.

Other experiments showed the importance of predation by sea stars (*Astropecten verrilli*) and speckled sand dabs (*Citharichthys stigmaeus*). Sea stars consume crab larvae soon after they settle to the bottom and begin metamorphosis. During the study, recruitments of two crabs, *Cancer gracilis* and *Portunus xantusii*, were much reduced by sea star predation. A caging experiment indicated that high-density populations of *P. xantusii* have important negative effects on some infaunal populations. Thus, sea star predation on young crabs is important to the maintenance of infaunal community organization. Sand dabs consume infauna, which are flushed into the water column or onto the sand surface by digging rays. This commensal behavior constitutes an important additional source of mortality for populations that are otherwise unavailable as food for sand dabs, which are visual predators.

Vanderhorst, J.R., J.W. Blaylock, P. Wilkinson, M. Wilkinson and G. Fellingham. 1980.

Recovery of Strait of Juan de Fuca intertidal habitat following experimental contamination with oil.

Batelle, Pacific Northwest Laboratories, Marine Research Laboratory, Sequim, Washington 98382.

Report for the Office of Environmental Engineering and Technology, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C. 20460.

ABSTRACT

This is a second year interim report on the effects of experimental oiling with Prudhoe Bay crude oil on recovery of intertidal infauna and epi-fauna of the Strait of Juan de Fuca, Washington State. It describes completed studies of the recovery of infauna as recovery rate relates to the experimental oiling, the site of study, tidal height, season of study, and duration of recovery. The report also describes the methods and initial results of studies of the effects from experimental oiling on epifauna colonization of hard substrates.

Full recovery is defined within the experimental framework for infauna as that composition and density of species which had colonized trays of untreated coarse substrate within the 15-month study period. The relevance of this definition is supported by presentation of data on composition and density of infauna at adjacent baseline stations as measured by other investigators. In terms of species composition, nearly full recovery of oiled substrates occurred in 15 months. For individual species densities, as well as overall abundance, however, oiled substrates had recovered only about one-half in 15 months. Total hydrocarbons in treated substrates were reduced from initial concentration by 85 and 97% for fine and coarse sediments, respectively, in 15 months. Based on rate of loss between 3 and 15 months, it is speculated that total hydrocarbons would have reached background levels in 18.5 months. Analyzed saturate compounds appeared to be lost from treated sediments at a rate similar to total oil. Analyzed aromatic compounds exhibited a much more rapid reduction in concentration than did saturate compounds or total oil.

As analyzed experimental variables, the site of study, tidal height, and sediment type, produced significant effects on the density of primary biological species. Overall, there were much higher densities at two feet below Mean Lower Low Water (MLLW) than at MLLW. Overall abundance appeared about equal between sediment types. Although not analyzed statistically, there appeared to be an order of magnitude higher density in the summer-fall experimental period than in the spring-summer experimental period.

The most severe effects from oiling on infauna density, as an expression of recovery, were seen for detritivorous and herbivorous species. The species for which significant effects on recovery were demonstrated were among those identified as having major trophic importance for a variety of bottom feeding fishes by other Strait of Juan de Fuca investigators.

The experimental oil treatment, while perhaps a "worst" case in the sense that the oil was mixed in sediment, was well within the concentration measured in sediments following some actual oil spills.

Zajac, R. and R.B. Whitlatch. 1982a.

Responses of estuarine infauna to disturbance. I. Spatial and temporal variation of initial recolonization

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Mar. Ecol. Prog. Ser. 10: 1-14.

ABSTRACT

Responses to disturbance of estuarine infauna were studied to test the hypothesis that seasonality, the estuarine environmental gradient and sediment composition would significantly affect recolonization. The study was conducted in a small estuary located in southeastern Connecticut, USA, using controlled disturbance experiments and sampling of the ambient infauna. Species composition in experimental plots and ambient sediments usually did not differ, either on a seasonal or areal basis. Numerically dominant species usually included the polychaetes *Streblospio benedicti, Capitella* spp. and *Polydora ligni,* and the oligochaete *Peloscolex gabriellae.* Other species included the polychaetes *Scoloplos fragilis, Hobsonia florida* and *Nereis virens,* the hemichordate *Saccoglossus kowaleski,* and the amphipods *Microdeutopus gryllotalpa* and *Corophium insidiosum.* At times, densities of these species exceeded or were equivalent to dominant species densities in experimental plots. There were usually significant differences in recolonization and ambient population dynamics due to seasonality and estuarine position. The effects of sediment composition on recolonization patterns of the various species were generally not significant. Seasonal trends in ambient and recolonization species densities were similar, with the highest responses to disturbance in the spring and summer. As ambient densities declined during the fall and winter, responses to disturbance did likewise. On an areal basis, the highest responses to disturbance occurred in the middle and upper portions of the estuary. Ambient densities followed a similar pattern, but peak densities in the early spring (May, 1979) were found in the lower portion of the estuary. Based on differences between ambient and recolonization population densities, only 1 species, *Polydora ligni,* exhibited a regular opportunistic response. Other species exhibited opportunistic responses, but in only 1 or 2 mo during the study. It is apparent, therefore, that species responses to disturbance were quite variable and no general pattern of recolonization could be applied to Alewife Cove with respect to seasonality and estuarine position. Due to this variation, and the historical component involved in disturbed habitats, hypotheses correlating species responses to disturbance with life history adaptations may not be generally applicable to estuarine soft-bottom communities.

Zajac, R. and R.B. Whitlatch. 1982b.

Responses of estuarine infauna to disturbance. II. Spatial and temporal variation of succession

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Mar. Ecol. Prog. Ser. 10: 15-27.

ABSTRACT

Infaunal successional patterns in Alewife Cove, a small estuary in southeastern Connecticut, USA, varied significantly seasonally and along the estuarine environmental gradient. Each study site exhibited different patterns of change in species composition and abundance. However, suites of species found during succession did not differ greatly from those found in ambient sediments. Species which exhibited the most variable population changes during succession were numerically dominant tubiculous polychaetes *(Streblospio benedicti, Capitella* spp., *Polydora ligni*, and an oligochaete *(Peloscolex gabriellae)*. Other species which exhibited significant activity were the polychaetes *Scoloplos fragilis, Hobsonia florida and Nereis virens*, the hemichordate *Saccoglossus kowaleski*, and the amphipods *Microdeutopus gryllotalpa* and *Corophium insidiosum*. At certain times, densities of these species exceeded or were equivalent to dominant species densities in ambient sediments and experimental plots. Timing of disturbance greatly influenced succession. Succession after an early spring disturbance was characterized by peak species densities and numbers. Succession following a fall disturbance was abbreviated with few species at low densities, while after a summer disturbance intermediate trends were found. Classification analysis of similarity between ambient and successional community structure indicated that recovery to ambient conditions occurred rapidly in the lower reach (14 to 30 d), while successional changes in the middle and upper basins continued at least until the end of the winter. It is apparent that estuarine succession can be quite variable and that re-establishment of community structure may occur over various time scales with no set seral stages. The physical and biological processes appearing to be important determinants of estuarine succession include (1) timing of disturbance, (2) habitat in which the disturbance takes place, (3) reproductive periodicity of infauna, (4) ambient population dynamics which generate the pool of recolonizers, (5) abiotic and biotic factors (e.g. food and space resources that affect the preceding 4 factors).

REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FOLLOWING MAN-INDUCED AND NATURAL-PHENOMENA-RELATED DISTURBANCES: HARBOR SEALS AND KILLER WHALES

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FINAL REPORT

to

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EXECUTIVE SUMMARY

Populations of marine mammals have suffered large reductions, sometimes to near extermination, by aboriginal and commercial harvests, incidental or indiscriminate killing, and epizootics during the past two centuries. After killing ended, many populations increased at annual rates varying from 7-21% in pinnipeds and 2-12% in cetaceans. The causes for recent steady declines, following population recoveries, of northern fur seals, northern sea lions, and harbor seals in the Bering Sea, Aleutian Islands, and western Gulf of Alaska, and of southern elephant seals in most of the southern ocean, remain unexplained.

Epizootics.--Recent epizootics killed over 18,000 seals (mostly harbor seals) in Europe, and an estimated several thousand at Lake Baikal; population responses following those reductions are undocumented. Historical occurrences of epizootics and the prevalence of antibodies to various viruses in current seal populations suggest that seals that survive these challenges provide nuclei for population recovery.

Climate.-- Seal and sea lion populations in the Pacific were reduced by the 1982-83 El Niño Southern Oscillation (ENSO) event. Recent studies have indicated only temporary demographic consequences. Historical, large-scale fluctuations in ocean conditions related to ENSOs may have influenced population changes in Antarctic pinnipeds, though not to the extent of affecting population persistence.

Overall long-term population data demonstrate the potential of pinnipeds and cetaceans to sustain high rates of growth following population reduction, even to very low abundance, so long as breeding and foraging habitats are not degraded.

Pollution.-- Fouling of pinnipeds and cetaceans by oil has evidently had insignificant effects on populations; substantial mortality has never been observed, even following catastrophic spills. The

effects of oiling depended on whether oil coated the body surface, was ingested, or aromatic hydrocarbons were inhaled. Most reports have been based on casual observations; results of systematic experiments have often been ambiguous.

Vulnerability of cetaceans is highest for species with small ranges, coastal/ice-dwelling/riverine habitats, limited diets, poor behavioral flexibility, and small populations. Species with large ranges, oceanic distribution, diverse prey, adaptable behavior, and large populations are least vulnerable. For pinnipeds, stressed or nursing animals, and recently-weaned pups are potentially vulnerable. But marine mammals are long-lived and even the loss of an entire cohort would have insignificant long-term demographic effects.

Prolonged inhalation of hydrocarbon vapors appears to pose the greatest risk to the viability of individuals. Animals with parasitic lung disease, which is relatively common in pinnipeds, would be especially vulnerable to respiratory challenges. Yet, for most pinnipeds, particularly in northern habitats, it is unlikely that petroleum vapors could become sufficiently concentrated to represent a threat.

Contaminants in food.--Pinnipeds are unlikely to directly ingest hydrocarbons, and their prey seem unlikely to accumulate residues. Thus, toxicity is not expected to be a significant health risk, except possibly in bearded seals, walruses, or harbor seals foraging in heavily contaminated benthic environments. Of greater significance is the potential direct effects of fouling on benthic communities, which may be transmitted to other parts of the food chain; for example, a reduction in octopus abundance might depress the recovery of harbor seals.

Killer whales consume a wide variety of prey, including fish, birds and mammals. They are unlikely to ingest toxic hydrocarbons, unless they prey on species that have accumulated residues.

Future research.--Because there are few data on pre-EVOS abundance of harbor seals and killer whales in the EVOS area, it is impossible to use simple counts of animals to decide whether a

population has recovered. For harbor seals, it may be possible to use early post-spill data on abundance, distribution, and pup production as a reference point for future assessments. However, other recovery criteria (e.g., habitat occupation; an arbitrarily-established, desired local population size; physical or physiological condition of individuals) need to be developed. Evaluation of the recovery process will require long-term monitoring of population abundance and seasonal distribution. Future research should document the movement patterns of harbor seals and killer whales in Prince William sound and their seasonal use of habitats in the EVOS area using satellite-linked or conventional VHF telemetry and intensive photo-identification studies (primarily killer whales). Surveys should cover a larger area and be conducted at all seasons of the year; this is especially needed for killer whales. Monitoring should be conducted at several year intervals--and at a level to provide statistically valid results-- to permit long-term, cost-effective evaluation.

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1.0. Introduction

1.1. Background

On 24 March 1989, around 11 million gallons of North Slope crude oil spilled into Prince William Sound from the grounded oil tanker EXXON Valdez. About 60% of the oil was not recovered and drifted or was blown southwest along the Kenai Peninsula toward Shelikof Strait, resulting in the fouling of over 1200 miles of mainland and island coastline and an unknown area of ocean bottom. Resident populations of harbor seals and killer whales may have been affected during the spill by inhalation of volatile, short-chain hydrocarbons, ingestion of oil, immediate destruction of prey resources and long-term food chain contamination. Evidently, substantial numbers of harbor seals became oiled in the EXXON Valdez oil spill (EVOS) area. Some were likely exposed to toxic aromatic hydrocarbons in areas very near the spill source. Killer whale numbers have declined in the EVOS area since 1989; known (photo-identified) whales have been reported missing from well-studied killer whale pods in nearby areas of Prince William Sound. Additional studies have been conducted on the distribution and abundance of killer whales in Prince William sound to determine the relationship of the EVOS to changes in whale abundance but results of those studies have not yet been published. When abstracts or summaries were included in source documents we quoted them directly in our annotated bibliography. When no abstracts or summaries were present in the documents reviewed we constructed new abstracts.

1.2. Objectives

Here we summarize, in the form of an annotated bibliography, published information on the population effects of oil spills on harbor seals and other relevant pinnipeds and killer whales and other relevant cetaceans throughout their ranges. We also summarize demographic information on the responses of pinniped and cetacean populations to other anthropogenic and natural disturbances and on rates and patterns of population recovery. We use this data base as a guide to understanding

daytime low tides and seasonal terrestrial abundance is greatest during the molt in spring or summer and least in winter; breeding occurs from late winter through early spring or summer depending on latitude (e.g., Schneider and Payne 1983, Stewart 1984, Terhune and Almon 1983, Thompson et al. 1989, Yochem 1987). Terrestrial abundance at a large haulout area on Tugidak Island near the EVOS area declined substantially (about 85%) from 1976 through 1988 for unknown reasons, although large numbers of pups were harvested annually from 1964 through 1972 (Pitcher 1990). The trend in Prince William Sound was not documented. The decline in abundance at Tugidak Island is sharp contrast to the steady increases in harbor seal populations in most other parts of the species' range during the past several decades (e.g., Harvey et al. 1990, Heide-Jorgensen and Harkonen 1988, Olesiuk et al. 1990a, Stewart et al. 1988, Stewart et al. 1992).

Seasonal site-fidelity and short- and long-distance movements of harbor seals have been documented in some areas (e.g, Brown and Mate 1983, Pitcher and MacAllister 1981, Yochem et al. 1987) as have seasonal, sexual, and age-class segregation (e.g., Allen et al. 1988, Godsell 1988, Kovacs et al. 1990, Thompson et al. 1990). No comparable data are available for the EVOS-Prince William Sound area. The diet of harbor seals is relatively broad with benthic and epibenthic species of cephalopods and fish generally predominating (e.g., Brown and Mate 1983, Harkonen 1987, Olesiuk et al. 1990b, Pierce et al. 1991, Pitcher 1980a, 1980b, Thompson et al. 1991).

Harbor seal populations have been increasing in most areas where they have been studied in recent years where commercial or subsistence harvesting is low or absent (e.g., Harvey et al. 1990, Heide-Jorgensen and Harkonen 1988, Olesiuk et al. 1990a, Stewart et al. 1988, Stewart et al. 1992). Documented rates of population increase are relatively high, around 5-22% per year (Table 1). Most of the increases have occurred after bountied and indiscriminate killing and harvesting were outlawed. Degree of recovery is generally impossible to judge as pre-exploitation abundances are unknown. In a few other areas, however, populations have declined or fluctuated at low levels. In

some cases chronic pollution is believed to be responsible for reproductive failures and depressed populations of harbor and other seals (Helle et al. 1976, Reijnders 1978, Zakharov and Yablokov 1990). There has also been a persistent decline in the western Gulf of Alaska around Tugidak Island (Pitcher 1990), and perhaps in Prince William Sound. Causal factors may include 1) degradation of habitat (reduction of prey resources, natural environmental changes, virulent pathogens, etc.) or 2) substantial undocumented mortality associated with commercial fishing operations or native subsistence harvest.

In 1988 an epizootic killed over 18,000 seals, mostly harbor seals in European waters. In Swedish and Danish waters of the Kattegat and Skagerak more than 5300 harbor seals died; the population had previously numbered about 9100 and had increased from 1978-1988 at more than 12% per year (Dietz et al. 1989, Heide-Jorgensen and Harkonen 1988). An epizootic in the Soviet Union's Lake Baikal in 1987 killed several thousand Baikal seals (Grachev et al. 1989). Disease outbreaks in other species in the western Atlantic, Pacific, and Antarctic were less severe (Borst et al. 1986, Geraci et al. 1982, Hinshaw et al. 1984, Laws and Taylor 1957, Smith et al. 1974, Vedros et al. 1971), but there is no evidence of long-term demographic consequences in those areas. There are no published data on population responses following the 1987 and 1988 disease outbreaks. No long-term population effects of oil pollution on harbor seals or any other pinnipeds have been documented; documentation of chronic effects of oil pollution on individuals has been equivocal (Geraci and St. Aubin 1987, St. Aubin 1990).

B. Other pinnipeds

Throughout the world, populations of many pinniped species have been increasing at relatively high rates. Northern elephant seals (Mirounga angustirostris), for example, have been increasing at about 14% per year for nearly one hundred years (Stewart 1992). The duration of increases for other species varies according to the time at which commercial harvesting ended; pre-exploitation

abundance of any of those species is unknown. Following sustained population growth in the early 1900s, northern fur seals (Callorhinus ursinus) in the Bering Sea declined substantially, for unknown reasons, from the 1960s through the late 1980s. Northern sea lions have decreased steadily during the past two decades throughout the Aleutian Islands and western Gulf of Alaska, whereas their populations in the eastern Gulf of Alaska, Canada and Oregon and Washington have remained relatively stable or increased slightly. Southern elephant seals have also been declining in most areas of the Southern Ocean in recent years, following a period of recovery from commercial harvesting (Laws 1992).

Low reproductive success and high pup mortality among several species of pinnipeds in the Pacific in 1982 or 1983 coincided with the 1982/83 El Niño Southern Oscillation (ENSO; De Long and Antonelis, 1991; DeLong et al., 1991; Guerra C. and Portflitt K., 1991; Majluf, 1992; Stewart and Yochem, 1991; Trillmich and Dellinger, 1992). These results were evidently related to reduction, redistribution or disappearance of prey populations near rookeries. There is little evidence of substantial adult mortality nor in long-term demographic effects from that intense oceanographic disturbance, except perhaps at the Galapagos Islands.

3.1.2. Cetaceans

A. Killer Whales

Killer whales are widely distributed in the world's oceans (Dahlheim 1981). They occur in deep pelagic waters and in coastal areas, along ice edges, and in pack ice as well as in the tropics (Mitchell and Reeves 1988). Local movements and distribution appear to be largely dictated by distribution and availability of prey (Dahlheim 1981, Braham and Dahlheim 1982, Heimlich-Boran 1988). A partial list of prey items by geographic area was presented by Anon. (1982). Killer whales consume a variety of marine vertebrates and invertebrates, including fish, cephalopods and mammals. There are differences in food habits between sympatric populations in some areas: resident pods in

British Columbia and Washington consume mainly fish (especially salmon) whereas transients feed mostly on marine mammals, especially harbor seals (Heimlich-Boran 1988).

Using photo-identification, Olesiuk et al. (1990c) calculated a number of population parameters for killer whales off British Columbia and Washington. They reported an annual rate of increase of 2.92%; the percentage of mature females pregnant varied from 2.7-4.1%. Neonate mortality was 43%. The mean life expectancy was 50.2 years for females and 29.2 years for males, with predicted maximum life spans of 80-90 and 50-60 years, respectively. From computer simulations the authors predicted that the killer whales in this region could sustain a maximum non-selective harvest of 2.84%. They further predicted that a stationary population at carrying capacity would comprise 37% juveniles, 20% mature males, 14% reproductive females, and 29% post-reproductive females. Leatherwood et al. (1990) reported the following age structure among Prince William Sound killer whales: 22.41% adult males, 9.48% adult females (defined as females in close association with a calf), 3.9% calves, and 64.22% immatures and others (this group includes immature animals, adult females not associated with calves, and recently matured males that lack a prominent dorsal fin).

From 1962-1977, a total of 66 killer whales was removed from a few pods in British Columbia and Washington by a live-capture fishery to supply captive whales for oceanaria. Since then, the cropped pods have had higher birth rates (4.56%), lower mortality rates (bulls, 2.5%; cows 0.46%; juveniles, 1.99%) and have increased in number faster (pod growth rate = 3.01%) than uncropped pods (birth rate = 3.15%, pod growth rate = 1.67%) in the same areas (Bigg 1982, Balcomb et al. 1982).

Leatherwood et al. (1990) documented a minimum of 221 killer whales in Prince William sound in 1987 from photographs of their dorsal fins and color patterns. Those whales belonged to nine "resident" and eight "transient" pods, as defined by Bigg (1982). Recent DNA research has supported the hypothesis that these pods are genetically distinct (Hoelzel and Dover 1991). The

combined mortality rate for all ages and both sexes from 1984-86 was 1.9% in three pods, but 7.4% in another (AB pod). The latter pod has been interfering with the blackcod (Anoplopoma fimbrica) longline fishery since 1985 and bullet wounds have been observed on some of its members. Leatherwood et al. (1990) did not report an annual rate of population increase for killer whales but noted that 9 calves were born in 1986 and 1987. In British Columbia and Washington, where killer whales have been studied using the same techniques, annual rates of increase ranged from 1.67 to 3.01% (Balcomb et al. 1982, Bigg 1982, Olesiuk et al. 1990c) and annual mortality rates from 0.7% (adult females) to 2.81% (adult males).

Geraci and St. Aubin (1987) and Geraci (1990) reviewed the effects of oil on cetaceans and included a table of reports of cetaceans associated with oil. Only one incident involving killer whales was found, in which two whales (one sick, one dead) were observed in association with diesel fuel (quantity unknown) off the Alaskan peninsula.

Aside from occasional reports of mass die-offs or strandings (e.g., Oritsland and Christensen 1982, Christensen 1990), the most significant cause of killer whale morality has been commercial whaling. For example, Christensen (1982) reported that 2399 killer whales were killed in Norwegian coastal waters between 1938 and 1980. This represented a mean annual catch of 57 whales. Christensen (1982) noted, however, that the length (and therefore presumably the age structure) of the catch did not change during that period. Although no population growth rates are available, the percentage of pregnant females ranged from 12-32.8%, as determined by catch data (Anon. 1982). Similar percentages of pregnant females have been calculated from Antarctic catch data (12.72-18.97%). Off Marion Island in the southern Indian Ocean, 36.3% of adult females observed had calves (Condy et al. 1978), although some may not have been young-of-the-year.

B. Other cetaceans

Population growth rates and related parameters have been measured in other species that have

experienced significant human disturbance, usually in the form of harvesting (either as target species, right whales for example; or incidental catch, dolphins in the Eastern Tropical Pacific (ETP) for example).

The relatively low birth and death rates of killer whales are mirrored by another large odontocete, the sperm whale. Females produce a calf only every 3-6 years, and the natural mortality rate is less than 1% per year (Gosho et al. 1984). A decrease in calving interval (from 6 to 5.2 years) has been documented in an exploited population off Durban, South Africa (Best et al. 1984).

Reilly and Barlow (1986) estimated that dolphins could approach a population growth rate of 9%, but they thought that rate was unlikely to be attained under most conditions. Barlow (1985) reported the following differences among a more intensively fished dolphin population in the ETP: smaller percent pregnant, larger percent lactating, and larger percent immature than less-exploited dolphin populations in the ETP. The highest rates of annual population increase in baleen whales are reported for southern right whales and range from 7.6% (Payne et al. 1990) to 11.7% (population as a whole) or 13% (cow-calf pairs) (Bannister 1990) (Table 2). Gray whales have increased at annual rates of about 4% or greater since the early 1900s, despite a harvest rate of about 1.2% per year (Reilly et al. 1983) and Bowhead whales, which also are harvested for subsistence purposes, increased at an annual rate of around 3% from 1978 through 1988 (Zeh et al. 1991). Moderate rates of increase for other whales were summarized by Best (1990). Reproductive rates have been reported for humpback whales; the mean calving rate (calves per mature female per year) is about 0.4 (Perry et al. 1990, Clapham and Mayo 1990). The mean calving interval for gray whales is 2.11 years and the birth rate (ratio of calves to adults) is about 0.14 (Reilly 1984).

3.2. Dependency of recovery on habitat protection, changes in management practices, and other restoration approaches.

In virtually all cases, recent population recoveries of pinnipeds and cetaceans has been

due to the termination of commercial harvesting or indiscriminate or incidental killing. Many species were reduced to very low levels during the harvesting periods and several were believed to have been exterminated. Presumably, foraging and breeding habitats were not degraded by the harvesting. The presence of abundant prey resources and good quality breeding habitat are probably the most important factors that allow sustained population growth, as soon as commercial exploitation ceases.

Quick resumption of population growth of eastern North Pacific pinnipeds (i.e., California sea lions, northern elephant seals, harbor seals) following the 1982/83 ENSO was evidently due to rapid recovery of prey resources; i.e., the degradation of habitat and reduction of carrying capacity was short-lived (Stewart, 1992; Stewart et al. 1992; Stewart and Yochem, unpubl; R. L. DeLong, pers. comm.). A consensus of recent literature on population modelling is the recognition that rapid and large population changes can occur with only moderate increases in adult mortality; population growth is less sensitive to changes in juvenile survival. Thus, if adult mortality is high during, after, or both, a population reduction (e.g., because of subsistence harvests or undocumented killing), the recovery may delayed or a continued decline may also occur. Changes in harbor seal management practices (i.e., documenting all subsistence takes with respect to age and sex composition of harvest in and near the EVOS area, reducing and strictly regulating subsistence harvests) would probably be the most effective means of stimulating rapid population recovery.

3.3. Indicators of recovery that are the most practical and cost effective to measure

There are few data available on the pre-EVOS status of killer whales and harbor seals in the affected EVOS area. For harbor seals, relative abundance and distribution and relative annual production of young would be indicators that could be directly compared with early post-spill data and with similar data from comprehensive data bases from other regions. However, collection of data on haulout patterns, movements, and diet would be useful for determining whether changes in local abundance of seals might be due to lowered reproduction among resident seals or simply to

movements of surviving seals to more favorable breeding or foraging habitats or to changes in haulout patterns related to dietary shifts.

Photo-identification studies (perhaps in combination with VHF or satellite telemetry) of killer whales should be continued to document relative pod sizes and composition, home range (of residents) and large-scale movements (of residents and transients), and reproductive rates. Those studies should be made over a broader area in Prince William Sound and during more seasons than previous studies. Monitoring in alternate years or every three years would probably be most efficient as the studies should be continued for 15 years or more to provide any useful information on population trends.

Bigg (1982) and Balcomb et al. (1982) measured birth rates, mortality rates and net population change in cropped versus uncropped pods with relatively good success.

3.4. Approaches and strategies for determining how indicators of recovery are best monitored and tested to determine when recovery has occurred

First, "recovery" must be defined for killer whales and harbor seals because there are few or no pre-EVOS data to compare with post-EVOS data. One guideline for evaluating "recovery" might be whether or not animals have regained the ability to maintain self-replicating or growing populations. To determine whether or not and when these abilities have been regained would require long-term studies of abundance coupled with an assessment of seasonal movements of animals in and out of the area and of the magnitude of immigration and emigration. The case of harbor seals in Prince William Sound is further complicated by a probable declining trend prior to the EVOS (cf. Pitcher 1990). To evaluate the health or demographic trends of local Prince William Sound populations of these species, a combination of approaches would be most productive and should be conducted every two or three years. Combinations of satellite and VHF telemetry, aerial and boat surveys, ground observations, dietary studies (for harbor seals) and photo-identification studies (for killer whales) should be used but should be planned carefully to give statistically valid results and to

avoid the possibility of the studies themselves (i.e., disturbance) complicating interpretations of movements, reproduction and trends in abundance.

These studies need to be integrated with research by other groups on benthic, epibenthic, and mid-water column fish and invertebrate communities to determine the effects of their recoveries on local killer whale and harbor seal distribution.

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6.0. Tables

Table 1. A summary of growth rates expressed as percent increase per annum in various pinniped populations.

SPECIES	AREA	RATE	PERIOD	NOTES	SOURCE
Phoca vitulina richardsi	Alaskan peninsula	-3.5	1976-85	E	1
"	Tugidak I.	-19.0	1976-79	E	2
"	"	-7.0	1982-88	E	2
"	British Columbia	12.5	1973-88	E	3
"	Oregon	8.1	1975-83	E, I, D	4
"	Gulf of Farallones, Double Pt.	7.6	1976-87	E, I	5
"	Gulf of Farallones, S. Farallon I.	17.0	1974-86	E, I	5
"	San Miguel I.	22.0	1958-76	E, I	6
"	"	5.0	1976-86	E, I	6
Phoca vitulina concolor	Massachusetts	11.9	1972-83	E, D	7
"	Kattegat-Skagerrak	12.0	1979-86	E	8
Callorhinus ursinus	Pribilof Is.	8.0	1911-24	E	9
"	"	0.0	1950-55	E	10

"	"	-6.0	1955-65	E	10
"	"	0.0	1965-75	E	10
"	"	-7.8	1975-81	E	10
"	"	-1.8	1981-86	E	10
"	Commander I.	0.0	1974-82	E	10
"	Robben I.	-5.8	1974-82	E	10
"	Bogoslof I.	57.0	1980-88	E	11
Eumetopias jubatus	Alaska	-2.7	1956-86	E	12
Arctocephalus tropicalis	Gough I.	15.9	1955-77	E	13
"	Marion I.	10.5	1951-74	E, I	14
"	"	12.9	1974-89	E, I	15
"	"	15.0	1974-81	E, I	16
"	Amsterdam I.	11.0	1956-81	E	14
"	"	7.8	1955-69	E	17
"	"	16.5	1969-81	E	14
"	Prince Edward I.	9.7	1982-87	E, I	15

Arctocephalus gazella	Heard I.	20.7	1962-88	I	18
"	Bird I.	13.1	1958-75	E	19
"	Marion Is.	15.1	1974-81	E	16
"	Prince Edward Is.	11.3	1981-89	E, I	15
Arctocephalus pusillus pusillus	Southern Africa, mainland colonies	7.5	1971-83	E	20
"	Southern Africa, island colonies	-3.5	1971-83	E	20
"	Southern Africa	5.8	1971-80	E	21
Arctocephalus australis	All stocks	11.0	1953-72	E	22
Arctocephalus townsendi	Isla de Guadalupe	7.5	1954-77	E	23
Mirounga angustirostris	San Miguel I.	13.6	1964-81	E, I	24
"	San Nicolas I.	16.5	1959-81	E, I	24
"	Año Nuevo	15.8	1968-80	E, I	24
"	Farallon I.	53.3	1974-80	E, I	24
"	Isla de Guadalupe	5.4	1965-77	E	24
"	Islas San Benito	5.9	1965-77	E	24

SPECIES	AREA	RATE	PERIOD	NOTES	SOURCE
Mirounga leonina	South Georgia	0.0	1951-85	E	25
"	Patagonia	5.1	1975-82	E	25
"	"	3.2	1982-90	E	25
"	Iles Kerguelen	-4.6	1970-77	E	25
"	Heard I.	-2.4	1949-85	E	25
"	Marion I.	-4.8	1974-83	E	25
"	"	-1.9	1983-89	E	25
"	Macquarie I.	-2.1	1949-85	E	25
Zalophus californianus	California	8.7	1927-46	E	23
"	"	6.7	1947-70	E	23
"	San Miguel I.	5.0	1971-81	E	26
Halichoerus grypus	United Kingdom	7.0	Early 1960s-late 1970s	E	27

NOTES: D = Relaxation from disturbance; E = Exploited population; I = Immigration

SOURCE: 1 = Pitcher 1986, cited in Hoover 1988; 2 = Pitcher 1990; 3 = Olesiuk et al. 1990; 4 = Harvey et al. 1990; 5 = Allen et al. 1989; 6 = Stewart et al. 1988; 7 = Payne and Schneider 1984; 8 = Heide-Jorgensen and Harkonen 1988; 9 = Lander 1981; 10 = York 1987; 11 = Loughlin and Miller 1989;

Table 1, continued

12 = Merrick et al. 1987; 13 = Bester 1980; 14 = Condy 1978; 15 = Wilkinson and Bester 1990; 16 = Kerley 1983; 17 = Hes and Rouse 1983; 18 = Shaughnessy and Goldsworthy 1990; 19 = York 1987, after Payne 1977; 20 = Butterworth et al. 1987; 21 = Shaughnessy and Butterworth 1981, cited in York 1987; 22 = Vaz-Ferreira 1982, cited in York 1987; 23 = Chapman 1981; 24 = Cooper and Stewart 1983; 25 = Laws In Press; 26 = DeMaster et al. 1982; 27 = Harwood 1981

Table 2. A summary of growth rates expressed as percent increase per annum in various cetacean populations.

SPECIES	AREA	RATE	PERIOD	NOTES	SOURCE
Balaenoptera musculus	Iceland	4.8	1969-88	E	1
"	"	5.2	1979-90	E	2
Megaptera noveangliae	Iceland	11.5	1970-88	E	1
"	"	13.8	1979-88	E	1
"	"	14.8	1979-90	E	2
"	Western Australia	4.8	1963-88	E	1
"	Eastern Australia	10.0	1983-87	E	1
"	NW Atlantic	9.4	1979-86	E	1
Eubalaena glacialis	Argentina	7.6	1974-86	E	1
"	Western Australia	11.7	1977-87	E	3
"	South Africa	6.8	1971-87	E	1
Balaena mysticetus	Bering/Beaufort/ Chuckchi Seas	3.1	1978-88	E	4
"	Bering/Chukchi Seas	3.0-4.5	1978-89	E	1

SPECIES	AREA	RATE	PERIOD	NOTES	SOURCE
Balaenoptera musculus	Iceland	4.8	1969-88	E	1
"	"	5.2	1979-90	E	2
Megaptera noveangliae	Iceland	11.5	1970-88	E	1
"	"	13.8	1979-88	E	1
"	"	14.8	1979-90	E	2
Eschrichtius robustus	California stock	2.5	1967-80	E	5
Orcinus orca	British Columbia	3.01	1973-81	E	6
"	"	1.67	1973-81	U	6
"	Puget Sound	2.3	1973-81	E	7

NOTES: E = Exploited population; U = Unexploited population

SOURCE: 1 = Best 1990; 2 = Sigurjonsson and Gunnlaugsson 1990; 3 = Bannister 1990; 4 = Zeh et al. 1991; 5 = Reilly 1984; 6 = Bigg 1982; 7 = Balcomb et al. 1982.

7.0. Appendix 1.

Annotated bibliography of the literature on recovery of ecosystems following man-induced and natural-phenomena-related disturbances: Harbor seals and killer whales.

Zakharov, V. M.; Yablokov, A. V. (1990)

Skull asymmetry in the Baltic Grey Seal: effects of environmental pollution

Ambio. 19. 266-269

ABSTRACT
The most dramatic increase in DDT and PCB levels in the Baltic occurred after 1955. The present study investigates whether morphological changes resulting from the disturbance in developmental stability can be found in the grey-seal populations born during the most significant period of pollution that occurred after 1960. Skull characteristics were examined in animals born before 1940 (pre-pollution group) and in animals born after 1960 (pollution group). It was shown that the pollution group had sharply increased levels of asymmetry in almost every character analyzed. The findings suggest a dramatic change in the developmental stability of the Baltic grey seal during the period of heavy pollution after 1960.

Zeh, J. E.; George, J. C.; Raftery, A. E.; Carroll, G. M. (1991)

Rate of increase, 1978-1988, of bowhead whales, Balaena mysticetus, estimated from ice-based census data

Mar. Mamm. Sci. 7 (2). 105-122.

ABSTRACT
The number of bowhead whales, Balaena mysticetus, passing within viewing range of the ice-based census at Point Barrow, Alaska, during spring migrations from 1978 to 1988 is estimated from the visual census data. The trend in the annual numbers yields an estimated rate of increase of 3.1% per year with a 95% confidence interval ranging from 0.1% to 6.2% for the Bering-Chukchi-Beaufort Seas bowhead stock during theis period. Alternative treatments of the data suggest less precise or somewhat lower estimates, but all results indicate that the stock was increasing.

York, A. E.; Hartley, J. R. (1981)

Pup production following harvest of female northern fur seals

Can. J. Fish. Aquat. Sci 38. 84-90.

ABSTRACT
Female northern fur seals (Callorhinus ursinus) were harvested commercially from 1956 to 1968 and pelagic collections were taken for research purposes from 1958 to 1974. Early survival rates (birth to age 2) for males increased from an average of 0.32 before the harvest to 0.38 afterwards. Numbers of female pups whose births were precluded by the harvest are estimated for the years 1956-79; these account for about 70% of the difference between the numbers of pups actually born and the level of pup births before 1956. Estimates of the increased numbers of pups due to the increase in the early survival rates are presented for the years 1958-74.

York, A. E. (1987)

On comparing the population dynamics of fur seals

NOAA Tech. Rep. NMFS 51. 133-140.

ABSTRACT
A relatively simple age-structured model applicabel to most species of fur seals was constructed. Using the model and available data on vital parameters and observed rates of increase or decrease of the various populations of fur seals, I investigated the interrelationships among the vital parameters and their effect on the rate on increase of the population. There are some similarities among the populations: (1) all must have high adult survivorship, i.e., greater than 85% per year; (2) changes in age at first reproduction alone do not greatly afrect the rate of increase of the population; and (3) small changes (not statistically detectable without very large sample sizes) in any combination of vital parameters can significantly change the reate of increase of the population. There are also two important dissimilarities: (1) the observed rates of population increase for the southern species (as high as 15-16% per year) are much higher than the maximum rate of increase observed for the Pribilof Island population of northern fur seals (8% per year); and (2) many of the southern populations of fur seals are increasing, whereas most of the populations ofnorthern fur seals have dereased recently or have remained stable. The first suggests that scientists must be circumspect in applying vital paramenters estimated for Callorhinus to Arctocephalus; the second implies that comparisons of population dynamics must take into account the environmental differences which affect the vital parameters. The model also allows one to estimate adult survival if the growth rate and the average age of the breeding females are known.

flipper-tags only. The proportion of days seals hauled out varied by time of day, period, and year. The largest proportion was ashore in early afternoon; some seals tended to haul out during daylight hours (0600-1800) and some at night (1800-0600). In 1982, individuals hauled out most often (i.e., the largest proportion of days) during the early molt period; the proportion of radio-tagged seals hauled out per day was also greatest during this period. The proportion of seals hauled out declined during late molt and post-molt periods. Thus, changing haul-out patterns are at least partially responsible for the observed seasonal changes in the number of seals hauled out (number ashore is highest in late spring, lowest in winter). Haul-out patterns in 1983 differed from those in 1982, which may have been due to the different age- and sex- class composition of the two samples. Alternatively, haul-out patterns in 1983 may have reflected a change in harbor seal feeding behavior in response to the effects of the 1982-1983 El Niño-Southern Oscillation event on prey abundance and availability. Factors such as parturition and molt also affected haul-out behavior. Adult females ashore outnumbered adult males during the reproductive period, perhaps because females needed to spend more time on land suckling their pups and resting. Seals also hauled out more often during the molt. The annual peak in the number of seals ashore which occurs during the early molt period is apparently caused by a temporary overlap of molting males and females; the sex ratio ashore is 1:1 during this period. Females molt earlier than males, however, and by the late molt period adult males ashore outnumbered adult females. Seals exhibited a high degree of site fidelity. No individual used more than four of the harbor seal haul-out sites at either island; seals that used more than one site had primary or "preferred" sites and were usually seen there. Primary sites were consistent between years during the molt period, when mating occurs, suggesting that mating is not random.

Yochem, P. K.; Stewart, B. S.; Mina, M.; Zorin, A.; Sadovov, V.; Yablokov, A. (1990)

Non-metrical analyses of pelage patterns in demographic studies of harbor seals

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 87-90

International Whaling Commission, Cambridge

ABSTRACT
Phenotypic variation in pelage patterns of North Pacific harbor seals has been observed and described by several researchers. We developed a classification scheme of non-metrical pelage characters (e.g., presence or absence of spots in various body areas) and tested intra- and inter-oberver variability in scoring black-and-white photographs of harbor and largha seals. Observer agreement was good overall, but some observers disagreed when scoring the more subjective characters (e.g., spot density). We also compared pelage patterns of harbor seals from San Miguel, Santa Rosa and San Nicolas islands and found inter-island differences in two characters.

the state of populations. Known forms of histopathology were added up by discovered changed patterns of seal spermatogenesis. During the last years as a result of efforts undertaken by different countries to limit pollutants waste the situation with pollution of the Baltic Seas was somewhat improved. However, the state of seal populations, as the last link of food chains, still causes grave worries. The following fact alone shows the gravity of the situation: at present the number of seals in all the Baltic Sea is similar to that in the Ladoga Lake alone. Investigations carried out under this project are only a part of national and international efforts of scientists aimed at investigations and improvement of the situations in the Baltic Sea, restorations of its seal population. In this respect experiments of the Swedish scientists on seal reproduction in captivity are of great interest (results of these studies are also here presented). The present book sums up only the first stage of cooperation between Soviet and Swedish scientists in the studies of Baltic seals. This cooperation must get more fundamental and extensive.

Yochem, P. K.; Stewart, B. S.; DeLong, R. L.; DeMaster, D. P. (1987)

Diel haul-out patterns and site fidelity of harbor seals (Phoca vitulina richardsi) on San Miguel Island, California in autumn

Mar. Mamm. Sci. 3. 323-332.

ABSTRACT
We studied the haul-out patterns and movements of harbor seals (Phoca vitulina richardsi) on San Miguel Island, California, from 23 October through 6 December 1982 by attaching a radio transmitter to each of 18 seals and monitoring their presence ashore with continuously scanning receivers. Seals hauled out at all hours although, on average, the largest proportion of tagged seals was ashore between 1300 and 1500 h. Median durations of haul-out bouts of individual seals ranged from 4.7 to 21.8 h; 81% of all haul-out bouts were less than 12 h and 3% were longer than 24 h. Eighty-one percent of the seals that were resighted at least twice used only the sites where they were tagged; two seals used two sites and one seal used three. Most seals were hauled out on fewer than 51% of the days sampled. On average, about 41% of tagged seals hauled out each day whereas an average of about 19% was hauled out during peak afternoon hours. Using telemetry data to correct a count of 412 seals made during an aerial survey, we estimated absolute abundance at about 2,168 seals; a modified Peterson mark-recapture model produced an estimate of about 1445 seals.

Yochem, P. K. (1987)

Haul-out patterns and site fidelity of harbor seals at San Nicolas and San Miguel Islands, California

Master of Science Thesis, San Diego State University, San Diego, CA

ABSTRACT
I used radiotelemetric and observational data to study haul-out behavior and site fidelity of harbor seals at San Nicolas and San Miguel islands, California, from 1982 through 1984. Thirty-seven harbor seals were radio-tagged and flippers-tagged and an additional 36 were marked with

widely may contact some oil as they move quickly through a fouled area, but are less likely to suffer long-term exposure.After a spill, oil is distributed primarily at the surface and on the seabed. Consequently, cetaceans that feed in these areas are more likely to contact oil than those that feed in the water column. These include skim-feeding right and bowhead whales, surface-lunging rorquals, and bottom-feeding gray whales- in other words, all mysticetes, except possibly the minke whale. Harbor porpoises and some dolphins may contact oil when they feed on flatfish and other bottom-dwelling prey. Dolphins that habitually force schools of prey to the surface may also be at risk. \As a group, baleen whales appear to be the most vulnerable in view of their generally low numbers, their peculiar feeding strategies, and their dependence on selected, localized habitats for feeding and reproduction. Among the odontocetes in North American waters, restrictive habitat increases the risk of exposure for belugas, narwhals, harbor porpoises, and bottlenose dolphins. Most other odontocetes are too mobile and wide-ranging for oil to present much of a threat.

Yablokov, A. V.; Olson (Editors), M. (1989)

Influence of human activities on the Baltic ecosystem

Gidrometeoizdat, Leningrad

ABSTRACT
Present volume is a result of studies of a group of Soviet and Swedish researchers united under the project "Research of toxicant influence on the dynamics of seal populations" of Soviet-Swedish cooperation in the field of environment protection sponsored by the USSR State Committee of Hydrometeorology and Swedish National Environment Protection Board. The volume contains studies presented at the Soviet-Swedish Symposium held in Moscow in 1986.

Cooperation between Soviet and Swedish scientists on the problems relating to seals started in 1982 on the initiative of the Swedish side who had obtained alarming data concerning an abrupt decrease of the number of grey and ringed seals as a result of the accumulation of polychlorbiphenyls in the seal organism. The Swedish side was represented by researchers from the Department of Vertebrate Zoology, Swedish National Museum of Natural History (Stockholm); Department of Pathology, Faculty of Veterinary Medicine, Swedish University of Agricultural Sciences (Uppsala) and Special Analytical Laboratory, Swedish National Environment Protection Board (Solna). The Soviet side involved researches from N.K. Koltzov Institute of Developmental Biology, USSR Ac. Sci. (Moscow); Institute of Experimental Meteorology (Obninsk); Institute of Applied Geophysics, USSR State Committee of Hydrometeorology (Moscow); Atlant NIRO (Kaliningrad); Institute of Biology, Ac. Sci. Latv. SSR (Salaspils) and Lymnological Institute, USSR, Ac. Sci. (Irkutsk). Joint work was related to three major aspects of the problem: 1) study of distribution and numbers of the Baltic seal; their nutrition and ecology; 2) investigation of pathological changes in the seal organisms; 3) chemical analysis of seal tissue samples for the content of pollutants. These three aspects are elucidated in the present volume. Summing up the studies carried out it should be said that important comparative evidence was obtained as to the content of pollutants in the Baltic, Ladoga and Baykal seals. It turned possible to discover earlier unknown and extremely alarming evidence related to the damage of skin and some skeleton elements (probably, as a result of disturbances of the organism hormonal balance). It was shown for the first time for Pinnipedia that the analysis of asymmetry of morphological structures could be used for estimating alterations in

populations, but not in field populations. Ecologists have treated changes more complex than a return to a simple equilibrium, such as the cyclical changes in populations of lynx and voles in the arctic, as special cases. Highly variable populations, such as insects, are usually thought to be driven by unpredictable changes in the weather. Here, we assemble 71 populations counted for over 50 years, and suggest that complex yet predictable population changes are more common than previously thought.

Woodley, T. H.; Read, A. J. (1991)

Potential rates of increase of a harbour porpoise (Phocoena phocoena) population subjected to incidental mortality in commercial fisheries

Can. J. Fish. Aquat. Sci 48. 2429-2435.

ABSTRACT
We estimated the potential intrinsic rate of increase (r) of the harbour porpoise (Phocoena phocoena) population in the Bay of Fundy and Gulf of Maine using empirical data on reproductive rates and several hypothetical survival schedules. Schedules of survival to maximum ages of 12 and 15 yr, were calculated from two potential natural mortality schedules combined with several schedules of incidental mortality estimates. The most realistic results were obtained when natural mortality of non-calves were calculated from Caughley's (1966. Ecology 47:906-918) smoothed age-frequency equatin for Himalayan thar (Hemitragus jemlahicus) and applied in conjunction with a range of calf natural mortality estimates. This model indicates that harbour porpoises have a limited capacity for population increase, and populations are unlikely to sustain even moderate levels of incidental mortality (4% of the population per year). Extending the maximum age used in the models from 12 to 15 yr does little to increase estimatges of r for the harbour porpoise population, and hence their susceptibility to incidental mortality.

Wursig, B. (1990)

Cetaceans and Oil: Ecologic Perspectives

In: Sea Mammals and Oil: Confronting the Risks

Geraci, J. R.; St. Aubin, D. J., eds. Pages 129-165

Academic Press, New York

ABSTRACT
Many aspects of behavior, diet, and habitat use may lead cetaceans into contact with spilled oil. Given the host of interacting variables, it is difficult to state precisely which species or individuals might be most vulnerable. However, several assumptions can be made.

Encounters with oil are likely to be prolonged in species that frequent restricted areas such as bays and estuaries. Examples are breeding and feeding humpback, gray, right, bowhead, and beluga whales, narwhals, bottlenose dolphins, harbor porpoises, and river dolphins. Cetaceans that range

Wilkinson, I. S.; Bester, M. N. (1988)

Is onshore human activity a factor in the decline of the southern elephant seal?

S. Afr. J. Antarct. Res. 18 (1). 14-17.

ABSTRACT
Comparison of areas of high and low human activity on Marion Island shows no difference in rates of decline of elephant seal numbers. Spatial distribution of births also shows no change in the period 1976 - 1986, suggesting that no shift in breeding population distribution has occurred in the period as a results of the level of human activity on Marion Island. Furthermore, comparisons of Marion Island with other breeding sites of elephant seals, where human activity is lower, show no signigicant differences in the rates of decline of the species. Direct onshore human disturbance is therefore rejected as a significant factor in the decline of the species.

Wilkinson, I. S.; Bester, M. N. (1990)

Continued population increase in fur seal, Arctocephalus tropicalis, and A. gazella, at the Prince Edward Islands

S. Afr. J. Antarct. Res. 20 (2). 58-83.

ABSTRACT
Population estimates of fur seals were obtained at the Prince Edward Islands during the 1987/88 and 1988/89 austral summers. The populations of Arctocephalus tropicalis at Marion Island and Prince Edward Island are increasing at a rate of 12.9% and 9.7% respectively. The Marion Island population is still in the recolonisation phase of rapid growth while the Prince Edward Island population is either still in the slow establishment phase or approaching maturity. The lack of previous data for Prince Edward Island prevents a comparison of growth rates. An apparent slowing of the rate of population growth in A. gazella at Marion Island ins conceivably the result of undercounts in 1974, giving an overestimate of growth between 1974 and 1981. As a result of this undercount the importance of immigration to A. gazella numbers at Marion Island may have been overemphasized previously. The apparent failure of the A. gazella population to move past the slow establishment phase may be a result of the absence of krill (Euphausia superba) in the vicinity of the Prince Edward Islands. Hybridization between the species is continuing.

Witteman, G. J.; Redfearn, A.; Pimm, S. L. (1990)

The extent of complex population changes in nature

Evol. Ecol. 4. 173-183.

ABSTRACT
Many models of animal populations show complete yet predictable patterns of density changes under simple and plausible assumptions. Yet one previous attempt to determine the extent and importance of complete dynamics concluded that they were likely only in some laboratory

Wells, R. S.; Scott, M. D. (1990)

Estimating bottlenose dolphin population parameters from individual identification and capture-release techniques

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 407-415

International Whaling Commission, Cambridge

ABSTRACT
Field studies begun in 1970 and continuing to date have identified at least three adjacent resident populations (or communities) of bottlenose dolphins along the central west coast of Florida. We have used photo-identification, mark-recapture techniques, behavioral observations, radio-tracking and brief captures for biological sampling to examine the structure and dynamics of these populations. Population designations are based on consideration of individual home ranges, social association patterns and genetics. Although the populations are relatively discrete in terms of ranges and associations, electrophoretic analyses of blood samples indicate that genetic exchange occurs between populations. Males travelling between populations appear to be the probable vectors for genetic exchange.

Most field effort has concentrated on the Sarasota dolphin population. Most of its members are identifiable from natural marks or tagging efforts over the last 20 years. This population consists of about 100 individuals. For the analyses presented here, we considered 116 dolphins identified during 1980-87. Of these, the sex was known for 90 dolphins and the age has been estimated for 79 dolphins. The long time span of the study and the high proportion of identifiable individuals has allowed us to estimate vital rates for this population. An annual recruitment rate to age 1 of 0.048 was countered by a minimum mortality rate of 0.910 and a mean annual loss rate from other causes of 0.029 (e.g., emigrations, mortalities for which carcasses were not recovered or undocumented changes in identifying characteristics). Immigration was infrequent, with a mean annual rate about 0.02. The mean fecundity rate was 0.144. Knowledge of maternal relationships allowed comparisons of the percentage of calves observed in the field vs the percentage of young of the year. Because of the prolonged period of association between mothers and calves, there were nearly six times as many mother-calf pairs as mothers with young of the year. To test the effectiveness of photo-identification techniques, we compared the number of correct identifications made in the field 'by eye' against the number identified from photographs. We identified 89% of these well-marked dolphins correctly by eye. Because virtually all the dolphins were marked in the most-heavily surveyed portion of the study area, it was also possible to test the accuracy and precision of mark-recapture methods. Both the Petersen and Schnabel methods underestimated the known population size, although the Schnabel estimate was less biased. This bias was likely due to heterogeneity of sighting probabilities; different age-sex classes were shown to have different sighting probabilities.

Weigle, B. (1990)

Abundance, distribution and movements of bottlenose dolphins (Tursiops truncatus) in lower Tampa Bay, Florida

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 195-201

Internation Whaling Commission, Cambridge

ABSTRACT
Boat surveys of bottlenose dolphins (Tursiops truncatus) inhabiting lower Tampa Bay, Florida, were conducted between April and October in 1983 and 1984. Objectives included: (1) examining the abundance and distribution of dolphins over 230km^2 in southern Tampa Bay and the adjacent Gulf of Mexico; (2) identifying individual animals using photographs of scars and other natural markings on the dorsal fin; and (3) characterizing the range of movement and interactions among recognizable dolphins.

A total of 70 surveys were carried out using a 5m or 12m vessel. School size and number of calves was evaluated, behavior recorded and individuals photographed. Photographs were classified based on location of fin notches and cataloged. Mean monthly dolphin school size was lowest in April (2.8) and highest in September (6.1). The largest schools were observed around the mouth of Tampa Bay where it joins the Gulf of Mexico. Zones with highest density were also around the Bay mouth. Mean density (dolphins/km^2) was highest from July (0.38) through September (0.36). Calves constituted 9.7% of all dolphins observed. Dolphins with distinct, naturally marked fins were recognizable in 142 of 319 schools; 246 animals were cataloged with 75 being sighted two to seven times. Thirty seven dolphins photographed three or more times were classified into three herds based on location of the sightings; a Tampa Bay herd, a Pinellas herd, and a Sarasota Bay herd. Members of the Tampa Bay herd were observed on both sides of the Bay and interacted with members of the Sarasota Bay and Pinellas herds. The large number of recognizable animals sighted only once (171) suggests that transient dolphins, perhaps nearshore or offshore animals, use lower Tampa Bay for foraging in the summer months, probably following schools of mullet inshore. An apparently open population of dolphins used the study area, creating a high potential for genetic mixing. Dolphin ranges within the study area were calculated to be up to 166km^2 and may represent only a portion of the total home range of the animals studied.

Waters, S.; Whitehead, H. (1990)

Population and growth paramenters of Galápagos sperm whales estimated from length distributions

Rep. int. Whal. Commn 40. 225-235.

ABSTRACT
The length distributions of female and immature sperm whales, Physeter macrocephalus, off the Galápagos Islands were studied using data collected between February-April 1985 and January-June 1987. Sperm whales were measured using a photographic technique. There were few small whales and most animals were between 8.6-10.2m. A simple population model estimated population and growth parameters for female and immature sperm whales off the Galápagos by comparing the Galápagos length distribution with that expected given certain population and growth parameters. The derived parameters were not always consistent with those currently accepted. The Galápagos data were most consistent with a significantly reduced pregnancy rate (2-4% of mature females per year) and smaller lenghts of females at physical maturity (10.2m), and suggested a low mean mortality of mature females if the population is near equilibrium.

Watkins, W. A. (1986)

Whale reactions to human activities in Cape Cod waters

Mar. Mamm. Sci. 2 (4). 251-262.

ABSTRACT
A review of whale observations of more than 25 years indicated that each of the species commonly observed within 35 km of Cape Cod reacted differently to stimuli from human activities, and that these responses have gradually changed with time. These reactions appeared to result mostly from three types of stimuli: primarily underwater sound, then light reflectivity, and tactile sensation. The whale reactions were related to their assessment of the stimuli as attractive, uninteresting or disturbing, their assessment of the movements of the sources of the stimuli as expected or unexpected. Whale reactions were modified by their previous experience and current activity: habituation often occurred rapidly, attention to other stimuli or preoccupation with other activities sometimes overcame their interest or wariness of stimuli, and inactivity seemed to allow whales to notice and react to stimuli that otherwise might have been ignored. The changes over time in the reactions of whales to stimuli from human activities were gradual and constantly varying with increased exposure to these activities.

sprat and small herring, while faecal analyses showed that >90% of common seal prey (by weight) were clupeoid fish. During the day, clupeoids concentrated in trenches and holes more than 12 m deep. Radio-tagged seals were located regularly over these areas. At night, clupeoid shoals rose in the water column and became more dispersed. Diel changes in seal activity patterns suggest that seals fed more often during the day. Prey sizes were estimated from the size of otoliths retrieved from seal faeces. Estimated sizes of clupeiods taken by seals were similar to the sizes of fish caught in trawls, even though estimates were not corrected to allow for partial digestion of otoliths. This suggests that the rapid otolith digestion rates previously reported from captive seals may have been artificially high, or that the Moray Firth seals selected fish larger than those caught in trawls.

Trillmich, F.; Limberger, D. (1985)

Drastic effects of El Niño on Galapagos pinnipeds

Oecol. 67. 19-22.

ABSTRACT
Population dynamics of pinnipeds living in the tropical upwelling ecosystem of the Galapagos were strongly influenced by the 1982-83 Southern Oscillation-El Niño (EN) event which was the strongest recorded in this century. The Galapagos fur seal (Arctocephalus galapagoensis) population lost the four youngest year classes (1980-1983) almost entirely and approximately 30% of the adult females and non-territorial males. Mortality of large territorial males was almost 100%. Most of the 1982 year class of Galapagos sea lions (Zalophus californianus wollebaeki) died and there was a much lower pup production in the breeding season following EN. Recurrent EN events must strongly influence age structure and average population size of these and other otariid species depending on tropical upwelling ecosystems.

Tsukagoshi, T. (1983)

Some peculiar phenomenons on killer whale, Orcinus orca.

Bull. Jap. Soc. Fish. Oceanogr. 44. 127-131.

ABSTRACT
LANGUAGE: Japanese. The author describes his experience of sighting killer whales (Orcinus orca), with [sic] happened only 3 times during his 30 years seafaring life. First he saw a single one attacking a sperm whale 200 miles south off the Shionomisaki Cape in April, 1953. The second time was in July, 1959, at 157-30E, 32-30W. The last time was in April, 1974, 20 miles south off Bali Island in Indonesia. On the second and third occasions a good amount of tuna and bonito were caught. He concludes that killer whales feed on tuna and donito in warm areas.

their haul-out behaviour at the beginning of moult. At this time, they hauled-out every day and, consequently, male behaviour became more synchronous. The change in behaviour of the male followed in 1985 was closely related to changes in abundance at the haul-out site that he used over this period. In contrast, females showed no sign of a similar change in behaviour at the beginning of moult, but appeared to spend more of their time at sea after lactation. During the winter, seals appeared to spend more time in offshore waters, although they regularly returned to the inshore study area to haul-out. At this time of year there was no marked diurnal haul-out pattern. There was a high degree of individual variation in the effect of the tidal cycle on activity patterns, wich appeared to be related to tide-related changes in food and habitat availability. Overall, however, the tidal cycle had less effect on haul-out behaviour in summer, when strong circadian patterns were more important. The variations in activity patterns found in this study are discussed in relation to seasonal changes in feeding activity and the demands of breeding and moult.

Thompson, P. M.; Harwood, J. (1990)

Methods for estimating the population size of common seals, Phoca vitulina

J. Appl. Ecol. 27. 924-938.

ABSTRACT
This study evaluates the use of two different survey techniques for providing an estimate of the size of the common seal population in Orkney, U.K. In August 1985, an aerial survey was made over the coast of Orkney during the seals' moult. These results were compared with those from a series of boat surveys made over a asample of this area during the pupping season, in June and July. Over twice as many seals were found hauled-out on the survey made during the moult, and it is recommended that future estimates of population size should be based on surveys made at this time of year. Time-lapse photography was used to look at changes in the number of common seals hauled-out in relation to the tidal cycle and the time of day. These data, together with data collected on the activity patterns of radio-tagged individuals, were used to provide correction factors to compensate for seals which were in the water at the time of the survey. The application of these correction factors to the survey total of 6616 produced a provisional estimate 9331 (95% C.L.s 8147-10515) for the size of the Orkney common seal population. This estimate is discussed in relation to previous estimates of the size of both the Orkney and the total British common seal populations.

Thompson, P. M.; Pierce, G. J.; Hislop, J. R. G.; Miller, D.; Diack, J. S. W. (1991)

Winter foraging by common seals (Phoca vitulina) in relation to food availability in the inner Moray Firth, N.E. Scotland

J. Anim. Ecol. 60. 283-294.

ABSTRACT
Parallel studies of fish distribution and the diet and activity of common seals were made to assess the relationship between the seals' winter feeding activity and the distribution and abundance of their prey. Echosounder and trawling surveys revealed that a large part of the fish biomass was

Thompson, P. M.; Rothery, P. (1987)

Age and sex differences in the timing of moult in the common seal, Phoca vitulina

J. Zool., Lond. 212. 597-603.

ABSTRACT
This study followed the progress of the annual moult within a population of common seals in Orkney, Scotland. Moulting seals were seem over a three-month period, from 7 June until 16 September. Yearlings were first to start moulting. Amongst older seals, females completed their moult an average of seven days earlier than immature males and 19 days earlier than mature males. Differences in the timing of moult appeared to be related to the age or reproductive status of the animals, and may be the result of differential changes in levels of the sex hormones.

Thompson, P. M. (1989)

Seasonal changes in the distribution and composition of common seal (Phoca vitulina) haul-out groups

J. Zool., Lond. 217. 281-294.

ABSTRACT
Seasonal changes in the distribution and composition of common seal haul-out groups were followed in a study area in Orkney, Scotland. A marking programme was also undertaken, using both conventional and radio-tags, to study individual movements between sites and seasonal changes in site-use. Certain haul-out sites were used only in the breeding season, while others were used during the winter. Seals were seen at one site all year round and at another during only the pre-pupping and moult period. On one island where two sites were used during the summer, there were significant differences in the sex ratio of groups at the two sites: at one site males predominated and few pups were seen; on another, nearby, mothers and pups were regularly seen, although the site was also used by males. There was also evidence for segregation of the sexes outside the breeding season. Repeated observations of marked seals showed that seals used sevral different haul-out sites throughout the year, and that the seasonal changes in abundance at different sites resulted from individual changes in site-use. These changes in site-use are discussed in relation to feeding movements, breeding requirements and the physical characteristics of different sites.

Thompson, P. M.; Fedak, M. A.; McConnell, B. J.; Nicholas, K. (1989)

Seasonal and sex-related variation in the activity patterns of common seals (Phoca vitulina)

J. Appl. Ecol. 26. 521-536.

ABSTRACT
Radio-telemetry was used to study common seal activity patterns around Orkney, and to assess the degree of individual, seasonal and sex-related variation in haul-out behaviour in 1984-86. During the summer, both males and females hauled-out regularly, in a marked dirunal pattern, but there were differences in other aspects of their haul-out behaviour. Males showed a marked change in

Testa, J. W.; Siniff, D. B.; Croxall, J. P.; Burton, H. R. (1990)

A comparison of reproductive parameters among three populations of Weddell seals (Leptonychotes weddellii)

J. Anim. Ecol. 59. 1165-1175.

ABSTRACT
(1) Tagged populations of Weddell seals at three sites in Antarctica were compared to resolve earlier differences in estimated reproductive parameters and to examine interannual patterns in adult reproduction. (2) The estimated reproductive rate from McMurdo Sound (0.68) was lower than that reported from the Vestfold Hills (0.80). The estimate from Signy Island was found to be biased upward and not comparable to the other two sites. (3) Average age at first sighting with pup was 6 years at McMurdo Sound, 7 years at Signy Island and 8 years at the Vestfold Hills. (4) Sampling at Signy Island and the Vestfold Hills was earlier in the breeding season and less intensive than at McMurdo Sound. Subsets of data from McMurdo were used to simulate the sampling regime at the other tow sites. The results were higher estimates of both reproductive parameters (0.80 pups female-1 and 7 years) such that there were no significant differences between sites. A similar sampling bias probably occurs at Signy and the Vestfold Hills and would account for the differences between sites. (5) Probability of sighting an adult female with a pup was found to correlate well with adult reproductive rate at McMurdo Sound and was used as an index to adult reproduction at all three sites. This reproductive index appears to have fluctuated in approximate synchrony at Signy Island and McMurdo Sound, sites separated by over 145° of longitude, but not at the Vestfold Hills.

Testa, J. W. (1991)

Temporal variability in Antarctic Marine Ecosystems: Periodic fluctuations in the phocid seals

Can. J. Fish. Aquat. Sci 48. 631-639.

ABSTRACT
Three species of seals around Antarctica have shown quasi-cyclic patterns in some aspect of their biology: the age structure of crabeater seals (Lobodon carcinophagus) around the Antarctic Peninsula has shown strong cohorts separated by 4- to 5-yr intervals; juvenile leopard seals (Hydrurga leptonyx) have appeared in unusually large numbers at Macquarie Island, also at 4- to 5-yr intervals; and Weddell seals (Leptonychotes weddellii) in McMurdo Sound have undergone fluctuations in reproductive rate every 4-6 yr. Complex demodulation was used to compare patterns among these three data sets and with the Southern Oscillation Index (SOI). All of the the seals data sets showed evidence of cyclical behavior when demodulated at a period of 5 yr. The Weddell seals were generally in phase with the SOI since the Weddell series began in 1970. The leopard seals and SOI were in phase in the 1960s, but thereafter the SOI series led the leopard seal series by about one quarter of a cycle. The crabeater series was more complicated, but similarities with the other data sets also were seen. If these tentative observations are confirmed, they point to large-scale oceanographic variation, possibly related to the El Niño-Southern Oscillation (ENSO), as an important mechanism in Antarctic marine ecosystems.

reproductive estimates of sighting biases associated with seals having had at least one pup (Parous) or having pupped that season (With-Pup). Age at first reproduction as deduced from an age-specific pupping schedule is strongly affected by both forms of sighting bias, but bias in sighting Parous females was the more important. Estimates of adult reproductions were affected minimally. Comparisons of reproductive estimates with those of Weddell seals at Signy Island are discussed with regard to the effects of sighting biases.

Testa, J. W.; Siniff, D. B. (1987)

Population dynamics of Weddell seals (Leptonychotes weddelli) in McMurdo Sound, Antarctica

Ecol. Monog. 57 (2). 149-165.

ABSTRACT
Populations dynamics of Weddell seals in McMurdo Sound, Antarctica, were studied from 1970 to 1984 using mark-recapture estimation, aerial surveys, age structure and magnitude of harvests, and direct counts of pup production. Similar data from earlier studies were used to reconstruct the history of the population during the period of human presence after 1956. Jolly-Seber estimates of population size indicated a general decline from 1970 to 1976, low numbers in 1976 and 1978, and relative stability from 1979 to 1984 at about 1500 adult seals. From 1970 to 1983, mean annual survival of adult females and male Weddell seals was estimated at 0.85 and 0.76. Counts made in aerial surveys in the summers of 1982/1983 and 1983/1984 were substantially below similar survey counts in the 1960s. Pup production in the breeding colonies also declined from 1967 to 1976, but has recovered and been stable since 1979. Collections spanning 28 yr indicated significant shifts in age structure characteristic of populations undergoing a rapid increase and then decline. The age structure of both sexes indicated a constant age of recruitment to the adult population at 5 yr, which corresponds closely with age of maturity in females. Generalized least squares and standard regression analyses failed to detect any correlation of adult survival or female reproductive estimates with population size or ice conditions, but there were significant trends in survival estimates from 1970 to 1983 that may be due to shifting age structure.

The most plausible interpretation of these data is that heavy harvests of seals to feed dog teams in the mid-1905s severely depleted the resident population of adult Weddell seals. When population studies began in the early 1960s the population was expanding rapidly, probably as a result of immigration by juveniles. The population declined to low levels in 1976-1978 and has been fairly stable since 1979, probably at a level lower than before harvesting began. Survival and reproductive parameters of these Weddell seals are low relative to other pinnipeds, suggesting that the adult population is at an equilibrium with its environment.

once bred on the Channel Islands in small numbers but they have not been seen since 1984. Guadalupe fur seals wander to the Channel Islands from their sole rookery in Mexico and may soon colonize them. Populations of northern elephant seals, California sea lions, harbor seals, and northern fur seals will probably continue to increase, although at temporarily reduced rates because of greater mortality and slower growth of pups and juveniles during the 1982-83 El Nino Southern Oscillation event. In addition, competition for food resources or breeding space, or both, will restrict further growth and some populations may stabilize abruptly by the end of the century.

Summers, C. F. (1978)

Trends in the size of British gray seal populations

J. Appl. Ecol. 15. 395-400.

ABSTRACT
Trends in size of the more important stocks of British Grey seals are presented. Together with their West Atlantic counterparts they are increasing exponentially. Attempts to control stock size have indicated that they are best reduced by adult culls and not by pup hunting.

Terhune, J. M.; Almon, M. (1983)

Variability of harbour seal numbers on haul-out sites

Aquat. Mamm. 10. 71-78.

ABSTRACT
The high variability in numbers of seals hauled out were interpreted as evidence for high population mobility. Most seals hauled out during low tide. Human disturbance affected the numbers of seals hauled out which limited the researchers abilities to estimate population size.

Testa, J. W. (1987)

Long-term reproductive patterns and sighting bias in Weddell seals (Leptonychotes weddelli)

Can. J. Zool. 65. 1091-1099.

ABSTRACT
The reproductive performance of tagged Weddell seals (Leptonychotes weddelli) was monitored at McMurdo Sound, Antarctica, from 1970 to 1984. An age-specific reproductive schedule revealed the major onset of pupping at age 6 years, and a mean age of first birth of 7.1 years. The average asymptotic pupping rate of 0.61 is reached by age 10. The cost of pupping in a given year is reflected in a 0.05 drop in the probability of pupping the following year. This cost is not evident in females over 7 years old, suggesting that postweaning condition affects newly mature females more than those that are fully mature. Annual adult reproductive rates ranged from 0.46 to 0.79, with a posible periodicity of 5 to 6 years. Simulations were conducted to determine the impact on

utililty of satellite telemetry in documenting seals' at-sea behavior and movements. We used records from a microprocessor-based time-depth recorder (TDR) to interpret location and diving records from the PTT. For the free-ranging harbor seal, we obtained at least one uplink during 70% (while the seal was at sea) to 82% (while she was ashore) of satellite passes and at least one location each day. Of 62 locations determined by Service Argos for the free-ranging seal, 20 were verified from TDR records to have been at sea; these indicated that the seal may have ranged up to 48 km from the haul-out site, although most locations were within 5 km. The accuracies of locations calculated when the seal was at sea were substantially less than when it was ashore (1.5km), thus limiting at-sea tracking of seals by satellite to rather gross movements. Fewer transmissions were detected and locations calculated when the seal was actively diving than when it was swimming near the surface as it departed from or returned to the haul-out site. Consequently, average dive durations indicated by the PTT were substantially shorter than those calculated from TDR records. Documentation of foraging areas and detailed at-sea movements using satellite technology may not be possible for pinnipeds unless PTT-transmission rates are increased substantially from the 1 per 45 sec maximum rate now permitted by Service Argos.

Stewart, B. S.; Yochem, P. K. (1991)

Northern elephant seals on the Southern California Channel Islands and El Nino

In: Pinnipeds and El Nino: Responses to environmental stress

Trillmich, F.; Ono, K., eds. Pages 234-243

Springer-Verlag, Berlin

ABSTRACT
Pup mortality of northern elephant seals increased at the Channel Islands in winter 1983 because of intense storms, astronomically high tides, and elevated sea level coincident with El Nino. Pregnant females arrived later in 1983, nursed their pups fewer days in 1983 and 1984 and were at sea feeding longer in spring 1983 than in other years.

Stewart, B. S.; Yochem, P. K.; DeLong, R. L.; Antonelis, G. A. (1992)

Status and trends in abundance of pinnipeds on the Southern California Channel Islands

In: Recent advances in California islands research

Hochberg, F. G., ed. Pages In Press

Santa Barbara Museum of Natural History, Santa Barbara, California, Santa Barbara

ABSTRACT
Pinnipeds were relatively uncommon on the Southern California Channel Islands in the early 1900s because of overexploitation by commercial sealers and indiscriminate killing. Populations of four of the species recorded have increased greatly during the past several decades. Northern sea lions

require further studies of temporal, geographic, and habitat influences on the proportions of seals ashore.

Stewart, B. S. (1989)

The ecology and population biology of the northern elephant seal, Mirounga angustirostris Gill 1866, on the Southern California Channel Islands

Ph.D. dissertation, University of California, Los Angeles, CA

ABSTRACT
The patterns of seasonal abundance, behavior, and population biology of northern elephant seals (Mirounga angustirostris) on the Southern California Channel Islands were studied from 1979 through 1987 to investigate the influences of crowding on colony growth and neonatal survival. Four primary peaks in terrestrial abundance of elephant seals are related to reproduction in winter and age- and sex-related differences in timing of the molt in spring and summer. The magnitudes of these peaks on San Nicolas Island varied among years. The magnitudes of these peaks on San Nicolas varied among years. Non-breeding season peaks in abundance are unreliable for assessing absolute abundance or trends in colony size, but annual fluctuations at one rookery may be useful indicators of temporary or long-term oceanographic or environmental changes or suggestive of demographic changes on other rookeries. An understanding of the demographics of all colonies is, however, essential for interpreting seasonal changes in abundance on each. Births continued to increase exponentially at average annual rates of 11.5% and 7.8% at San Nicolas and San Miguel islands, respectively. Crowding during the breeding season but insignificant effects on increases in births in most habitats and the greatest rates of increase in births occurred at densities very near the carrying capacities (K) of the breeding habitats (i.e., at about 0.75 K). Pre-weaning pup mortality was independent of densities on rookeries and remained low at about 4% on San Nicolas Island and generally less than 6% on San Miguel Island. Crowding on some beaches where female distribution did, however, influence the tenure of lactating females and growth of their pups. Females were evidently in poorer physical condition in 1983 and 1984 than in other years presumably because of decreased food abundance or altered prey distribution which may have required them to range further when at sea from late 1982 through early 1984 during an intense ocean warming event. Consequently, parous females arrived on rookeries later in 1983, nursed their pups fewer days in 1983 and 1984 which resulted in pups being weaned in poorer condition and were at sea feeding longer in spring 1983 than in other years. They also conceived a significantly greater proportion of male progeny in 1984 than in other years.

Stewart, B. S.; Leatherwood, S.; Yochem, P. K.; Heide-Jorgensen, M. P. (1989)

Harbor seal tracking and telemetry by satellite

Mar. Mamm. Sci. 5. 361-375.

ABSTRACT
We tested a satellite Platform Transmitter Terminal (PTT) in the laboratory (on a float and on captive seals) and on a free-ranging harbor seal in the Southern California Bight to investigate the

Stewart, B. S.; Karl, S. A.; Yochem, P. K.; Leatherwood, S.; Laake, J. L. (1987)

Aerial surveys for cetaceans in the former Akutan, Alaska, whaling grounds

Arctic 40 (1). 33-42.

ABSTRACT
Randomized aerial surveys were flown between 26 July and 26 August 1984 to search for cetaceans in two areas of southwestern Alaska: one on both Bering Sea and Pacific Ocean sides of the Aleutian islands near the defunct Akutan shore-whaling station, which operated from 1912 through 1939, the other overlapping continental slope and shallow continental shelf waters between the Aleutians and the Pribilof Islands. Surveys were made at altitudes between about 150m and 245m from a Partenavia P68 Observer with a plexiglass nose bubble, which permitted center-line viewing. Searches covered 3940 nautical miles (nm), including some 2403 nm of random transects. Sightings were made of gray whales (10 sightings, 14 individuals), fin whales (3,11), minke whales (1,1), unidentified beaked whales (1,6), Dall's porpoises (47,131, killer whales (8,26) and harbor porpoises (4,7). A Fourier series model was used to estimate density of Dall's porpoises as 115 individuals (CV =0.263) per 1000 nm^2 on the whaling grounds and 16.6 individuals (CV = 0.0) per 1000nm^2 in the Bering Sea north of the whaling grounds. These estimates are comparable to those previously reported for the same general areas (97.2 animals per 1000nm^2, SD =49.5). There were too few sightings of other cetaceans to permit calculation of meaningful density estimates. At least four species of great whales (blue, fin, humpback and sperm) were sufficiently abundant during the first four decades of this century to support significant whaling activities within about 100nm of Akutan (more than 5300 whales were caught during 23 years of whaling, 1912-39). Although previous studies of the fisheries showed a downward trend in catch per unit of effort and an increase in distance traveled to take whales, whales were still being taken at relatively high rates (0.28-0.51 whales per gross catcher day) at the end of the fishery in 1939. Populations of fin, humpback, blue and sperm whales were probably significantly reduced by shore and pelagic whaling conducted widely in the North Pacific since 1939. The low number of sightings on the present surveys probably means that populations on and near the whaling grounds remain depressed from such activities.

Stewart, B. S.; Antonelis, G. A., Jr.; DeLong, R. L.; Yochem, P. K. (1988)

Abundance of harbor seals on San Miguel Island, California, 1927 through 1986

Bull. So. Cal. Acad. Sci. 87 (1). 39-43.

ABSTRACT
Counts of harbor seals ashore were made each year at San Miguel Island in southern California from 1973 through 1986. Historical counts were available for 1927, 1958, 1964, 1965, and 1969. The data indicated that the colony increased about 22% per year from 1958 through 1986 overall, but that the rate of increase may have declined somewhat after 1976. Counts of terrestrial abundance of seals were corrected using radiotelemtry data to yield estimates of absolute abundance. Hauling patterns may have changed during the 1982/83 El Niño Southern Oscillation which makes interpretations of trends in abundance after 1983 problematic. The authors concluded that accurate determinations of absolute abundance of harbor seals on the Channel Islands and elsewhere will

young pinnipeds in cold, ice-bound waters has been borne out following the discharge of residual oil in the Gulf of St. Lawrence in 1969.

Pinnipeds show little behavioral or physiologic reactions to the noxious characteristics of oil. Incidental ingestion during feeding, exposure to vapor concentrations that might be expected under natural conditions at sea, and limited surface fouling with relatively fresh oil do not appear to cause significant distress. Pinnipeds trapped near the source of a spill, or forced to emerge in heavy accumulations of oil in leads and around rookeries, exhibit the most severe effects. For fur seals, experimental studies indicate that surface fouling will decrease the insulative value of the pelt, possibly leading to thermal and energetic stress. Individuals of all species and groups that are compromised by pre-existing disease, or stressed by an unfavorable habitat, intra-specific competition, or unusual enviornmental conditions may be the most vulnerable to the effects of oil exposure.

Stewart, B. S. (1984)

Diurnal hauling patterns of harbor seals at San Miguel Island, California

J. Wildl. Manage. 48. 1459-1461.

ABSTRACT
Harbor seals haul-out on a variety of substrates (tidal sand and mud bars, intertidal rocks and reefs, ice floes and glacial drift, sand and cobble beaches, and man-made floats and rafts) in various parts of their range. In some areas, hauling areas are accessible only at or near low tide and consequently surveys of seal populations are timed with respect to tide only. Using time-lapse photography the author documented year-round patterns of terrestrial abundance of harbor seals at haul-outs on San Miguel Island in southern California where beaches are accessible at all tides. Seals exhibited strong diurnal patterns; few were ashore in early morning or late afternoon and peak abundance was between 1200 and 1400 hrs throughout the year. Tide did not influence the timing of haulout but seals were more abundant ashore at afternoon low tides compared to afternoon high tides when corrected for hour of the day. Human intrusion (persons on site, aircraft and helicopters, etc.) disrupted hauling patterns on 21% of the days (n=272). Maximum yearly terrestrial abundance was in late May and early June when seals were molting. The author concluded that estimates of population size on the southern California Channel Islands can be made more reliable by standardizing survey times to early afternoon. In other parts of the species' range where supralittoral hauling space is available and used by seals, studies of diurnal influences on hauling patterns may be desirable before estimates of population size and growth are made based on low tide censuses.

Smith, T. D. (1983)

Changes in size of three dolphin (Stenella spp.) populations in the eastern tropical Pacific

U.S. Fish. Bull. 81. 1-13.

ABSTRACT
Dolphins from three populations, one of Stenella attenuata and two of S. longirostris, have been killed incidentally in the yellowfin tuna purse seine fishery in the eastern tropical Pacific, two populations since about 1959 and the other since about 1969. Size changes in these populations are estimated from numbers killed each year, population size estimates in 1979, and net recruitment rates. Ranges of values for some parameters are considered, accounting for some uncertainties. Assuming central values of the ranges of maximum net recruitment rate (3%) and the population level giving maximum net productivity (65%), one S. longirostris population, the eastern spinner dolphin, is near 20% of pre-exploitation levels: the S. attenuata population, the northern offshore spotted dolphin, is between 35 and 50%: and the second S. longirostris population, the whitebelly spinner dolphin, is between 58 and 72% of pre-exploitation levels.

Smith, T. G.; Geraci, J. R.; St. Aubin, D. J. (1983)

Reaction of bottlenose dolphins, Tursiops truncatus, to a controlled oil spill

Can. J. Fish. Aquat. Sci 40. 1522-1525.

ABSTRACT
Three captive bottlenose dolphins, Tursiops truncatus, were observed in an ocean pen measuring 14 x 11 m divided into three equal areas by oil-containment booms. Each dolphin was placed in the pen alone for 4 d with no oil present, and 2 d with tar-colored mineral oil in one of the areas. We noted their area of surfacing, underwater movements, dive times, and reactions. After a few brief contacts with the oil, dolphins completely avoided surfacing in the slick. The oil also acted as a temporary barrier restricting their underwater movement.

St. Aubin, D. J. (1990)

Physiologic and toxic effects on pinnipeds

In: Sea Mammals and Oil: Confronting the Risks

Geraci, J. R.; St. Aubin, D. J., eds. Pages 103-107

Academic Press, New York

ABSTRACT
Oil fouling has been implicated in the deaths of pinnipeds, though much of the evidence has been circumstantial. Large-scale mortality has never been observed, even after some of the more catastrophic spills. In general, the prediction that spilled oil would have its greatest impact on

Slooten, E.; Lad, F. (1991)

Population biology and conservation of Hector's dolphin

Can. J. Zool. 69. 1701-1707.

ABSTRACT
During the past decade, Hector's dolphins, Cephalorhynchus hectori, have suffered an alarming level of mortality due to entanglement in commercial and amateur gill nets. In this paper we study two Leslie matrix population models that incorporate known features of dolphin fertility and mortality, focussing on the information they provide regarding age distributions and maximum population growth rates. The simplest model specifies constant survival rates over many age-classes. The second model uses more realistic curves of age-sepcific survival rates. The results indicate that Hector's dolphin, like most other small cetaceans, has a low potential for population growth. Growth rates of 1.8-4.9% per year are likely to be the maximum possible for Hector's dolphin population, and C. hectori (and C. commersonii) populations are likely to be declining under recent levels of net entanglement. Survival rarte estimates from free-living populations, subject to natural and net-entanglement mortality, showed decreasing populations. Even with the most optimistic reproductive parameters, survival rates would need to be some 5-10% higher than those observed in populations subject to gill-net entanglement before population growth could coccur. The likely consequences of a reduction in entanglement mortality through conservation management are explored using the survivorship curve model. These simulations show that the age structure of the population can have an important effect on changes in the size and growth rate of the populaztion during the recovery phase following a reduction in entanglement mortality.

Smith, R. I. L. (1988)

Destruction of Antarctic terestrial ecosystems by a rapidly increasing fur seal population

Biol. Conserv. 45. 55-72.

ABSTRACT
The terrestrial environment of Signy Island, South Orkney Islands, maritime Antarctic, is undergoing rapid and possibly irreversible change caused by a natural biological agent. During the past decade there has been a dramatic increase in the number of Antarctic fur seals Arctocephalus gazella coming ashore on the island during the short summers. It is not known whether significant numbers of seals were present on the island prior to the initiation of commercial hunting in the early 1820s. The impact that the continuing increase of these seals had made on the island's terrestrial and freshwater environments has been sudden and locally devastating. The fragile cryptogram-dominated vegetation has suffered physical damage from which it may be impossible to recover. These seals are also frequenting several of the island's freshwater lakes which are becoming increasingly eutrophic. The long-term implications of this impact are causing serious concern for the future of the lowland terrestrial and freshwater ecosystems on Signy Island if the fur seal population continues to increase.

Shaughnessy, P. D.; Goldsworthy, S. D. (1990)

Population size and breeding season of the Antarctic fur seal Arctocephalus gazella at Heard Island-1987/88

Mar. Mamm. Sci. 6 (4). 292-304.

ABSTRACT
Breeding colonies of the antarctic fur seal Arctocephalus gazella on Heard Island (53°10'S, 73°30'E) are situated on the sheltered northern and eastern coasts on flat vegetated terrain near streams and pools. Pupping in the 1987/88 summer began on 21 November, with 90% of births in 26 d. The median birth date was 11 December. Pup counts at Heard Island made in seven breeding seasons from 1962/63 to 1987/88 show an exponential rate of increase of 21%, which may be inflated due to undercounting in early years. The total of 248 births in 1987/88 represents an exponential increase of 37% since the previous year, but pups nay have been undercounted then. Based on the number of pups born, the breeding population is estimated at 870-1,120. During the breeding season, the largest number oi animals ashore was 835. Many non-breeding fur seals began hauling out from early January and 15,000 animals were estimated to be ashore by late February, a far larger number than expected from the size of the breeding population. Both the breeding and non-breeding components of the population may be augmented by immigration. The source of immigrants may be undiscovered breeding colonies of this species in the northwestern sector of the Kerguelen Archipelago or the concentration at South Georgia. Further censuses are required at Heard Island to monitor the population growth.

Slater, L. M.; Markowitz, H. (1983)

Spring population trends in Phoca vitulina richardi in two central California coastal areas

Calif. Fish Game 69. 217-226.

ABSTRACT
Two areas separated by about 17km with comparable numbers of harbor seals were surveyed in Spring 1980. Population trends in the two areas were significantly different with a decline at the San Mateo County sites. In contrast to this area which had a low pupping rate, nursery herds were observed at the two Santa Cruz County sites. A group composed almost exclusively of males awas observed in San Mateo County. Since there is no indication of movement between the areas, these contrasting distributions are interpreted as resulting from differences in habitat characteristics and frequency of human encroachment.

surveys conducted in the pelagic eastern tropical Pacific during June to November 1982, 1986 and 1987. Substantial changes were observed in relation to previously reported winter distributions for spotted and/or spinner dolphin schools (Stenella attenuata and/or S. longirostris) and for striped dolphin schools (S. coeruleoalba). These dolphin species were sighted in abundance west of 120°W along 10°N coincident with seasonal shoaling of a thermocline ridge. No seasonal distribution changes were observed for common dolphin schools (Delphinus delphis); as in the winter, they occupied upwelling-modified waters of the region. Highest-density areas for the 3 school types were statistically different between spotted/spinner dolphin school and common dolphin schools. Striped dolphin schools could not be discriminated from the other 2 types based on these habitat variables, indicating other factors or processes contribute to the observed spatial separation of the 3 distributions.

Renouf, D.; Gaborko, L.; Galway, G.; Finlayson, R. (1981)

The effect of disturbance on the daily movements of harbour seals and grey seals between the sea and their hauling grounds at Miquelon

Appl. Anim. Ethol. 7. 373-379.

ABSTRACT
The movements of harbour seals and grey seals through a narrow channel connecting their hauling grounds with the sea were recorded during the daylight hours from 14 to 27 June 1980. There was only a slight increase in seabound travel after the seals were disturbed by humans, and the animals did not necessarily go to sea when the sand flats they hauled out on were flooded by the high tide. There was no recognizable diurnal pattern to their movements, and no relationship between the direction and intensity of the traffic and various meteorological factors.

Schneider, D. C.; Payne, P. M. (1983)

Factors affecting haul-out of harbor seals at a site in southeastern Massachusetts

J. Mamm. 64. 518-520.

ABSTRACT
Several factors affected the number of seals appearing near shore at Manomet, but only tide and disturbance had any significant effect on the percentage hauling out. Occasional disturbance did not affect the total number of seals in the study area, but may nonetheless be important if the number of hours spent out of water is critical.

of 2.5% during 1967-1980, concurrent with an annual exploitation of approximately 1.2%, i.e. net reproduction was near 3.7% per year. In light of this net reproduction, vital-rate estimates for the circa 1967 population were re-evaluated. The most likely values during that period were: pregnancy rate of 0.467, mean age at sexual maturity of 8 years, adult survival of 0.945 and juvenile survival of 0.899. To estimate maximum net rate of increase, biologically defined limits of pregnancy rate, age at sexual maturation and juvenile survival were used to generate a Leslie matrix, with adult survival held constant at the 1967 level. The dominant eigenvalue of the matrix was calculated as 1.069. If a stable age structure can be assumed in populations at a very low level, this indicates a possible maximum net rate of increase approaching 6.7% per year.

Reilly, S. B.; Barlow, J. (1986)

Rates of increase in dolphin population size

U.S. Fish. Bull. 84 (3). 527-533.

ABSTRACT
Annual finite rates of increase in dolphin population size were estimated to vary up to a maximum of 1.09, using simulation, based on ranges in vital rates. Vital rate ranges were defined from values reported in the literature where possible, otherwise by making assumptions about biological or logical limits. Given information on current values, or limits, of one or more vital rate, one can use the figures presented to deterimine ranges of possible rates of increase in population size. The highest rates estimated here (up to 1.09) are probably unrealistic, because of the unlikely combinations of high fecundity and low mortality needed to achieve them.

Reilly, S. B. (1987)

Reanalysis of rate of change in the California-Chukotka gray whale stock, 1967/68 - 1979/80

Rep. int. Whal. Commn 37. 347-349.

ABSTRACT
A statistical analysis of the relationships among annual population estimates, mean annual visibility and mean distance offshore of passing whales from the 1967-1980 Monterey gray whale censuses indicates that there was in fact a significant positive rate of change in gray whale abundance during those years.

Reilly, S. B. (1990)

Seasonal changes in distribution and habitat differences among dolphins in the eastern tropical Pacific

Marine Ecol. Prog. Ser. 66. 1-11.

ABSTRACT
Large-scale patterns of dolphin distribution and oceanography were studied from research-vessel

Reijnders, P. J. H. (1985)

On the extinction of the southern Dutch harbour seal population

Biol. Conserv. 31. 75-84.

ABSTRACT
The harbour seal population in the southern part of the Netherlands, the Delta area, has decreased sharply since about 1953. Causes for the observed decrease, such as hunting pressure, habitat limitation through construction works, disturbance and water pollution, are discussed. As in the Wadden Sea, where the seal population has been studied more intensively, the initial sharpest decrease was caused by overhunting, probably followed by the impact of pollution. Construction works have had a secondary effect, as by the time these began, numbers were already very much reduced.

Reilly, J. J.; Fedak, M. A.; tedak, M. A. (1991)

Rates of water turnover and energy expenditure of free-living male common seals (Phoca vitulina)

J. Zool., Lond. 223. 461-468.

ABSTRACT
The water and energy metabolism of free-living male common seals (Phoca vitulina) during the mating season was investigated using labelled water methods. All three seals, which were captured on two occasions, were in negative energy balance during the study. The daily energy expenditure of one animal, estimated using doubly-labelled water was 52.5 MJ. This is equivalent to six times the basal metabolic rate predicted from Kleiber's (1975) allometric equation. Rates of water turnover were slightly lower than predicted from the allometric equation of Richmond, Langham and Trujillo (1962). The observed rates of water turnover and energy expenditure are considerably higher than those of seals which fast during the mating season, and are consistent with the observed differences in behaviour between males of the common seal and other pinniped males during mating.

Reilly, S. B. (1984)

Observed and maximum rates of increase in gray whales, Eschrichtius robustus

In: Reproduction in whales, dolphins and porpoises. Reports of the International Whaling Commission (Special Issue 6)

Perrin, W. F.; Brownell, R. L. Jr.; DeMaster, D. P., eds. Pages 389-399

International Whaling Commission, Cambridge

ABSTRACT
Shore station censuses indicate that the California stock of gray whales increased at an annual rate

(Callorhinus ursinus) and Steller sea lions (Eumetopias jubatus) in the Bering Sea and Gulf of Alaska.

Ray, G. C.; Dobbin, J. A.; Salm, R. V. (1978)

Strategies for protecting marine mammal habitats

Oceanus 21 (2). 55-67.

ABSTRACT
The protection of marine mammal species requires identification of areas of special biological significance, or 'critical habitats'. Recent legislation and research work have emphasised the value of a habitat approach to management, which the authors have attempted to illustrate by means of a management model, based on walrus (Odobenus rosmarus divergens) populations in the Bering Sea. The model integrates data on : 1) the hydrography of the study area, 2) the distribution, life history, food habits and community structure of the walrus, 3) existing and proposed socioeconomic activities, 4) legal and jurisdictional matters. Areas of high vulnerability are identified by mapping the mating grounds, pupping grounds, migration routes and food supply, and then overlaying additional data in a colour-coded system. This gives a visual presentation of potential conflicts and responsibility for action, which may be used as a strategic planning tool for protection measures such as the establishment for sanctuaries. The article concludes with a discussion of the usefulness of this and other approaches to management problems.

Reijnders, P. J. H. (1983)

The effect of seal hunting in Germany on the further existence of a harbour seal population in the Dutch Wadden Sea

Zeit. Saugetierkunde 48. 50-54.

ABSTRACT
Calculated influence of dispersal and hunting pressure on seals in the Wadden Sea. Due to pollution effects pup production in the Dutch seal population is too low compared to the stable population in Schleswig-Holstein. Nevertheless, aerial surveys showed that the total number of seals remained fairly stable at about 500 specimens since 1974. It is demonstrated that since hunting was stopped in Niedersachsen and Schleswig-Holstein unrestricted dispersal in the Wadden Sea area could take place. It is calculated that the Dutch seal population in 1980 contained 41% animals originating from outside the area. Besides another 15% of the animals were repatriated by seal nursery stations. Abstinence of hunting in the whole area is of vital importance for the further existence of a harbour seal population in the Dutch Wadden Sea.

Pitcher, K. W.; McAllister, D. C. (1981)

Movements and haulout behaviour of radio-tagged harbour seals, Phoca vitulina

Can. Field Nat. 95. 292-297.

ABSTRACT
Movements, haulout area fidelity, and haulout frequency of harbor seals (Phoca vitulina) were studied in the Kodiak Island area, Alaska, by relocating radio-tagged animals captured on a large hauling area. Eight of 35 radio-tagged seals were found on hauling areas other than the capture site. The longest movement was 194 km and one seal crossed 74 km of open ocean. Movement rates up to 27 cm/d were recorded. There appeared to be considerable fidelity to one or two specific haulout location by individual radio-tagged animals. Resident, radio-tagged sealsx of a large hauling area were hauled out during 50% of the daily radio checks in June and 41% from 1 August to 5 September. On an individual basis, frequency of haulout ranged from 16 to 80% of the days.

Pitcher, K. W. (1986)

Variation in blubber thickness of harbor seals in southern Alaska

J. Wildl. Manage. 50 (3). 463-466.

ABSTRACT
Measurements of blubber thickness, sculp weights, and other morphometric data were obtained from 559 harbor seal (Phoca vitulina) collected along the southern Alaskan coast in order to evaluate seasonal fatness in relation to sex and age and to compare indices of fatness. In the older age classes females were fatter than males. Older seals of both sexes were fatter than younger animals. Adolescent and mature animals of both sexes were fatter during winter than during the reproductive and molt periods. Sculp weight divided by total body weight, sculp weight divided by standard length and condition index were all correlated positively with blubber thickness. These findings facilitate comparisons of fatness in populations regionally or over time.

Pitcher, K. W. (1990)

Major decline in number of harbor seals, Phoca vitulina richardsi, on Tugidak island, Gulf of Alaska

Mar. Mamm. Sci. 6 (2). 121-134.

ABSTRACT
Tugidak Island, located in the Gulf of Alaska, was once the site of one of largest local concentrations of harbor seals (Phoca vitulina richardsi) in the world. This population, which probably consisted of about 20,500 animals in the mid-1960s, declined by about 85% between 1976 and 1988. The population appeared to decline more rapidly during the late 1970s than during the 1980s. Causes for the decline are not apparent. There appear to be both similarities and dissimilarities between this decline and recent declines in abundance of northern fur seals

(calves/female/year) of 0.58, but this value may be inflated by sighting biases. In southeastern Alaska, multiple sightings of 41 mature females provided an estimated calving rate of 0.37, which we believe is a polygynous mating system involving male-male competition for mature females. In southeastern Alaska, the foraging strategies of humpback whales appear to be noncompetitive and, on occasion, cooperative.

Pierce, G. J.; Thompson, P. M.; Miller, A.; Diack, J. S. W.; Miller, D.; Boyle, P. R. (1991)

Seasonal variation in the diet of common seals (Phoca vitulina) in the Moray Firth area of Scotland

J. Zool., Lond. 223. 641-652.

ABSTRACT
Seasonal variation in the diet of common seals (Phoca vitulina) in the Moray Firth, north-east Scotland, was determined from analysis of faecal samples collected at haul-out sites during each month of 1988. Data on diet of common seals in 1987 are also presented. Limitations of the methods available for quantification of diet are discussed. Although some of the observed variation in diet from month to month may reflect changes in the sampling regime, a clear seasonal pattern was apparent, with clupeids predominating in the winter and sandeels in the summer. The trends observed are consistent with opportunistic feeding on the most abundant prey.

Pitcher, K. W. (1980)

Food of the harbor seal, Phoca vitulina richards, in the Gulf of Alaska

U.S. Fish. Bull. 78 (2). 544-549.

ABSTRACT
A total of 548 harbor seals were collected by rifle throughout the Gulf of Alaska from 1973 through 1978. Stomach contents were sorted and prey remains identified as an index of diet. Fishes composed 74.5%, cephalopods 21.5% and decapod crustaceans 4.0% of the prey identified.

A minimum of 27 species of fish were identified belonging to 13 families. Cephalopods included both octopus and squids of the family Gonatidae. The five top-ranked prey of harbor seals in the Gulf of Alaska were walleye pollock, octopus, capelin, eulachon, and Pacific herring. Either walleye pollock or octopus was the top-ranked food in all marine areas and eulachon was dominant in the estuarian and freshwater habitats of the Copper River Delta. Walleye pollock was the top-ranked item in the eastern areas: northeastern Gulf of Alaska, Prince William Sound, and the Kenai coast. In the western areas: Lower Cook Inlet, Kodiak, and the Alaska Peninsula, octopus had the highest ranking. In Lower Cook Inlet, octopus and shrimps made up over 60% of both total occurrences and volumes which was nearly twice the percentages in other areas. Salmon were found in the diet of harbor seals from both Prince William Sound and the Kodiak Island area only during the summer. In the Kodiak area, feeding on Pacific sand lance appeared to be greatest in the fall while use of capelin seemed to peak in the spring. Use of Pacific herring by harbor seals appeared greatest in the spring in Prince William Sound.

Perrin, W. F.; Reilly, S. B. (1984)

Reproductive parameters of dolphins and small whales of the family Delphinidae

In: Reproduction in whales, dolphins and porpoises. Reports of the International Whaling Commission (Special Issue 6)

Perrin, W. F.; Brownell, R. L. Jr.; DeMaster, D. P., eds. Pages 97-133

International Whaling Commission, Cambridge

ABSTRACT
The purposes of this review are to describe and critique methods used to estimate reproductive parameters, to summarize estimates in the literature and to examine patterns in the estimates and their implications. Reviewed are gestation period, fetal growth rate, size at birth, size and age at attainment of sexual maturity, average size and age of adults, maximum size, asymptotic length, ovulation rate, pregnancy rate, calving interval, length of lactation, weaning age, length of "resting" period, age and sex structure, and birth rates. Also discussed are the effects on the estimates of seasonality, schooling segregation, geographical variation and exploitations and the relationships between parameters.

Perry, A.; Baker, C. S.; Herman, L. M. (1990)

Population characteristics of individually identified humpback whales in the central and eastern North Pacific: a summary and critique

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 307-317

International Whaling Commission, Cambridge

ABSTRACT
Methods developed to obtain and record photographs of tail flukes and accompanying sighting data for humpback whales are described. Published descriptions of the migratory movement, abundance, reproductive histories and social organization of individually identified humpback whales based on our long-term studies in Hawaii and southeastern Alaska and other studies in the eastern and central North Pacific are reviewed. Biases and limitations associated with the collection and analysis of photographic data are discussed and additional methods that can be useful in describing population parameters for humpback whales and other cetacean species are suggested.

Humpback whales in the North Pacific, like those in the North Atlantic, appear to form geographically isolated feeding herds which intermingle on one or more wintering grounds. Mark-recapture analyses of resighting data suggest a seasonal population of 327 to 421 in the southeastern Alaska feeding region, and 1,113 to 1,701 on the Hawaiian wintering grounds. In Hawaii, multiple sightings of 18 sexually mature females provided an estimated calving rate

Perrin, W. F.; Oliver, C. W. (1982)

Time/area distribution and composition of the incidental kill of dolphins and small whales in the U.S. purse-seine fishery for tuna in the eastern Tropical Pacific, 1979-80.

Rep. int. Whal. Commn 32. 429-444.

ABSTRACT
Data are presented for 4,642 spotted dolphins, Stenella attenuata; 1,745 spinner dolphins, S. longirostris; 99 striped dolphins, S. coeruleoalba; 1,535 common dolphins, Delphinus delphis; two bottlenose dolphins, Tursiops truncatus; one Pacific white-sided dolphin, Lagenorhynchus obliquidens; and one false killer whale, Pseudorca crassidens. Possible source of biases in the samples are discussed.

Perrin, W. F.; Henderson, J. R. (1984)

Growth and reproductive rates in two populations of spinner dolphins, Stenella longirostris, with different histories of exploitations

In: Reproduction in whales, dolphins and porpoises. Reports of the International Whaling Commission (Special Issue 6)

Perrin, W. F.; Brownell, R. L. Jr.; DeMaster, D. P., eds. Pages 417-430

International Whaling Commission, Cambridge

ABSTRACT
A model of density-dependent change in net reproductive rate (births minus deaths) has been used in assessing status of dolphin stocks in the eastern tropical Pacific. The eastern spinner population has been estimated to be at a lower fraction of original size (17-25%) than is the population of whitebelly spinners (58-72%). Higher reproductive rates would be expected in the former than in the latter on the basis of the density-dependent model, provided the latter is above its level of maximum net production. Based on analyses of over 4,000 specimens collected through 1978: (1) there is a relative paucity of fully adult males in the eastern spinner population (possibly resulting in lower average fertility), (2) the eastern spinner female attains sexual maturity about one tooth-layer unit (probably one year) earlier than does the whitebelly spinner, (3) ovulation rates in young females is lower in the eastern spinner population, and (4) the proportion of all females which are sexually mature is lower in the eastern spinner population. Gross annual reproductive rates (proportion female X proportion of females mature X pregnancy rate) are not differnet in the two populations (about 8-10% in both cases). This comparison does not confirm the hypothesis that a density-dependent increase in gross reproduction occurs in the spinner dolphin.

Payne, R.; Rowntree, V.; Perkins, J. S.; Cooke, J. G.; Lankester, K. (1990)

Populations size, trends and reproductive parameters of right whales (Eubalaena australis) off Peninsula Valdes, Argentina

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 271-278

International Whaling Commission, Cambridge

ABSTRACT
Photo-identification of individual whales, based on natural marking, has been used to study a population of southern right whales, Eubalaena australis, on their winter assembly grounds around Peninsula Valdes, Argentina. Right whales have raised patches of roughened skin (callosities) on their heads. The pattern of callosities differs between individuals. This enables known individuals to be monitored over time. Photographs of individual whales have been obtained from aerial surveys conducted each year between June and December from 1971 through 1986. A total of 909 distinct idividuals were identifed over the period, of which 481 were identified in more than one season. These data have been used to estimate various population parameters. The mean calving interval is estimated to be 3.6 years (95% confidence interval 3.3 to 4.1 years). It is estimated that there were 99 (SE 18) calvings in the population in 1986, which implies a total population of about 1,200 in that year. The population is estimated to be increasing at a rate of 7.6% p.a. (SE 1.7%). These estimates should be treated with caution until the validity of the underlying assumptions has been verified.

Pechmann, J. H. K.; Scott, D. E.; Semlitsch, R. D.; Caldwell, J. P.; Vitt, L. J.; Gibbons, J. W. (1991)

Declining amphibian populations: the problem of separating human impacts from natural fluctuations

Science 253. 892-895.

ABSTRACT
Reports of declining amphibian populations in many parts of the world are numerous, but supporting long-term census data are generally unavailable. Census data from 1979 to 1990 for three salamander species and one frong species at a breeding pond in South Carolina showed fluctuations of substantial magnitude in both the size of breeding populations and in recruitment of juveniles. Breeding population sizes exhibited no overall tredn in three species and increased in the fourth. Recent droughts account satisfactorily for an increase in recruitment failures. These data illustrate that to distinguish between natural population fluctuations and declines with anthropogenic causes may require long-term studies.

Ono, K. A.; Boness, D. J.; Oftedal, O. T. (1987)

The effect of a natural environmental disturbance on maternal investment and pup behavior in the California sea lion

Behav. Ecol. Sociobiol. 21. 109-118.

ABSTRACT
Observed changes in maternal investment due to an environmentally induced decrease in food supply (the 1983 El Niño-Southern Oscillation) are compared with a priori predictions for the California sea lion (Zalophus californianus). Changes in behavior, growth and mortality of offspring were also examined. Data collected in the first two months postpartum for the years before (PRE), during (EN), and the two years after (POST1 and POST2) the 1983 El Niño indicate that females initiated postpartum feeding trips earlier during the food shortage, and spent more time away on individual feeding trips in both the El Niño year and the year after. Perinatal sex ratios (female:male) in the years PRE, EN, POST1 and POST2 were 1:1, 1.4:1, 1.1:1 and 1:1.4, respectively. Fewer copulations were observed during the El Niño year, but this difference was not statistically significant. Pups spent less time suckling in the food shortage year and the year following, but attempted to sneak suckle more. Pups were less active and played on land less in the El Niño and following year. Finally, maternal investment as measured by milk intake of offspring was decreased, pups grew more slowly, and suffered increased mortality during the food shortage year. Despite expected sex differences in maternal investment and pup behavior in response to food shortage, there were no sex-biased differences in response in either females or pups. As expected, the food shortage did not affect adult males since they migrate north during the non-breeding season where the environmental perturbation was less severe.

Oritsland, T.; Christensen, I. (1982)

A mass stranding of killer whales at Lofoten, northern Norway, in June 1981

Rep. int. Whal. Commn 32. 642.

ABSTRACT
A report of a mass stranding in which 14 killer whales out of a pod of about 30 ran ashore.

Payne, P. M.; Schneider, D. C. (1984)

Yearly changes in abundance of harbor seals, Phoca vitulina, at a winter haulout site in Massachusetts

U.S. Fish. Bull. 82. 440-442.

ABSTRACT
Harbor seals increased at a Massachusetts coastal haul-out site at around 11.9% per year from 1972 through 1980 mostly from dispersal of seals from rookeries in Maine. The growth was thought to have been facilitated by protection of seals from bountied hunting after the passage of the Marine Mammal Protection Act in 1972.

Olesiuk, P. F.; Biggs, M. A.; Ellis, G. M. (1990)

Life history and population dynamics of resident killer whales (Orcinus orca) in the coastal waters of British Columbia and Washington State

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 209-243

International Whaling Commission, Cambridge

ABSTRACT

Life history parameters are derived for the resident form of killer whale in the coastal waters of British Columbia and Washington State based on the demographic changes observed in two communities (closed to immigration and emigration) that were monitored between 1973-4 and 1987. Females have a mean life expectancy of 50.2 year, typically give birth to their first viable calf at 14.9 years of age, produce an average of 5.35 viable calves over a 25.2 year reproductive lifespan and have a maximum longevity of about 80-90 years. Calving is diffusely seasonal with most births occurring in October-March. Neonate mortality is approximately 43%. The estimated proportion of mature females pregnant varies from 0.274 in April to 0.411 in September. Males have a mean life expectancy of 29.2 years, typically attain sexual maturity at 15.0 years and physical maturity at 21.0 years of age, and have a maximum longevity of about 50-60 years. Mortality curves are U-shaped for both females and males, but the curve is narrower for males. There is no evidence of density dependence in the life history parameters as a result of cropping prior to the start of the study or as the populations increased during the study.

The derived life history parameters are used to develop a sex- and age-specific matrix population model and to calculate life tables. The model accurately emulates the demographic changes observed during the study. Population projections indicate that both communities represent stable populations below their carrying capacity. These populations had a finite annual rate of increase of 2.92% and were composed of 50% juveniles, 19% mature males, 21% reproductive females and 10% post-reproductive females. Discrepancies between the sex- and age-structure of the study populations and those of a stable population can be largely attributed to the selective cropping of pods prior to the start of the study. Simulations indicate that the population could sustain a maximum non-selective harvest of 2.84%; or maximum selective harvests of 4.70% of juveniles or 8.34% of adults, which represented total population harvest levels of 1.89% and 3.17% respectively. Sensitivity analyses reveal that populations are robust to changes in mortality rates, particularly adult mortality rates, which implies that density dependence is expressed primarily through changes in reproductive parameters. It is predicted that (1) a stationary population at carrying capacity will comprise 37% juveniles, 20% mature males, 14% reproductive females and 29% post-reproductive females; and (2) in a stationary population, females surviving to the end of their 14.0 year reproductive lifespan will produce an average of 2.0 calves.

population in British Columbia was estimated to have numbered 75000-88000 in 1988, compared with 9000-10500 when the species was protected in 1970. Despite the recent increases, which probably reflect the recovery from historic kills, there was no evidence of density-dependent changes in the population growth rate.

Olesiuk, P. F.; Bigg, M. A.; Ellis, G. M.; Crockford, S. J.; Wigen, R. J. (1990)

An assessment of the feeding habits of harbour seals (Phoca vitulina) in the Strait of Georgia, British Columbia, Based on Scat Analysis

Can. Tech. Rep. Fish. Aquatic Sci 1730. 1-135.

ABSTRACT
Seasonal and regional variations in the diet of harbour seals in the Strait of Georgia were described based on 2841 scat samples collected from 58 sites (11 estuaries and 47 non-estuary haulouts) in all months, and the diet compared with the diet in other regions of the province based on 159 samples. Prey remnants were separated from other faecal matter using an elutriator and prey identified using a wide variety of structures including otoliths, teeth, vertebrae, cranial, appendicular and caudal elements, scutes and spines. Otoliths alone provided an incomplete and biased representation of the diet. We derived and employed a new index, referred to as a split-sample frequency of occurrence, to assess the relative importance of prey. The validity of the assumptions underlying the index, and scat analyses in general, were addressed. Annual prey consumption was estimated by combining dietary information with data on the abundance and distribution of seals and estimates of their daily food requirements. The diet in the Strait of Georgia was dominated by Pacific hake and herring, which comprised 42.6 and 32.4% of the overall diet respectively. The former was consumed primarily during April-November, which coincided with the post-spawning dispersal and movement of hake to shallower water, and the latter mainly during December-March, which coincided with the pre-spawning emigration of herring into the Strait of Georgia. Annual hake consumption in 1988 was estimated at 4214 tonnes, which represented 3.5% of the total stock biomass or 71% of mean recent commercial harvests. Annual herring consumption was estimated at 322.6 tonnes, which represented 3.2% of the total stock biomass or 27% of mean recent commercial harvests. Salmonids comprised 4% of the overall diet and consisted mainly of adult salmon that were taken as they returned to rivers to spawn, especially in estuaries. However, predation on trout also appeared to have been significant in localized areas. Annual salmonid consumption was estimated at 394 tonnes, which represented approximately 2.8% of mean recent annual excapement. Lingcod comprised 3.0% of the overall diet and were preyed upon mainly during November-April when males were defending nets. Annual lingcod consumption was estimated at 294 tonnes, which was roughly equivalent to the recent commercial and sport harvests combined. Other important prey in the Strait of Georgia were plainfin midshipman (3.4% of overall diet), surfperches (2.3%), cephalopods (2.1%), flatfishes (1.2%), sculpins (1.2%) and rockfishes (1.1%). The Strait of Georgia data, and the limited data collected from other regions, indicate the harbour seal is an opportunistic predator in that diets varied regionally and seasonally depending on the local availability of prey.

Newby, T. C. (1973)

Changes in the Washington State Harbor seal population, 1942-1972

Murrelet 54. 4-6.

ABSTRACT
A major decline of harbor seals was noted in the Nisqually Delta in southern Puget Sound from the 1940s through the 1960s due to extensive bounty hunting. The total Washington population declined from about 5,000 to 6,000 seals in the 1930s to fewer than 2,000 in 1971.

Nishiwaki, M.; Sasao, A. (1977)

Human activities disturbing natural migration routes of whales

Sci. Rep. Whales Res. Inst. 29. 113-120.

ABSTRACT
Human activities which disturbed natural migration routes of 2 whale populations were investigated. In Tokyo Bay (Japan) the annual catch of the Baird's beaked whale (Berardius bairdii) in the Boso whaling grounds is between 50-300. Although the whales showed no signs of average body length decrease, an apparent decrease of whales despite increasing catch per unit effort indicates that the maritime transportation has disturbed the migration routes of these whales. This also occurs on the northern coast of Kyushyu. The reason for the catch decline cannot be damage by whaling as in the minke whale (Balaenoptera acutorostrata). Catch per unit effort is, as a whole, increasing, but the number of whales caught is decreasing without average body length decrease. Great numbers of vessels are coming into and going out of both areas, and the number is still increasing. Not only these whales, but also various species of marine mammals may be troubled by the bay traffic. Warning about the activities by man which disturb or expel wild animals from their natural habitats and migration routes are suggested.

Olesiuk, P. F.; Bigg, M. A.; Ellis, G. M. (1990)

Recent trends in the abundance of harbour seals, Phoca vitulina, in British Columbia

Can. J. Fish. Aquat. Sci 47. 992-1003.

ABSTRACT
Aerial censuses of harbour seals (Phoca vitulina) were conducted in the Strait of Georgia (1966-88), the lower Skeena River (1977-87), off the southwest coast of Vancouver Island (1976-87), off the northeast coast of the Queen Charlotte Islands (1986), in Jervis Inlet (1987), and at the entrance to Queen Charlotte Strait (1988). The estimated number of seals in the Strait of Georgia, the primary study area, increased from 2170 in 1973 to 15180 in 1988; the number in the lower Skeena River from 520 in 1977 to 1590 in 1987; and the number off southwestern Vancouver Island from 210 in 1976 to 1130 in 1987. The trends indicated that populations throughout British Columbia had been increasing at a rate of about 12.5%/year since 1973. Based on the density of seals in the areas surveyed, and the relative distribution of bounty and commercial kills, the total post-pupping

the whaling stations provide evidence of encounters with killer whales (though there is no way of telling where or when the attempts at predation occurred). Jukker whales enter embayments along the coast of Newfoundland and are known from as far up the St. Lawrence as the Saguenay River confluence. In the past at least, they apparently preyed on the formerly large population of white whales, Delphinapterus leucas, in the St. Lawrence Estuary. There are few records from Nova Scotia and the Bay of Fundy. In New England, killer whales are sighted annually off Cape Cod, pparticularly in autumn, presumably as they follow migrating bluefin tuna, Thunnus thynnus, inshore. Winter records from the southeast U.S., the Bahamas and the West Indies support the hypothesis that at least some killer whales in the western North Atlantic undertake a north-south seasonal migration. However, there are also summer records in the Caribbean region. Therefore, two or more stocks may occur in the Northwest Atlantic or the migration scheme may be complicated.

Neff, J. M. (1990)

Effects of oil on Marine Mammal Populations: Model Simulations

In: Sea Mammals and Oil: Confronting the Risks

St. Aubin, J. R.; St. Aubin, D. J., eds. Pages 35-54

Academic Press, New York

ABSTRACT
The effect of an oil spill on a population of marine mammals can be assessed in a number of ways. One is to use a mathematical model that incorporates information on the behavior of spilled oil with data on the life history of the species in question. Also needed is some understanding of direct and indirect effects of oil on individuals--the kind of information usually generated from field observations and experimental studies. The advantage of a computer model is that it always produces a result: a prediction of impact. Modeling may be applied as part of risk assessment when developimg offshore oil reserves. Models were created for the impacts of oil on marine mammals in the Southern California Bight, northern fur seals in the Bering Sea, bowhead and gray whales in Alaskan waters and sea otters in California. These modeling efforts are examples of the state of development of the approach. They can be quite sophisticated, incorporating a full range of environmental influences on oil and movements of animals that might contact it. When assumptions are made regarding mortality, the models can project the rate and degree to which a population recovers. A notable weakness in this scheme is that for most species, effects of contact are poorly understood, and the premise that contact is fatal is both extreme and results in gross overestimates of the impact of a spill. It is critical then to define more precisely how oil affects an animal. This can be done by combining direct observations and experimental studies with an understanding of life history, habitat use, social organization, demography, and other elements that can be used to measure the vulnerability of an animal to oil.

Aleutian Islands, during June-July of 1984-86. Counts of northern sea lions from these surverys were compared with counts made in 1956-62 and 1975-79. These data indicated that the number of adults and juveniles onshore declined 52% from 140,000 animals in 1956-60 to 68,000 in 1985 - an annual rate of decline of at least 2.7%. Numbers have declined throughout the region, with the greatest declines in the eastern Aleutian Islands (79%) and the least in the central Aleutian Islands (8%). This was not due to emigration because significant increases have not been noted elsewhere. Between the 1960s and mid-1970s, there were large decreases in the eastern Aleutian Islands and western Gulf of Alaska, and a major increase in the central Aleutian Islands. Beginning in the late 1970s declines occurred in all areas. The cause of the declines are unknown, but they may be associated with disease, prey availability or quality, or a combined effect of these and other factors. Factors which may contribute to the declines include the pre-1973 commercial harvests, entanglement of juveniles in marine debris, incidental takes in fisheries, and killing by fisherman.

Mikhalev, Y. A.; Ivashin, M. V.; Savusin, V. P.; Zelenaya, F. E. (1981)

The distribution and biology of killer whales in the Southern Hemisphere

Rep. int. Whal. Commn 31. 551-566.

ABSTRACT
Biological and distributional data for Southern Hemisphere killer whales, collected between 1961/62 and 1978/79 are analysed. It appears that killer whales are found in warm waters in winter and migrate into high latitudes in the summer. From the available data six populations of killer whales are proposed (classified by their winter distribution): Western American; Eastern American; Western African; Eastern African; Western Australian; Eastern Australian; although it is believed that further populations will be determined in the future for the open waters of the Atlantic, Indian and Pacific Oceans. The migration appears to be linked with that of its prey species, in particular the minke whale. Morphological and reproductive data are presented and discussed. A new species of killer whale, the dwarf killer whale Orcinus nanus is proposed.

Mitchell, E.; Reeves, R. R. (1988)

Records of killer whales in the western North Atlantic, with emphasis on eastern Canadian waters

Rit Fiskideildar 11. 161-193.

ABSTRACT
Published records of killer whales, Orcinus orca, in the western North Atlantic, from central Labrador (about 55°N) south to the West Indies, were compiled. We also compiled unpublishe records, with emphasis on eastern Canadian waters, from statistics of Canada's east-coast shore whaling industry, data from Canadian whale sighting and tagging cruises in 1966-1973, the files of the Arctic Biological Station and other sources.

Although killer whales were taken only rarely by whalers in southern Labroador, Newfoundland and Nova Scotia, these whales were known to frequent the whaling grounds. In addition to the writen and verbal reports of observations by the whalemen, the wounds and scars on mysticetes landed at

top-down, driving functions in a Bering Sea model, which accordingly cannot be used to analyze or manage their populations. Some Soviet models are tantalizing but ill-specified. The introduction of harbor seals in well-chosen lakes might give more insights into system roles than would more elaborate modelling. We wonder if pinniped ecology is well served by too many enthusiasts operating under too many restraints.

McLaren, I. A. (1990)

Pinnipeds and Oil: Ecologic Perspectives

In: Sea Mammals and Oil: Confronting the Risks

Geraci, J. R.; St. Aubin, D. J., eds. Pages 55-101

Academic Press, New York

ABSTRACT
Pinnipeds share many characteristics with other marine mammals, and indeed with large mammals in general, expecially in demographic features, energetics, and social behavior. This allows us to draw on a wide range if empirical and theoretical literature to assess possible responses of pinnipeds to an environmental impact. Their amphibious nature poses special circumstances under which they face such threats. If we take as a premise that an oil pollution catastrophe has produced a large kill of pinnipeds, it is important to consider the rate at which the population is restored to its original level. Indeed, rate of return to "mormality" is often an explicit component of environmental impact statements. The rate of recovery depends on the species and circumstances; the estimates available are for populations of pinnipeds under conditions that probably produce close to the maximun values. Those closer to equilibrium should show a less enhanced rate of increase following substantial reduction of numbers. A population already limited by the carrying capacity of the environment may not be capable of producing an immediate population response. Some species, such as the northern fur seal and Steller's sea lion, are indeed declining, presumably because the carrying capacity of their environments is in some way deteriorating. For these, a catastrophic kill might not be followed by population recovery. The rate of recovery of a seal population will also depend on the segments of the population that are killed. Loss of a year's offspring is more quickly compensated than is an equivalent loss of all age groups from the population, particularly of adults. Yet even the long recovery time for populations at equilibrium before a catastrophe might be optimistic if individuals in crowded environments fail to respond to population reduction.

Merrick, R. L.; Loughlin, T. R.; Calkins, D. G. (1987)

Decline in abundance of the northern sea lion, Eumetopias jubatus, in Alaska, 1956-1986

U.S. Fish. Bull. 85. 351-365.

ABSTRACT
Aerial, ship, and onshore surveys were conducted to assess the abundance of northern sea lions, Eumetopias jubatus, in southwestern Alaska, from the central Gulf of Alaska through the central

enough food since they and their young were in poor condition and suffered higher mortality. Sea lions were similarly affected.

McLaren, I. A.; Smith, T. G. (1985)

Population ecology of seals: retrospective and prospective views

Mar. Mamm. Sci. 1 (1). 54-83.

ABSTRACT
This review focuses on population ecology, with critical accounts of past work and future possibilities in age determination, body growth and condition, estimating abundances, mortality rates and lifespans, reproduction, comparative life histories, population dynamics, population modelling and seals in ecosystems. We suggest ways to reduce errors in age determination and to improve methods of obtaining and presenting growth data. Generalized van Bertalanffy growth equations are promoted as a basis for analyzing species differences and intra-population variation in body lengths. Indices other than blubber thickness may be better for following body condition. Catch-effort and survival-index methods of estimating abundances have limited applicability, total counts are only locally useful, and sample counts may only be accurate for scattered, ice-breeding species. Some new techniques for population indices are promising. Pre-adult mortality remains difficult to assess. Although not always recognized, adult mortality rates do increase with age, as well described by Gompertz functions. Existing estimates of lifespans are unreliable, and a new approach is outlined. There are methodological problems in estimating ages of maturity. Corpora albicantia should not be used for back-extrapolation, and more study is needed of use of teeth annuli as indicators of maturity. Age-specific proportions of females parous based on reproductive tracts may disagree with proportions recruited in breeding groups, suggesting that the former may often be in error. Allometric relationships among body sizes and life-history variables need more reliable data, especially since the residuals of such relationships are of greater interest. Brain size may be a better scalar. Direct evidence of density dependence in population growth of seals is sparse. Early survival has been more widely shown to be density-dependent, but only among polygynous species where crowding on land may be a byproduct of sexual selection; there is as yet no good evidence of trophic restraints. Evidence of density dependence of ages of maturity is generally unconvincing. Predation, especially by sharks, my be critical in some species. Characteristics of equilibrium populations might profitably be sought in mass remains in middens and historic kill sites. More attention should be paid to the search for density-dependent influences. Supposed impacts of fisheries and pollutions are not wholly convincing. Natural epidemics may keep some populations below resource or space saturation, and some high-latitude species may show large year-to-year variations in recruitment and abundances. Evidence for such density-independent effects should be sought in residuals of growth curves and in teeth layers. Although surplus yield and production/biomass models have been tried, realistic pinniped models must be completely age-structured and time-dependent. Simple models have questionably assumed stationarity to derive life-history parameters. The best available estimates of density dependence of such parameters give no resolution when extrapolated toward equilibrium, and only limited efforts have been made to introduce stochasticity. Better data, not improved model structures, are needed for better understanding. Recent work has contradicted the assumed voraciousness of seals, but their system impacts and dependencies are not well understood. Extended Lotka-Vloterra equations used to model Antarctic food webs, including seals, are merely heuristic. Fixed seal biomasses enter as

Lowry, L. F.; Frost, K. J.; Loughlin, T. R. (1988)

Importance of walleye pollock in the diets of marine mammals in the Gulf of Alaska and Bering Sea, and implications for fishery management

Proc. Int. Symp. Biol. Mgmt. Walleye Pollock Nov. 1988, Anchorage, Alaska.

ABSTRACT
Approximately 31 species of marine mammals occur at least seasonally in portions of the Gulf of Alaska and Bering Sea. Walleye pollock are eaten to some degree by euryphagous baleen whales, including fin, minke, humpback, and sei whales, and have been found in the stomachs of sperm whales and Dall's porpoise. Pollock may be a seasonally important food for belukha whales, harbor porpoises, and killer whales. Pollock are the most important food (35% of total energy intake) of northern fur seals in the eastern Bering Sea in summer and are also eaten in the Gulf of Alaska. Pollock composed 58% of the stomach contents of Steller sea lions and 21% of the stomach contents of harbor seals collected in the Gulf of Alaska, and are also important prey in the Bering Sea. Pollock are important foods for spotted and ribbon seals when they are associated with the Bering Sea ice front during March-June, and are sometimes eaten by bearded seals.

Foraging activities of marine mammals may affect walleye pollock populations by: (1) influencing abundance of certain size/age classes directly through predation; (2) influencing the productivity of pollock populations by feeding on the same prey base (e.g., copepods, euphausiids, and forage fishes); and (3) preying on species that are competitors or predators of pollock. Conversely, pollock fisheries may affect marine mammals by altering the abundance and age-class structures of pollock stocks and incidentally killing marine mammals during fishing activities. Available data are not adequate to accurately model or monitor interactions between marine mammals, pollock populations, and pollock fisheries. Clearly both fisheries and marine mammals remove large amounts of pollock from a complex and dynamic ecosystem. Changes in population status of marine mammals, whether or not they are directly caused by fishing activities, may have major consequences for fishery management.

Majluf, P. (1991)

El Nino effects on pinnipeds in Peru

In: Pinnipeds and El Nino: Responses to environmental stress

Trillmich, F.; Ono, K., eds. Pages 55-74

Springer-Verlag, Berlin

ABSTRACT
The foraging behaviour, diet, pup growth and mortality of the fur seals and sea lions in Peru under EN and non-EN conditions are compared. During the EN, female fur seals had to dive more often to greater depths and they spent longer times at sea foraging. They were still not able to obtain

Loughlin, T. R.; Miller, R. V. (1989)

Growth of the northern fur seal colony on Bogoslof Island, Alaska

Arctic 42 (4). 368-372.

ABSTRACT
Northern fur seal, Callorhinus ursinus, pups were first observed on Bogoslof Island, southeast Bering Sea, in 1980. By 1988 the population had grown at a rate of 57%/year to over 400 individuals, including 80+ pups, 159 adult females, 22 territorial males, and 188 subadult males. Some animals originated from rookeries of the Commander Islands, whereas others are probably from the Pribilof Islands. In 1983 and 1985 over 50% of the females were estimatd to be >6 years of age, based on vibrissae color. The rookery is in the same location where solitary male fur seals were seen in 1976 and 1979 and is adjacent to a large northern sea lion rookery.

Lowry, L. F.; Frost, K. J. (1981)

Feeding and trophic relationships of phocid seals and walruses in the Eastern Bering Sea

In: The eastern Bering Sea shelf: oceanography and resources, Vol. 2

Hood, D. W.; Calder, J. A., eds. Pages 813-824

Office of Marine Pollution Assessment, NOAA, BLM, Seattle

ABSTRACT
Recent data on food habits of five species of phocid seals and walruses (Odobenus rosmarus) in the eastern Bering Sea are reviewed. Harbor seals (Phoca vitulina richardsi), spotted seals (Phoca largha), and ribbon seals (Phoca fasciata) all feed to a large extent on pelagic and semidemersal fishes. Demersal fishes are eaten by all three of these species but appear to be of greatest importance in the diet of ribbon seals. Crustaceans and octopus (Octopus spp.) are also eaten. Ringed seals (Phoca hispida) also feed on pelagic and semidemersal fishes. Crustaceans make up a considerable portion of the diet of ringed seals, especially young animals. Bearded seals (Erignathus barbatus) and walruses feed primarily on benthic organisms. Walruses feed almost exclusively on clams. Clams, crabs and shrimp make up the bulk of the diet of bearded seals. Geographical, seasonal, year-to-year, and age-related variations in feeding are evident in all species for which sufficiently large samples have been examined. Harbor, spotted, ribbon, and ringed seals all depend primarily on a pelagic food web and compete for food with one another and with fur seals (Callorhinus ursinus), sea lions (Eumetopias jubatus), cetaceans, and seabirds. Walruses and bearded seals compete for clams in some areas. Gray whales (Eschrichtius robustus) feed on benthic crustaceans, which are also eaten by bearded seals and walruses. Commercial fisheries harvest a portion of the food resource of Bering Sea pinnipeds which may influence populations of some species. Available data on foods of phocid seals and walruses are inadequate in all sesaons and in all regions excerpt the northen Bering Sea. Data are lacking for all species in southern and central regions during winter months, for walruses in all areas and seasons, and for harbor seals in the southeastern Bering Sea.

Loughlin, T. R.; Nelson, R., Jr. (1986)

Incidental mortality of northern sea lions in Shelikof Strait, Alaska

Mar. Mamm. Sci. 2 (1). 14-33.

ABSTRACT
The incidental catch of northern sea lions (Eumetopias jubatus) in the walleye pollock (Theragra chalcogramma) joint-venture fishery in Shelikof Strait, Alaska, was studied during 1982-1984 to assess the nature and magnitude of the catch. Data were obtained by placing U.S. observers on foreign processing vessels. Dead sea lions recovered from trawl nets were counted, sexed and measured; teeth were removed for age determination by dental laminae; and stomach contents were analyzed. Although the fishery has continued to expand both in number of boats and estimated total catch (74,136 metric tons [t] in 1982 to 171,539 t in 1984), the estimated incidental catch of northern sea lions has declined (ranging from 958 to 1,436 in 1982, 216 to 324 in 1983 and 237 to 355 in 1984). Of the sea lions processed, 73 percent were caught between 2000 and 0500 h, probably during net retrieval. Most caught sea lions were females ranging in age from 1-25 yr with a mean age of 6.43 yr; 79 percent of the females were sexually mature and probably part of the reproducing population. Males had a mean age of 4.8 yr and only 12 percent were old enough to obtain and defend territories. Analysis of stomach contents showed that the sea lions consumed pollock the same size as that taken by the commercial fishery. The impact of the incidental catch on the Gulf of Alaska sea lion population is unknown.

Loughlin, T. R.; Merrick, R. L. (1988)

Comparison of commercial harvest of walleye pollock and norther sea lion abundance in the Bering Sea and Gulf of Alaska

In: Proceedings of the International Symposium on Biological Management (89-1)

Melteff, B., ed. Pages 679-700

Alaska Sea Grant, Anchorage

ABSTRACT
Northern sea lions are declining in most of Alaska and the synergistic effects of commercial fisheries have been mentioned as one plausible reason for the decline. We examined walleye pollock commercial fishing catch data for 1971-1986 to assess the possible role of the indirect effect of fish removal on northern sea lion abundance trends in the Bering Sea and Gulf of Alaska. The commercial catch in areas near major sea lion rookeries was compared with trends in sea lion abundance and correlation coefficients calculated. Results from the analysis were inconclusive although in some areas, such as the eastern Aleutian Islands and central Gulf of Alaska, high correlation between the amount of fish caught and sea lion abundance trends were apparent, while in other areas the correlation was equivocal.

Leatherwood, S.; Matkin, C. O.; Hall, J. D.; Ellis, G. M. (1990)

Killer whales, Orcinus orca, photo-identified in Prince William Sound, Alaska, 1976 through 1987

Can. Field Nat. 104 (3). 362-371.

ABSTRACT
Individual Killer Whales, Orcinus orca, were identified from photographs taken incidental to other research (1976-1983) or during intensive studies of the species (1984-1987) in Prince William Sound (PWS), Alaska. The 232 identified animals were grouped into pods, based on observed associations, and assigned to the following conservatively defined age/sex categories: adult males (52, 22.41%), adult females (22, 9.48%), calves born in 1986 or 1987 (9, 3.9%) or 'immatures/others' of both sexes (149, 64.22%). Because of imprecision, this last category may include some adult females, as an animal was only classified as adult female if it was closely associated with a calf, and some recently matured adult males. Age/sex composition in PWS is similar to that noted for other areas of the eastern North Pacific and for Iceland, but caution is indicated in using such data. There were at least 13 births in PWS from 1985 through 1987. In 1984, calves were grouped with 'juveniles'. The 4 newborn calves first detected in 1985 are now classified as 'immature/others'. The combined mortality rate of 1.9% in three pods (AB, AE, AI) is similar to that in British Columbia and Washington (1.7 percent), while that in AB pod (7.4 percent) is significantly higher. Members of AB pod have been interfering with a longline fishery for Sablefish (Blackcod), Anoplopoma fimbrica, since 1985. At least 10 (possibly 14) members of AB pod were reported wounded by gunshot between late 1984 and fall 1986, some apparently fatally. There were no new bullet wounds detected in 1987. Although no carcasses were found, from 1986 to 1987, there were apparently 7 deaths in AB pod, 2 in AE pod, and one each in AK and AN pods, leaving a documented minimum population of 221 whales in PWS by the end of the 1987 season.

Loughlin, T. R.; Rugh, D. J.; Fiscus, C. H. (1984)

Northern sea lion distribution and abundance: 1956-80

J. Wildl. Manage. 48 (3). 729-740.

ABSTRACT
The present distribution and abundance of the northern sea lion (Eumetopias jubatus) was determined from surveys made between 1975 and 1980 and compared to estimates made approximately 20 years earlier. The previous population estimate of 240,000-300,000 is similar to our estimate of 245,000-290,000. Declines appear to have occurred in the eastern Aleutian Islands, Pribilof Islands, and near Kodiak Island in the Gulf of Alaska. Increases may have occurred prinicipally in the western and central Aleutians and west of Kodiak Island. Seasonal movements and indirect and direct effects by humans are considered the likely causes for regional changes in distribution and abundance.

Laws, R. M. (1992)

History and present status of southern elephant seal populations.

In: Elephant seals

Le Boeuf, B. J.; Laws, R. M., eds. Need Page Numbers

University of California Press, Berkeley

ABSTRACT
The population history (sealing) and recent trends are reviewed for southern elephant seal (Mirounga leonina) colonies. The colony at South Georgia has remained stable over the past several decades, one new colony on the South American Atlantic coast has increased, whereas colonies at many other locations have, for unknown reasons, declined.

Leatherwood, S.; Bowles, A. E.; Krygier, E.; Hall, J. D.; Ignell, S. (1984)

Killer whales (Orcinus orca) in southeast Alaska, Prince William Sound, and Shelifkof Strait; a review of available information

Rep. int. Whal. Commn 34. 521-530.

ABSTRACT
Information on killer whales in summarized from a formal sightings network, 1976-1981 (Southeast Alaska), aerial surveys, 1976-1978 and small boat surveys, 19976-1982 (Prince Willian Sound), aerial surveys, 1982-1983 (Shelikof Strait), and interviews with marine scientists, fishermen and other knowledgeable mariners (all areas). Although present year-round, killer whales in each area increase in numbers and concentrate in specific areas in late summer through early fall, apparently in response to concentrations of salmon. In Prince William Sound, one group apparently remains within a limited home-range (less than 25 km radius) in Knight Island Passage each summer. Minimum counts from portions of the three areas are 93, 80 and 66 whales, respectively. Data indicate concurrent presence of killer whales in other unstudied portions of all three areas; so, 'populations' in each area certainly number in excess of 100 animals. Herbs included an average of 4-6 animals (n = 890) in Southeast Alaska. Of the three areas surveyed, Prince Willian Sound and Southeast Alaska appear most suitable as areas for long-term observational studies of killer whales of the sort pioneered in inland waters of Washington and British Columbia.

birthing in the region while the proportion of males increased through the breeding season at the other site. No increase in the number of adults, in total, was detected over the study period, suggesting that sexual segregation and not a change in haul-out frequency was responsible for the disparity in the sex structure of the two groups. The proportion of juveniles was signigicantly greater at the male dominated site than at the nursery site.

Krieber, M.; Barrette, C. (1984)

Aggregation behaviour of harbour seals at Forillon National Park, Canada

J. Anim. Ecol. 53. 913-928.

ABSTRACT
(1) In order to explain the aggregation behaviour of harbour seals (Phoca vitulina) at their landing sites, two possibilities were investigated: grouping in response to resting site distribution, or in response to changes in individual time-energy budget. (2) To verify if seals aggregated according to the distribution of their landing sites, we studied their site selection. Although seals select sites with distinctive features, they frequented only those whose area was sufficient or that were close enough to other suitable sites to hold a tight resting group. Hence, the distribution of landing sites was ruled out as the sole factor explaining aggregation. (3) By a closer look into time budgeting, we found that membership in a group generated an individual benefit. This takes the form of an increased time allocation to sleep in larger and tighter groups. While individual scanning rate decreased with group size and proximity, overall vigilance increased with group size and decreased with proximity. Although evidently desiring to join larger and tighter groups, seals saw their density regulated on each site by aggressive interactions. Rate of aggressive interaction did not vary with density, but the proportion leading to departures increase with density. No fighting advantage was found in larger size, but the first animal to land on the site was generally the winner. (4) Changes in the landing behaviour in relation to weather were consistent with other studies. However, seasonal weather trends could not fully explain the increase in group size from spring to autumn, during which time the proportion of used space remained roughly constant.

Lander, R. H. (1981)

A life table and biomass estimate for Alaskan fur seals

Fish. Res. 1. 55-70.

ABSTRACT
Data on growth rates (8% per year, 1911-1924), adult female survival, immature female survival, and fecundity are presented for Callorhinus at the Pribilof Islands.

and have their last calf before age 40 years, even though they may live up to 63 years. In contrast males have a maximum longevity of only 46 years and probably continue to be capable of reproduction until death. In males, puberty begins at 7 to 17 (X = 14.6) years and social maturity at an average of 17 years.

The age composition suggests that the total mortality rate is lowest in the post-pubertal stage and that it increases after age 28 (male) or age 46 (female). Males have a higher total mortality rate than females at any given age. The juvenile total mortality rate is probably higher than that of post-pubertal animals. These differences in total mortality rates may reflect differences in natural mortality rates. Using an hypothetical stationary population model, we estimate that the total annual mortality rate over all age classes is 8.3% (male) and 4.5% (female). Thus there are more reproductive females than adult males. The mating system is polygynous. Males may migrate between schools after weaning. However, females probably stay in their mother's school for life, so that the breeding schools are essentially matrilineal kinship groups.

Kerley, G. I. H. (1983)

Relative populations sizes and trends, and hybridization of fur seals Arctocephalus tropicalis and A. gazella at the Prince Edward Islands, Southern Ocean

S. Afr. J. Zool. 18. 388-392.

ABSTRACT
Fur seals were counted at the Prince Edward Islands during the 1981/1982 austral summer. Classified counts, adjusted for pup undercounting and mortality, pregnancy rate and seasonal haulout patterns, of Arctocephalus tropicalis and A. gazella are presented. These populations have entered a phase of rapid growth, as indicated by higher rates of population growth than previously found. The possible role a A. gazella immigration is unknown. There has been an increase in the number of breeding localities used by both species . At present the extent of hybridization between these two species appears limited, possibly by behavioural, ecological and genetic processes.

Kovacs, K. M.; Jonas, K. M.; Welke, S. E. (1990)

Sex and age segregation by Phoca vitulina concolor at haul-out sites during the breeding season in the Passamaquoddy Bay region, New Brunswick

Mar. Mamm. Sci. 6 (3). 204-214.

ABSTRACT
The size and composition of groups of harbor seals at two haul-out sites were studied during the breeding season of 1989, in the Passamaquoddy Bay region of Atlantic Canada. Evidence of segregation both by age and sex was found in the distinct compostion of the two groups. One group contained mainly males and no pups, and the other had a sex ratio not significantly different from one and contained pups. The proportion of females increased at the nursery site with the onset of

Kannan, N.; Tanabe, S.; Ono, M.; Tatsukawa, R. (1989)

Critical evaluation of polychlorinated biphenyl toxicity in terrestrial and marine mammals: increasing impact of Non-ortho and Mono-ortho coplanar polychlorinated biphenyls from land to ocean

Arch. Environ. Contam. Toxicol. 18. 850-857.

ABSTRACT
Residues of potentially toxic non-ortho chlorine substituted coplanar 3,3',4,4'-tetra-3,3',4,4',5-penta-, 3,3'4,4',5,5'-hexachlorobiphenyl and their mono- and di-ortho analogs (2,3',4,4',5-penta-,2,3,3',4,4'-penta, 2,3,3',4,4',5-hexa and 2,2'3,3'4,4'-hexa, 2,2'3,4,4',5-hexachlorobiphenyl) wer determined in humans, dogs, cats (terrestrial), a finless porpoise (Neophocoena phocoenoides-coastal), Dall's porpoises (Phocoenoides dalli, dalli), Baird's beaked whales (Berardius bairdii) and killer whales (Orcinus orca-open ocean). Among the coplanar polychlorinated biphenyl (PCB) congeners, the concentration of the di-ortho congeners was the highest and the non-ortho congeners was the lowest. However, all three coplanar PCBs occurred at significantly higher levels than toxic polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). The relative biocentration and metabolic capacity of terrestrial and marine mammals to these chemicals, suggest that the toxic threat of coplanar PCBs increases from land to ocean, but the reverse is true for PCDDs and PCDFs. The toxic threat of coplanar PCBs to higher aquatic predators such as cetaceans was principally assessed by 2,3,7,8-T4CDD Toxic Equivalent Analysis which is based on the induction of arylhydrocarbon hydroxylase (AHH) and ethoxyresorufin)-deethylase (EROD). Analysis indicates, in particular, that the bioaccumulation of toxic 3,3',4,4',5-penta-and 2,3,3',4,4'-pentachlorobiphenyls in carnivorous marine mammals is a cause for considerable concern.

Kasuya, T.; Marsh, H. (1984)

Life history and reproductive biology of the short-finned pilot whale, Globicephala macrorhynchus, off the Pacific coast of Japan

In: Reproduction in whales, dolphins and porpoises. Reports of the International Whaling Commission (Special Issue 6)

Perrin, W. F.; Brownell, R. L. Jr.; DeMaster, D. P., eds. Pages 259-310

International Whaling Commission, Cambridge

ABSTRACT
After a period of heavier exploitation in the 1940s, the short-finned pilot whale has been hunted at a lower rate of several hundreds per year by a small-type-whaling and drive fishery off the Pacific coast of Japan. Age data from 373 females and 170 males obtained from 27 schools which were stranded or driven during the 17-years period from 1965 cover all months except March, April, September and November. Breeding is diffusely seasonal, with a single parturition peak in July-August. A single calf is born at a mean body length of 140 cm after 14.9 months gestation and nursed for a minimum of about two years. Calves of older cows may be nursed for considerably longer than this. Females mature at 7-12 (X = 9.0) years, produce an average of four to five calves,

Jones, M. L. (1990)

The reproductive cycle in gray whales based on photographic resighting of females on the breeding grounds from 1977-82

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 177-182

International Whaling Commission, Cambridge

ABSTRACT
Gray whales (Eschrichitus robustus) with distinctive natural markings were systematically photographed in San Ignacio Lagoon, Mexico from 1977 to 1982. In this paper, information is presented on breeding cycles for individually known females, including the range of values observed for length of calving interval and the relative frequencies of different length calving intervals (expressed in years). About 6,000 photographs were taken and 562 different gray whales were identified. Among these were 55 sexually mature females that were followed through 2 to 6 seasons on their winter breeding grounds; they produced a total of 115 calves over the 6-year period.

The length of time between the birth of consecutive calves was documented for 42 cows. Calving intervals ranged from 1-4 years, but were predominantly 2 years (1 calf every other year). The observed intervals were: 1 year (n = 1), 2 years (n = 48), 3 years (n = 6) and 4 years (n = 5). The mean length of the calving interval, or breeding cycle, for the population from 1977-82, was estimated as 2.11 (SD = 0.403) years.

Jonsgard, A.; Lyshoel, P. B. (1970)

A contribution to the knowledge of the biology of the killer whale Orcinus orca (L.)

Norw. J. Zool. 18 (1). 41-48.

ABSTRACT
Biological data from 1413 killer whales caught by Norwegian whalers in northeastern North Atlantic waters in the period 1938-1967 are examined. Four more killer whales were examined by two Norwegian biologists in 1967. The distribution and migration of killer whales in these waters seem to be dependent upon the distribution and migration of the herring. Mammals are eaten by larger killer whales. Females and males seem to attain sexual maturity when about 16 and 19 feet long respectively. The young are very close to 7 feet in length at birth. The breeding season may stretch over several months, although there is some evidence that relatively more calves are born in late autumn and winter. In length, adult females and males seldom exceed 26 and 30 feet respectively.

mitochondrial genome. Mitochondrial DNA variation indicated that two sympatric populations in the northeastern Pacific were as genetically distinct as North Pacific populations from a South Atlantic population. The two sympatric populations are known to pursue different foraging strategies. DNA fingerprinting showed very low levels of variation within populations relative to comparisons between allopatric populations, suggesting inbreeding. These results are consistent with predictions about the genetic structure of Killer whale populations based on behavioural observations and variation in colour morphology.

Hoover, A. A. (1988)

Harbor seal

In: Selected marine mammals of Alaska

Lentfer, J. W., ed. Pages 125-157

Marine Mammal Commission, Washington, D.C.

ABSTRACT
The life history and population biology of harbor seals in Alaska are reviewed and conservation, management, and research issues are discussed.

Jefferson, T. A. (1990)

Status of Dall's porpoise, Phocoenoides dalli, in Canada

Can. Field Nat. 104 (1). 112-116.

ABSTRACT
Dall's porpoise, Phocoenoides dalli, is one of the most commonly sighted cetaceans throughout its range in temperate waters of the North Pacific Ocean and surrounding seas. Dall's porpoises are common both offshore and in deep inshore waters of British Columbia. There appear to be few serious conservation problems in the eastern Pacific at present, although little is known of the behavior and ecology of this species. Probably the major threat facing this species in Canada is environmental contamination by such substances as organochlorines and heavy metals. Much more research is needed before these threats can be properly assessed but, in the meantime, a consevative approach to porpoise management is suggested.

Hindell, M. A. (1991)

Some life-history parameters of a declining population of southern elephant seals, Mirounga leonina

J. Anim. Ecol. 60. 119-134.

ABSTRACT
Mark-resight data were analysed for thirteen cohorts from a declining population of southern elephant seals branded at Maxquarie Island between 1951 and 1965. First year survival was essentially stable during the 1950s at about 46% for females and 42% for males. there was a dramatic fall in first year survival during the 1960s, declining to less than 2% for both sexes in 1965. Post-year-1 survival did not change between the 1950s and the 1960s. Comparisons with a stable population of southern elephant seals at South Georgia indicated that both first year and adult survival were lower in the Macquarie Island population. There were no changes in the age at first breeding of the Macquarie Island seals during the study, but this was on average 1 year later than at South Georgia. It is hypothesized that the current decline in elephant seal numbers at several of their major breeding islands is due to the populations returning to pre-sealing levels after they had risen to abnormally high levels with the end of commercial exploitation early this century. Possible tests of the hypothesis include studying the diet and foraging behaviour of southern elephant seals to gain an understanding of the predator-prey relationships, continuing to census the Macquarie Island population to determine if the population levels out at around the estimated pre-sealing levels, and monitoring northern elephant seal populations which were also severely exploited but are currently increasing rapidly.

Hoelzel, A. R.; Ford, J. K. B.; Dover, G. A. (1991)

A paternity test case for the killer whale (Orcinus orca) by DNA fingerprinting

Mar. Mamm. Sci. 7. 35-43.

ABSTRACT
The minisatellite DNA profiles from four captive killer whales (two adult males, a female and her calf) were compared to determine paternity between two potential fathers. One of the males was clearly excluded, while the other shared all paternal bands with the calf. The background of this technique, and its potential applications in captive breeding programs and field studies are discussed.

Hoelzel, A. R.; Dover, G. A. (1991)

Genetic differentiation between sympatric killer whale populations

Hered. 66. 191-195.

ABSTRACT
The genetic variation within and between putative Killer whale (Orcinus orca) populations was examined by DNA fingerprinting nuclear genomes and sequencing the D-loop region of the

an occlusion in one or both of the uterine horns, the proportion of both single (26%) and bilateral occlusions (16%) increasing with age. This membranous occlusion sealed up the uterine tract, forming a closed chamber with varying amounts and types of fluid. The average position of the occlusion was just over 60 mm from the tip of the horn, ranging from near the tip to the bifurcation. Other reproductive failures averaged 5%. Major changes took place in the reproductive status even during the period 1974-79, with the proportion of pregnant females dropping from over 30% to under 20% and cases of occlusion increasing from 35% to 59%. The numerous reproductive failures, possibly linked with hormonal imbalance and/or severe infections, at present form the most serious threat to the future of the Baltic seal population.

Hellou, J.; Huang, Y. S.; Upshall, C.; Ni, I. H.; Payne, J. F. (1991)

Polycyclic aromatic hydrocarbons in harp seals (Phoca groenlandica) from the Northwest Atlantic

Arch. Environ. Contam. Toxicol. 21. 135-140.

ABSTRACT
There is virtually no information available on concentrations of polycyclic aromatic hydrocarbons (PAH) in seals from any of the world's oceans. The largest harp seal population in the world is found in Canadian waters of the Northwest Atlantic. Samples of muscle tissue obtained from twenty eight harp seals ranging in age from foetuses to animals 22 years old were analyzed for total PAH and lipid content. Concentrations were determined in terms of crude oil and chrysene equivalents in line with recommendations of the International Oceanographic Commission. Overall,, relatively low concentrations were found, the highest values being less than 1 ppm in terms of chrysene equivalents and 4 ppm in terms of petroleum hydrocarbon equivalents. There was no evidence of bioaccumulation with age, the concentrations in juvenile seals (1-5 years) being higher than concentrations in older animals (6-20 years). t here was also no correlation between PAH concentration and fat content. There is a possibility that the animals having elevated levels of PAH are from the Gulf of St. Lawrence herd, indicating the importance of obtaining more information on PAH levels on marine mammals and other organisms from this and similar regionally contaminated seas.

Hes, A. D.; Rouse, G. P. (1983)

Population increase in the sub-Antarctic fur seal Arctocephalus tropicalis at Amsterdam Island

S. Afr. J. Antarct. Res. 13. 29-34.

ABSTRACT
The population of fur seals at Amsterdam Island increased 7.8% per year between 1955 and 1969.

are used to estimate changes in population size over the past century. After protection was introduced in the 1960s and 1970s the harbor seal population in the area increased at an exponential rate of 0.12 and exceeded 5,000 animals in 1986. The present rate of population growth is used for modelling the influence of fertility and age-specific mortality. It is found that the observed high rate of increase in only realistic if female feritily rate is very high, the range of juvenile mortality rate is 0.33-0.52 and adult mortality is less than 0.15. Commonly cited higher mortality rates are not realistic in the Kattegat-Skagerrak area.

Heimlich-Boran, J. R. (1988)

Behavioral ecology of killer whales (Orcinus orca) in the Pacific Northwest

Can. J. Zool. 66. 565-578.

ABSTRACT
Killer whales (Orcinus orca) were found to use different physio-graphic regions of their habitat in unique ways. Resident whales fed more in areas of high relief subsurface topography along salmon migratory routes, and may use these geographic features to increase feeding efficiency. Transient whales fed in shallow protected areas around concentrations of their prey, harbor seals (Phoca vitulina). Whales traveled across deep, featureless areas in moving from one feeding area to another. Whales rested depending on the previous sequence of behaviors and played in open water areas or adjacent to feeding areas. The location of food resources and habitiats suitable for prey capture appears to be the prime determining factor in the behavioral ecology of these whales. These patterns of behavior most likely represent cultural mechanisms that have been learned through trial and error experiences leading to successful foraging strategies.

Helle, E. (1980)

Lowered reproductive capacity in female ringed seals (Pusa hispida) in the Bothnian Bay, northern Baltic Sea, with special reference to uterine occlusions

Ann. Zool. Fennici 17. 147-158.

ABSTRACT
The reproduction of female ringed seals, Pusa hispida (Schreber), was studied in 225 specimens trapped with seal nets in October-November at Simo, on the northern Bothnian Bay (65°35'N, 25°00'E), and 28 specimens shot on the ice of the Bothnian Bay in April-May, 1973-79.

The ovulation frequency in mature specimens was 0.984. The sizes of the corpora lutea and c. albicantia were not dependent on maternal age. The c. luteum of the pregnant females was larger on average than the regressing c. luteum or c. albicans of the non-pregnant females in October-November, some 4 months after implantation. The proportion of normal pregnant females averaged 28%, decreasing from a maximum of 52% in the group aged 7-8 years to 8% in the females over 25 years of age. Females with normal ovulation but no macroscopic uterine signs of pregnancy, i.e. a missed pregnancy, were almost as common, reaching a maximum of 68% among the newly matured females aged 5-6 years, and averaging 23% thereafter. An average of 42% had

the Kattegat-Skagerrak are slightly smaller than the other two subspecies and have a relatively high rate of reproduction.

Harvey, J. T.; Brown, R. F.; Mate, B. R. (1990)

Abundance and distribution of harbor seals (Phoca vitulina) in Oregon, 1975-1983

Northwest. Nat. 71. 65-71.

ABSTRACT
Harbor seals were observed on 32 haulout sites in Oregon during aerial counts conducted from 1975 to 1983; 90% were seen on 14 sites. The greatest number of seals seen on a haulout was 985 recorded at Cape Arago in July 1982. Counts of harbor seals in 1982 and 1983 were 38.6% greater than counts from 1975 to 1980. These data indicate an increase in numbers of harbor seals in Oregon, an increase corroborated by other information, namely, lower counts made before 1975 and increased use of new haulout sites since 1975. Between 1975 and 1983, numbers within bays increased, whereas numbers on most offshore rocks remained somewhat constant. Decreased harassment and mortality since implementation of the Marine Mammal Protection Act of 1972 doubtless allowed harbor seals to increase in numbers and to reoccupy protected haulout sites in bays.

Harwood, J. (1981)

Managing gray seal populations for optimum stability

In: Dynamics of large mammal populations

Fowler, C. W.; Smith, T. D., eds. Pages 159-172

John Wiley and Sons, New York

ABSTRACT
The gray seal population (as measured by pup production) in the United Kingdom increased 6-7% annually from the mid-1960s through the late 1970s. Data collected over the past several decades are used to derive life table parameters and population projection matrices for British grey seals.

Heide-Jorgensen, M. P.; Härkönen, T. J. (1988)

Rebuilding seal stocks in the Kattegat-Skagerrak

Mar. Mamm. Sci. 4 (3). 231-246.

ABSTRACT
The harbor seal (Phoca vitulina) population in the Kattegat-Skagerrak area has been dwindling for several centuries due to excessive hunting pressure. Corrected hunting statistics during 1890-1976

present paper compares feeding habitats at two different localities. Three families of fish, gadoids, pleuronectids and clupeoids were predominant in the seals' diet at a rocky shore habitat. Pleuronectids made up 75% of the diet at a sandy shore habitat. Temporal variations in feeding habits are also examined. The results indicate that harbour seals are opportunistts in their choice of prey species, but some locally abundant species do not appear in the diet.

Härkönen, T.; Heide-Jorgensen, M. P. (1990)

Density and distribution of the ringed seal in the Bothnian Bay

Holarct. Ecol. 13. 122-129.

ABSTRACT
A modified strip census of basking ringed seals in the Bothnian Bay was carried out during the last week of April and the first week of May 1988. Of the total ice covered area, 23174 km^2, 3236 km^2 (14%) was covered by the transects. The mean density in the area was 0.101 ringed seals km^2, with substantial regional and local variation. Highest densities were found in the compact drift ice area. The estimated total population of ringed seals on the ice was 2093 in the Bothnian Bay proper and 248 in the North Quark. The 95% confidence limits of the estimates are ±24%.

Härkönen, T. J.; Heide-Jorgensen, M. P. (1990)

Comparative life histories of east Atlantic and other harbour seal populations

Ophelia 32 (3). 211-235.

ABSTRACT
During the seal epizootic in 1988 tissue samples were collected from harbour seals, Phoca vitulina vitulina, that died in the Kattegat-Skagerrak area. The material is used for describing life history and estimating vital parameters of East Atlantic harbour seals. From a similar size at birth of 81 cm and 8.7kg, females and males become sexually mature at 127 and 130 cm, which is close to 85% of the asymptotic lengths of 146 and 156 cm. Asymptotic weight is 67 and 75 kg for females and males respectively, but shows considerable fluctuation during seasons of parturition, mating and moulting. During lactation females lose 26 kg (35%), and males decrease from 72 to 62 kg during the July mating period. Females have a mean age at sexual maturity of 3.72 years and a mean age at first parturition of 4.64. Males mature one year later. The overall pregnancy rate of females was 92% from age 3 to age 36, with lowered reproductive success after the age of 25 years. Ovulation occurs mainly during July, with a distinct peak during the last two weeks of the month. Maximum age for females was 36 and for females was 36 and for males 341 years, and the sex ratio is skewed in favour offemales in older segments. Based on an exponential rate of population increase ($r=0.11$) survival rates were calculated at 0.91 for adult males, whereas age-specific pregnancy rates were used to demonstrate possible combinations of juvenile and adult survival in females. The East Atlantic harbour seal is identical in the schedule of its reproductive cycle to the subspecies Phoca vitulina concolor and P. vitulina richardsi, but differs in seasonal timing of reproduction. Harbour seals in Alaska exhibit greater asymptotic length and weight, but no statistically significant differences in growth or reproduction could be detected between subspecies. The harbour seals in

Guerra C., C. G.; Portflitt K., G. (1991)

El Nino effects on pinnipeds in northern Chile

In: Pinnipeds and El Nino: Responses to environmental stress

Trillmich, F.; Ono, K., eds. Pages 47-54

Springer-Verlag, Berlin

ABSTRACT
The changes in abundance and distribution of the southern sea lion and the south American fur seal are documented along the northern Chilean coast during the 1982-83 El Nino.

Hamilton, P. K.; Mayo, C. A. (1990)

Population characteristics of right whales (Eubalaena glacialis) observed in Cape Cod and Massachusetts Bays, 1978-1986

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 203-208

International Whaling Commission, Cambridge

ABSTRACT
Right whale, Eubalaena glacialis, occurrence in Cape Cod and Massachusetts Bays was investigated from 1978 through 1986. Using photo-identification techniques, a total of 113 individual whales were identified with a maximum of 47 whales sighted during a calendar year. Although whales were sighted in all months of the year except December, peak abundance occurred from February through April. Mothers with calves consistently appeared in April or later. The mean calving interval of nine mature females was three years. Residency in the study area varied from one to 165 days. An unusual summer residency group, including nine mother/calf pairs, present in the study area from July through October 1986, is discussed.

Harkonen, T. (1987)

Seasonal and regional variations in the feeding habits of the harbour seal, Phoca vitulina, in the Skagerrak and the Kattegat

J. Zool., Lond. 213. 535-543.

ABSTRACT
Studies of the feeding of harbour seals have been carried out at the Tjarno Marine Biological Laboratory since 1977. The studies are based on fish otoliths found in faeces at seal haulouts. The

seven. A decrease in the occurrence of mothers and calves in nearshore waters off the west coast of Maui, Hawaii during the 1977-88 study period was demonstrated.

Godsell, J. (1988)

Herd formation and haul-out behavior in harbour seals (Phoca vitulina)

J. Zool., Lond. 215. 83-98.

ABSTRACT
Haul-out patterns of individually marked harbour seals Phoca vitulina during the breeding season indicated that herds which formed along the extensive beaches of Sable Island, Canada did not represent stable social units. There was large variation in the number, size and composition of herds and no segregation of seals by age, sex or breeding condition. Marked seals hauled out with many different individuals but not frequently nor consistently with the same ones. Pairs of seals which hauled out in the same herds for up to 30% of their times ashore generally occurred together in only one area, which suggests that associations between individuals were the consequence of similar site use rather than because of social cohesion. However, nursing females showed high levels of site fidelity; this behaviour probably serves as a safeguard against possible pup loss. Low levels of interactions between seals when ashore indicated that social relationships between adults were neither established nor maintained on land. Fights and displays may establish dominance relationships among breeding males while in the water but these did not appear to influence male haul-out patterns. Other than mother-pup relationships, social factors played little, if any, role in the formation or composition of harbour seal herds in a habitat where haul-out space was not limited.

Gosho, M. E.; Rice, D. W.; Breiwick, J. F. (1984)

The sperm whale, Physeter macrocephalus

Mar. Fish. Rev. 46 (4). 54-64.

ABSTRACT
This article reviews the status of the sperm whale, Physeter macrocephalus. The following topics are addressed: distribution and migration, life history and ecology, exploitation and population size, and management. Females attain sexual maturity at 9 yrs and produce a calf every 3-6 yrs. Males have a prolonged puberty, beginning at 9 yrs and ending at 20 yrs. Natural mortality rates range form 0.005-0.009/year.

Gerrodette, T.; Gilmartin, W. G. (1990)

Demographic consequences of changed pupping and hauling sites of the Hawaiian Monk Seal

Conserv. Biol. 4 (4). 423-430.

ABSTRACT
During the last 30 years, changes in the size of Hawaiian monk seal populations at several locations have been associated with the amount and type of human disturbance. Recreational beach activities caused monk seals to alter their pupping and hauling patterns. Survival of pups in suboptimal habitats was low, leading to gradual population declines. During the last decade at Kure Atoll, the process has been reversed: human disturbance on beaches has decreased, and traditional pupping and hauling sites have been reestablished. Subsequently, high survival rates of young seals, coupled with two successful enhancement programs for female pups, have led to dramatic changes in the age and sex composition of the population. Based on these changes, the monk seal population at Kure Atoll soon should begin to increase. Apparently small behavioral changes in such vital activities as feeding and reproduction can have large demographic consequences. Therefore, monitoring of endangered species should include data on habitat use and age and sex composition, as well as estimates of abundance.

Glockner-Ferrari, D. A.; Ferrari, M. J. (1990)

Reproduction in the humpback whale (Megaptera novaeangliae) in Hawaiian water, 1975-1988: the life history, reproductive rates and behavior of known individuals identified through surface and underwater photography

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 161-169

International Whaling Commission, Cambridge

ABSTRACT
Humpback whales were studied in the waters off the west coast of Maui, Hawaii during the period 1975-88 using photographic techniques. Using surface and underwater photographs of color pattern characteristics, 584 adults and 268 calves were identified. Using photographs of the undersurface of the fluckes, 210 adults and 2 calves were identified. Resighting histories were compiled for 69 individuals. Intervals between first and last sighting ranged from 1-13 years. One known male, observed in ten different years over a 13 year interval, was estimated to be a minimum of either 18 or 23 years of age (depending on certain assumptions) when last sighted. Of 34 resighted mothers, 31 produced more than one calf: 1 had seven calves, 1 had six calves, 2 had four calves, 6 had three calves and 21 had two calves. Maximum calving intervals were 1 year (n=7), 2 years (n=17), 3 years (n=8), 4 years (n=9), 5 years (n=5), 6 years (n=1), 7 years (n=1) and 9 years (n=2). Of the calves, 52.9% were males and 47.1% females. One male calf was later resighted at 6, 7 and 10 years of age. Evidence suggests that this individual reached sexual maturity by age

saxitoxin (STX), a dinoflagellate neurotoxin responsible for paralytic shellfish poisoning in humans. We propose a line of evidence to explain how whales, by virtue of their diving adaptations, may be particularly vulnerable to this systemic neurotoxin. Absence of STX in New England waters and shellfish during the episode suggests that the mackerel, representing the northern stock which spawns in the Gulf of St. Lawrence, accumulated the toxin there and delivered it to the Gulf of Maine and Cape Cod Bay in the fall of 1987. These findings challenge common perceptions of the manner in which planktonic toxins move through the food chain, and offer new insights into natural mortality and strandings of marine mammals. It seems appropriate to search for STX and other phytotoxins when investing marine mammal mortalities.

Geraci, J. R. (1990)

Physiologic and toxic effects on cetaceans

In: Sea Mammals and Oil: Confronting the Risks

Geraci, J. R.; St. Aubin, D. J., eds. Pages 167-198

Academic Press, New York

ABSTRACT
An oil spill at sea adds an element of risk to the environment of a whale or dolphin. Fresh crude oil or volatile distillates release toxic vapors that can damage sensitive tissues; harmful fractions may be swallowed or consumed through contaminated prey; and thicker tarry substances with entrapped debris may linger at the surface, plugging the vital baleen and degestive apparatus of whales that engulf them.

In spite of numberous observations of cetaceans in spills, none of these effects has been detected, or at least recorded with any certainty. Experimental evidence shows that dolphins can see oil at the surface and that they prefer to avoid it. Other cetaceans seem to be comparably equipped to detect oil. Yet in the wild, whales and dolphins have been observed swimming and feeding in its presence without apparent ill effect. Perhaps, in these instances, the stimulus was not noxious enough, or perhaps cetaceans disregard oil when they are engaged in more engrossing or important activities. Unlike furbearers, cetaceans do not lose heat through fouling of the skin. Furthermore, cetacean epidermis is nearly impenetrable, even to the highly volatile compounds in oil, and when skin is breached, exposure to these fractions does not impede the progress of healing. There is no evidence that oil or tar balls significantly foul the feeding apparatus of baleen whales; laboratory studies suggest that such fouling has only transient effects.Current technology provides the means to probe deeper- to the molecular level, if necessary- for damage by oil to cetaceans. Probing may satisfy our scientific curiosity, but would not bring us closer to an understanding of the central question. On the whole, it is quite improbable that a species or population of cetaceans will be disabled by a spill at sea, whatever the likelihood that one or a few animals might be affected or even killed. Yet some habitats, and therefore their residents, are more vulnerable than others. The ice-edge, refuge for bowheads, narwhals, and beluga whales, is a riskier trap for them than pelagic waters. And in coastal areas with bustling oil production activity, dolphins might be the unwitting sentinels of a deteriorating environment. The stage is now set for decisions to identify, wisely utilize, and monitor such habitats.

of crude, residual, and refined motor oils, and diesel slicks thicker than 17 mm. They could not detect 6-mm thicknesses of leaded gasoline or transparent mineral oil. One dolphin's ability to detect oil improved with experience. While blindfolded, one dolphin could detect 12-mm-thick samples of two crude oils, Bunker C and mineral oil, but only when the latter two were churned and contained air bubbles. We conclude that dolphins detect the thicker concentrations of oil that occur near the souce of an oceanic spill, but not lightly colored or refined products that tend to disperse into thin films.

Geraci, J. R.; St. Aubin, D. J. (1987)

Effects of offshore oil and gas development on marine mammals and turtles

In: Long-term environmental effects of offshore oil and gas development

Boesch, D. F.; Rabalais, N. N., eds. Pages 587-617

Elsevier Applied Science, London

ABSTRACT
During the past five years, studies on marine mammals have brought us closer to an understanding of basic behavioral and physiological responses to oil. For example, experiments have shown that dolphins can detect oil and, under certain circumstances, will avoid it. Oil can cause subtle damage to their skin, the full impact of which is still being assessed. Thre trheat to otters and polar bears is unequivocal. Oiled fur is ineffective as an insulator, and attempts to groom can lead to oil ingestion. Fouling of baleen has short-term effects on water flow and feeding efficiency, although the consequences may not be as great as was predicted. Noise and disturbance associated with offshore production may be within the limits of tolerance for some species.

The full range of effects on turtles is poorly understood. Young turtles can eat tarballs which seal their moughs and interfere with normal feeding. Oil fouling of nests can lead to embryonic abnormalities and hatchling mortality. Turtles are particularly vulnerable to disturbances during the nesting season.The greatest impact of offshore oil and gas activities may result not from direct mortality, but rather through subtle alterations of habitat, in association with intrinsic stressors within the environment. We provide recommendations which reflect our interpretation of the most significant data gaps and emphasize the need for selective long-term monitoring.

Geraci, J. R.; Anderson, D. M.; Timperi, R. J.; St. Aubin, D. J.; Early, G. A.; Prescott, J. H.; Mayo, C. A. (1989)

Humpback whales (Megaptera novaeangliae) fatally poisoned by dinoflagellate toxin

Can. J. Fish. Aquat. Sci 46. 1895-1898.

ABSTRACT
During a 5-wk period beginning in late November, 1987, 14 humpback whales, Megaptera novaeangliae, died in Cape Cod Bay after eating Atlantic mackerel, Scomber scombrus, containing

population is similar to reported declines of breeding populations of elephant seals in the Kerguelen province. The population of moulting seals at the Windmill Islands is larger than previously thought and its status is unknown. The Vestfold Hills' and Windmill Islands' populations are the only known aggregations of southern elephant seals in Greater Antarctica. The accessibility of suitable areas on the Antarctic coast for moulting during summer is shown to be the reason for selection of these sites.

Tagging studies show that elephant seals from the Vestfold Hills and the Windmill Islands migrate to and from the Kerguelen province, and that up to 40% of the seals moulting in the Vestfold Hills return to moult the following year. The Kerguelen Plateau and the Antarctic coast represent important foraging grounds for sub-adult, male elephant seals.

Geraci, J. R.; Smith, T. G. (1976)

Direct and indirect effects of oil on ringed seals (Phoca hispida) of the Beaufort Sea

J. Fish. Res. Board Can. 33. 1976-1984.

ABSTRACT
Ninety-six ringed seals (Phoca hispida) were taken from nets at Brown's Harbour, Northwest Territories in the fall of 1974. Comparison with two other new samples from 1971 and 1972 revealed a lower proportion of young-of-the-year and a lower mean weight of seals in all age-classes. Six seals immersed in Norman Wells crude oil for 24 h at the field netting site suffered only transient eye problems and minor kidney and possibly liver lesions; no permanent damage was observed. Three seals transported to the University of Guelph all died within 71 min after oil was introduced into their pool. Hematologic and blood chemical studies indicate that death was caused by oil superimposed on the stress of captivity. Six, 3-4 wk-old wild whitecoat harp seal (P. groenlandica) pups at the Magdalen Islands, Quebec, were coated with crude oil. No significant differences in core body temperatures were noted and no deleterious effects were observed. Five captive ringed seals at Guelph were subjected to a cumulative dosage of Norman Wells crude oil fed with their fish food. High dosage (75 ml) and low dosage (25 ml) of crude oil were also fed to two groups of six harp seal pups. No significant lesions or behavioral changes were noted. These experiments were of an acute nature and reflect the effects of a brief contact with oil only. Effects of longer contact as would probably be the case in an offshore oil well blowout situation are discussed. Possible effects of large-scale offshore oil fields are also considered.

Geraci, J. R.; St. Aubin, D. J.; Reisman, R. J. (1983)

Bottlenose dolphins, Tursiops truncatus, can detect oil

Can. J. Fish. Aquat. Sci 40. 1516-1522.

ABSTRACT
Two trained bottlenose dophins, Tursiops truncatus, were tested for their ability to detect visually 12 different oils and 22 oil mixtures confined at the surface in small cylinders. Detection thresholds were established in tests using progressively lighter substances. The animals detected 6-mm slicks

Most of the radioactivity was found in the polar fraction of plasma and urine. 4. Plasma cortisol levels were somewhat elevated by captive holding, and increased markedly after oil-exposure. Conrtisol half-life decreased after oil exposure from 1 3/4 to 1 hr.

Everitt, R. D.; Braham, H. W. (1980)

Aerial Survey of Pacific harbor seals in the southeastern Bering Sea

Northwest Sci. 54 (4). 281-288.

ABSTRACT
Between June 1975 and June 1977, five aerial surveys were conducted along the eastern Aleutian Islands, and throughout Bristol Bay to study the distribution and abundance of the harbor seal (Phoca vitulina richardsi) during the breeding season. The number of group sightings and the total number of seals observed varied significantly with the tide height ($P<0.01$). Fifty-seven percent more seals were observed on a low tide than in the same area surveyed near high tide. Three locations - Port Moller, Port Heiden, and Ginder River along the north side of the Alaska Peninsula - accounted for 78 percent of the study area population count, and for approximately 8.5 percent of the entire Alaska population estimate. A minimum abundance for the study area is estimated at 29,000 animals.

Fowler, C. W. (1988)

Population dynamics as related to rate of increase per generation

Evol. Ecol. 2. 197-204.

ABSTRACT
Inflection points in animal population growth curves (expressed as a fraction of equilibrium population levels) are correlated with rates of increase per generation. The inflection point declines with increasing rates of increase per generation. This apparent unifying principle of population dynamics is independent of phenomena related to body size since the rate of increase per generation is not correlated with body size. Species as diverse as whales and bacteria appear to conform to the pattern. More studies of the observed relationships are to be encouraged.

Gales, N. J.; Burton, H. R.Burton (1989)

The past and present status of the southern elephant seal (Mirounga leonina Linn.) in Greater Antarctica

Mammalia 53 (1).

ABSTRACT
Counts of southern elephant seals at the Vestfold Hills from 1958 to the present reveal that the population has declined by half to two thirds. The decline of this predominantly male, moulting

DeLong, R. L.; Antonelis, G. A.; Oliver, C. W.; Stewart, B. S.; Lowry, M. C.; Yochem, P. K. (1991)

Effects of the 1982-83 El Nino on several population parameters and diet of California sea lions on the California Channel Islands

In: Pinnipeds and El Nino: Responses to environmental stress

Trillmich, F.; Ono, K., eds. Pages 166-184

Springer-Verlag, Berlin

ABSTRACT
Births declined at all rookeries in the Southern California Bight in 1983. The magnitude of the decline in births varied among rookeries with decreases of 30% at San Miguel Island, 43% at San Nicolas Island, 62% at San Clemente Island, and 71% at Santa Barbara Island. In 1984 births increased on San Miguel Island, decreased further on San Nicolas Island, and remained low on Santa Barbara and San Clemente islands. In 1986 numbers of pups born on all islands were still 10% below the numbers born in 1982. The weights of male and female pups showed similar annual trends declining about 25% to 35% at San Miguel and San Clemente Islands from 1982 to 1983. Pups weights remained low in 1984 and did not return to 1982 values until 1985. It was not clear whether the declines in births resulted from reduced pregnancy rates among females, increased female mortality or both.

DeMaster, D. G.; Miller, D. J.; Goodman, D.; DeLong, R. L.; Stewart, B. S. (1982)

Assessment of California sea lion fishery interactions

Trans. North Am. Wild. Nat. Res. Conf. 47. 253-264.

ABSTRACT
California sea lions on the Southern California Channel Islands increased at rates of 4 to 6% from 1971 through 1981. A growth rate of about 5% per year is thought to be a minimum estimate of the maximum rate of population change for this species.

Engelhardt, F. R. (1982)

Hydrocarbon metabolism and cortisol balance in oil-exposed ringed seals, Phoca hispida

Comp. Biochem. Physiol. 72C (1). 133-136.

ABSTRACT
1. Ringed seals were esposed experimentally to oil contamination by feeding of a [14C] naphthalene marked crude oil in fish for up to 4 days at a rate of 5 ml/day. 2. Mixed function of oxygenase (MFO) activity, measured as aryl hydrocarbon hydroxylase in liver and kidney, was found to be induced, in particular in kidney tissue where the activity increased 3-fold. 3. MFO induction correlated with a high degree of conversion of crude oil hydrocarbons to water-soluble metabolites.

Dahlheim, M. E. (1981)

A review of the biology and exploitation of the killer whale, Orcinus orca, with comments on recent sightings from Antarctica

Rep. int. Whal. Commn 31. 541-546.

ABSTRACT
Killer whales, Orcinus orca, are cosmopolitan in distribution. At present, a single species is recognized; however, various geographical races may exist. Population estimates are not available on a worldwide basis. Killer whales are usually found in pods and most activities appear to be group orientated. A population birth rate of 4-5% is suggested. Various other life history parameters of O. orca are discussed. Killer whales appear to be opportunistic feeders. Distributions of this species seems to be dependent upon the distribution and migration of prey items. A worldwide summary of the exploitation and utilization of this species is given for the years 1948-80.

Davis, M. B.; Renouf, D. (1987)

Social behaviour of harbour seals, Phoca vitulina, on haulout grounds at Miquelon

Can. Field Nat. 101 (1). 1-5.

ABSTRACT
A breeding colony of more than 700 harbour seals (Phoca vitulina) on the French island of Miquelon was observed during 1982. Behavioural interactions among different age and sex classes were documented, and the spatial organization of seals on the haulout grounds was assessed photographically. The study revealed a consistent hauling out pattern, and a predictable arrangement of animals on the beach, with a high degree of site tenacity. Our obasevations are discussed in light of existing theories of the social organization of harbour seal.

DeLong, R. L.; Antonelis, G. A. (1991)

Impact of the 1982-1983 El Nino on the northern fur seal population at San Miguel Island, California

In: Pinnipeds and El Nino: Responses to environmental stress

Trillmich, F.; Ono, K., eds. Pages 75-83

Springer-Verlag, Berlin

ABSTRACT
After 14 years of increasing production (following colonization), northern fur seal pup births declined at San Miguel Island in 1983 by 60% at Adams Cove and 64% at Castle Rock. Births increased at annual rates of 15 and 21% following the decline in 1983 but had not recovered to the 1982 level by 1987.

quantitative data on squid diets of Sperm Whales, Physeter catodon, albatrosses and certain seals show the importance of Mesonychoteuthis, Moroteuthis and Kondakovia, although other taxa are as important for certain species (e.g., octopods for seals). All these squid are rarely caught by net-hauls and data from predators presently provide the best conspectus of the abundance of the Southern Ocean epi- and meso-pelagic squid of potential commercial importance. Fish are less important to predators than Krill and squid, although the total consumption (77% by seals, especially Elephant, Fur, Arctocephalus gazella, and Weddell, Lepotonychotes weddelli, seals) is a substantial proportion (e.g., at least 38% for Notothenia rossii at South Georgia) of estimated standing stocks, which may therefore be appreciably under-estimated. Seabirds (cormorants, penguins) mainly take immature nototheniids; Fur Seals mostly eat adult Champsocephalus and are thus now in direct potential competition with commercial operations.

Croxall, J. P.; McCann, T. S.; Prince, P. A.; Rothery, P. (1988)

Reproductive performance of seabirds and seals at South Georgia and Signy Island, South Orkney Islands, 1976-1987: Implications for Southern Ocean monitoring studies

In: Antarctic Ocean and Resources Variability

Sahrhage, D., ed. Pages 261-285

Springer-Verlag, Berlin

ABSTRACT

Aspects of the reproductive performance over the last decade of Black-Browed, Grey-Headed and Wandering Albatrosses, Gentoo and Macaroni Penguins and Antarctic fur seals, at Bird Island, South Georgia and for Adelie and Chinstrap Penguins at Signy Island, south Orkney Islands, are summarized and reviewed. Breeding success of the Wandering Albatross, which breeds in winter and eats fish and squid, has remained constant, while population size has declined gradually but significantly. The other species at South Georgia, which breed in summer and feed extensively on krill, have shown major fluctuations in some or all of: breeding population size, breeding success, foraging trip duration and offspring growth rate. 1977-78 and 1983-84 were summers of particularly poor reproductive performance by almost all species; circumstantial evidence realint this to reduced availability of krill is discussed. The fluctuations in reproductive performance of the krill-eating, summer-breeding penguins at Signy Island are not synchronized with those at South Georgia; they correlate best (especially for Chinstraps, which suffered badly in 1980-81 and 1982-83) with the date of ice break-out in late spring. Numerous parameters of albatross, penguin and fur seal biology are reviewed in terms of their sensitivity and suitability for detecting changes in the marine environment.

seal foraging trips were twice as long in 1984 as in 1985 and total mass-specific energy expended by females during these trips was signigicantly greater. In addition, females were significantly lighter at parturition in 1984, and both pup mortality and the proportion of pups that died from starvation were double the 1985 values. Female condition at parturition and average foraging-trip duration (i.e., offspring-provisioning rate) appear to reflect prey availability. The similarity between years in mass increase suggests that females do not return to feed their pups until they replenish their own reserves. Antarctic fur seal females may have a limited ability to increase the relative time spent foraging because even in normal years only 5% of their time at sea is spent resting. This contrasts with northern fur seals, Callorhinus ursinus, which typically spend 17% of their time at sea inactive. Apparently these northern seals can increase their foraging effort by increasing the proportion of time spent foraging. This would account for the observed between-year difference in at-sea FMR of C. ursinus while foraging-trip duration remained fairly constant.

Croxall, J. P.; Prince, P. A.; Ricketts, C. (1985)

Relationships between prey life-cycle and extent, nature and timing of seal and seabird predation in the Scotia Sea

In: Antarctic nutrient cycles and food webs

Siegfried, W. R.; Condy, P. R.; Laws, R. M., eds. Pages 516-533

Springer-Verlag, Berlin

ABSTRACT
The impacts of seals and breeding seabirds on prey resources in the Scotia Sea are assessed, and for seabirds seasonal changes are modelled. Although the data available are the best for any part of the Southern Ocean important deficiencies exist, which are summarized. Total consumption is estimated as 23 x 106 t, fairly evenly divided between seabirds and seals and between South Georgia and the rest of the area. Krill, Euphausia superba, (70%) is much more important than squid (16%) or fish (8%) but there are few data on winter diets. The main consumers of Krill are Crabeater Seals, Logodon carcinophagus, Macaroni, Eudyptes chrysolophus, and Chinstrap, Pygoscelis antarctica, penguins, with penguins accounting for 76% of the intake by birds. Peak demand is in February; consumption estimates are high compared with stock assessments and reasons for this are discussed. Despite variations between seasons, species, and sites, Krill (mostly sexually mature individuals, 35-45 mm long) taken by predators and by net-hauls in the southern Scotia Sea are generally similar, although the largest Krill are absent from predator samples. At South Georgia, however, most predators take 45-55 mm long Krill which are rare in net-hauls; possible causes and implications of this important discrepancy are discussed. The significance of differential predation on male and female Krill (bias favoring males in the south and females at South Georgia) is evaluated in terms of seasonal changes in energy content (due to lipogenesis), and it is suggested that the latter might be a factor influencing timing of breeding in certain predators. Other aspects of krill-predator interactions, including diving patterns and catching rates, are reviewed; more data on Krill demography and on seasonal variations in the age, sex and status of Krill taken by predators are required to assess critically predator-prey interactions. Elephant Seals, Mirounga leonina, take perhaps 75% of squid eaten by predators. A comparison of

100 m of the shore. Aspects of hunting, attacking, feeding and resting behaviour are discussed. The body measurements of a young male found on a beach are given.

Condy, P. R. (1978)

Distribution, abundance, and annual cycle of fur seals (Arctocephalus spp.) on the Prince Edward Islands

S. Afr. J. Wildl. Res. 8. 159-168.

ABSTRACT
The following annual growth rates are presented for A. tropicalis: 10.5% (1951-1974), Marion Island; 11.0% (1956-81), 16.5% (1969-81), Amsterdam Island.

Cooper, C. F.; Stewart, B. S. (1983)

Demography of northern elephant seals, 1911-1982

Science 219. 969-971.

ABSTRACT
Northern elephant seals (Mirounga angustirostris) were hunted to near extinction in the 19th century. Protection has allowed tham to recolonize former habitat on islands off California, where the population is increasing more than 14 percent per year. Immigration of young pregnant females from Baja California initiated the California rookeries but is responsible for only a small part of recent population growth. Almost 25,000 northern elephant seal pups were born in the species' range in Mexico and the United States in 1982 in comparison with only six known births in 1911.

Costa, D. P.; Croxall, J. P.; Duck, C. D. (1989)

Foraging energetics of Antarctic fur seals in relation to changes in prey availability.

Ecol. 70 (3). 596-606.

ABSTRACT
This research examines the energy budget of breeding female Antarctic fur seals, both when food was plentiful and when it was scarce. The energy expenditure and change in body mass of lactating gemale Antarctic fur seals, Arctocephalus gazella, foraging at sea was measured in two years using doubly labeled water at South Georgia Island. There was no difference between years in mass gain, water influx, mass-specific field metabolic rate (FMR), or absolute FMR. Mean at-sea FMR over both years was 9.52 ± 0.55 W/kg ($n = 22$), a value that is 6.7 times the predicted basal rate but only 1.9 times the FMR measured onshore. Comparable results have been reported for similar-sized northern fur seals.

Krill, the nearly exclusive prey of breeding females, were very scarce in 1984 at South Georgia. Fur

Clark, D. W. (1986)

Archaeological and historical evidence for an 18th-Century "Blip" in the distribution of the northern fur seal at Kodiak Island, Alaska

Arctic 39 (1). 39-42.

ABSTRACT
Recovery of fur seal Callorhinus ursinus remains from archaeological sites on Kodiak Island, Alaska, shows a low harvest prior to late prehistoric and early historic time. Then there is a pronounced increase in the frequency of fur seal bones in refuse layers. Russian records do not show any significant take of fur seals from Kodiak, but by the end of the 18th century and the beginning of the next century there are reports that this animal, formerly abundant in the area, had become rare. This may indicate that conditions had reverted to their earlier prehistoric state.

Colbourne, P. L.; Terhune, J. M. (1991)

Harbour seals (Phoca vitulina) do not follow herring movements in the Bay of Fundy, Canada

Ophelia 33 (2). 105-112.

ABSTRACT
Aerial surveys of hauled-out harbour seals (Phoca vitulina) were conducted along the mainland New Brunswick coast of the Bay of Fundy, 1-2 times monthly from January to mid-December 1987. A gradual summer increase and autumnal decreasein seal numbers were observed. Atlantic herring (Clupea harengus) in the Bay of Fundy move onshore and are caught in weirs between May and November. Comparison of the seals' distribution on haul-out sites with that of the Atlantic herring catch indicates that both species moved independently of each other. The seals' bi-weekly movements to different regions within the Bay appear to be random.

Condy, P. R.; van Aarde, R. J.; Bester, M. N. (1978)

The seasonal occurrence and behaviour of killer whales Orcinus orca, at Marion Island

J. Zool., Lond. 184. 449-464.

ABSTRACT
The paper describes the occurrence of Killer whales at Marion Island (Prince Edward group) in the south Indian Ocean from August 1973 to November 1976. They occur seasonally, being most numerous from October to December. Their occurrence is synchronized with the seasonal haul out of Southern elephant seals, but the seasonality of King, Rockhopper and Macaroni penguins is also likely to influence their occurrence. The largest herds occur in October, the month during which the mean group size is also largest. Sex and age composition are given, adult males being significantly more numerous than adult females, while 36.3% of the latter had calves. Hunting activity appears to be greatest between 15.00 and 17.00 hrs, and most Killer whales were seen within

Christensen, I. (1990)

A note on recent strandings of sperm whales (Physeter macrocephalus) and other cetaceans in Norwegian waters

Rep. int. Whal. Commn 40. 513-515.

ABSTRACT
Strandings of 27 sperm whales on the coast of Norway and sightings of an additional 9 dead and drifting whales in Norwegian coastal waters in 1988 and 1989 are recorded. Also reported are the strandings of other cetaceans, including 6 killer and 7 pilot whales, which also occurred in these years. Factors accounting for the death of the stranded whales are discussed.

Clapham, P. J.; Mayo, C. A. (1990)

Reproduction of humpback whales (Megaptera novaeangliae) observed in the Gulf of Maine

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 171-175

International Whaling Commission, Cambridge

ABSTRACT
A high level of effort in the Gulf of Maine between the years 1979 and 1987 has produced detailed resighting histories of individual humpback whales, Megaptera novaeangliae, allowing us to conduct a study of reproduction in this population. The crude birth rate during this period ranged from 0.045 to 0.103 (mean=0.079), with no significant year-to-year variation. An alternative measure gave a mean reproductive rate of 0.41 calves per mature female per year. Sixty-five females were observed with a total of 120 calves. Thirty-one females were observed with more than one calf during the study. Observed calving intervals were: 1 year (n-2), 2 years (n=36), 3 years (n=14), 4 years (n=2) and 5 years (n=1); 52 of the 55 intervals involved complete resighting histories between years of known calving. Five calves born during the study period were observed with calves of their own in later years. Data from these whales, and from other mothers whose age can be estimated, suggest that the majority of females attain sexual maturity by the age of six. Of 94 calves born prior to 1987, 72 (76.6%) were resighted in at least one year after separation from their mothers, providing further support for the belief that the composition of a humpback whale feeding stock is determined matrilineally. Eleven of a possible 13 calves were observed to the age of 6 years and may therefore have survived to breeding age. Two others were probably lost to entanglements in commercial fishing gear, which may represent a significant source of mortality in this population. The value of using variation in the shape, size and scarring of the dorsal fin to identify individuals is discussed.

Christensen, I. (1982)

Killer whales in Norwegian coastal waters

Rep. int. Whal. Commn 32. 633-641.

ABSTRACT
Observations reported by whalers and fishermen indicate that killer whales are present in all areas of the Norwegian coast throughout the year. No migration pattern has been discovered, but killer whales occur in the greatest numbers in the Lofoten and More areas and off the southern west coast. A mean catch of 57 killer whales per year over the period 1938-1980 has not changed the length distribution in the catch. Decreasing fatness from 1951 to 1968 may have been caused by a decreasing availability of food. Reported weights indicate that meat constitutes 40% of total body weight, blubber 29%, bones 22%, and viscera 9%. Feeding behaviour and pod organization is described from recorded observations. Female killer whales seem to reach sexual maturity at a length of 15 feet, and an age of about 6 years. Matings occur throughout the year, with a maximum in October-December. A gestation period of 12 months and one birth every second year is indicated. Preliminary age determiniations indicate continued growth in groups of body length up to 20-25 years and a life span of at least 35 years.

Christensen, I. (1984)

Growth and reproduction of killer whales, Orcinus orca, in Norwegian coastal waters

In: Reproduction in whales, dolphins and porpoises. Reports of the International Whaling Commission (Special Issue 6)

Perrin, W. F.; Brownell, R. L., Jr.; DeMaster, D. P., eds. Pages 253-258

International Whaling Commission, Cambridge

ABSTRACT
Length data and reproductive material collected by coastal whalers during the period 1938-67 and 1978-81 are analysed. Female killer whales attain sexual maturity at a length of 15-16 ft (4.6-4.9 m) and an age of about 8 years, and males at about 19 ft (5.8 m) and 15 years. Mating occurs throughout the year, with a maximum in October-December. The birth rate seems to be one calf every three years. Preliminary age determinations indicate that physical maturity is attained at 20-25 years, with a life span of at least 35 years.

Butterworth, D. S.; David, J. H. M.; McQuaid, L. H.; Xulu, S. S. (1987)

Modeling the population dynamics of the South African fur seal Arctocephalus pusillus pusillus

NOAA Tech. Rep. NMFS 51. 141-164.

ABSTRACT
Aerial survey and tag-recapture assessments of fur seal pup population numbers are considered at the 23 breeding colonies around the southeastern and western coasts of southern Africa during the period 1971-83. Exponential growth curves are fitted for each colony assuming a constant relative bias berween the various assessment methods used. The pup population for all colonies combined is estimated to have grown at an average annual rate of 3.9% (SE 1.1%). The population is now dominated by four major mainland colonies which contribute 78% to the 1983 total pup population estimate of 310,000. Mainland colonies have increased over the period considered at an average annual rate of 7.5% (SE 1.5%), while island colonies have declined at 3.5% (SE 0.9%) per annum. Estimation of change in growth rate suggests that this rate has increased over the period though not significantly (P=0.07).

No direct assessments are available for adult and juvenile survival rates for the South African fur seal Artocephalus pusillus pusillus, but limitations can be placed on possible ranges of values. an approach is usggested which imposes the constraint of a population dynamics model for adult females upon these ranges, estimates of total pup population size and growth rate, and knowledge of the average annula harvest of pups from 1971 to 1983. This provides refined probability distributions for various demographis paramenters; the annual average pup harvesting rate is estimated to have been 38% (SE 5%), and the annual adult female survival rate 0.92 (SE 0.02%). An example is given of how the approach can be extended to provide estimates for the total population and to detect possibel density-dependent effects, priority should be given to further assessments of the major mainland colonies, particularly those at Wold and Atlas Bays.

Chapman, D. G. (1981)

Evaluation of marine mammal population models

In: Dynamics of large mammal populations

Fowler, C. W.; Smith, T. D., eds. Pages 277-296

John Wiley & Sons, New York

ABSTRACT
Population models used for a variety of marine mammals are classified (growth models, yield models, multispecies and ecosystem models). Population size estimates and exponential growth rates are presented for several species.

Reevaluation and new estimates of stock abundance and vital rate parameters are needed for white whales because under present harvest levels 44% of the defined harvested stocks are being exploited at or above replacement yield.

Brown, R. F.; Mate, B. R. (1983)

Abundance, movements, and feedng habits of harbor seals, Phoca vitulina, at Netarts and Tillamook Bays, Oregon

U.S. Fish. Bull. 81. 291-301.

ABSTRACT
Patterns of seasonal abundance of harbor seals at Netarts and Tillamook Bays, Oregon, were documented by recording numbers of seals hauling out on tidally exposed sand flats in both bays. Harbor seal abundance at Tillamook Bay coincided with the annual return (October-November) of chum salmon, Oncorhynchus keta, to a hatchery on Whiskey Creek. Observations of seals preying on adult salmon resulted in estimated losses of 6.1, 7.2, and 1.5% of the total chum returns for 1978, 1979, and 1980, respectively, due to seal predation in the Whiskey Creek area. Other prey species of harbor seals at Netarts Bay were identified by the recovery of prey hard parts from seal feces collected on haul-out areas. The Pacific sand lance, Ammodytes hexapterus, was the most frequently identified prey item. Ten species of flatfish (Order Pleuronectiformes) were identified as harbor seal prey with five species (Parophyrs vetulus, Glyptocephalus zachirus, Citharichthys sordidus, Microstomus pacificus, and Lyopsetta exilis) ranking among the seven most frequently occurring food items. In general, benthic and epibenthic fish appeared to be important in the harbor seal diet. Distributions, abundances, and estimated sizes of identified prey species indicated that harbor seals had fed both in Netarts Bay and in the nearshore ocean. Movements of radio-tagged harbor seals between Netarts Bay and Tillamook Bay were common (45.4% of tagged seals made at least one move between bays). Tagged harbor seals frequented at least four different estuaries and one coastal haul-out area, ranging from 25 to 550 km from the tagging area.

Budylenko, G. A. (1981)

Distribution and some aspects of the biology of killer whales in the South Atlantic

Rep. int. Whal. Commn 31. 523-525.

ABSTRACT
Killer whales (Orcinus orca) are widely distributed in the South Atlantic. Data are presented which were obtained from the whaling vessel Yuri Dolgorukiy for the 15 years 1960-75 in the months November-May. During this period killer whales were observed in warm, temperate and cold waters.

In temperate waters, the bulk of the diet consists of dolphins and fish, while in the colder water, minke whales are the dominant food species. Killer whales are most commonly seen in groups of about 10 animals. Groups of 10-20 animals are less common and groups of over 100 are occasionally seen. The size of the killwe whale groups is deterimined by the hunting strategy.

high natural mortality rates, possibly a result of shark predation and overexposed breeding sites in the reduced range, may make eastern Canadian harbor seals particularly vulnerable to hunting.

Braham, H. W.; Dahlheim, M. E. (1982)

Killer whales in Alaska documented in the Platforms of Opportunity Program

Rep. int. Whal. Commn 32. 643-646.

ABSTRACT
Sighting records of over 1,100 killer whale (Orcinus orca) groups from Alaskan waters obtained from 1958 to 1980 are now in the National Marine Mammal Laboratory's Platforms of Opportunity Program data base. From a preliminary analysis, and with as yet no correction for sighting effort, killer whales are distributed primarily over the continental shelf in water less than 200 m deep in the eastern North Pacific (southeast Alaska to the eastern Aleutian Islands) but seem to concentrate near the 200 m contour over the shelf slope in the southeastern Bering Sea. In the Gulf of Alaska over 60% of our sightings were within 20 km of shore, while in the North Pacific from Kodiak Island to Unimak Pass they were uniformly distributed from shore to beyond 56 km. Pod size ranged from 1-100 animals, with only 1% of the groups containing 20 or more individuals. From a review of the literature, and inlight of our sightings of concentrations near areas of known high productivity of fishes and other marine mammals, killer whales appear to fedd upon fish when locally abundant and to switch to marine mammals when fish are less available.

Braham, H. W. (1984)

Review of reproduction in the white whale, Delphinapterus leucas, narwhal, Monodon monoceros, and Irrawaddy dolphin, Orcaella brevirostris, with comments on stock assessment

In: Reproduction in whales, dolphins and porpoises. Reports of the International Whaling Commission (Special Issue 6)

Perrin, W. F.; Brownell, R. L. Jr.; DeMaster, D. P., eds. Pages 81-89

International Whaling Commission, Cambridge

ABSTRACT
Estimates of vital reproductive parameters for white whales, Delphinaperus leucas, have been made over the past 20 years as a result of data collected from a long, but intermittent history of exploitation. Based on two dentinal growth layers per year, reported in the literature, they may live to 25-30 years. Females become sexually mature at 5 years of age and males at 8 years; they begin active breeding 1-3 years later. Evidence is presented which suggests that estimating age using current methods may result in error in ages at which certain life history events occur. From an observed pregnancy rate of 0.41, and assuming an average gestation period of 14.5 months and a crude birth rate of 0.33-0.38, a gross annual reproductive rate of 0.09-0.12 is estimated. Observed rates are 0.09-0.14. Most vital reproductive rates are unknown for narwhals, Monodon monoceros. Almost no life history information is available on the Irrawaddy dolphin, Orcaella brevirostris.

Blix, A. S.; Grav, H. J.; Ronald, K. (1979)

Some aspects of temperature regulation in newborn harp seal pups

Am. J. Physiol. 236 (3). R188-R197.

ABSTRACT
Harp seals are born on the drifting ice of the North Atlantic Ocean during arctic winter when temperatures of -20°C, occasionally in combination with wind of 10 m/sec, might prevail for days. At birth the pups lack subcutaneous blubber and the wet infantile fur has a conductance value of 30.0 W•m-2•°C-1 as compared with only 2.0 W•m-2•°C-1 when dry. While still wet immediately after birth the pups are nevertheless able to retain body core temperature by shivering. This activity leads to reduction of muscle fat and glycogen stores. Nonshivering thermogenesis commences in thermogenic adipose tissue by virtue of loosely coupled mitochondria. Thermogenic adipose tissue is found at birth both as a subcutaneous layer along the back and as internal deposits around venous plexuses in the neck, on the pericardium, on the kidneys, and the abdominal walls. After about 3 days of sucking the subcutaneous adipose tissue loses its thermogenic function being gradually transformed into blubber, whereas the internal deposits persist at least until the pups venture into water at the age of 3-4 wk.

Boal, J. (1980)

Pacific harbor seal (Phoca vitulina richardii) haul out impact on the rocky midtidal zone

Marine Ecol. Prog. Ser. 2 (4). 265-269.

ABSTRACT
A study of haul out and adjacent non-haul out rocks of the Pacific harbor seal Phoca vitulina richardii (Gray), on the Monterey Peninsula of California, revealed significant differences in algal morphology and per cent composition, and in numbers of animals present. It is suggested that the mechanical and chemical impact imposed by the seals on the haul out sites are responsible for these differences.

Boulva, J.; McLaren, I. A. (1979)

Biology of the harbor seal, Phoca vitulina, in eastern Canada

Bull. Fish. Res. Board Can.Need Pages.

ABSTRACT
The biology of harbour seals in eastern Canada is reviewed. Population surveys and estimates, rates of decrease of bounty kill and age structure of heavily vs. lightly exploited populations all suggest an overall decline of about 4% per year between 1950 and 1973 in the Maritimes. Best estimates of pre-weaning and post-weaning mortality rates, produce near equilibrium in population simulation. If females were fertile 1 year younger this would only allow a very small sustainable yield. The very

breeders despite the increased density on the west coast. The small breeding population of southern elephant seals (Mirounga leonina) either remained stable, or declined very slowly, over the past 17 years.

Bigg, M. (1982)

An assessment of killer whale (Orcinus orca) stocks off Vancouver Island, British Columbia

Rep. int. Whal. Commn 32. 655-666.

ABSTRACT
A study of photographically identifiable individual killer whales was undertaken during 1973-81. In all, 30 pods were found, containing about 260 whales. A pod is a long term family or kinship group which periodically joins with others to form communities. Around Vancouver Island there are two resident communities and one transient community. The three communities do not associate with one another. Resident and transient killer whales differ in pod size and behaviour. The coastal range of movements for most resident pods is probably about 300 nm. Transient pods appear to range further. Births occur mainly during fall and winter. At birth, lengths average about 8 ft. First pregnancies generally occur at 16 ft, or at an age of at least 6.7 years. Sexual maturity occurs in males at 19 ft, or at an age of at least 12 yrs. A long term stability in pod compostition permits direct measurement of vital statistics. The rate of calf production to an average age of six months is 10.30% per cow. The minimum interval between calving is three years. Many cows apparently rarely give birth. Annual natural mortality rates average 2.80% for bulls, 0.70% for cows and 2.30 % for juveniles. Pods increase at an average net rate of 2.52% per year. Exploited pods have a slightly higher productivity than unexploited pods.

Bjorge, A. (1991)

Status of the harbour seal Phoca vitulina L. in Norway

Biol. Conserv. 58. 229-238.

ABSTRACT
The current estimate of the number of harbour seal Phoca vitulina in Norwegian waters, including Svalbard, is 4129, based on actual counts of seals at the haul-out sites during the period 1977-88. Comparison with an estimate obtained during the early 1960s indicates that there has been little change in the overall number of harbour seals in Norway during the last 25 years. Three distinct types of habitats are utilized by harbour seals in Norway--open rocky coasts, deep fjords and estuarine sandbanks. The habitat types and the status of legislative protection of harbour seals and their habitats are described.

Best, P. B. (1990)

Trends in the inshore right whale population off South Africa, 1969-1987

Mar. Mamm. Sci. 6 (2). 93-108.

ABSTRACT
Results of annual aerial surveys of the right whale population along the southern coast of South Africa from 1971 to 1987 are analysed. About 91.5% of cows with calves and 82% of unaccompanied adults on the South African coast in spring are found within the standard survey area, with some indications that the range is expanding up the west coast. In the nearshore region, most right whales (90%) are found within 1.85 km, and all cows with calves within 0.93 km of the coast. Within the standard survey area, specific areas of concentration can be predictably identified, both for cows with calves and unaccompanied adults. Although total counts (and counts expressed per hour flown) have increased overall, by a best estimate of 6.8% (95% CL 4.6, 9.0) per year from 1971 to 1987, some concentration areas for both classes have failed to show an increas over the same time period. Photographic flights since 1979 have permitted the movements of individually identified abult females to be monitored between successive calves. In at least one concentration area fro which no overall increase between 1971 and 1987 was apparent (Mossel Bay), a large net emigration rate was found, nearly all of which involved a shift to the main nursery area to the west, off De Hoop. Reasons for the dissimilar dynamics of different concentration areas are not yet known.

Best, P. B. (1990)

Recovery rates in whale stocks that have been protected from commercial whaling for at least 20 years

Rep. int. Whal. Commn 40. 129-130.

ABSTRACT
Population growth rates are presented for five whale species (gray, right, bowhead, humpback, blue) that have been protected from commercial harvest for at least 20 years.

Bester, M. N. (1990)

Population trends of Subantarctic fur seals and southern elephant seals at Gough Island

S. Afr. J. Antarct. Res. 20 (1). 9-12.

ABSTRACT
The Subantarctic fur seal (Arctocephalus tropicalis) population at Gough Island in the South Atlantic Ocean is continuing to increase rapidly since its recovery from exploitation. The intrinsic rate of increase is however slowing down on established breeding colony beaches in the western sector as congested conditions develop. The reate of increase on the more recently colonised breeding colony sites on the east coast is high but some beaches here remain unexploited by

low. If post-census pup survival is density dependent, the estimated RPC if too high. If adult survival is density dependent, there is very little bias in the estimate. The results incidate that pup counts can be reliable indicators of population growth, but caution should be used in interpreting the results unless density feedback mechanisms have been identified.

Best, P. B.; Canham, P. A. S.; Macleod, N. (1984)

Patterns of reproduction in sperm whales, Physeter macrocephalus

In: Reproduction in whales, dolphins and porpoises. Reports of the International Whaling Commission (Special Issue 6)

Perrin, W. F.; Brownell, R. L., Jr.; DeMaster, D. P., eds. Pages 51-79

International Whaling Commission, Cambridge

ABSTRACT
From ovarian activity the peak period of breeding in the sperm whale seems to occur between October and December in the Southern Hemisphere and between April and June in the Northern Hemisphere. While large males (over 13.7m in length) may be the prime breeding animals, the density of spermatozoa in seminal fluid suggests that males may be physiologically fertile at an average length of 12.5m. Gestation (estimated from the difference between peaks of mating and calving) may last 15 to 16 months, though a comparison of neonatal and adult brain weights indicates a longer period (18.9 months). Equal numbers of male and female calves are born at an average length (from an examination of 15 neonates) of 4.00 ± 0.13 m; sexual dimorphism in size at birth cannot be demonstrated. Sperm whale milk is composed on average of $35.5 \pm 1.3\%$ total solids, $24.4 \pm 1.2\%$ fat, $9.1 \pm 0.3\%$ protein and $0.7 \pm 0.04\%$ ash. Diving ability of newborn animals seems to be relatively poor. Neonates demonstrate a strong 'following response' that wanes repidly with age. An interdependence of school members is suggested from behavioural observations. Calves grow to about 6.1 m in length at one year of age and weigh 2,698 kg, or an increase of 1,673 kg since birth. Tests for lactose in stomach contents were positive in males up to 13 years of age and in females up to 7 1/2 years. Solid food is taken for the first time fefore the age of one year. Juvenile sperm whales tend to eat smaller and younger squid than adults. Heart weight relative to body weight may be about twice that of adults, suggesting a higher metabolic and thus feeding rate. Criteria for accurate measurement of reproductive (=pregnancy) rates are discussed. Mean calving interval for Donkergat (west coast of South Africa) is estimated as 5.2 years and 6.0-6.5 years for Durban (east coast of South Africa). A decrease in the calving interval from 6 to 5.2 years at Durban was observed between 1962-65+1967 and 1973-75. The mean duration of lactation may increase with the age of the female. Some of the older juveniles found with lactose in their stomach may represet offspring of older females in an extended period of lactation. The benefits of possible communal suckling by sperm whale calves are discussed.

Barlow, J. (1985)

Variability, trends, and biases in reproductive rates of spotted dolphins, Stenella attenuata

U.S. Fish. Bull. 83 (4). 657-669.

ABSTRACT
Temporal changes were examined in three parameters that affect reproduction of spotted dolphin populations in the easatern Pacific. Of mature females, percent pregnant decreased markedly from the period 1971-1973 to the period 1974-83. Within the period 1974-83, percent pregnant remained relatively constant. Of pregnant females, percent lactating increased during the period 1971-83. The percentage of sexually mature females did not change. Potential biases in the measurement of the three parameters were identified by examining the effects of sampling conditions. The percentage of mature females that are pregnant and the percentage of pregnant females that are lactating were found to be robust to sampling conditions. The percentage of mature females in a sample was found to depend significantly on the number of dolphins killed per set, and annual variability was too large to be explained by random sampling error. Comparisons between two populations show that the more exploited population has a lower percent pregnant, although the opposite might be expected from density compensatory effects. Percent lactating and percent immature were higher in the more exploited population.

Bayer, R. D. (1985)

Six years of harbor seal censusing at Yaquina Estuary, Oregon

Murrelet 66. 44-49.

ABSTRACT
Harbor seals regularly hauled out at Yaquina Estuary only during tides lower than about +0.3m. Few seals (and no pups) were present during the pupping season in May and June. The greatest numbers hauled out in August or September; a smaller secondary peak appeaared in February intwo of six years. Seal abundance was about the same from 1977-1983, with the summer maximum ranging from 40 to 72 seals.

Berkson, J. M.; DeMaster, D. P. (1985)

Use of pup counts in indexing population changes in pinnipeds

Can. J. Fish. Aquat. Sci 42. 873-879.

ABSTRACT
A series of population simulations were used to test the accuracy of estimating the discrete rates of population change (RPC) from annual pup counts. The simulations indicate that pup counts can give a biased estimate of RPC, and the the magnitude and direction of bias depends on which life history parameters are density dependent and on the maximum rate of population change. In general, if pre-census pup survival is density dependent the estimated RPC using pup counts is too

Puget Sound, North America increased in number at a rate of 2.3% per year. The average adult female reproductive rate was observed to be 0.089 calves per year, and the average mortality rate for all whales was calculated to be 0.010 per year.

Bannister, J. L. (1990)

Southern right whales off Western Australia

In: Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission (Special Issue 12)

Hammond, P. S.; Mizroch, S. A.; Donovan, G. P., eds. Pages 279-288

International Whaling Commission, Cambridge

ABSTRACT
Southern right whale aerial counts and head callosity photographs from southern Western Australia, over some eleven years to 1987, have provided information on: a significant population increase, at least in cow-calf pairs; differences in some body characters (lip callosities, some body markings) compared with animals off South Africa and Argentian; pattens of distribution and dispersal slong the coast; and reproduction (most mating activity unlikely to be taking place on the coast, one animal first seen as a probable yearling giving birth nine years later, calving interval averaging three years). Up to 81 individuals (including 21 calves) have been identified in one year along some 1,100 km of coastline. Point estimates of rates of population increase ranged from 11.7% (all animals to 13.0% (cow-calf pairs).

Barham, E. G. (1982)

Marine mammals in Monterey Bay, California, during the years 1950-1955

Calif. Fish Game 68 (4). 213-223.

ABSTRACT
Over about a 5-year period, 180 sightings of 12 marine mammal species and three unidentified mammal categories were made during 239 weekly sea trips. Most frequently sighted were the Pacific white-sided dolphins and Dall's porpoise. Mean herd sizes were 13.90 and 5.98 animals, respectively. The white-sided dolphin was absent from early May to early September; the majority of sighting occurred from December to March. Dall's porpoise was seen around the calendar, but more frequently during the last half of the year. Killer, short-finned pilot, and sperm whales were noted only in that same period. The majority of gray whale sightings were correlated with their winter migrations, but a few stragglers were seen as late as July. No seasonality is evident from the humpback whale sightings. Northern fur seals were observed only from January to June. Two northern elephant seals and one sea otter were noted.

Anonymous (1982)

Report of the Workshop on Identity, Structure and Vital Rates of Killer Whale Populations, Cambridge, England, June 23-25, 1981

Rep. int. Whal. Commn 32. 617-631.

ABSTRACT
Results of the workshop are summarized in this report. Killer whale pregnancy rates (% of mature females pregnant) from catch data were corrected for a 15-month gestation period as follows: Norway 12%-32.8%, Antarctic 13.74%-18.97%. A partial list of food items by geographic area is included in the appendices.

Baker, J. R.; McCann, T. S. (1989)

Pathology and bacteriology of adult male Antarctic fur seals, Arctocephalus gazella, dying at Bird Island, South Georgia

Br. vet. J. 145. 263-275.

ABSTRACT
A high mortality rate occurs in Antarctic fur seal males on the breeding beaches of Bird Island, South Georgia. The main causes of death were infections of fighting wounds and pneumonias. The bacteria involved appear to be opportunistic pathogens, predominantly various strains of streptococci.

Baker, J. R. (1989)

Natural causes of death in non-sucking grey seals (Halichoerus grypus)

Vet. Rec. 125. 500-503.

ABSTRACT
Thirty-four grey seals which died of natural causes were examined. They ranged in age from aborted fetuses to adults, but suckling pups were excluded from the study. The commonest primary cause of death was pneumonia and a varitey of parasitoses occurred as secondary lesions.

Balcomb, K. C., III; Boran, J. R.; Heimlich, S. L. (1982)

Killer whales in Greater Puget Sound

Rep. int. Whal. Commn 32. 681-685.

ABSTRACT
From 1974 to 1980 killer whales (Orcinus orca) in a previously exploited population in Greater

Allen, S. G.; Ainley, D. G.; Page, G. W.; Ribic, C. A. (1984)

The effect of disturbance on harbor seal haul out patterns at Bolinas Lagoon, California

U.S. Fish. Bull. 82 (3). 493-500.

ABSTRACT
We studied harbor seals at Bolinas Lagoon, California, from May 1978 to June 1979. Field observation and two time lapse motion picture cameras were used to monitor the numbers of seals and of disturbances, and to provide information on tidal height. Peak numbers occurred during the summer. During nonbreeding seasons, high numbers occurred at low tides, and during the breeding season they occurred in early afternoon except when haul out areas were flooded. Seals were disturbed by humans on 71% of days monitored; people in canoes were the primary source of disturbance. Human activities closer than 100 m caused seals to leave haul out sites more than activities at greater distances.

Allen, S. G.; Ribic, C. A.; Kjelmyr, J. E. (1988)

Herd segregation in harbor seals at Point Reyes, California

Calif. Fish Game 74 (1). 55-59.

ABSTRACT
A mixed class aggregation of harbor seals resides at Double Point, California. Seals are present year round but are more abundant during the March through June breeding season. Seals were segregated by sex and age class witin the herd, and patterns chnged during the season. Early in the 1984 and 1985 breeding seasons the herd was equally composed of males, females, and immatures, but mid-way was composed of mostly females and pups. Late in the season more males and immatures were present. We hypothesize that changes in segregation patterns are related to intolerance of males and immature by pregnant females and females with pups.

Allen, S. G.; Huber, H. R.; Ribic, C. A.; Ainley, D. G. (1989)

Population dynamics of harbor seals in the Gulf of the Farallones, California

Calif. Fish Game 75 (4). 224-232.

ABSTRACT
We surveyed harbor seals, Phoca vitulina, in the Gulf of the Farallones, California, at all known haul-out sites from march 1982 through February 1984, and studied them intensively at two haul-out sites, Double Point and the South Farallon Islands, from 1976 to 1986. Though present year round, seals were most abundant onshore during the breeding/molt season (March-July). The relative abundance of seals onshore at Double Point during the 1987 breeding season was double the number in 1976, and at the South Farallon Islands, numbers in 1986 were four times higher than in 1974. Individual females observed at Double Point during two 3-year sets had a 0.89 and 0.92 probability of parturition in successive years.