

# NORTHERN ALASKA RESEARCH STUDIES



FILE COPY

## Secondary Productivity of Impounded Wetlands in the Prudhoe Bay Oil Field: Implications for Waterbirds

by

Kenneth Kertell

Randall Howard

LGL Alaska Research Associates, Inc.

Prepared for

BP Exploration (Alaska) Inc.

**Secondary Productivity of Impounded Wetlands  
in the Prudhoe Bay Oil Field:  
Implications for Waterbirds**

**by  
Kenneth Kertell  
and  
Randall Howard**

**May 1992**

**Prepared by  
LGL Alaska Research Associates, Inc.  
4175 Tudor Centre Drive, Suite 101  
Anchorage, Alaska 99508-5917**

**Prepared for  
BP Exploration (Alaska) Inc.  
Environmental and Regulatory Affairs Department  
P.O. Box 196612  
Anchorage, Alaska 99519-6612**

**SECONDARY PRODUCTIVITY OF IMPOUNDED  
WETLANDS IN THE PRUDHOE BAY OILFIELD:  
IMPLICATIONS FOR WATERBIRDS**

by  
**Kenneth Kertell  
and  
Randall Howard**

**May 1992**

**This report was prepared under contract to BP Exploration  
(Alaska) Inc. Inquiries about this report may be addressed  
to:**

**BP Exploration (Alaska) Inc.  
Environmental and Regulatory Affairs Department  
Special Studies  
P.O. Box 196612  
Anchorage, Alaska 99519-6612**

## Executive Summary

In summer 1991, BP Exploration (Alaska) Inc. (BPX) and LGL Alaska Research Associates, Inc. (LGL) initiated a study of secondary productivity in impoundments in the Prudhoe Bay oil field. Benthic invertebrates in impoundments and natural ponds were compared to see if the two were similar in biomass and species diversity. A literature review was conducted to evaluate waterbird use of natural and artificial wetlands on the Arctic Coastal Plain and elsewhere, and to identify those wetland characteristics that most influence invertebrate availability.

Five impoundments and five natural ponds were chosen for invertebrate sampling. Impoundments and ponds were less than 0.5 ha in size. Impoundments ranged in age from 10 to 20 years. Invertebrates were sampled in June, July, and August at each of these ten water bodies. Within each water body, three microhabitats were sampled: unvegetated margin, emergent vegetation at the margin, and bottom substrate near the center. Biomass analyses ultimately were conducted on six water bodies (three pond and impoundment pairs) and taxonomic analyses were conducted on two water bodies (one pond and impoundment pair). Analyses were conducted on samples collected during June and August only.

Results of the study are as follows:

- Mean chironomid biomass declined and mean oligochaete biomass increased between June and August for all ponds and impoundments combined. Changes in dry weight biomass were not significant, however.
- In June and August, the mean biomass of both

chironomids and oligochaetes was significantly greater in samples collected from impoundments than natural ponds.

- Seventeen chironomid taxa were collected from the GC-2 impoundment and 13 from the GC-2 pond. Of the 23 total identified taxa, 10 (43%) were found only in the GC-2 impoundment, whereas 6 (26%) were found only in the GC-2 pond. Seven taxa were common to both water bodies. Numbers of taxa declined markedly at both the GC-2 pond and impoundment in August compared with June.
- At the GC-2 impoundment, *Chironomus* larvae dominated in both abundance and biomass during the June sampling period. Because of their large size relative to other chironomid larvae, larvae of the genus *Chironomus* may be particularly important as a potential food for waterbirds on the Arctic Coastal Plain. The abundance of *Chironomus* larvae declined in August relative to the larvae of other chironomid genera.
- Collectors (chironomids feeding on fine organic matter) comprised 60.8% and 78.5% of all identifiable chironomids collected from the GC-2 pond and impoundment, respectively, during June. Predators (chironomids feeding on living animal tissue) were the most important feeding group at the GC-2 pond in August, making up 55.2% of all chironomids. Collectors declined in importance during August to 32.7% of total larvae collected at the GC-2 pond. At the GC-2 impoundment in August, however, the percent-

age distribution of chironomids within major feeding categories was almost identical to that observed in June.

- Impoundments had a greater amount of emer-

gent vegetation, but also had deeper water at the center, steeper shoreline gradients, and less exposed sediment at the periphery in late summer than natural ponds.

## Table of Contents

EXECUTIVE SUMMARY .....	iii
TABLE OF CONTENTS .....	v
LIST OF FIGURES .....	vii
LIST OF TABLES .....	ix
INTRODUCTION .....	1
Impoundments .....	1
OBJECTIVES .....	1
BACKGROUND AND RATIONALE .....	2
STUDY AREA .....	3
METHODS .....	4
Data Collection .....	4
Sample Analysis .....	5
Change in Scope of Sample Analysis .....	5
Data Analysis .....	6
Waterbird Use of Wetlands on the Arctic Coastal Plain .....	6
RESULTS .....	8
Physical Characteristics of Ponds and Impoundments .....	8
Water Quality Characteristics of Ponds and Impoundments .....	8
Chironomid and Oligochaete Biomass .....	9
Between Sampling Periods .....	9
Within Sampling Periods .....	9
Chironomid Taxa .....	10
Chironomid Trophic Organization .....	15
Chironomid Size .....	17

DISCUSSION .....	19
Invertebrates in Natural and Artificial Wetlands .....	19
Wetland Characteristics Important to Waterbirds .....	19
Emergent Vegetation .....	19
Water Quality .....	19
Water Body Age .....	20
Water Body Size .....	20
Water Depth, Shoreline Gradient, and Bottom Substrate .....	21
Invertebrate Size and Abundance .....	21
Seasonal Changes in Chironomid Biomass .....	22
Waterbird Use of Natural Wetlands on the Arctic Coastal Plain .....	23
Divers .....	23
Surface-feeders .....	31
Waders .....	36
Summary .....	36
CONCLUSIONS .....	39
LITERATURE CITED .....	41
APPENDICES .....	45
APPENDIX A Numbers of invertebrates collected from samples at the GC-2 pond and impoundment in June 1991, Prudhoe Bay, Alaska .....	46
APPENDIX B Numbers of invertebrates collected from samples at the GC-2 pond and impoundment in August 1991, Prudhoe Bay, Alaska .....	47
APPENDIX C Numbers of invertebrates collected from samples at the E-Pad pond and impoundment in June 1991, Prudhoe Bay, Alaska .....	48
APPENDIX D Numbers of invertebrates collected from samples at the E-Pad pond and impoundment in August 1991, Prudhoe Bay, Alaska .....	49
APPENDIX E Numbers of invertebrates collected from samples at the P-Pad pond and impoundment in June 1991, Prudhoe Bay, Alaska .....	50
APPENDIX F Numbers of invertebrates collected from samples at the P-Pad pond and impoundment in August 1991, Prudhoe Bay, Alaska .....	51
APPENDIX G Biomass values for chironomids and oligochaetes in replicates used for ANOVA (June).....	52
APPENDIX H Biomass values for chironomids and oligochaetes in replicates used for ANOVA (August) .....	53
APPENDIX I References used for invertebrate identification .....	54
APPENDIX J Number of chironomid taxa in different functional feeding groups collected from the GC-2 pond and impoundment in June and August 1991, Prudhoe Bay, Alaska .....	56
ACKNOWLEDGMENTS .....	57

## List of Figures

Figure 1	Generalized locations of sites used in 1991 for secondary productivity study, Prudhoe Bay, Alaska .....	Following p. 4
Figure 2	Locations of the E-Pad pond and impoundment in relation to oil field facilities at Prudhoe Bay, Alaska .....	Following p. 4
Figure 3	Locations of the GC-2, CC-2, and H-Pad ponds and impoundments in relation to oil field facilities at Prudhoe Bay, Alaska .....	Following p. 4
Figure 4	Locations of the P-Pad pond and impoundment in relation to oil field facilities at Prudhoe Bay, Alaska .....	Following p. 4
Figure 5	Changes in chironomid and oligochaete dry weight biomass between June and August 1991, Prudhoe Bay, Alaska .....	10
Figure 6	Biomass of chironomids in natural ponds and impoundments during June 1991, Prudhoe Bay, Alaska .....	11
Figure 7	Biomass of oligochaetes in natural ponds and impoundments during June 1991, Prudhoe Bay, Alaska .....	12
Figure 8	Biomass of chironomids in natural ponds and impoundments during August 1991, Prudhoe Bay, Alaska .....	13
Figure 9	Biomass of oligochaetes in natural ponds and impoundments during August 1991, Prudhoe Bay, Alaska .....	14
Figure 10	Composition of wetland habitat at Storkersen Point (Bergman et al. 1977) and at three NPR-A study areas (Teshekpuk Lake, Island Lake, and Square Lake) (Derksen et al. 1979) .....	24
Figure 11	Observations of Oldsquaws (by wetland class) during periods of the summer at Storkersen Point in 1971-1973 (Bergman et al. 1977) and at five NPR-A study areas (Island Lake, Teshekpuk Lake, Square Lake, Meade River, and Singilik) in 1978 (Derksen et al. 1979) .....	25



Figure 12	Observations of Oldsquaw and Northern Pintail broods (by wetland class) at five NPR-A study areas (Island Lake, Teshekpuk Lake, Square Lake, Meade River, and Singilik) in 1977 and 1978 (Derksen et al. 1979) .....	26
Figure 13	Diet of Oldsquaws collected from Shallow- <i>Carex</i> (Class II) and Shallow- <i>Arctophila</i> (Class III) ponds at West Long Lake (NPR-A) in 1979 and 1980 (Taylor 1986) .....	27
Figure 14	Diet of Oldsquaws collected from Deep-open "nonfish" and "fish" (Class V) lakes at West Long Lake (NPR-A) in 1979 and 1980 (Taylor 1986) .....	28
Figure 15	Observations of King and Spectacled eiders (by wetland class) during periods of the summer at Storkersen Point in 1971-1973 (Bergman et al. 1977) .....	30
Figure 16	Observations of King Eider broods (by wetland class) at Storkersen Point in 1971-1973 (Bergman et al. 1977) and King and Spectacled eider broods at five NPR-A study areas (Island Lake, Teshekpuk Lake, Square Lake, Meade River, and Singilik) in 1977 and 1978 (Derksen et al. 1979) .....	32
Figure 17	Observations of Pacific Loons (by wetland class) during periods of the summer at Storkersen Point in 1971-1973 (Bergman et al. 1977) and at three NPR-A study areas (Square Lake, Teshekpuk Lake, and Island Lake) in 1977 and 1978 (Derksen et al. 1970) .....	33
Figure 18	Observations of Pacific Loon nest locations (by wetland class) at Storkersen Point (Bergman and Derksen 1977) and Pacific and Red-throated loon broods at five NPR-A study areas (Island Lake, Teshekpuk Lake, Square Lake, Meade River, and Singilik) in 1977 and 1978 (Derksen et al. 1979) .....	34
Figure 19	Observations of Northern Pintails (by wetland class) during periods of the summer at Storkersen Point in 1971-1973 (Bergman et al. 1977) and at five NPR-A study areas (Island Lake, Teshekpuk Lake, Square Lake, Meade River, and Singilik) in 1978 (Derksen et al. 1979) .....	35
Figure 20	Observations of shorebirds (all species combined) during periods of the summer at two NPR-A study areas (Island Lake and Teshekpuk Lake) in 1978 (Derksen et al. 1979) .....	37

## List of Tables

Table 1	Responses of birds to impoundments in Arctic Alaska .....	3
Table 2	Characteristics of ponds and impoundments at Prudhoe Bay, Alaska .....	4
Table 3	Dominant foods, feeding methods, and food sizes of different trophic feeding groups used to classify invertebrates at Prudhoe Bay, Alaska .....	7
Table 4	Wetland classification system used to describe patterns of waterbird use on the Arctic Coastal Plain .....	8
Table 5	Water quality measurements for natural ponds and impoundments used to sample invertebrates in 1991, Prudhoe Bay, Alaska .....	9
Table 6	Chironomid taxa reported by Butler et al. (1980) for natural ponds at Barrow and by this study for natural ponds and impoundments at Prudhoe Bay .....	15
Table 7	Counts of chironomids (by habitat type) collected from the GC-2 pond and impoundment in June and August 1991, Prudhoe Bay, Alaska .....	16
Table 8	Numbers of chironomids in different functional feeding groups collected from the GC-2 pond and impoundment in June and August 1991, Prudhoe Bay, Alaska .....	17
Table 9	Mean biomass, mean number, and relative mean weight of chironomids collected in different habitats at the GC-2, P-Pad, and E-Pad ponds and impoundments in June 1991, Prudhoe Bay, Alaska .....	18
Table 10	Mean biomass, mean number, and relative mean weight of chironomids collected in different habitats at the GC-2, P-Pad, and E-Pad ponds and impoundments in August 1991, Prudhoe Bay, Alaska .....	18
Table 11	Protein content of selected freshwater pond invertebrates important to waterbirds .....	22

Table 12	Aggregate percent volume of invertebrates eaten by, and available to, Oldsquaws in Shallow- <i>Carex</i> (II) ponds, Shallow- <i>Arctophila</i> (III) ponds, and Deep-open "nonfish" and "fish" (V) lakes at West Long Lake, Alaska (Taylor 1986) .....	29
Table 13	Summary of use patterns at Shallow- <i>Carex</i> (Class II) ponds by Arctic Coastal Plain waterbirds in relation to time of season .....	38
Table 14	Summary of use patterns at Flooded tundra (Class I) wetlands by Arctic Coastal Plain waterbirds in relation to time of season .....	38
Table 15	Generalized comparisons between two impoundment types and their analogous natural wetland classes .....	39

# Secondary Productivity of Impounded Wetlands in the Prudhoe Bay Oil Field: Implications for Waterbirds

## INTRODUCTION

Within oil fields in arctic Alaska, water impounded beside gravel roads and pads constitutes one of the major human-induced landscape disturbances in terms of acreage affected (Walker et al. 1987). Because a major environmental protection goal of the U.S. Fish and Wildlife Service is "to maintain overall wildlife habitat productivity" (FWS 1989), scientists and agency personnel have voiced concern about the potential negative effects of impoundments on wildlife populations, and options for mitigating negative effects are being considered.

One potential option for mitigation is to modify or rehabilitate impoundments rather than drain them. For rehabilitation plans to be successful, they must be based on a knowledge of how wildlife populations are affected by impoundments. At present, this knowledge is inadequate for making effective decisions about rehabilitation. To meet the need for more information, LGL, under contract to BPX, initiated, in June 1991, a program to study secondary productivity in impoundments as one measure of their potential value as waterbird habitat.

## Impoundments

Although jurisdictionally the entire North Slope is considered "wetland," in this report, *wetland* refers to a class or type of water body (e.g., impoundment or natural pond) unless stated otherwise. We define *impoundments* as ponds created by anthropogenic alterations to the landscape surface. Within the Prudhoe Bay oil field, most instances of impounded water occur where gravel roads and pads block drained thaw-lake basins or other low-lying areas (Alexander and Miller 1978,

Brown et al. 1984, Walker et al. 1986, Walker et al. 1987).

The amount of acreage flooded by impoundments usually peaks as snowmelt ends around mid-June. In the Prudhoe Bay oil field, many of the flooded areas drain by mid-summer after ice in road culverts thaws and surface run-off rates subside (Alexander and Miller 1978, Klinger et al. 1983, Walker et al. 1987).

In temporarily flooded areas and in shallow, permanent water bodies, enhanced primary production is often the most noticeable effect during the growing season (Klinger et al. 1983, Walker et al. 1987). Coinciding with increased primary production is a deepened thaw in summer (Walker et al. 1987). Increasing depth of thaw in impoundments often leads to some level of thermokarst (i.e., subsidence caused by melting of ice in soils).

Temporary and permanent impoundments together account for a major proportion of the acreage disturbed in the Prudhoe Bay region. For example, in an intensively developed part of the Prudhoe Bay oil field, impoundments covered nearly 20% of the landscape, compared with 11% covered by gravel roads and pads and 35% covered by all kinds of disturbances combined (Walker et al. 1986). In the Prudhoe Bay oil field as a whole (total area = 300 km<sup>2</sup> or 186 mi<sup>2</sup>), 2.8% of the total area was reportedly covered by impoundments (Walker et al. 1987), compared with about 2% (Senner 1989) to 4% (Walker et al. 1987) covered by gravel.

## OBJECTIVES

This study addressed two major objectives:

**(1) Conduct preliminary sampling of benthic invertebrates in impoundments and in natural ponds that resemble impoundments.**

The purpose of invertebrate sampling was to determine if the faunal groups of benthic invertebrates important as food sources for birds are different in biomass or diversity between natural ponds and impoundments.

**(2) Evaluate the literature on waterbird use of impoundments and natural ponds.**

The purposes of the literature review were (1) to summarize studies comparing invertebrate productivity and waterbird use of natural and artificial water bodies, and (2) describe waterbird food habits and use of natural water bodies on the Arctic Coastal Plain of Alaska. The review provided a framework for evaluating those characteristics of water bodies that most influence invertebrate productivity, and through an understanding of how birds use natural water bodies on the Arctic Coastal Plain, a basis for recommending future mitigation techniques for impoundments with similar attributes.

## BACKGROUND AND RATIONALE

Few investigators have studied the ecological effects of impoundments. The relevant studies that have been done (Troy 1982, 1983, 1985; Pollard et al. 1990) suggest that impoundments may have varying effects on waterbird species, depending on the species and the type of use in question (Table 1). Some species appear to avoid impoundments; a few others apparently are attracted to them, and others may be affected very little by their presence.

An accurate determination of the value of wetlands to waterbirds by direct measurement of levels of bird use is often difficult because of methodological problems. These problems are particularly apparent in arctic Alaska, where levels of bird use may be both low and highly variable in time and space (Troy 1982, 1983; Pollard et al. 1990). Thus, researchers often resort to measures of primary (i.e., plant) productivity (Truett and Kertell 1992) or secondary (i.e., invertebrate) productivity as indicators of the value of a habitat (or wetland type) to waterbirds that consume plants or invertebrates (Howard 1974, Klopatek 1988, Truett and Kertell 1989).

Existing data suggest that primary productivity in arctic impoundments may be equal to or greater than that in similar-sized natural ponds, but there are almost

no comparable data with respect to invertebrates. Aquatic invertebrates are particularly suited for use in environmental impact assessment because of their high species diversity, wide occurrence, and importance in the functioning of natural ecosystems (Rosenberg et al. 1986).

Invertebrate productivity may be particularly important in arctic water bodies, because high levels of animal protein are required by breeding waterbirds (Weller 1988). Female waterfowl, for example, consume a high proportion of invertebrates. The highly digestible sources of protein and energy, and essential amino acids, contained in invertebrates are thought to be essential for egg laying and incubation (Serie and Swanson 1976, Swanson et al. 1979). Invertebrates are also important to ducklings, which depend on foods of high energy and protein quality for rapid growth and feather development early in life (Driver et al. 1974). Few duck species are able to acquire substantial energetic or nutritional resources from consumption of plant material alone during these nutritionally demanding periods (Fredrickson and Reid 1988).

Both the zooplankton and the benthic invertebrates of arctic ponds are consumed by birds (Wetzel 1983, Hobbie 1984), but we measured only the latter. Benthos populations tend to dominate the biomass (Butler et al. 1980), and they are temporally and spatially less variable in abundance than the zooplankton (Hobbie 1984). The abundance and stability of the benthic populations insure a more dependable food source for birds (Butler 1982a) and result in less effort required for investigators to adequately sample the benthos and to interpret the results.

Among arctic freshwater benthos, the larvae of midges (Chironomidae) dominate the diversity as well as the biomass (Butler et al. 1980, Hobbie 1984). They are consumed in abundance by pond-feeding shorebirds (Holmes 1966) and waterfowl (Krapu and Swanson 1975, Swanson et al. 1979, Taylor 1986). For these reasons this project focused on chironomids.

Most large chironomid species in arctic ponds have a seven-year life cycle (Butler et al. 1980), which is one reason their abundance is temporally stable. Smaller chironomid species require about four years to mature (Butler and Anderson 1990). The older life stages of the larvae of large species undoubtedly provide the majority of food for birds, because younger larvae are too small for many of the bird species to feed profitably upon them (Holmes 1966). Total annual productivity of pond invertebrates is largely a conse-

Table 1. Responses of birds to impoundments in Arctic Alaska (adapted from Pollard et al. 1990).

Animal Group or Species	Nature and Timing of Animal Response	Location and Kind of Impoundment	Information Source	How Documented
All shorebirds tested except Semipalmated Sandpiper	Sightings less numerous on impounded side of road	Roadsides with and without impoundments, West Dock Road, Prudhoe Bay oil field	Troy 1982	Paired plot censuses
All shorebird nests	Total nests less numerous in roadside areas with impoundments than without	Temporary and permanent impoundments, near West Dock road, Prudhoe Bay oil field	Troy 1982	Paired plot censuses
All waterfowl species tested and Semipalmated Sandpiper	Sightings more numerous on impoundment side of road	Roadsides with and without impoundments, West Dock Road, Prudhoe Bay oil field	Troy 1982	Paired plot censuses
Lesser Golden-Plover, Semipalmated and Buff-breasted Sandpiper, Dunlin	Avoided impoundments	Temporary and permanent impoundments beside West Dock gravel roads, Prudhoe Bay oil field	Troy 1983	Seasonal abundance in 50 x 50 grid units; statistical comparisons
Northern Pintail, King Eider, Red-necked Phalarope	Attracted to impoundments		Troy 1983	Seasonal abundance in 50 x 50 grid units; statistical comparisons
Most shorebirds and waterfowl	Apparent avoidance for nesting	Impoundments (mostly permanent) along West Dock Road, Prudhoe Bay oil field	Troy 1985	Plot censuses
All waterfowl	Sightings more numerous in impoundments than natural ponds; sightings more numerous in impoundments with <i>Arctophila</i> than those without	Impoundments (mostly permanent) in Prudhoe Bay, Kuparuk, and Endicott oil fields	Pollard et al. 1990	Seasonal abundance in study plots containing entire waterbody or portion of waterbody; statistical comparisons

quence of the summertime growth of these older life stages of chironomids (Butler et al. 1980).

Three principal habitats for chironomids were identified in tundra ponds: pond centers, pond margins, and zones of emergent vegetation (Butler et al. 1980). Pond centers and margins usually are unvegetated habitats consisting of fine, unconsolidated sediments and irregularly spaced peaty sediments, respectively. Sediments in stands of plants along the shore support a fauna similar to that in sediments in pond centers, but in addition have a number of Orthoclaadiinae (*Psectrocladius*, *Cricotopus*) (Butler et al. 1980). In zones with emergent plants in natural ponds near Barrow, midges of the genera *Corynoneura*,

*Paratanytarsus*, and *Trichotanytarsus* were common, as were caddisflies of the genera *Limnophilus* and *Macrasema* and stoneflies of the genus *Nemoura*. In the centers of the ponds, the dominant benthic animals were midge larvae of the genera *Chironomus*, *Procladius*, and *Tanytarsus* (Hobbie 1984). Different bird species often feed in different combinations of these chironomid habitats. These habitat types also occur in impoundments at Prudhoe Bay (pers. obs).

#### STUDY AREA

Sites selected for study were located in the Prudhoe Bay oil field (Figs. 1-4). These sites were of two kinds: impoundments and natural ponds. Natural

Table 2. Characteristics of ponds and impoundments used for invertebrate sampling at Prudhoe Bay, Alaska. Ponds and impoundments used to determine invertebrate biomass are shaded.

Water Body Pair	Area (ha)		Age (years)		Amt of Emergent Vegetation (% of total shoreline)		Exposed Sediment on 13 August (% of total area)		Mean Shoreline Gradient (n=3)		Mean Water Depth at Center on 13 Aug. (n=5)	
	Pond	Imp.	Pond	Imp.	Pond	Imp.	Pond	Imp.	Pond	Imp.*	Pond	Imp.
GC-2	0.11	0.13	-	15	20	60	3	0	5°	29°	8 cm	75 cm
P-Pad	0.10	0.10	-	10	15	85	8	0	4°	21°	16 cm	43 cm
E-Pad	0.18	0.10	-	19	5	40	11	40	4°	2°	16 cm	10 cm
CC-2	0.21	0.15	-	18	10	40	10	0	6°	11°	22 cm	56 cm
H-Pad	0.23	0.25	-	20	10	60	16	0	4°	18°	15 cm	40 cm

\*For impoundments, shoreline gradient was measured adjacent to gravel roads and pads only.

ponds were chosen because we wished to compare their secondary productivity with that of impoundments. Characteristics of study locations are provided in Table 2.

Ten impoundments were selected prior to the field season using a 1984 map showing impoundment locations and dates of first appearance in the oil field (Lederer et al. 1984). All sites were situated upslope from roads where no water body existed prior to road construction. Large-scale color infrared (CIR) photographs taken in late summer of 1989 and 1990 were used to determine which of these impoundments were likely to still be present in 1991.

Five impoundments were chosen for sampling during a visit to the field on 19 June 1991. Sites were chosen according to the following criteria: (1) water permanence, (2) presence of an unvegetated center with some emergent vegetation growing at the margin, (3) lack of resident fish (water bodies without fish have a greater abundance and richness of invertebrates; at Barrow, fish are present only in waters deeper than 1.7 m), and (4) availability for sampling in late June. To eliminate potential differences in secondary productivity that might result from differences in soil type, only impoundments located in alkaline (versus acidic) soils were selected for study. The distribution of alkaline and acidic soil types was determined using a soils map provided in Walker et al. (1980). Only water bodies less than 0.5 ha in size met the above criteria. Selected impoundments ranged in age from 10 to 20 years (Table 2).

A natural pond near to each of the five impound-

ments and similar with respect to surface area and microhabitat features (i.e., having an unvegetated center and emergent vegetation at the margin) was then selected. Although natural ponds were used for comparison with impoundments, they were sometimes slightly different in size. These differences resulted from our inability to accurately determine the boundaries of impoundment basins in early summer when adjacent roads and pads blocked the movement of spring runoff and caused temporary flooding.

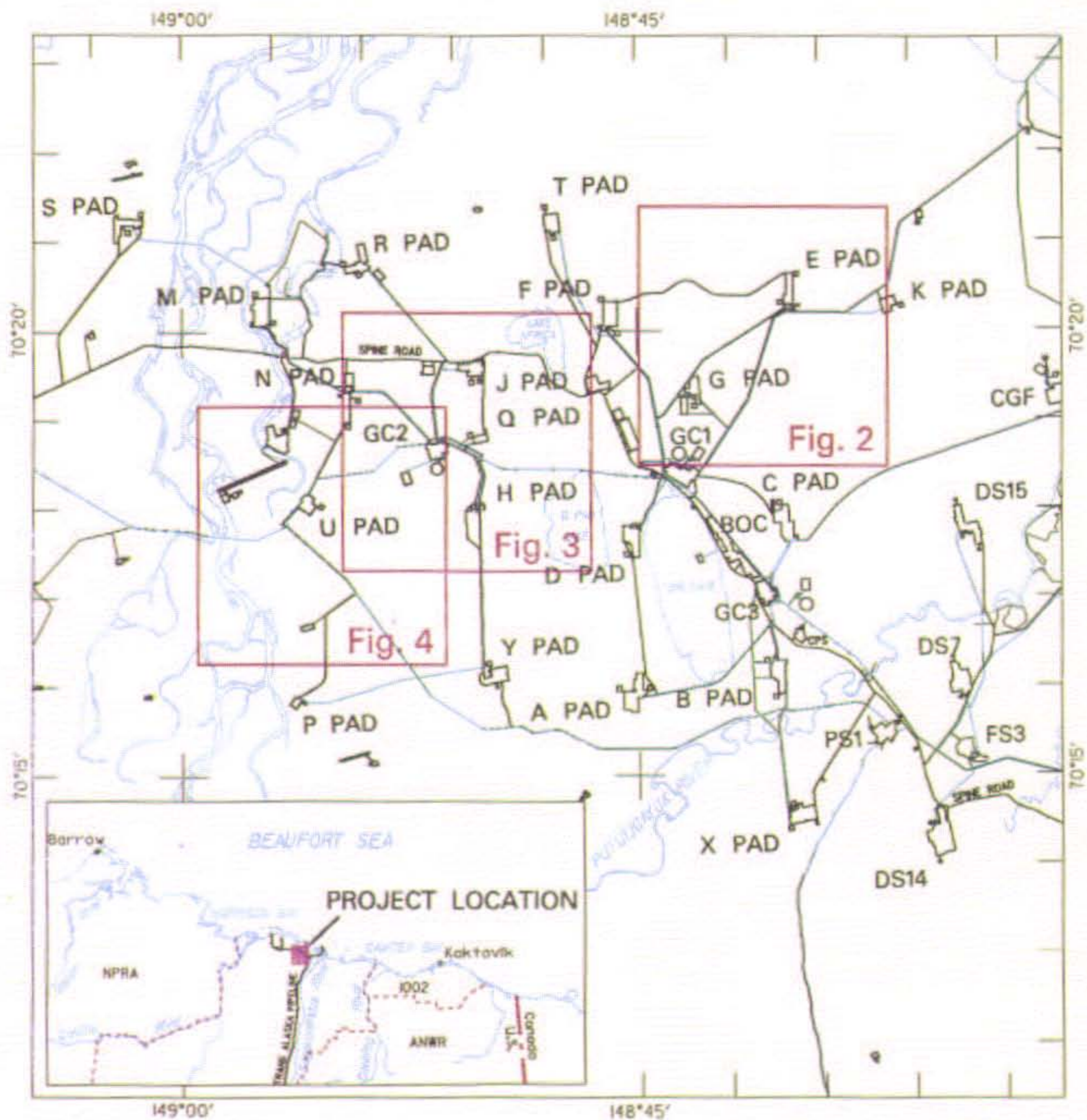
## METHODS

### Data Collection

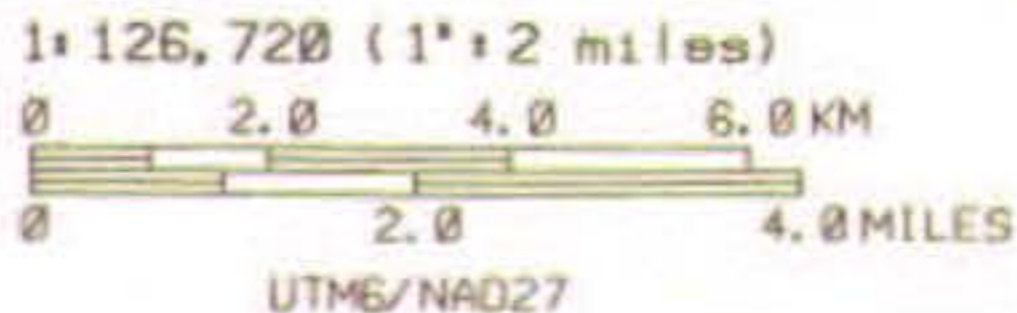
Invertebrates were sampled in June, July, and August. The June period (21–23 June) was selected to provide biomass estimates before emergence of adult insects, the July sampling period (16–17 July) was included to provide mid-season biomass estimates, and the August period (13–14 August) was selected to provide biomass estimates after emergence and dispersal of most adult insects and after peak of predation by birds on remaining larvae.

Within each water body, three microhabitats were sampled: unvegetated margin, emergent vegetation at the margin, and bottom substrate near the center. Macroinvertebrates were collected using a Wildco-Ekman grab fitted with a custom-fabricated 18-inch-tall sample chamber. The modified chamber enabled us to sample emergent vegetation and unvegetated bottom sediments using the same sampling device, thus standardizing the volume of sediments collected at each

## SECONDARY PRODUCTIVITY STUDY



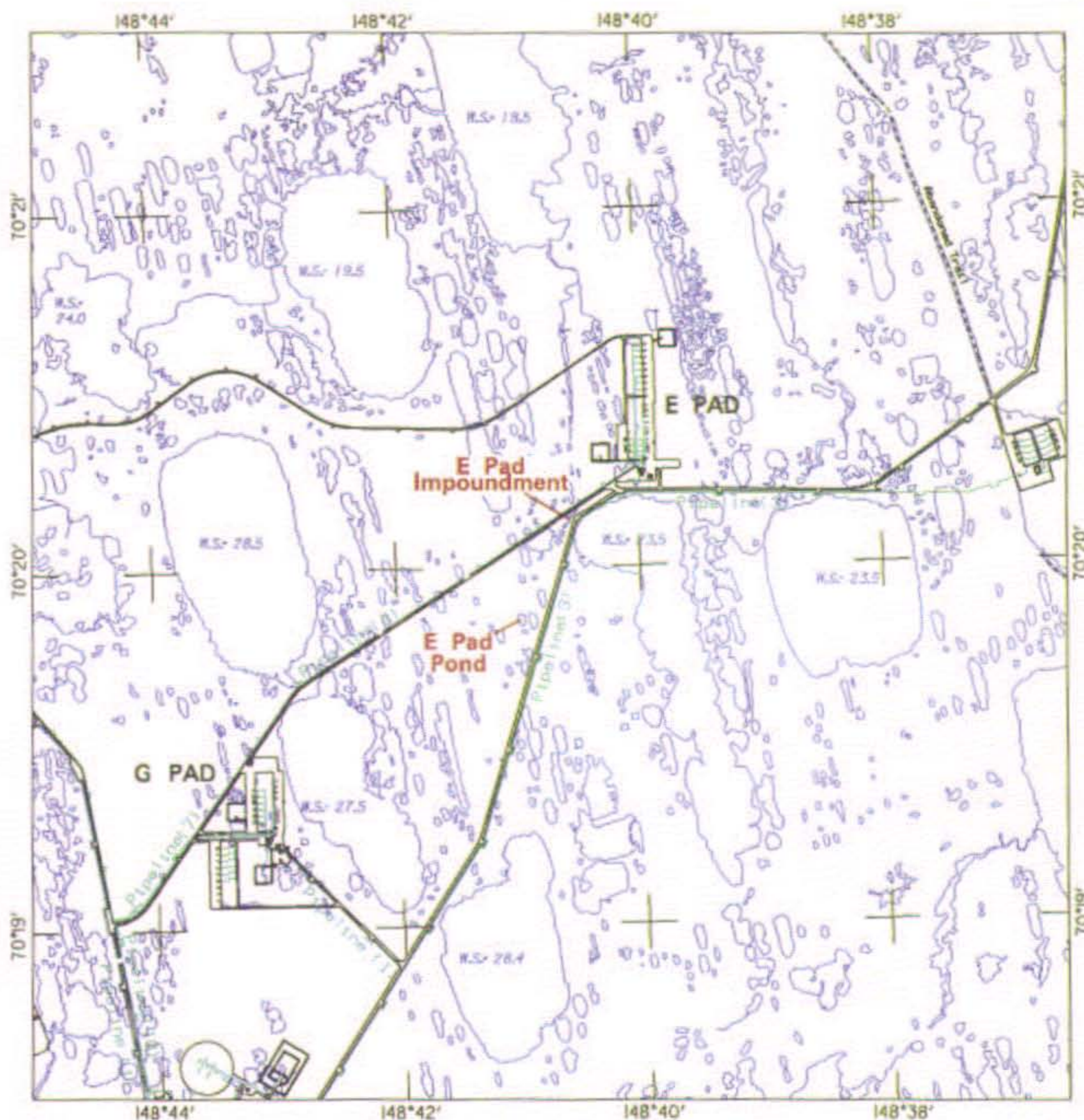
Generalized location of sites used for Secondary Productivity Study, Prudhoe Bay, Alaska. Figs. 2-4 show specific study site locations.



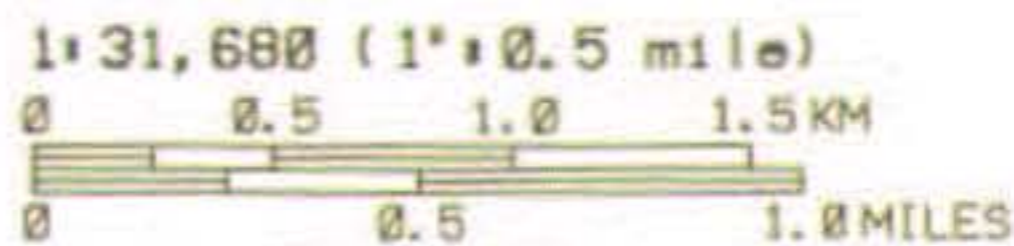
Base mapping from USGS 1:63,360 series. Facilities updated from aerial photography through 1988.



## SECONDARY PRODUCTIVITY STUDY



Location of E Pad pond and impoundment in relation to oil field facilities at Prudhoe Bay, Alaska.

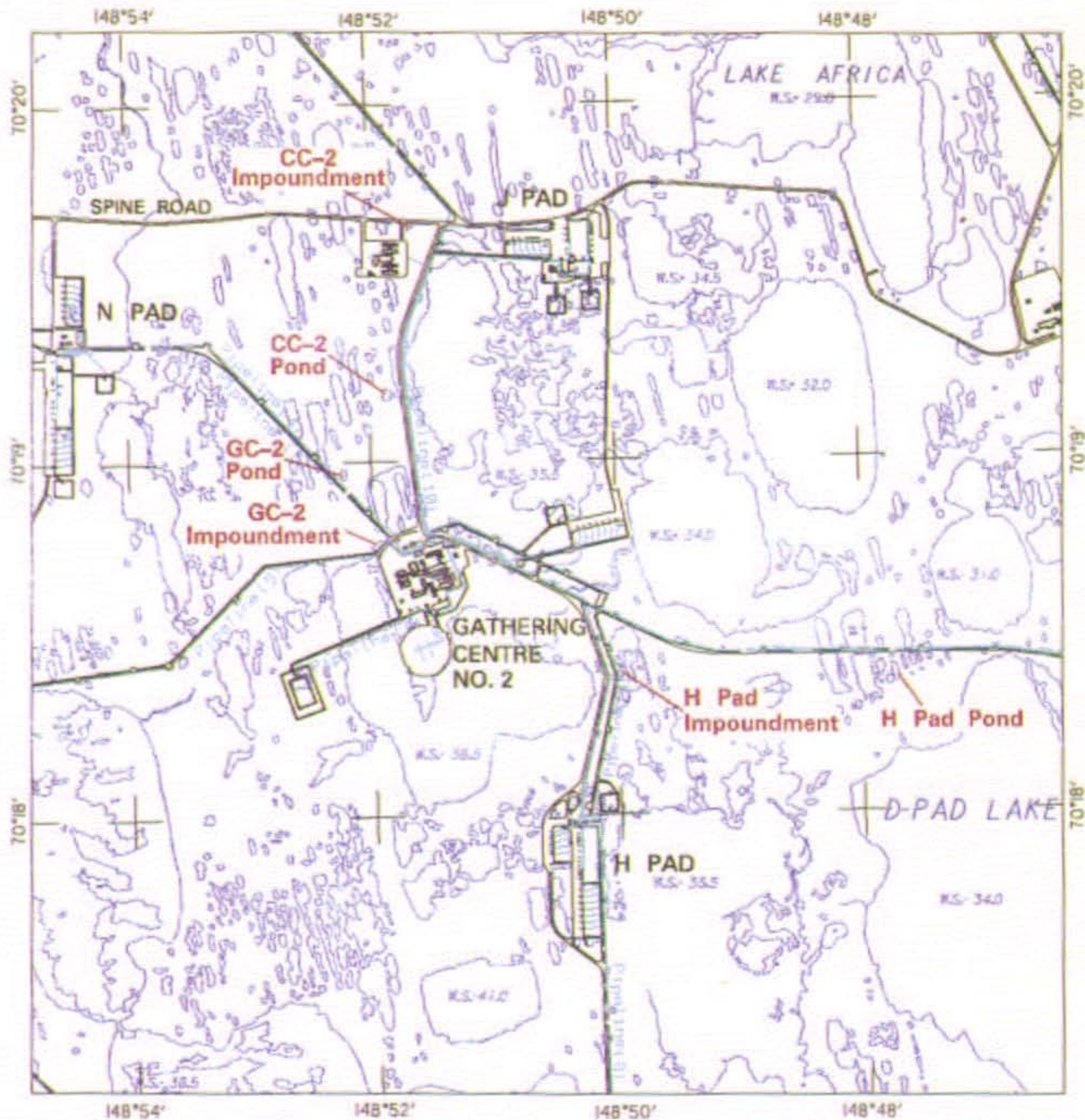


Base mapping from  
 1973 aerial photography  
 facilities updated 1988.

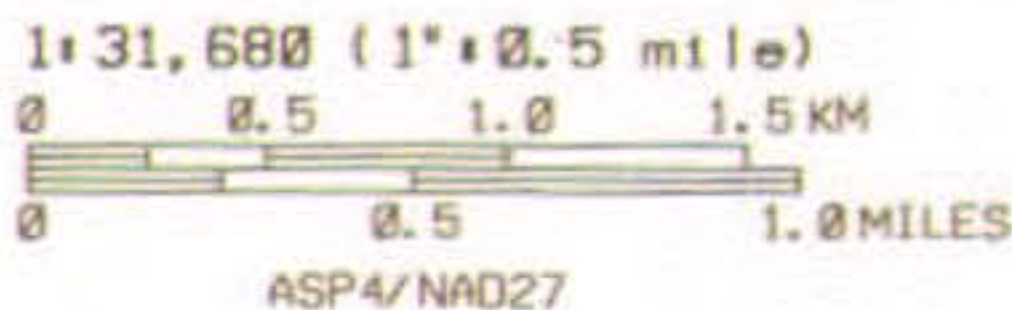
ASP4/NAD27

LGL, Feb. 1992, TG10604

## SECONDARY PRODUCTIVITY STUDY



Location of GC-2, CC-2, and H Pad ponds and impoundments in relation to oil field facilities at Prudhoe Bay, Alaska.

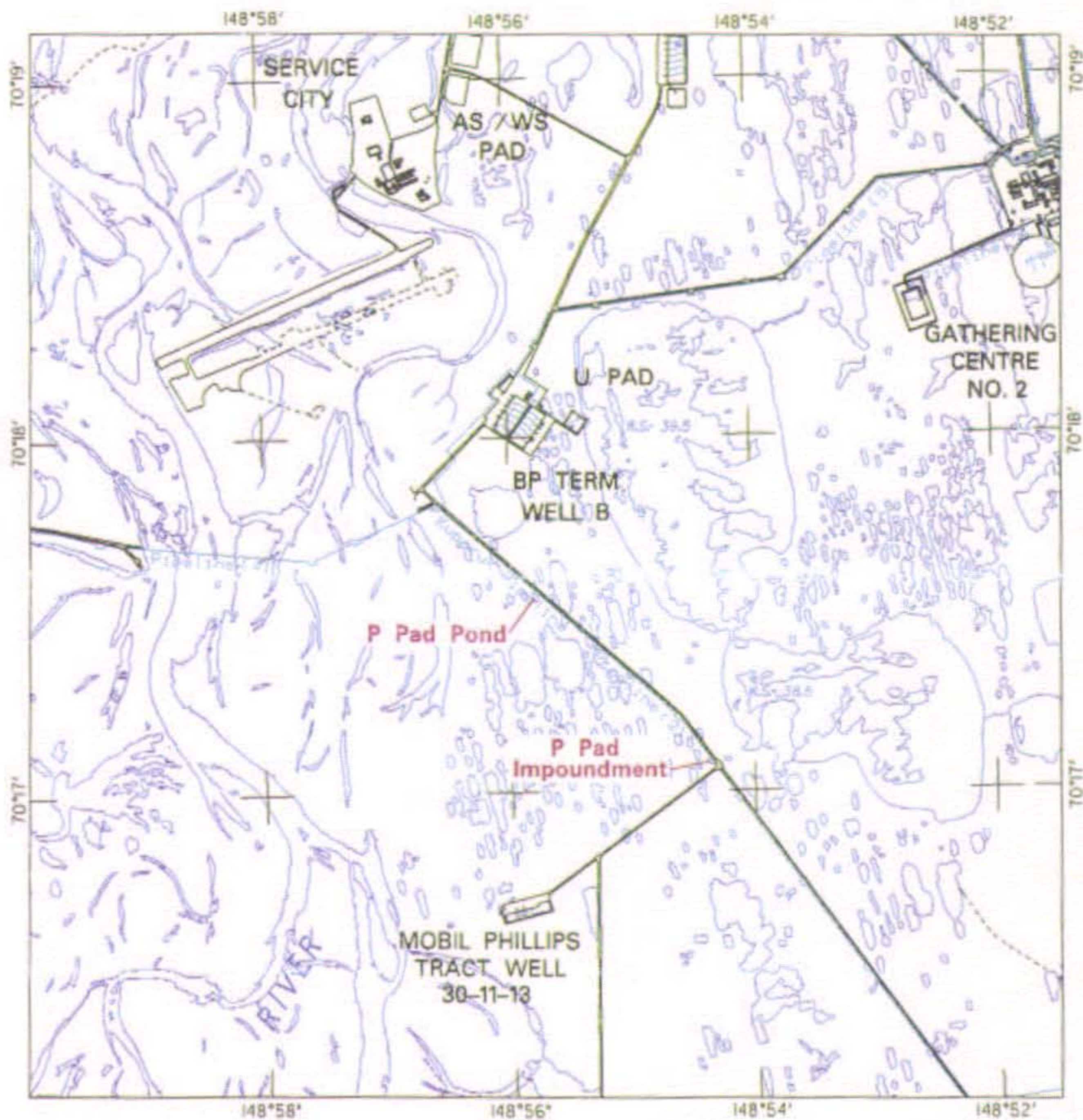


Base mapping from  
1973 aerial photography  
facilities updated 1988.

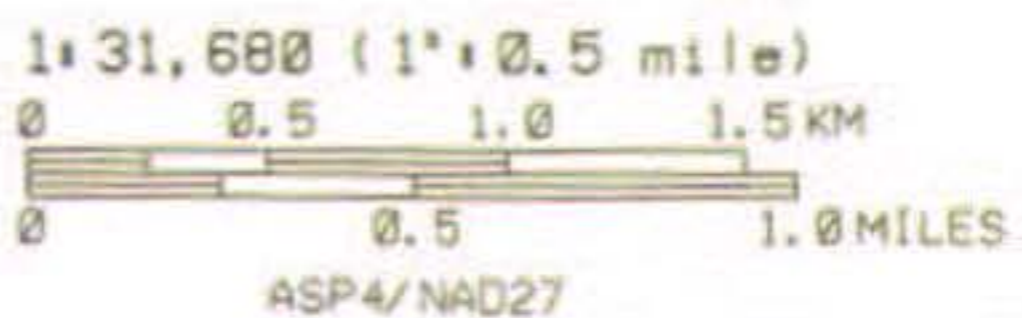
ASP4/NAD27

LGL, Feb. 1992, T010606

## SECONDARY PRODUCTIVITY STUDY



Location of P Pad pond and impoundment in relation to oil field facilities at Prudhoe Bay, Alaska



Base mapping from  
 1973 aerial photography,  
 facilities updated 1988.

LGL, Feb. 1992, T010607

habitat type.

During each sampling period, six grab samples were collected from each habitat. This resulted in an overall total of 540 samples (10 water bodies x 3 sampling periods x 3 habitat types per water body x 6 grab samples). Samples were washed in the field using a Wildco wash bucket (Cat. No. 190) with a brass wire cloth bottom (No. 30 mesh). Remaining sediment and organisms were placed in plastic bags and preserved with 5–10% formalin. At the end of each sampling period, samples were packaged in 3.5- and 5-gallon plastic buckets and shipped to Bryan, Texas, where LGL maintains laboratory facilities.

Additional information collected during each sampling period included water temperature (pocket thermometer), conductivity (Hanna Model 0661-40 Dissolved Solids Tester), pH (Hanna Piccolo), and water and thaw depths (metal metric rule). Amount of emergent vegetation, shoreline gradient, and the distribution and extent of exposed shoreline were recorded at each water body during the final sampling period only.

Surface area, amount of emergent vegetation, and extent of exposed sediment were determined for each water body using an electronic digital planimeter and large-scale (1"=100') CIR photographs. These estimates were made from CIR photographs taken on 13 August 1991. Shoreline gradient was measured with a metric rule.

### Sample Analysis

In the laboratory, samples were rinsed through a 0.5-mm mesh sieve to remove as much sediment as possible. The remaining material was examined using a binocular dissecting microscope, and all macroinvertebrates were removed and counted. Of the 540 samples collected, 90 were scheduled to be used for taxonomy and 450 were scheduled for use in the biomass analysis.

After initial sorting and weighing, it was determined that only chironomids and oligochaetes were abundant enough for biomass analyses. Thus, pond productivity was based on biomass estimates for these two groups. The cost of determining biomass values for remaining taxa was too high considering their low numbers. Numbers of invertebrates by major taxa collected from ponds and impoundments are provided in Appendices A-F. To obtain biomass estimates, chironomids and oligochaetes were oven-dried overnight at 60°C and weighed on an analytical balance to the

nearest 0.0001 g. Biomass values are provided in Appendices G and H.

For identification, chironomid larvae usually were mounted on slides and examined through a microscope at magnifications ranging from 100 to 1000x. The slide mount provided a permanent archive or voucher specimen for each identification. Larvae were identified to the lowest practical taxonomic level using references listed in Appendix I.

The following procedure was used to prepare permanent slide mounts for chironomid identification:

- 1) Specimens preserved in 70% alcohol were blotted dry and placed in a drop or two of CMCP-10 high viscosity, colorless, mountant (Catalog #16300, Polysciences Inc., Washington, PA) on a standard microscope slide.
- 2) A small scalpel was used to cut off the head capsule, if the entire larvae could not be positioned vertical side up. The head capsule and posterior end of the abdomen were most important for identification.
- 3) The head capsule (positioned vertical side up) and body were covered with a cover slip (usually 15 or 18 mm in diameter), and the tips of forceps were used to apply enough pressure to the head capsule to spread mouthparts, antennae, etc. so they would be visible.
- 4) Each slide was labelled, placed on a flat surface to dry overnight, and checked periodically to remove air spaces.

### Change in Scope of Sample Analysis

A common obstacle to including benthic macroinvertebrates in monitoring and impact assessment studies is the high cost in labor associated with separating specimens from collected substrate and then identifying them (Jackson and Resh 1989). This proved to be the case for this study. The time and cost required for sample analysis far exceeded expectations because 1) samples were considerably richer in invertebrates than was anticipated based on published information and a conversation with M. Butler (pers. comm. 1991), and 2) the amount of substrate from which the invertebrates were sorted was much greater than expected.

Consequently, a revised plan was submitted that included the following recommended changes in scope:

- 1) Analysis of invertebrate samples from six water bodies instead of ten. The six water bodies selected were P-Pad, GC-2, and E-Pad ponds and impoundments. These pairs provide good spatial representation of the study area.
- 2) Analysis of samples from only two sampling periods (June and August).
- 3) Analysis of three samples per habitat for biomass determinations, for a total of 108 samples (6 water bodies x 3 habitats per water body x 3 samples per habitat x 2 sampling periods).
- 4) Analysis of one sample at each of two water bodies (GC-2 pond and impoundment pair) in June and August for taxonomy, for a total of 12 samples (2 water bodies x 3 habitats x 2 sampling periods). This reduction was necessary because of the high cost of taxonomic analyses compared to biomass analyses.

#### Data Analysis

One-way analysis of variance (ANOVA) and orthogonal contrasts were performed on chironomid and oligochaete biomass data. Data were transformed [ $\ln(x+1)$ ] based on results of Bartlett's test for homogeneity of between-group variances which indicated inequality of variances among water bodies. The use of orthogonal contrasts allowed one contrast per degree of freedom for group sources of variance [see Pequegnat et al. (1990) for a description and sample calculation]. Each contrast was stated as an hypothesis which could be tested statistically. Hypotheses are listed below. Analyses were conducted using SYSTAT statistical software (SYSTAT, Inc., Evanston, IL) installed on a Macintosh IIfx computer.

- $H_{01}$  = There are no significant differences in chironomid and oligochaete dry weight biomass between early and late summer for all water bodies combined.
- $H_{02}$  = There are no significant differences in chironomid and oligochaete dry weight biomass between ponds and impoundments in early or late summer for all water bodies combined.
- $H_{03}$  = There are no significant differences in chironomid and oligochaete dry weight biomass between pond centers and pond edges (margins and emergent vegetation

habitats) in early or late summer.

$H_{04}$  = There are no significant differences in chironomid and oligochaete dry weight biomass between impoundment centers and impoundment edges (margins and emergent vegetation habitats) in early or late summer.

$H_{05}$  = There are no significant differences in chironomid and oligochaete dry weight biomass between pond margins and pond emergent vegetation habitats in early or late summer.

$H_{06}$  = There are no significant differences in chironomid and oligochaete dry weight biomass between impoundment margins and impoundment emergent vegetation habitats in early or late summer.

Chironomid genera were assigned to different trophic groups according to a system described in Merritt and Cummins (1984) and from information in Butler et al. (1980). In this system, organisms were classified as collectors, predators, shredders, and scrapers according to their method of feeding and their dominant food (Table 3).

#### Waterbird Use of Wetlands on the Arctic Coastal Plain

The importance of wetland diversity in satisfying the annual needs of waterbirds is widely recognized (Swanson et al. 1979; Weller 1988, 1990). Water bodies of different sizes and depths are unique in terms of plant life-forms, composition of the invertebrate community, and the seasonal succession of invertebrates (Swanson et al. 1979, Weller 1988). Birds are wide-ranging vertebrates that link different water bodies spatially by responding to asynchronous changes in levels of aquatic invertebrate abundance, biomass, and perhaps nutritional quality (Weller 1988, Kaminski and Prince 1981).

We reviewed the results of previous studies to better understand how and when different natural water bodies on the Arctic Coastal Plain are used by waterbirds. For this review we chose only studies that used a common wetland classification system, that developed by Bergman et al. (1977) for use at Storkersen Point and subsequently used to evaluate water bodies in the National Petroleum Reserve-Alaska (NPR-A) by Derksen et al. (1979) and Taylor (1986). Common use of this system provides a preliminary framework

Table 3. Dominant foods, feeding methods, and food sizes of trophic feeding groups used to classify chironomids at Prudhoe Bay, Alaska.

Feeding Group	Dominant Food	Feeding Method	Size of Food (microns)
Collectors	Decomposing fine organic matter	Filterers (water column feeders)	<10 <sup>3</sup>
		Gatherers (sediment or water surface feeders)	<10 <sup>3</sup>
Predators	Living animal tissue	Carnivores	>10 <sup>3</sup>
Shredders	Living plant tissue	Herbivores	>10 <sup>3</sup>
	Decomposing plant tissue (coarse organic matter)	Detritivores	>10 <sup>3</sup>
Scrapers	Periphyton (algae attached to a substrate)	Herbivores	<10 <sup>3</sup>

for evaluating studies at several Arctic Coastal Plain locations and extrapolating results to Prudhoe Bay.

The Bergman system describes eight wetland classes based on size, water depth, emergent vegetation, basin geomorphology, and water chemistry. It does not include terrestrial habitats or areas with saturated soils. An important criterion in the system is the presence or absence of *Carex aquatilis* or *Arctophila fulva*, the dominant emergent plants in these wetlands. The eight wetland classes are described in Table 4. Natural ponds selected for our study were Shallow-*Carex* (Class II) ponds according to criteria described by Bergman et al. (1977). They are shallow (less than 30 cm in depth), have a gently sloping shoreline, and contain emergent *C. aquatilis* around an open central zone.

Several species of invertebrate-eating birds considered common at Prudhoe Bay were chosen to evaluate use patterns relative to these wetland classes. Patterns of use were based on information from Bergman et al. (1977), Derksen et al. (1979), and Taylor (1986), but use summaries were sometimes supplemented with information on food habits from other sources when such information was important to the discussion. Species were grouped into management guilds. A guild is a group of species that exploit resources in a similar way (Root 1967); a management guild is a group of species that respond in similar ways

to anthropogenic changes to the environment (Verner 1984). These guilds encompassed a range of foraging patterns and simplified discussions of how different waterbirds used wetland types in the breeding season.

Three management guilds were identified based on similarities in food type and the way food is captured: 1) divers [Oldsquaw (*Clangula hyemalis*), Pacific Loon (*Gavia pacifica*), King Eider (*Somateria spectabilis*), and Spectacled Eider (*Somateria fischeri*)], 2) surface-feeders [Northern Pintail (*Anas acuta*)], and 3) waders (shorebirds). We recognize that guild affiliations may not always be mutually exclusive; for example, divers frequently feed on invertebrates at the water surface during summer. Sixteen percent (n=70) and 17% (n=248) of the Oldsquaws observed feeding during summer at West Long Lake and Storkersen Point, respectively, fed on or near the surface without diving (Taylor 1986). At Storkersen Point, young King Eiders dived readily, but adults were observed diving on only three occasions (n=131); feeding by adults was almost entirely from the surface, usually on invertebrates in bottom sediments (Bergman et al. 1977). However, for purposes of evaluating the potential impacts of deep-water impoundments, the fact that eiders feed occasionally by diving suggests that invertebrates in deep water sediments remain accessible to them.

Table 4. Wetland classification system used to describe patterns of waterbird use on the Arctic Coastal Plain. The system was developed by Bergman et al. (1977).

Class	Type	Description
Class I	Flooded tundra	Temporary wetlands formed during the spring when melt water overflows stream basins or is trapped in vegetated tundra depressions. In June, water depths rarely exceed 10 cm and by August surface water is absent or only a few cm deep. Wetland basins are poorly defined because <i>Carex aquatilis</i> and other plants tolerant of periodic flooding cover all or most of the area.
Class II	Shallow- <i>Carex</i>	Shallow ponds with a gently sloping shoreline surrounded by, and usually containing, emergent <i>C. aquatilis</i> with an open central zone. In June, water depths range from 10-30 cm but by August decrease due to evaporation and drainage.
Class III	Shallow- <i>Arctophila</i>	Ponds containing <i>Arctophila fulva</i> in the central zone and <i>A. fulva</i> and/or <i>C. aquatilis</i> near shore. Water depths range from 20-50 cm and pond margins occasionally are exposed during August.
Class IV	Deep- <i>Arctophila</i>	Large ponds or lakes with abrupt shorelines and flat or gently sloping bottoms. Stands of <i>A. fulva</i> are found near shore, but no aquatic plants are found in the central zone.
Class V	Deep-open lakes	Large lakes with abrupt shorelines, sublittoral shelves, and a deep central zone. Taylor (1986) divided this class into Deep-open "Fish" lakes and Deep-open "Nonfish" lakes depending on whether or not they contained least cisco. Thus, they were classified individually by Taylor (1986) to more accurately evaluate habitat use by Oldsquaws.
Class VI	Basin-complex	Large, partially drained basins. Basin-complex wetlands may contain any of the other wetland classes (Derksen et al. 1979, Taylor 1986).
Class VII	Beaded-stream	Small, often intermittent streams consisting of a series of channels linked to pools. Stream pools often correspond to Shallow- <i>Arctophila</i> or Deep- <i>Arctophila</i> wetlands. During the spring thaw, beaded streams may flood surrounding lowlands to create Flooded tundra wetlands.
Class VIII	Coastal wetlands	Brackish or subsaline wetlands bordering the Beaufort Sea, and dominated by <i>Carex subspathacea</i> and <i>Puccinellia phryganodes</i> at basin margins and adjacent flats.

## RESULTS

### Physical Characteristics of Ponds and Impoundments

Ponds and impoundments were all less than 0.5 ha in size (Table 2). Ponds, however, differed from impoundments in amount of emergent vegetation and in physical characteristics such as water depth, shoreline gradient, amount of exposed sediment, and nature of bottom substrate. Impoundments had a much greater amount of emergent vegetation (measured as percent of total shoreline): averaging 50% versus 12% for ponds (Table 2). With the exception of the E-Pad site, which was effectively drained by a culvert, impound-

ments also averaged deeper at the center (45 cm versus 15 cm), had steeper shoreline gradients (16° versus 5°), and had less exposed sediment at the periphery (8% versus 10%) than natural ponds (Table 2). General observations made during invertebrate sampling indicated that a large percentage of the bottom substrate of impoundments was composed of peaty sediments and drowned tundra vegetation. Natural ponds, on the other hand, had bottom substrates of fine sand or silt.

### Water Quality Characteristics of Ponds and Impoundments

Table 5 shows pH and conductivity measurements for all ponds and impoundments sampled for inverte-

Table 5. Water quality measurements for natural ponds and impoundments used for invertebrate sampling at Prudhoe Bay, Alaska. Ponds and impoundments used to determine invertebrate biomass are shaded.

Water Body Pair	pH		Conductivity ( $\mu\text{S}/\text{cm}$ )		Sampling Period
	Pond	Imp.	Pond	Imp.	
GC-2	7.86	7.49	100	200	June
	8.33	8.09	300	500	July
	8.47	8.35	300	600	August
P-Pad	8.40	7.68	300	200	June
	8.52	8.12	400	300	July
	8.42	8.51	300	300	August
E-Pad	7.50	8.13	200	200	June
	8.65	8.56	300	500	July
	8.51	8.69	300	600	August
CC-2	8.35	8.00	300	400	June
	7.94	8.15	500	500	July
	8.40	8.39	400	500	August
H-Pad	8.50	7.43	200	200	June
	8.43	8.27	400	200	July
	8.41	8.35	400	200	August

brates at Prudhoe Bay. With the exception of the H-Pad pond, pH values increased from June to August at all water bodies. In June, mean pH was higher at natural ponds ( $\bar{X}=8.12$ ,  $SD=0.43$ ) than at impoundments ( $\bar{X}=7.75$ ;  $SD=0.31$ ). The difference was less in July, and by August mean pH values were almost identical: 8.44 ( $SD=0.5$ ) for natural ponds and 8.45 ( $SD=0.15$ ) for impoundments.

Mean conductivity readings were greater for impoundments compared to natural ponds during all periods. For impoundments, mean conductivity was 240 ( $SD=89.4$ ) in June, 400 ( $SD=141.42$ ) in July, and 440 ( $SD=181.66$ ) in August. For natural ponds, mean conductivity was 220 ( $SD=83.7$ ) in June, 380 ( $SD=83.67$ ) in July, and 340 ( $SD=54.77$ ) in August.

### Chironomid and Oligochaete Biomass

#### Between Sampling Periods

Mean chironomid biomass declined from 20.8 mg to 13.8 mg and mean oligochaete biomass increased from 12.8 mg to 28.7 mg between June and August for all ponds and impoundments combined (Fig. 5). However, because of high variability between samples,

overall changes in dry weight biomass were not statistically significant.

#### Within Sampling Periods

In early summer (June), the mean biomass of both chironomids and oligochaetes (Figs. 6, 7) was significantly greater ( $P<0.05$ ) in samples collected from impoundments (28.1 mg and 18.7 mg, respectively) than natural ponds (13.5 mg and 6.8 mg, respectively). For both chironomids and oligochaetes, this difference was primarily the result of the much greater biomass in impoundment edge habitats (29.1 mg and 25.3 mg, respectively) compared with the same habitats in natural ponds (3.2 mg and 7.9 mg, respectively). Edge habitats include both unvegetated margins and emergent vegetation zones.

Within impoundments in June, edge habitats had a significantly greater biomass of oligochaetes than centers (25.3 mg versus 5.5 mg,  $P<0.0001$ ), but chironomid biomass was not significantly different between centers (26.1 mg) and edge habitats (29.1 mg). Within natural ponds, habitat comparisons were significant only for chironomids: centers had a significantly greater biomass compared with edge habitats (34.2 mg



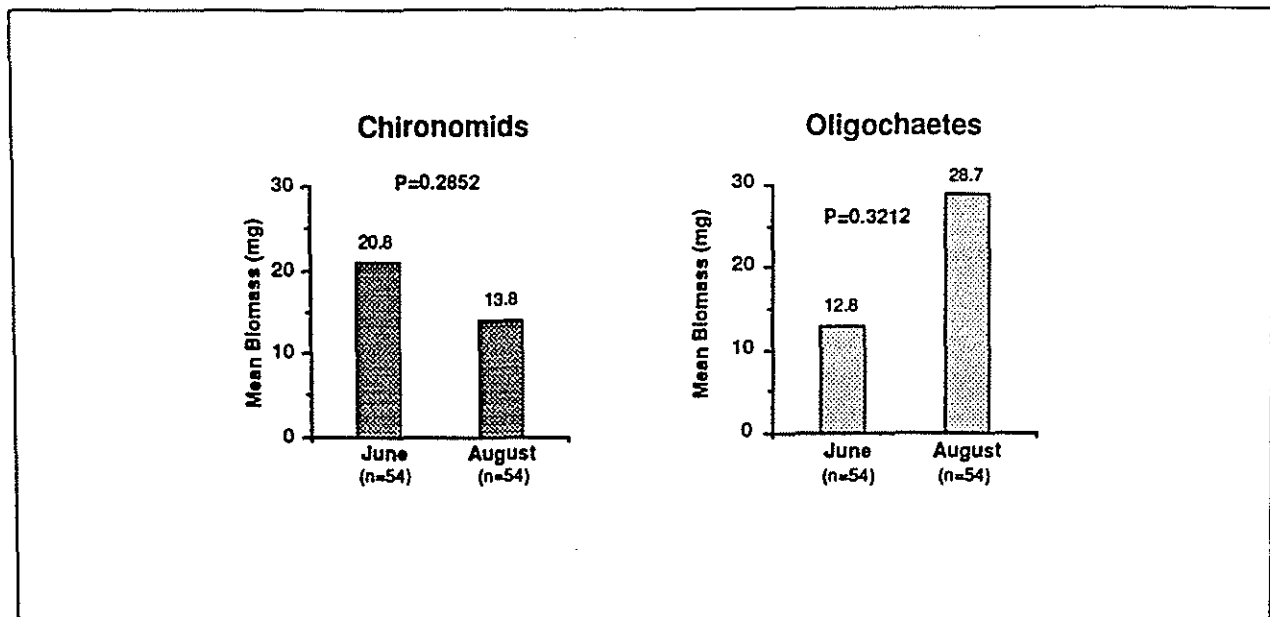


Figure 5. Changes in chironomid and oligochaete dry weight biomass between June and August 1991, Prudhoe Bay, Alaska. Mean biomass values for June and August are for ponds and impoundments combined. Sample sizes (n) are based on nine biomass samples from each of three habitat types (center, margin, emergent) for both chironomids and oligochaetes.

versus 3.2 mg,  $P < 0.0001$ ). In June, mean biomass of chironomids was greater than mean oligochaete biomass in both ponds (13.5 mg versus 6.8 mg) and impoundments (28.1 mg versus 18.7 mg).

In late summer (August), mean biomass values for both chironomids and oligochaetes (Figs. 8, 9) again were significantly greater ( $P < 0.05$ ) in samples collected from impoundments (21.1 mg and 52.5 mg, respectively) than natural ponds (6.5 mg and 4.9 mg, respectively). As in June, greater oligochaete biomass in impoundments (Fig. 9) was primarily the result of the much greater biomass in impoundment edge habitats (66.9 mg) compared with the same habitats in natural ponds (5.8 mg). For chironomids (Fig. 8), the difference resulted from greater biomass values in both impoundment centers (28.5 mg) and edge habitats (17.3 mg) compared with the same habitats (12.7 mg and 3.4 mg, respectively) in natural ponds.

Within impoundments in August, edge habitats had a significantly greater biomass of oligochaetes than centers (66.9 mg versus 23.6 mg,  $P = 0.0097$ ) and centers had a significantly greater biomass of chironomids than edges (28.5 mg versus 17.3 mg,  $P = 0.0083$ ). Within natural ponds, habitat comparisons again were significant only for chironomids: centers had a significantly greater biomass than edges (12.7 mg versus 3.4 mg,  $P < 0.0001$ ), and emergents had a significantly greater biomass than unvegetated margins (4.8 mg ver-

sus 1.9 mg,  $P = 0.0026$ ). In August, mean biomass of chironomids was slightly greater than mean biomass of oligochaetes in natural ponds (6.5 mg versus 4.5 mg), while mean biomass of oligochaetes was considerably greater than mean biomass of chironomids in impoundments (52.5 mg versus 21.1 mg).

#### Chironomid Taxa

The revised project scope resulted in taxonomic examination of the GC-2 water bodies only. A total of 21 chironomid genera were identified from ponds and impoundments at Prudhoe Bay during June and August (Table 6). This is nearly identical to the number of chironomid taxa identified by Butler et al. (1980) from natural ponds at Barrow (Table 6). At Prudhoe Bay, a total of 23 identified taxa (genera and species) were counted from the GC-2 pond and impoundment alone (Table 7). Of the 23 taxa, 17 were present in the GC-2 impoundment and 13 in the GC-2 pond (Table 7). Ten taxa (43%) were found only in the GC-2 impoundment, whereas 6 taxa (26%) were found only in the GC-2 pond. Seven taxa were common to both water bodies. There were more chironomid taxa collected from impoundment versus natural pond habitats during both June and August. In August, numbers of taxa declined markedly at both water bodies compared with June (Table 7).

In June, prior to emergence of adult chironomids,

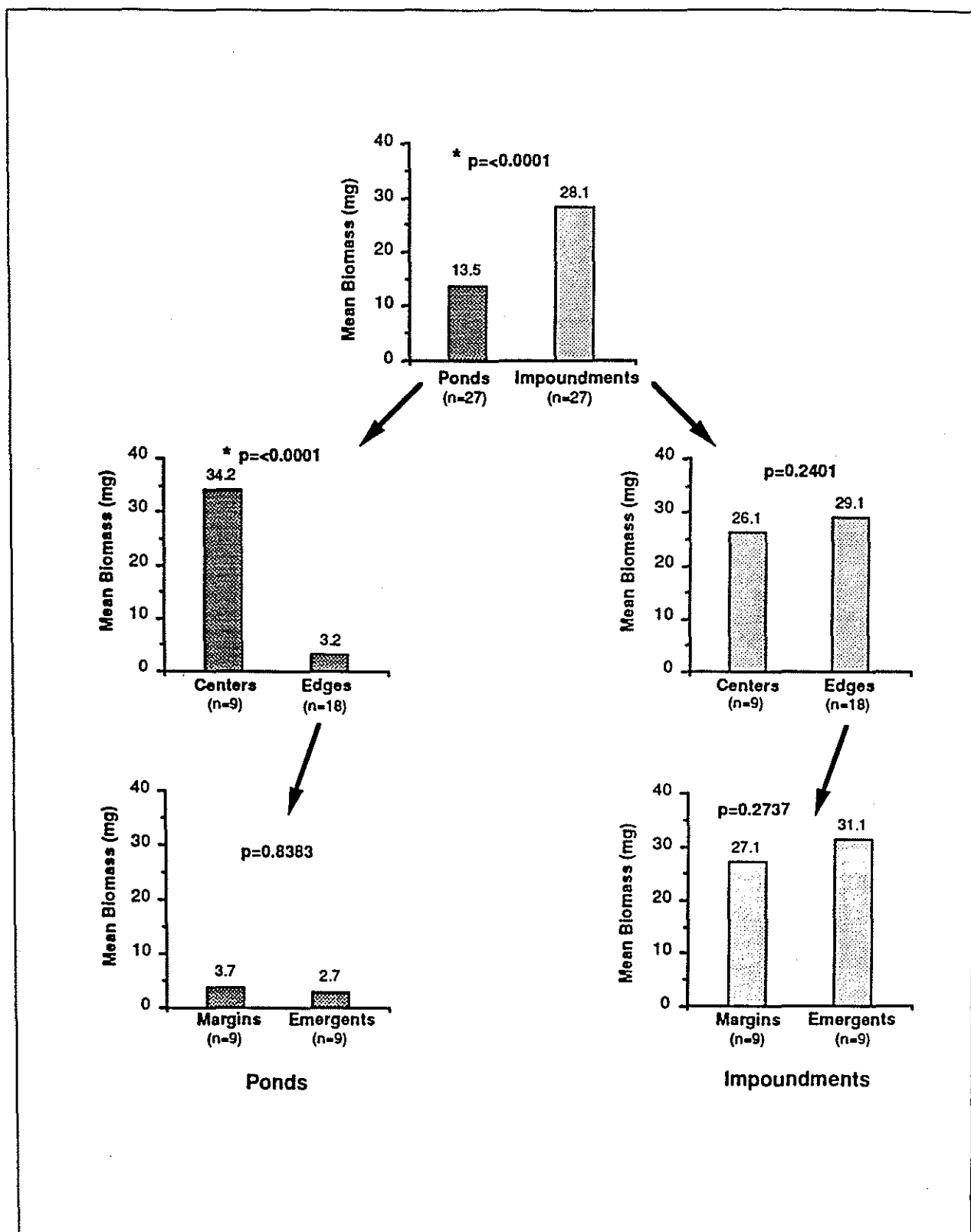


Figure 6. Biomass of chironomids in natural ponds and impoundments during June 1991, Prudhoe Bay, Alaska. Probabilities with an asterisk depict biomass values that are significantly different ( $P < 0.05$ ). Sample sizes ( $n$ ) are based on nine biomass samples from each habitat type. Biomass values for ponds and impoundments (top graph) are for all habitats combined (centers, margins, and emergents). Edges refer to margins and emergents combined.

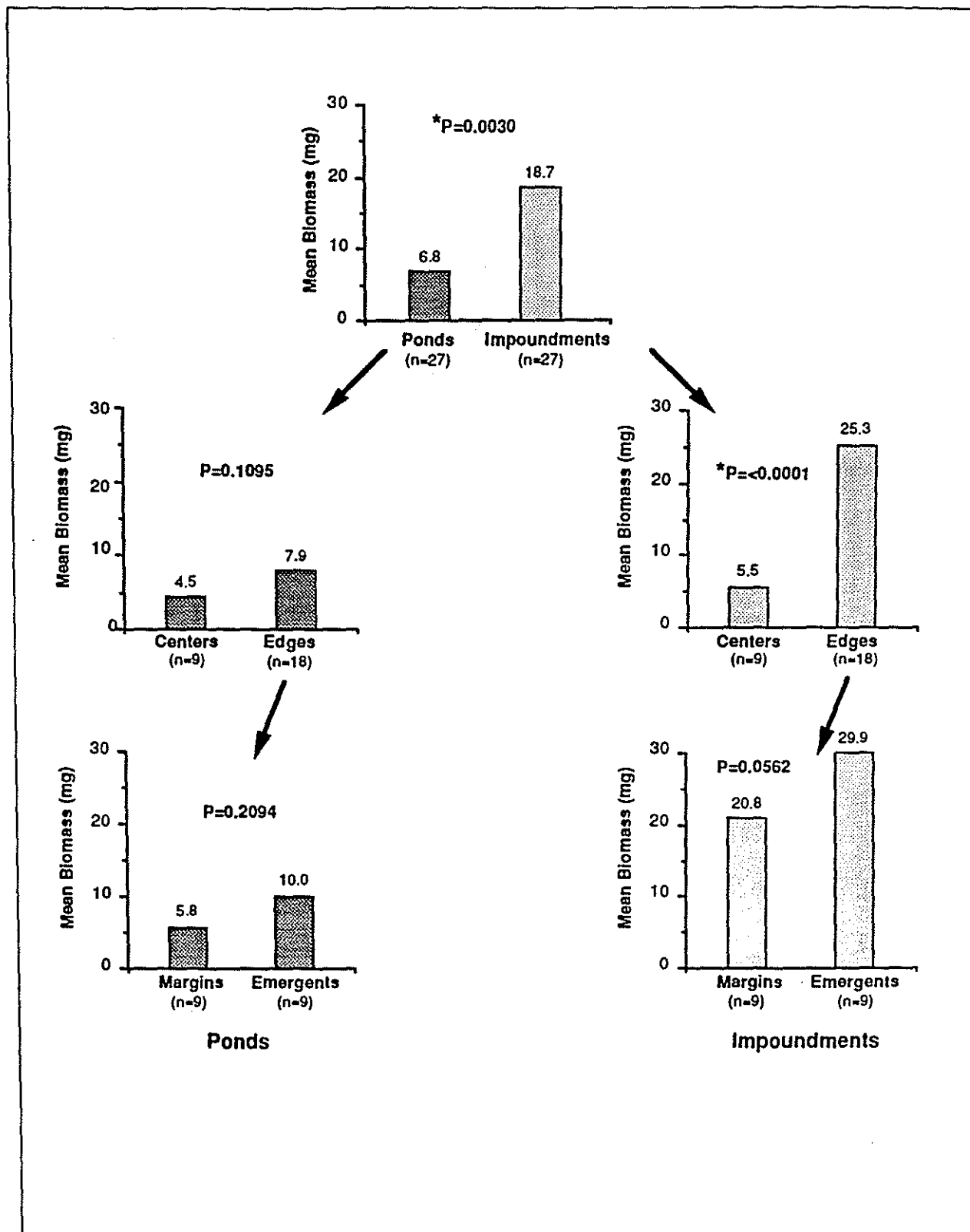


Figure 7. Biomass of oligochaetes in natural ponds and impoundments during June 1991, Prudhoe Bay, Alaska. Probabilities with an asterisk depict biomass values that are significantly different (<0.05). Sample sizes (n) are based on nine biomass samples from each habitat type. Biomass values for ponds and impoundments (top graph) are for all habitats combined (centers, margins, and emergents). Edges refer to margins and emergents combined.

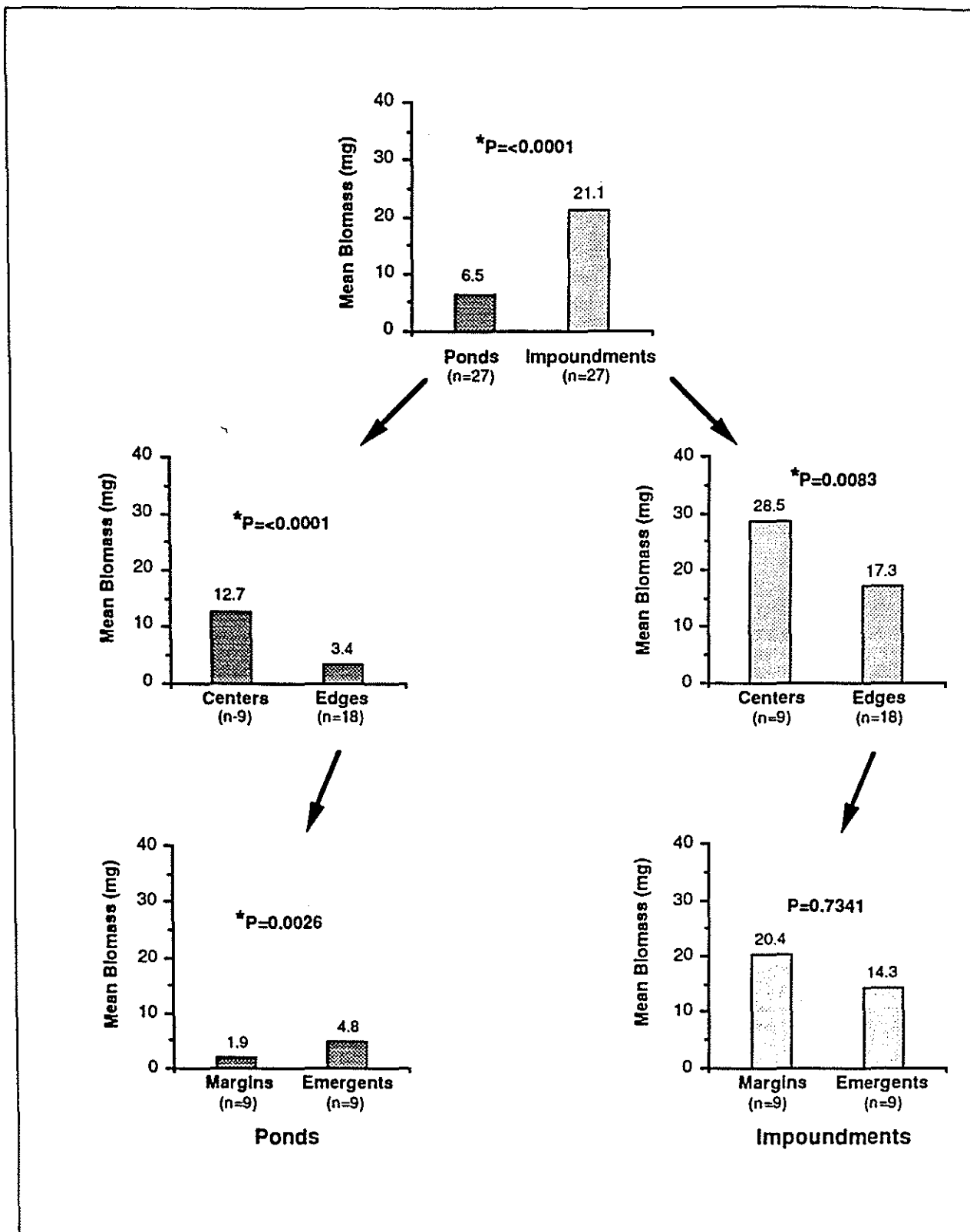


Figure 8. Biomass of chironomids in natural ponds and impoundments during August 1991, Prudhoe Bay, Alaska. Probabilities with an asterisk depict biomass values that are significantly different (<0.05). Sample sizes (n) are based on nine biomass samples from each habitat type. Biomass values for ponds and impoundments (top graph) are for all habitats combined (centers, margins, and emergents). Edges refer to margins and emergents combined.

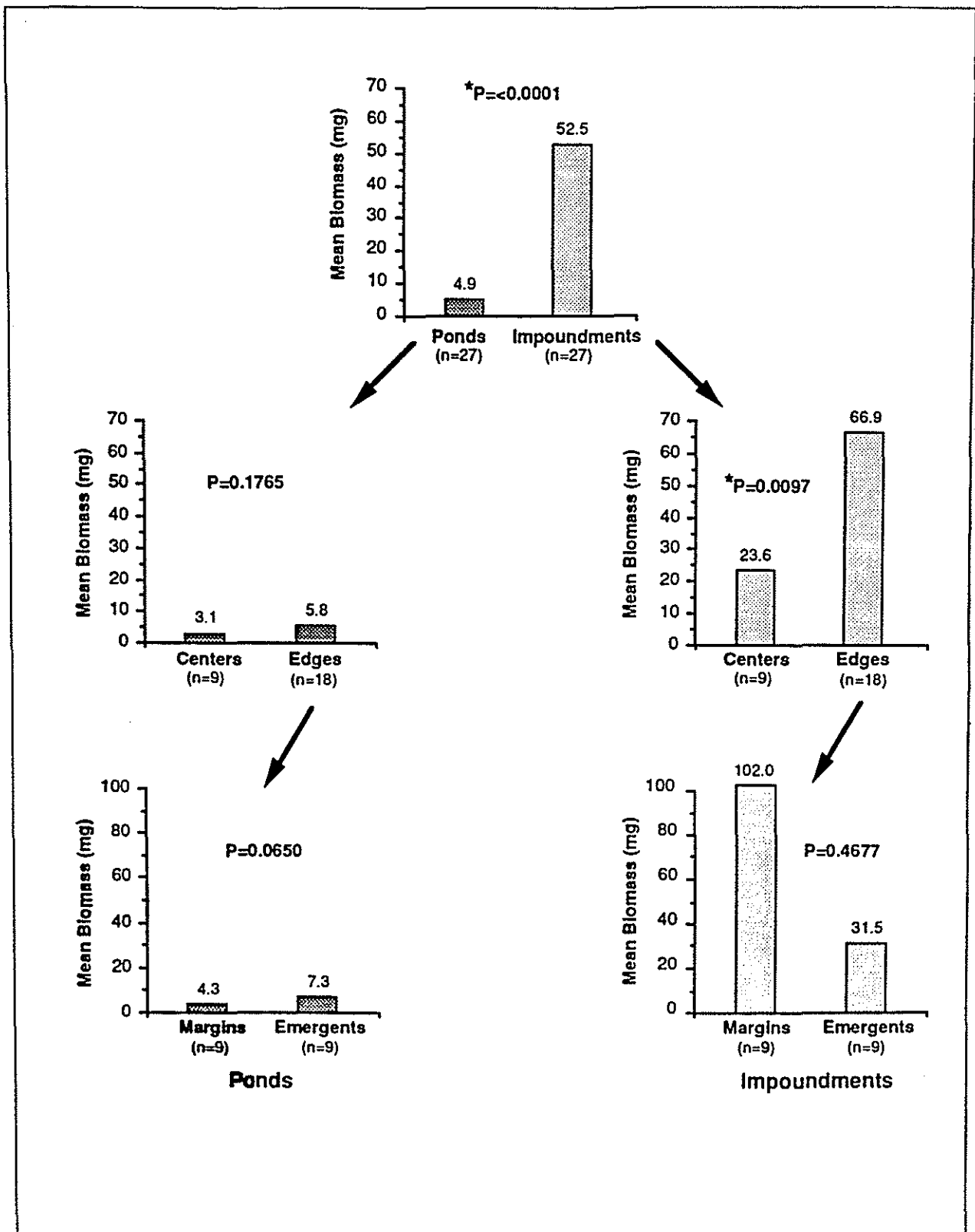


Figure 9. Biomass of oligochaetes in natural ponds and impoundments during August 1991, Prudhoe Bay, Alaska. Probabilities with an asterisk depict biomass values that are significantly different (<0.05). Sample sizes (n) are based on nine biomass samples from each habitat type. Biomass values for ponds and impoundments (top graph) are for all habitats combined (centers, margins, and emergents). Edges refer to margins and emergents combined.

the genus *Chironomus* accounted for over 44% of all individuals collected from the GC-2 impoundment, but only about 16% of individuals collected from the GC-2 pond (Table 7). At the GC-2 pond, *Tanytarsus* was the most important genus in terms of total individuals. In August, *Procladius* and *Orthoclaadiinae* (sp C) were the most important genera at the GC-2 pond and im-

poundment, respectively. *Chironomus* larvae declined dramatically in abundance at both water bodies during the August sampling period (Table 7).

### Chironomid Trophic Organization

Collectors comprised 60.8% (26.0% filterers and 34.8% gatherers) and 78.5% (24.2% filterers and

Table 6. Chironomid genera reported by Butler et al. (1980) for natural ponds at Barrow and by this study for natural ponds and impoundments at Prudhoe Bay.

Genus	Butler et al. 1980	This study
<i>Acricotopus</i>		x
<i>Bryophaenocladus</i>	x	
<i>Chironomus</i>	x	x
<i>Cladotanytarsus</i>	x	x
<i>Constempellina</i>	x	
<i>Corynoneura</i>	x	x
<i>Cricotopus</i>	x	x
<i>Derotanypus</i>	x	x
<i>Dicrotendipes</i>	x	
<i>Endochironomus</i>		x
<i>Eudactylocladius</i>	x	
<i>Eukiefferiella</i>		x
<i>Lapposmittia</i>	x	
<i>Limnophytes</i>	x	
<i>Mesosmittia</i>	x	
<i>Metrionemus</i>	x	
<i>Orthoclaadiinae</i>		x
<i>Orthocladus</i>	x	
<i>Parachironomus</i>		x
<i>Parakiefferiella</i>	x	x
<i>Paratanytarsus</i>	x	x
<i>Phaenopsectra</i>		x
<i>Procladius</i>	x	x
<i>Propillocerus</i>		x
<i>Psectrocladius</i>	x	x
<i>Pseudosmittia</i>	x	x
<i>Stictochironomus</i>	x	x
<i>Tanytarsus</i>	x	x
<i>Thienemannimyia</i>		x
<i>Tribelos</i>		x
<i>Trichotanypus</i>	x	
Number of genera	22	21

Table 7. Counts of chironomids (by habitat type) collected from the GC-2 pond and impoundment in June and August 1991, Prudhoe Bay, Alaska.

Taxa	Margin		Emergent vegetation				Center				Total Pond				Total Imp.					
	Pond		Imp.		Pond		Imp.		Pond		Imp.		June		Aug		June		Aug	
	June	Aug	June	Aug	June	Aug	June	Aug	June	Aug	June	Aug	No.	%	No.	%	No.	%	No.	%
<i>Acricotopus</i>					14								14	5.6	0		0		0	
<i>Chironomus sp A</i>			26	1			15	3	39		21	5	39	16	0		62	20.9	9	8.3
<i>Chironomus sp B</i>			29	2			27	6			14		0		0		70	23.6	8	7.4
<i>Chricotopus laricomalis group</i>	2				6		2						8	3.2	0		2	0.7	0	
<i>Cladotanytarsus</i>				1			1				1		0		0		2	0.7	1	0.9
<i>Corynoneura</i>			2				1		11				11	4.4	0		3	1.0	0	
<i>Cricotopus intersectus group</i>	1						1						1	0.4	0		0		0	
<i>Derotanypus</i>							1				3		0		0		4	1.3	0	
<i>Diptocladus</i>											1		0		0		1	0.3	0	
<i>Eukiefferiella</i>			2	3					9			13	9	3.6	0		2	0.7	16	15
<i>Orthoclaadiinae sp C</i>			2				1				3	31	0		0		6	2.0	31	29
<i>Orthoclaadiinae sp D</i>											1		0		0		1	0.3	0	
<i>Parachironomus</i>								1					0		0		0		1	0.9
<i>Parakiefferiella</i>					1								1	0.4	0		0		0	
<i>Paratanytarsus</i>	1	1	35	1	4		20	20	3		9	1	8	3.2	1	1.7	64	21.5	22	20
<i>Phaenopsectra</i>					1								1	0.4	0		0		0	
<i>Procladius</i>	1	3	21	1	1	7	1		37	21	8	13	39	16	31	53.5	30	10.1	14	13
<i>Propillocerus</i>							1					8	0		0		9	3.0	0	
<i>Psectrocladius</i>	1				12								13	5.2	0		0		0	
<i>Psectrocladius sp E</i>							2						0		0		2	0.7	0	
<i>Psectrocladius sp F</i>							3						0		0		3	1.0	0	
<i>Tanytarsus</i>			6		4	3	1		53	15	1	3	57	23	18	31.0	8	2.7	3	2.8
<i>Thienemannimyia</i>	4				11	1			1				16	6.4	1	1.7	0		0	
unidentified (pupae & larvae)	1	2	15		1	1	11	1	31	4	2	2	33	13	7	12.1	28	9.4	3	2.8
<b>Total</b>	<b>11</b>	<b>6</b>	<b>123</b>	<b>9</b>	<b>54</b>	<b>12</b>	<b>76</b>	<b>31</b>	<b>153</b>	<b>40</b>	<b>70</b>	<b>68</b>	<b>250</b>	<b>100</b>	<b>58</b>	<b>100</b>	<b>297</b>	<b>100</b>	<b>108</b>	<b>100</b>
Number of identifiable taxa	6	2	8	6	9	3	13	4	7	2	11	6	13		4		16		9	
Density (number per sq. m.)	489	267	6133	400	2444	533	3867	1378	8178	1778	3200	3022	3704		859		4400		1600	

Table 8. Numbers and percentages of chironomids in different feeding groups collected from the GC-2 pond and impoundment in June and August 1991, Prudhoe Bay, Alaska.

Feeding Group	Water Body							
	GC-2 Pond				GC-2 Pond			
	June		August		June		August	
	No.	%	No.	%	No.	%	No.	%
Collectors	152	60.8	19	32.7	233	78.5	90	83.3
Filterers	(65)	(26.0)	(19)	(32.7)	(72)	(24.2)	(25)	(23.1)
Gatherers	(87)	(34.8)	—	—	(161)	(54.2)	(65)	(60.2)
Predators	55	22	32	55.2	34	11.4	14	13
Shredders (Herbivores)	9	3.6	—	—	2	0.7	—	—
Scrapers	1	0.4	—	—	—	—	1	0.9
Unidentified	33	13.2	7	12.1	28	9.4	3	2.8
TOTAL	250	100	58	100	297	100	108	100

54.2% gatherers) of all chironomids collected from the GC-2 pond and impoundment, respectively, during June (Table 8). Predators were next in abundance, making up 22.0% of identifiable chironomids from the GC-2 pond and 11.4% from the GC-2 impoundment. Shredders (herbivores) were uncommon at both water bodies (3.6% at GC-2 pond and 0.7% at GC-2 impoundment), and scrapers were represented only at the GC-2 pond (0.4%).

Predators were the most important feeding group at the GC-2 pond in August, making up 55.2% of total chironomids (Table 8). Collectors, on the other hand, declined in importance to 32.7% of total larvae. At GC-2 impoundment, however, the percentage distribution of collectors and predators was almost identical to that observed in June. Scrapers were represented only at the GC-2 impoundment (0.9%). Shredders (herbivores) were absent from August samples. Number of chironomid taxa in different feeding groups in June and August is provided in Appendix J.

The importance of the differences between the GC-2 pond and impoundment is unclear. The feeding categories are broad and our knowledge of the ecological significance of these categories to the overall functioning of the invertebrate community is incomplete (Merritt and Cummins 1984), as is our knowledge of their significance to waterbirds.

#### Chironomid Size

Tables 9 and 10 show relative weights of indi-

vidual chironomids collected from different habitats at the GC-2, P-Pad, and E-Pad ponds and impoundments during June and August. Weights were derived by dividing mean biomass by mean number of individuals (all taxa combined) and not by weighing individual chironomids; thus, they are useful only as a general index for water body comparison.

In June (Table 9), mean weights of individual chironomids were similar at the P-Pad and E-Pad ponds and impoundments, but mean weights of individuals from the GC-2 impoundment were much greater (0.74 mg) than those at the GC-2 pond (0.16 mg). The difference between the GC-2 pond and impoundment apparently resulted from the large number of *Chironomus* larvae present in the latter (Table 7). A random sample of *Chironomus* larvae collected in June from the GC-2 impoundment ranged in body length from 5-15 mm ( $n=8$ ). The dominant genera at the GC-2 pond in June, on the other hand, were *Tanytarsus*, *Acricotopus*, and *Thienemannimyia*, which average smaller in size.

In August (Table 10), mean larval weights were considerably greater at the GC-2 and E-Pad impoundments (0.46 mg and 0.51 mg, respectively) compared to the GC-2 and E-Pad ponds (0.16 mg and 0.18 mg, respectively). However, weight differences between the GC-2 pond and impoundment were less in August (0.46 mg versus 0.16 mg) than in June (0.74 mg versus 0.16 mg), possibly due to the decline in numbers of large *Chironomus* larvae (less than 16% of total individuals) in the GC-2 impoundment during the August



Table 9. Mean biomass, mean number, and relative mean weight of chironomids collected in different habitats at the GC-2, P-Pad, and E-Pad ponds and impoundments in June 1991, Prudhoe Bay, Alaska.

Water Body	Habitat	Mean Chironomid Biomass (mg)		Mean Chironomid Count		Mean Individual Weight (mg)		Dominant Genus in Sample	
		Pond (n=3)	Imp. (n=3)	Pond (n=3)	Imp. (n=3)	Pond (n=3)	Imp. (n=3)	Pond	Imp.
GC2	Center	32.70	43.27	166.33	99.67	0.20	0.43	<i>Tanytarsus</i>	<i>Chironomus</i>
	Emergent	2.00	74.77	9.33	87.67	0.21	0.88		
	Margin	1.13	53.27	16.33	58.67	0.07	0.91		
	All Habitats					0.16	0.74		
P Pad	Center	63.77	33.03	193.67	342.33	0.33	0.10	<i>Acricotopus</i>	<i>Chironomus</i>
	Emergent	3.30	18.43	44.00	116.00	0.08	0.16		
	Margin	2.60	26.90	27.33	152.67	0.10	0.18		
	All Habitats					0.17	0.15		
E Pad	Center	3.03	1.93	86.00	24.33	0.04	0.08	<i>Thienemannimyia</i>	<i>Chironomus</i>
	Emergent	2.90	0.07	38.67	2.33	0.08	0.03		
	Margin	7.23	1.20	103.00	6.67	0.07	0.18		
	All Habitats					0.06	0.09		

Table 10. Mean biomass, mean number, and relative mean weight of chironomids collected in different habitats at the GC-2, P-Pad, and E-Pad ponds and impoundments in August 1991, Prudhoe Bay, Alaska.

Water Body	Habitat	Mean Chironomid Biomass (mg)		Mean Chironomid Count		Mean Individual Weight (mg)		Dominant Genus in Sample	
		Pond (n=3)	Imp. (n=3)	Pond (n=3)	Imp. (n=3)	Pond (n=3)	Imp. (n=3)	Pond	Imp.
GC2	Center	12.27	61.67	61.50	90.30	0.20	0.68	<i>Procladius</i>	<i>Orthocladiinae</i>
	Emergent	2.57	23.37	18.00	118.25	0.14	0.20		
	Margin	1.67	45.30	10.80	88.50	0.15	0.51		
	All Habitats					0.16	0.46		
P Pad	Center	21.37	11.23	199.30	120.70	0.11	0.09	<i>Thienemannimyia</i>	<i>Eukiefferiella</i>
	Emergent	4.63	10.40	51.70	127.30	0.09	0.08		
	Margin	3.73	13.93	17.30	96.00	0.22	0.15		
	All Habitats					0.14	0.11		
E Pad	Center	4.40	12.67	40.00	21.30	0.11	0.59	<i>Procladius</i>	<i>Orthocladiinae</i>
	Emergent	7.27	9.03	57.70	13.00	0.13	0.69		
	Margin	0.40	2.00	1.30	8.30	0.31	0.24		
	All Habitats					0.18	0.51		

Table 9. Mean biomass, mean number, and relative mean weight of chironomids collected in different habitats at the GC-2, P-Pad, and E-Pad ponds and impoundments in June 1991, Prudhoe Bay, Alaska.

sampling period (Table 7). Nevertheless, a random sample of *Chironomus* larvae from the GC-2 impoundment center ranged from 11 to 17 mm (n=5) in body length. *Procladius* larvae from the GC-2 impoundment center also averaged large in size (6–18 mm body length; n=13).

## DISCUSSION

### Invertebrates in Natural and Artificial Wetlands

Few studies have been conducted comparing invertebrate populations in natural and artificial water bodies. In North Dakota, natural water bodies had a significantly higher invertebrate density and a higher diversity of invertebrate taxa than did artificial water bodies (Rossiter and Crawford 1983, Kreil 1986). During a study of wetlands in New Brunswick and Nova Scotia, however, Whitman (1976) reported significantly more invertebrates important as spring foods of breeding waterfowl in impoundments than in natural ponds. Kadlec (1962) also noted high invertebrate populations in impoundments in Michigan.

Studies comparing waterbird use at ponds and impoundments showed mixed results. For example, although invertebrate density and diversity were higher in natural versus artificial ponds in North Dakota (Rossiter and Crawford 1983, Kreil 1986), Kreil found a higher mean waterfowl density in artificial ponds, and Rossiter and Crawford found no significant correlation between brood use and macroinvertebrate densities. In New Brunswick and Nova Scotia, however, numbers of broods were higher on impoundments than natural marshes (Whitman 1976), and in southern Quebec use of impoundments by duck broods was greater on those impoundments with higher densities of aquatic invertebrates (Belanger and Couture 1988).

### Wetland Characteristics Important to Waterbirds

Productivity and availability of invertebrates for waterbirds are strongly governed by 1) the amount of emergent vegetation, 2) water quality, 3) water body age, 4) water body size, and 5) water depth, shoreline gradient, and bottom substrate. Age has been shown to be particularly important in determining invertebrate productivity in impoundments.

#### *Emergent Vegetation*

The greater amount of emergent vegetation in im-

poundments at Prudhoe Bay may be important to waterfowl production. Emergent vegetation provides habitat for aquatic invertebrates, nesting and brood cover, and visual isolation from other nesting pairs (Rumble 1989, Weller 1990). Kadlec (1962) determined that amount of plant cover was more important than the kind and amount of invertebrate food available in determining the number of broods produced in a given area, and Hudson (1983) concluded that the positive correlation between brood production and pond age was probably a result of more and denser vegetation in older ponds. In North Dakota, constructed water bodies had more plant taxa, families, and species than natural ponds (Kreil 1986).

Water bodies with an interspersed pattern of emergent vegetation and open water are considered the most suitable for breeding waterfowl (Nelson and Kadlec 1984). Belanger and Couture (1988) found that brood use was greatest on impoundments with emergent vegetation covering at least 30% of the surface area and on those with more than 30 stems per m<sup>2</sup> of emergent plants. Kaminski and Prince (1981) found that the greatest density and species diversity of dabbling duck pairs occurred on water bodies with a 50:50 (compared with 30:70 or 70:30) ratio of emergent vegetation to open water.

#### *Water Quality*

The pH values for ponds and impoundments at Prudhoe Bay appear to fall within a range considered normal for invertebrate growth. According to Pinder (1986), many species of invertebrates are tolerant of pH values ranging from 6.0 to 9.0. However, within this range, some species have a relatively narrow range of favorable pH, and outside of this range, decreasing pH results in the occurrence of fewer species (Pinder 1986). Optimum pH values for different invertebrate taxa at Prudhoe Bay are unknown.

For natural ponds at Prudhoe Bay, pH values followed the same general trend as those reported by Prentki et al. (1980) for natural ponds at Barrow; pH was low early in the summer, but then rose to a plateau in early July. However, pH values in impoundments were higher in August than in July.

Water temperature measurements were collected too infrequently to be useful for assessing potential differences between natural ponds and impoundments. On the Arctic Coastal Plain, water temperature changes rapidly in response to changes in air temperature and solar radiation (Miller et al. 1980). It is reason-

able to assume, however, that secondary productivity is greater in warmer years. At Barrow, chironomid larval growth was more rapid at water temperatures of 10°C and 15°C than at 5°C (Butler et al. 1980).

#### **Water Body Age**

Several researchers have noted declines in numbers of waterfowl using impoundments some years after impoundment creation (Kadlec 1962, Whitman 1976, Danell and Sjoberg 1982). This has been attributed to a decline in invertebrate populations resulting from exhaustion of soil nutrients (Lokemoen 1973, Whitman 1976, Uresk and Severson 1988), particularly nitrogen and phosphorus. In newly formed natural ponds at Barrow, phosphorus concentration and algal photosynthesis were 20 times and 200 times higher, respectively, than in old ponds (Hobbie 1984). However, Hobbie did not provide specific age ranges for newly formed and old ponds.

Impoundments used to determine invertebrate biomass for this study ranged in age from 10 to 20 years, and biomass productivity was still high compared with natural ponds. Whitman (1976) found that the most notable decline in nutrients and total numbers of invertebrates in impoundments in eastern Canada occurred between three and four years after initial flooding. However, impoundments more than seven years old continued to have larger invertebrate populations than natural marshes (Whitman 1976). The size of the decline in invertebrate numbers was largely attributable to a decline in chironomids, which are early colonizers of newly created impoundments. Danell and Sjoberg (1982) found that chironomid larval biomass decreased from 55 g/m<sup>2</sup> to less than 10 g/m<sup>2</sup> between the third and the eighth years in an artificial lake in northern Sweden. They also noted a decrease in mean individual larval weight during this period. In Manitoba, Kaminski and Prince (1981) found that abundance and biomass of invertebrates were much reduced in older impoundments.

#### **Water Body Size**

Wetland size has been considered important to waterfowl; as size increases, the numbers of species, individuals, and broods also increase in some pattern (Rumble and Flake 1983, Weller 1988). Thus, size has been considered an important feature in the design of impoundments for waterbirds. Brown and Dinsmore (1986) found that 10 of 25 species did not use wetland types smaller than 5 ha in Iowa. Belanger and Couture

(1988) examined a variety of habitat parameters for 29 man-made ponds in southern Quebec and found that brood use was greatest on ponds equal to or exceeding 0.5 ha in size. Based on studies in the Northern Great Plains, Lokemoen (1973) and Uresk and Severson (1988) recommended that 0.6 ha be the minimum size for constructed wetlands.

Impoundments chosen for the present study represent the lower extreme of the size range considered optimal for attracting large numbers of birds. Although large water bodies are more likely to attract a greater number of both individuals and species, Weller (1988) suggested that small ponds may be crucial for some species and tend to be seriously undervalued in many assessments of bird habitats. Based on a study of 18 artificial wetlands of different sizes in North Dakota, Rossiter and Crawford (1983) concluded that because wetlands vary in their seasonal importance to birds, all wetlands are important regardless of size. Ruwaldt et al. (1979) found that small stock ponds ( $\bar{X}$ =0.10 ha) in North Dakota received heavy use by surface-feeding ducks.

For waterfowl on the Arctic Coastal Plain, small ponds apparently satisfy special food and social requirements. Compared with large (deep) water bodies, small (shallow) ponds contain a high diversity of aquatic invertebrates (Derksen et al. 1979). Breeding females that select a diversity of foods in such ponds increase the probability that they will obtain a balance of essential nutrients not provided by a single food type (Sugden 1973). Further, the importance of small, shallow ponds as feeding sites increases during the summer as decreasing water levels concentrate free swimming organisms and provide access to benthic organisms in the pond bottom (Bergman et al. 1977).

Small ponds also may provide territorial pairs with partial isolation from other pairs during the nesting season (Patterson 1976), thereby decreasing interactions that might disrupt nesting (Dzubin 1969). If, as Dzubin suggested, the true measure of carrying capacity is the proportion of adults that breed (as opposed to the total numbers of adults a particular habitat supports), then the availability of small ponds may be important in regulating the size of breeding populations for some waterfowl species. Managers have successfully created artificial wetlands with complex configurations to provide isolation for breeding pairs (Weller 1990).

The potential value of an individual water body is often a function not only of its size but also of its prox-

imity to nearby water bodies. Rumble and Flake (1983) found that, although the size of a given pond was important, the number of wetland basins within a 1.6-km radius of the pond was also important in determining levels of use by waterfowl broods. Similarly, Brown and Dinsmore (1986) and Klopatek (1988) suggested that wetland complexes increase species richness over solitary wetlands of similar size. Lokemoen et al. (1984) suggested that the best waterfowl habitats contain between 12 and 40 wetland units per km<sup>2</sup> occurring in various sizes and shapes.

Because roads and pads concentrate impoundments in specific areas, small permanent impoundments at Prudhoe Bay often occur in close association with other impounded wetlands. Thus, they may attract a greater variety of waterbirds than similarly sized but more isolated natural ponds. Such was the case at the GC-2 impoundment, which was isolated from a much larger impoundment by the construction of a new gravel road. A pair of Pacific Loons nesting in the large impoundment on several occasions were observed feeding in this small, adjacent impoundment.

#### **Water Depth, Shoreline Gradient, and Bottom Substrate**

Processes affected by water depth and bank gradient include water permanence, invasion and survival of aquatic vegetation, and habitat selection and feeding by birds. What constitutes ideal water depth depends on the management objective; consequently, management and design features may not be compatible for all waterbird guilds. Weller (1990) suggested that maintaining water depths of 15 to 45 cm benefits surface-feeding ducks like Northern Pintails because such conditions allow them to swim but still tip up for food. Lokemoen (1973) recommended that, for dabbling ducks, impoundments should be less than 60 cm deep over 30% to 70% of the pond area. For diving ducks, Uresk and Severson (1988) and Hudson (1983) recommended that maximum impoundment depth should not exceed 1 m. Rundle and Fredrickson (1981) reported that managing water depth solely for waterfowl attracted less than 50% of available shorebird species in Missouri. They suggested that shorebirds are attracted to shallow water (0–5 cm) interspersed with exposed, saturated soil.

Midge larvae are more accessible to shorebirds and waterfowl, and thus more heavily used, in ponds and lakes with gently contoured shorelines than in steep-banked ponds and lakes (Holmes and Pitelka

1968, Bergman et al. 1977, Derksen et al. 1979, Martin 1983). Uresk and Severson (1988) found that impoundments with gently sloping shorelines received greater use by waterfowl in the Northern Great Plains, and they considered shoreline gradient the most important variable for estimating bird use. Kreil (1986) found that constructed wetlands with steep shoreline gradients had lower total invertebrate densities than those with more gentle shoreline gradients. Rossiter and Crawford (1983) recommended that, for maximum use by waterbirds, bank gradients not exceed a 10:1 to 20:1 slope (5°–10°).

Impoundments may undergo large changes in water level due to spring flooding and/or subsequent drainage. Thus, nesting near or in impoundments could have adverse effects on some species. Impoundments could attract nesting birds during the pre-flooding period in late spring; later, rising water levels could flood the nest, or falling water levels could expose the nest to arctic fox predation. Murphy et al. (1989) reported two Canada Goose nests that were flooded by rising water in an impoundment at Prudhoe Bay; and Belant and Anderson (1991) reported four Common Loon nests that were abandoned due to a water level increase in a Wisconsin impoundment. Whether this is a widespread problem for invertebrate-eating waterbirds is not known.

The peat content of pond sediments varies among ponds and often is greater at pond centers than at edges (Butler et al. 1980). Presumably, benthic habitats in impoundments usually contain higher levels of peat and drowned vegetation than those in ponds, because impoundments are younger and their sediments less well decomposed. In natural ponds, faunal differences caused by differences in sediment peat content are slight (Butler et al. 1980). However, the effects of impoundment substrate type on benthic organisms and waterfowl feeding efficiency are unknown.

#### **Invertebrate Size and Abundance**

Size and abundance of chironomids and oligochaetes are important in determining the potential profitability to waterbirds of foraging in a particular water body. The two may not always be positively correlated, however. Butler (1982b) showed, for example, that Tanytarsini (*Tanytarsus* was the most abundant genus in the GC-2 pond center) sometimes equaled or exceeded *Chironomus* larvae in abundance at Barrow ponds. However, because of their large size, the *Chironomus* larvae always dominated in biomass: av-

erage annual production of *Tanytarsus* was only 8% that of *Chironomus*.

At the GC-2 impoundment in June, *Chironomus* larvae dominated in both abundance and biomass. Because of their large size relative to other chironomid larvae, larvae of the genus *Chironomus* may be particularly important as a potential food for waterbirds on the Arctic Coastal Plain (Butler and Anderson 1990). At Barrow, Butler (1982a) observed Steller's Eiders and Oldsquaws frequently feeding in pond centers where *Chironomus* larvae dominated macroinvertebrate biomass.

Some waterfowl show a strong preference for the largest size classes of chironomid larvae. In Alaska, for example, over 88% (by number) of larvae in the esophagi of Oldsquaws collected from small natural ponds in early summer at West Long Lake (NPR-A) were over 5 mm in length, despite the fact that larvae over 5 mm represented only 6.4% of total larvae available in the habitat at that time (Taylor 1986). A similar pattern of selection for large larvae was observed for deep lakes (Taylor 1986).

Chironomids and oligochaetes dominate the macroinvertebrate faunas of most arctic freshwater ponds and lakes (Butler 1982a). At West Long Lake (NPR-A), for example, chironomids and oligochaetes were the most abundant invertebrates collected from ponds and lakes by Taylor (1986). Although chironomids and oligochaetes are important to waterfowl, the degree to which they are important may not always be apparent from studies comparing food use with food availability in the habitat. For example, in small ponds [i.e., Shallow-*Carex* (Class II)] at West Long Lake (NPR-A), chironomids made up almost 80% of the aggregate percent volume of invertebrates sampled in early summer, but they comprised only about 30% of the diet of Oldsquaws collected from these ponds (Taylor 1986). One might conclude, in this case, that Oldsquaws "avoided" chironomids and oligochaetes (see Taylor 1986:75), and that their abundance was not a good indicator of the functional value of these water bodies. However, this may not be true.

A particular food item is often much more important to an animal than its occurrence in the diet may suggest. According to Johnson (1980), an animal may choose a specific habitat or site because a food item is abundant there—so abundant, in fact, that the consumer need only use small amounts of it to satisfy its nutritional requirements. While stoneflies and fairy shrimp provide a nutritious food source for Oldsquaws

(Table 11), they are subject to large seasonal fluctuations in abundance and are therefore eaten opportunistically according to their availability. The seasonal and year-to-year stability of chironomid biomass, on the other hand, may provide ducks (and shorebirds) with a reliable food resource (Butler 1982a), which is also highly proteinaceous (Table 11).

Chironomid size and density may also explain greater use of water bodies (versus terrestrial habitats) in late summer by shorebirds. At Barrow, shorebirds feed on midge larvae from mid-July through the end of summer (Holmes and Pitelka 1968). Adult tipulids emerge during a three-week period beginning about mid-July (MacLean and Pitelka 1971, Custer and Pitelka 1978, Martin 1983), the time when most shorebirds move to ponds, lakes, and coastal habitats. Chironomid larvae in ponds were preferred by Dunlin over those occurring in terrestrial habitats, because only in pond sediments did chironomid larvae exceed the minimum acceptable size for predation (more than 5 mm in length; Holmes 1966). Furthermore, final instar *Chironomus* larvae are approximately equal in size to the crane fly, *Pedicia hannahii*, but are present in much greater densities on the Arctic Coastal Plain (Martin 1983). When pond water levels are low, high prey density may outweigh the disadvantage of feeding on smaller prey than would otherwise be available in terrestrial habitats (Martin 1983).

### Seasonal Changes in Chironomid Biomass

Identifying temporal changes in secondary productivity is important for assessing the role of invertebrates in aquatic systems. As suggested earlier, stable production and standing stock of some species of arctic chironomids may be important to invertebrate-eating waterbirds that depend on a reliable food source. At

Table 11. Protein content of selected freshwater pond invertebrates important to waterbirds. Values are from Sugden (1973), Driver et al. (1974), and Krapu and Swanson (1975).

Item	Protein (% of dry weight)
Fairy shrimp	71.9
Chironomid larvae	66.4
Oligochaetes	60.2
Gastropods	58.9
Cladocerans	31.8

Barrow, *Chironomus* larvae showed low seasonal variation in biomass (Butler 1982b).

The decline in chironomid biomass between June and August at Prudhoe Bay may have resulted from the emergence of final instar larvae and from predation prior to the August sampling period. All pond chironomid species on the Arctic Coastal Plain apparently begin their emergence within six weeks after the spring thaw (Butler et al. 1980); in the Arctic, emergence is timed to coincide with rising or peak water temperature (Pinder 1986). A major loss of biomass occurs when final instar cohorts emerge (Butler 1982b). The magnitude of the loss depends on the abundance and average weight of individual larvae within each of these cohorts (Butler 1982b). Armstrong and Nudds (1985) suggested that the seasonally variable nature of invertebrate abundance in small water bodies may result from size-dependent predation by predators like ducks.

#### Waterbird Use of Natural Wetlands on the Arctic Coastal Plain

Here we summarize the use patterns and food habits of Arctic Coastal Plain waterbirds according to their guild membership. Figures showing use by species (all age and sex classes combined) accompany discussions of use by different age and sex classes, when such information is provided. Studies in the NPR-A were conducted at Island Lake, Teshekpuk Lake, Square Lake, Meade River, and Singilik by Derksen et al. (1979) and at West Long Lake by Taylor (1986). To simplify the discussion, sites studied by Derksen et al. (1979) are referred to as "NPR-A study sites". West Long Lake is referred to separately.

Impoundments of different sizes and depths may be unique in their ability to satisfy the seasonal needs of waterbirds, and should perhaps be classified and evaluated separately according to those criteria used to classify natural water bodies. In the Prudhoe Bay oil field, two important impoundment types—small permanent impoundments and large seasonal impoundments—are analogous to naturally occurring Shallow-*Carex* (Class II) ponds and Flooded tundra (Class I) wetlands, respectively. We treat the small permanent impoundments selected for this study as being analogous to Shallow-*Carex* ponds.

Information on wetland availability at Storkersen Point, Teshekpuk Lake, Island Lake, and Square Lake is included to show how waterbird use patterns are to some degree related to the abundance of different water body types at these locations (Fig. 10). However,

we avoid absolute statements of water body value in favor of an approach that emphasizes the importance of a diversity of water body types. Many current habitat evaluation models rely heavily on habitat use/availability data and assume that greater use occurs in higher-quality habitat (Hobbs and Hanley 1990). However, recent literature shows that this assumption is not always valid because factors other than habitat characteristics (e.g., social behavior during the breeding season, population density, and changes in food supply) may affect an animal's use of a site and our perception of that use (Johnson 1980, Van Horne 1983, Hobbs and Hanley 1990).

#### Divers

Principal diving waterbirds at Prudhoe Bay include Pacific Loon, Oldsquaw, and King Eider. The Spectacled Eider is uncommon in the oil field but is included in the discussion because of concern by the U.S. Fish and Wildlife Service for recent population declines on the Yukon-Kuskokwim Delta in western Alaska (Kertell 1991, 1992) and because it may soon be included on the federal List of Threatened and Endangered Species (USFWS pers. comm. 1991).

In early summer (June), Oldsquaws (Fig. 11) often congregated on Deep-open (V) lakes at NPR-A study areas (Derksen et al. 1979). According to Taylor (1986), nonbreeding and subadult Oldsquaws remained on Deep-open (V) "nonfish" lakes throughout the summer at West Long Lake. At Storkersen (Fig. 11), Oldsquaws were observed most commonly on Shallow-*Carex* (II) and Shallow-*Arctophila* (III) ponds during the pre-nest period in early summer (Bergman et al. 1977).

At Storkersen and NPR-A study sites, breeding pairs dispersed in early summer to Shallow-*Carex* (II) and Deep-*Arctophila* (IV) ponds (Bergman et al. 1977, Derksen et al. 1979). At West Long Lake, incubating females continued to feed primarily in Shallow-*Carex* (II) ponds, but nonbreeding females or failed breeders often used Shallow-*Arctophila* (III) ponds (Taylor 1986). At Storkersen Point, single females (including at least one nesting female) were observed feeding in Shallow-*Carex* (II) ponds throughout the season (Bergman et al. 1977).

During mid-summer at Storkersen and NPR-A study sites (Fig. 11), Oldsquaws showed a preference for those water bodies used in early summer (Bergman et al. 1977, Derksen et al. 1979). The majority of late-season observations (Fig. 11) at Storkersen and NPR-

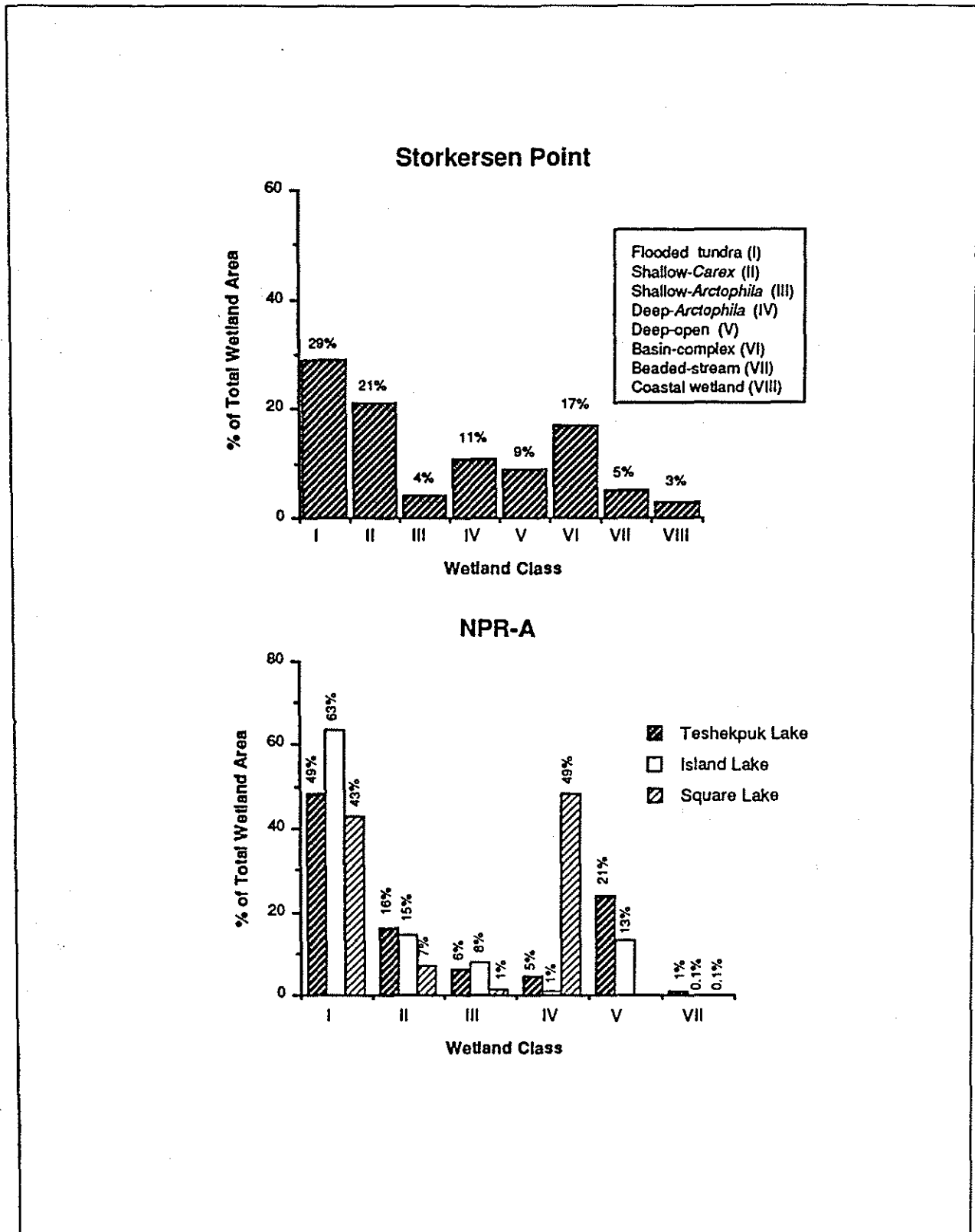


Figure 10. Composition of wetland habitat at Storkersen Point (Bergman et al. 1977) and at three NPR-A study areas (Teshekpuk Lake, Island Lake, and Square Lake) (Derksen et al. 1979). At NPR-A, Derksen et al. (1979) did not include Coastal (VIII) wetlands in their classification system, and excluded Basin-complex (VI) wetlands from overall wetland composition.

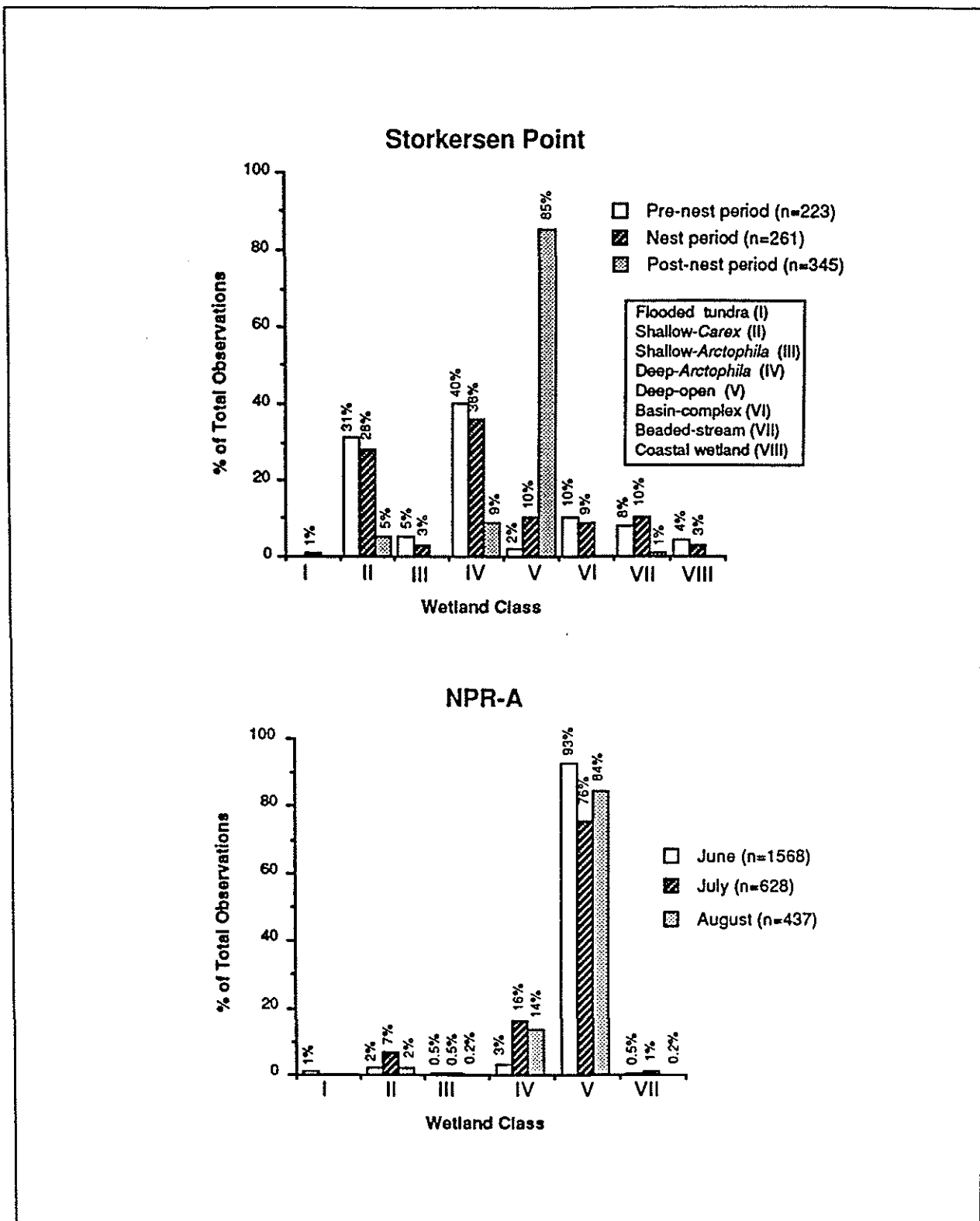


Figure 11. Observations of Oldsquaws (by wetland class) during periods of the summer at Storkersen Point in 1971-1973 (Bergman et al. 1977) and at five NPR-A study areas (Island Lake, Teshekpuk Lake, Square Lake, Meade River, and Singilik) in 1978 (Derksen et al. 1979). At NPR-A, Derksen et al. (1979) did not include Coastal (VIII) wetlands in their classification system, and excluded Basin-complex (VI) wetlands from wetland use by Oldsquaws. Use periods at Storkersen are comparable to those used at the NPR-A.



A study sites were from Deep-open (V) lakes, which were important molting areas (Bergman et al. 1977, Derksen et al. 1979). Taylor (1986) observed the same trend at West Long Lake. Broods were observed most commonly on Deep-*Arctophila* (IV) lakes, Deep-open (V) lakes, and Shallow-*Carex* (II) ponds (Fig. 12) at NPR-A study sites (Derksen et al. 1979).

At West Long Lake, Oldsquaws collected from Shallow-*Carex* (II) ponds (Fig. 13) had eaten primarily stonefly nymphs (Plecopterans) in early summer (51%) and fairy shrimp (Anostracans) in mid-summer (71.5%), while those collected from Shallow-*Arctophila* (III) ponds (Fig. 13) had eaten mostly cladocerans (45.9%) during mid-summer (Taylor 1986). Chironomids (larvae and pupae) comprised about 20% of the diet in both wetland classes (Figure 13, Table 12). In Deep-open "nonfish" lakes (V), chironomid larvae comprised over 95% of the diet in early summer (Fig. 14, Table 12), but the diet shifted to cladocerans (29.3% and 57.1% in mid- and late summer, respectively) and anostracans (20.4% and 14.3% in mid- and late summer, respectively) as the summer progressed (Taylor 1986). Chironomid larvae were the dominant food (78.1%) of Oldsquaws (Fig. 14, Table 12) in Deep-open "fish" lakes (V) in late summer (Taylor 1986).

Although two Oldsquaws collected at Storkersen Point contained "noticeable volumes" of stonefly nymphs, chironomid larvae were considered dominant in the overall diet of adults there (Bergman et al. 1977).

Chironomids and oligochaetes were eaten in much lower proportions than expected (Table 12) based on their occurrence in Shallow-*Carex* (II) ponds (early summer), Shallow-*Arctophila* (III) ponds (mid-summer), and Deep-open (V) "nonfish" lakes (mid- and late summer) at West Long Lake (Taylor 1986). In Deep-open (V) "nonfish" lakes (early summer) and Deep-open (V) "fish" lakes (late summer), on the other hand, chironomid larvae were selected in virtually the same proportion (Table 12) as their occurrence (Taylor 1986). Plecopterans (Nemouridae nymphs) were eaten by Oldsquaws in much greater proportions than expected (Table 12) during early summer in Shallow-*Carex* (II) ponds (Taylor 1986).

Upon arrival at Storkersen Point, King Eiders concentrated feeding activity in Basin-complex (VI) wetlands (Fig. 15) before dispersing to nesting sites near Shallow-*Carex* (II) and Deep-*Arctophila* (IV) ponds, where single females were observed feeding throughout the nesting season (Bergman et al. 1977). Spec-

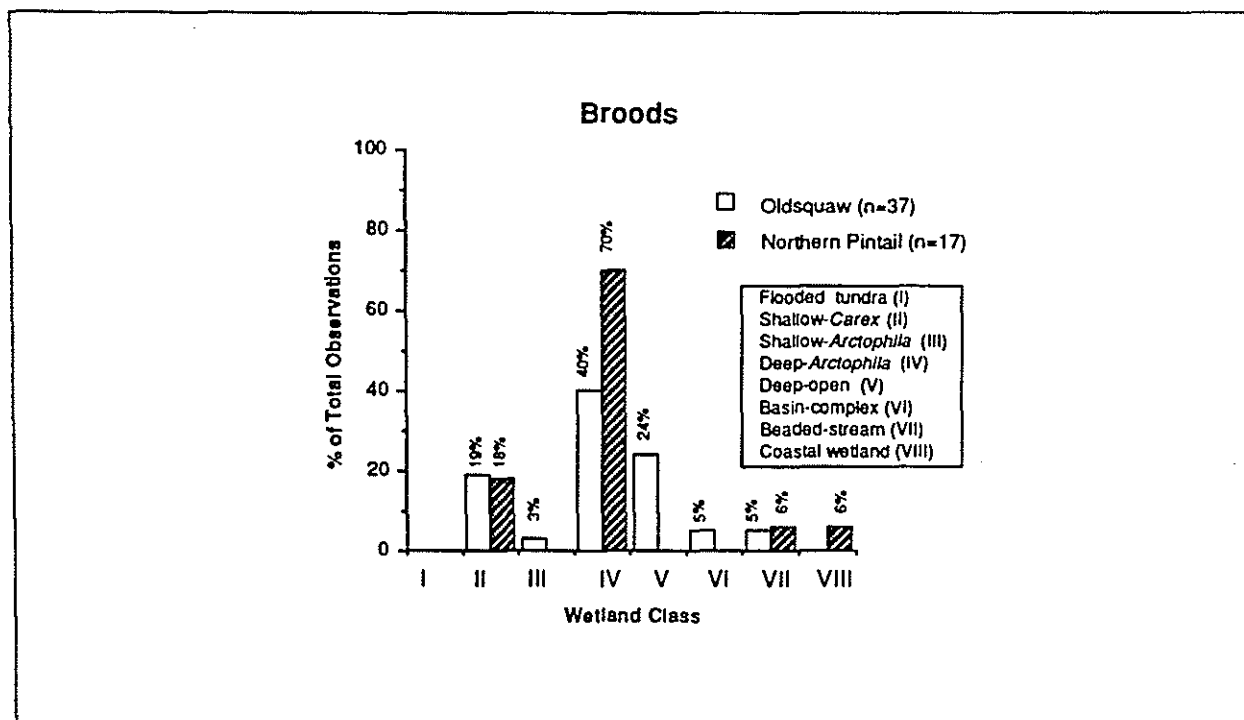


Figure 12. Observations of Oldsquaw and Northern Pintail broods (by wetland class) at five NPR-A study areas (Island Lake, Teshokpuk Lake, Square Lake, Meade River, and Singiluk) in 1977 and 1978 (Derksen et al. 1979). Class VIII wetlands refers in this case to Rivers and Upland tundra pools, two wetland types created by Derksen et al. (1979).

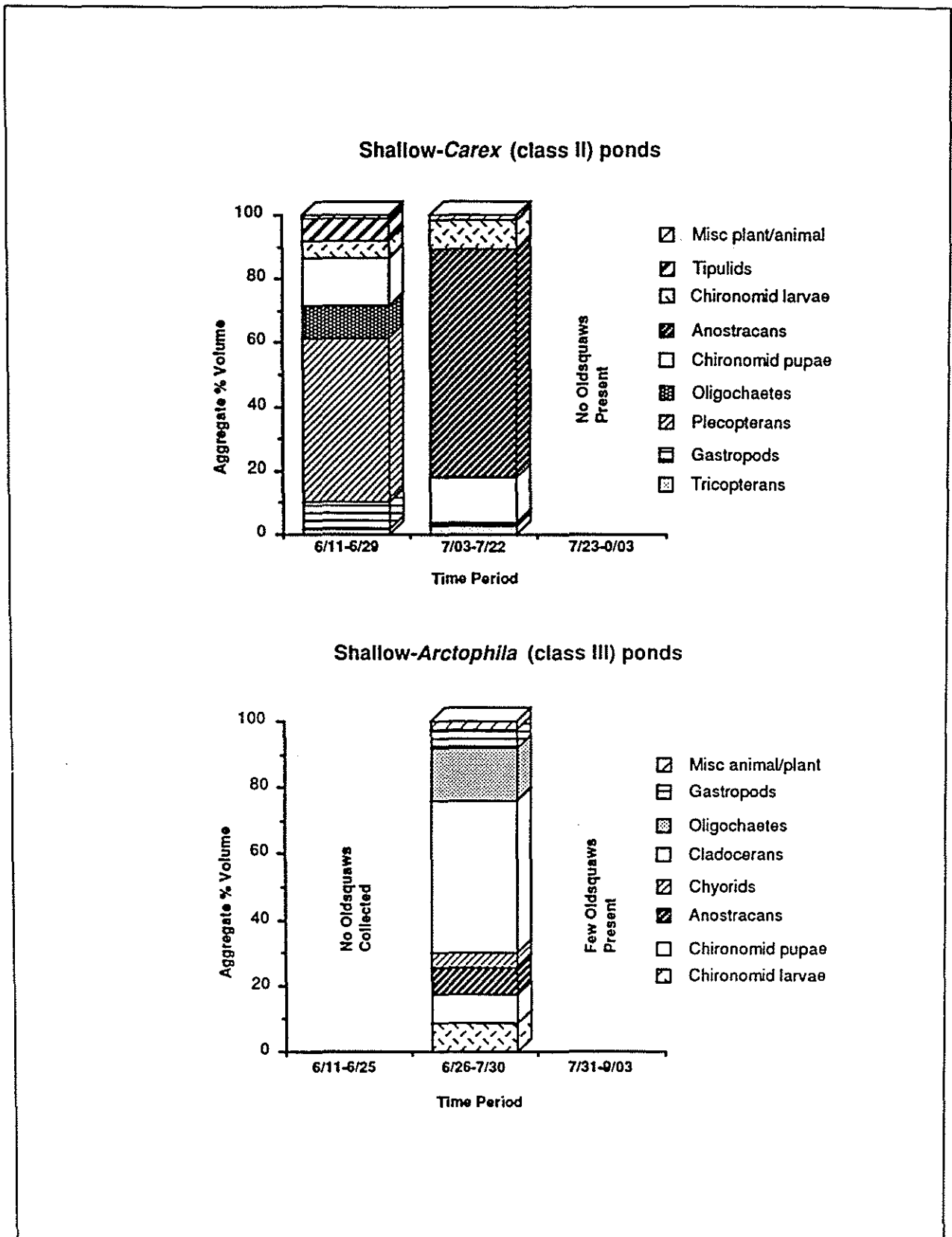


Figure 13. The diet of Oldsquaws collected from Shallow-Carex (Class II) and Shallow-Arctophila (Class III) ponds at West Long Lake (NPR-A) in 1979 and 1980 (Taylor 1986). See Table 12 for exact percentages.

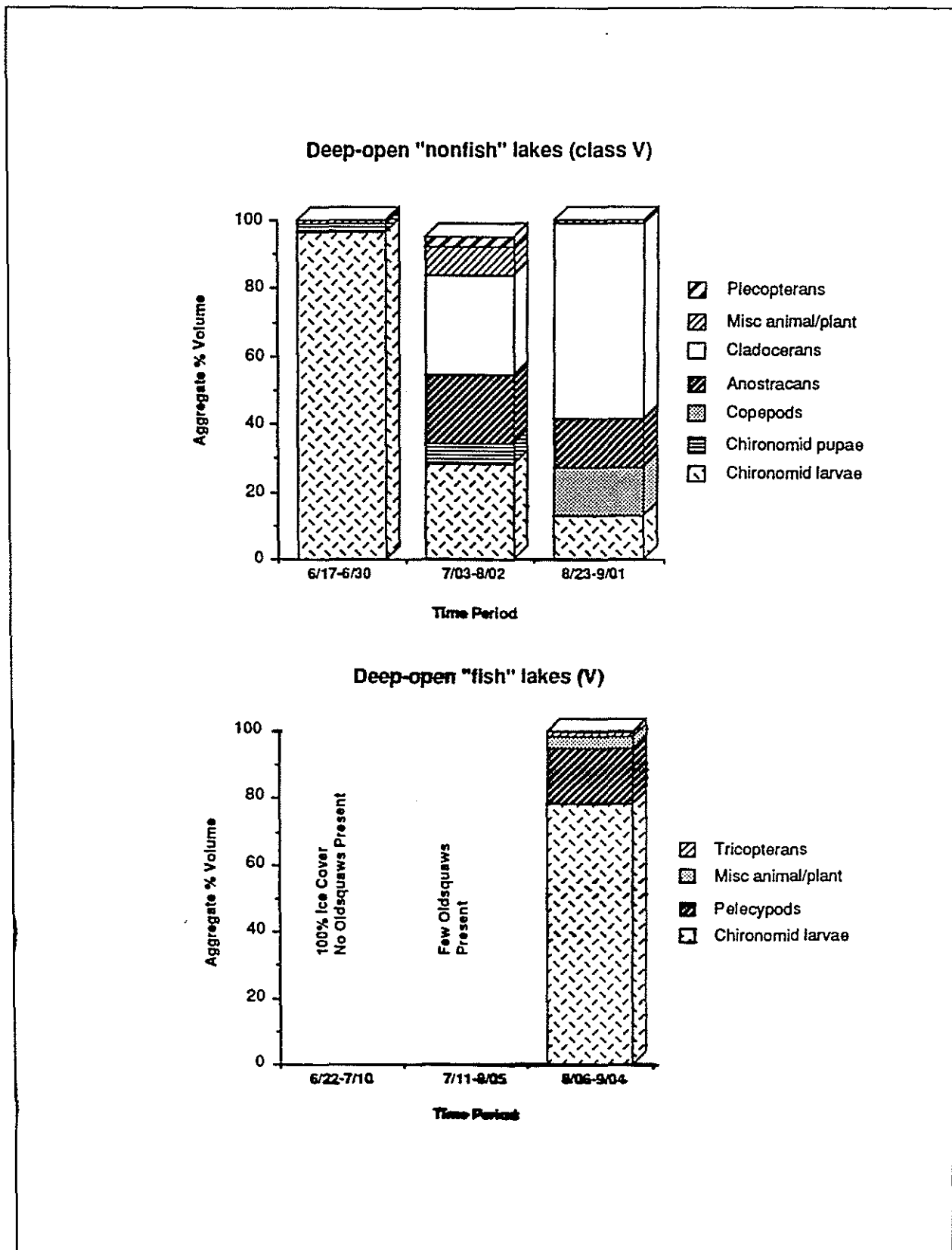


Figure 14. The diet of Oldsquaws collected from Deep-open "nonfish" and "fish" (Class V) lakes at West Long Lake (NPR-A) in 1979 and 1980 (Taylor 1986). See Table 12 for exact percentages.

Table 12. Aggregate percent volume<sup>1</sup> of invertebrates eaten by, and available to, Oldsquaws in Shallow-Carex (II) ponds, Shallow-Arctophila (III) ponds, and Deep-open "nonfish" (V) and "fish" (V) lakes at West Long Lake, Alaska (Taylor 1986). TR = <0.1%.

Taxa	Shallow-Carex (II)				Shallow-Arctophila (III)		Deep-open "nonfish" (V)						Deep-open "fish" (V)	
	Early (%)		Mid (%)		Mid (%)		Early (%)		Mid (%)		Late (%)		Late (%)	
	Eaten	Avail	Eaten	Avail	Eaten	Avail	Eaten	Avail	Eaten	Avail	Eaten	Avail	Eaten	Avail
Chironomids (larvae)	5.4	32.5	9.1	no info	8.7	37.9	96.6	97.8	28.3	85.7	13.1	33.3	78.1	87.0
Chironomids (pupae)	14.9	8.8	14.2	no info	8.4		2.5	0.3	5.9	1.3				
Oligochaetes	10.2	37.5	1.1	no info	15.8	44.6		1.9				36.4		
Plecopterans (nymphs)	51.0	2.5	TR	no info					3.3					
Anostracans			71.5	no info	8.4				20.4	1.0	14.3	TR		
Tricopterans	1.8		2.7	no info					0.8				1.3	
Gastropods	8.6	3.5	TR	no info	5.9	2.5								
Tipulids (larvae)	7.0	15.1		no info			0.7							
Chytrids			TR	no info	4.5									
Cladocerans			TR	no info	45.9	11.0			29.3	1.2	57.1	27.1		
Copepods	TR			no info		3.8	TR		TR		14.3	2.1	TR	
Pelecypods				no info										16.8 13.0
Misc. animal/plant	1.0		1.5	no info	2.4		TR		7.2		1.2			3.8
TOTAL <sup>2</sup>	99.9	99.9	100.1		100.0	99.8	99.8	100.0	95.2	89.2	100.0	98.9	100.0	100.0

<sup>1</sup>Aggregate percent volume eaten is from Tables 1-6 in Taylor (1986:37-43). According to Taylor (pers comm. 1992), this information more accurately reflects Oldsquaw food habits than does information in Figures 8-19 which are based on smaller sample sizes (see Taylor 1986:65-77).

<sup>2</sup>Totals are based on information from Taylor (1986) and do not always equal 100%.

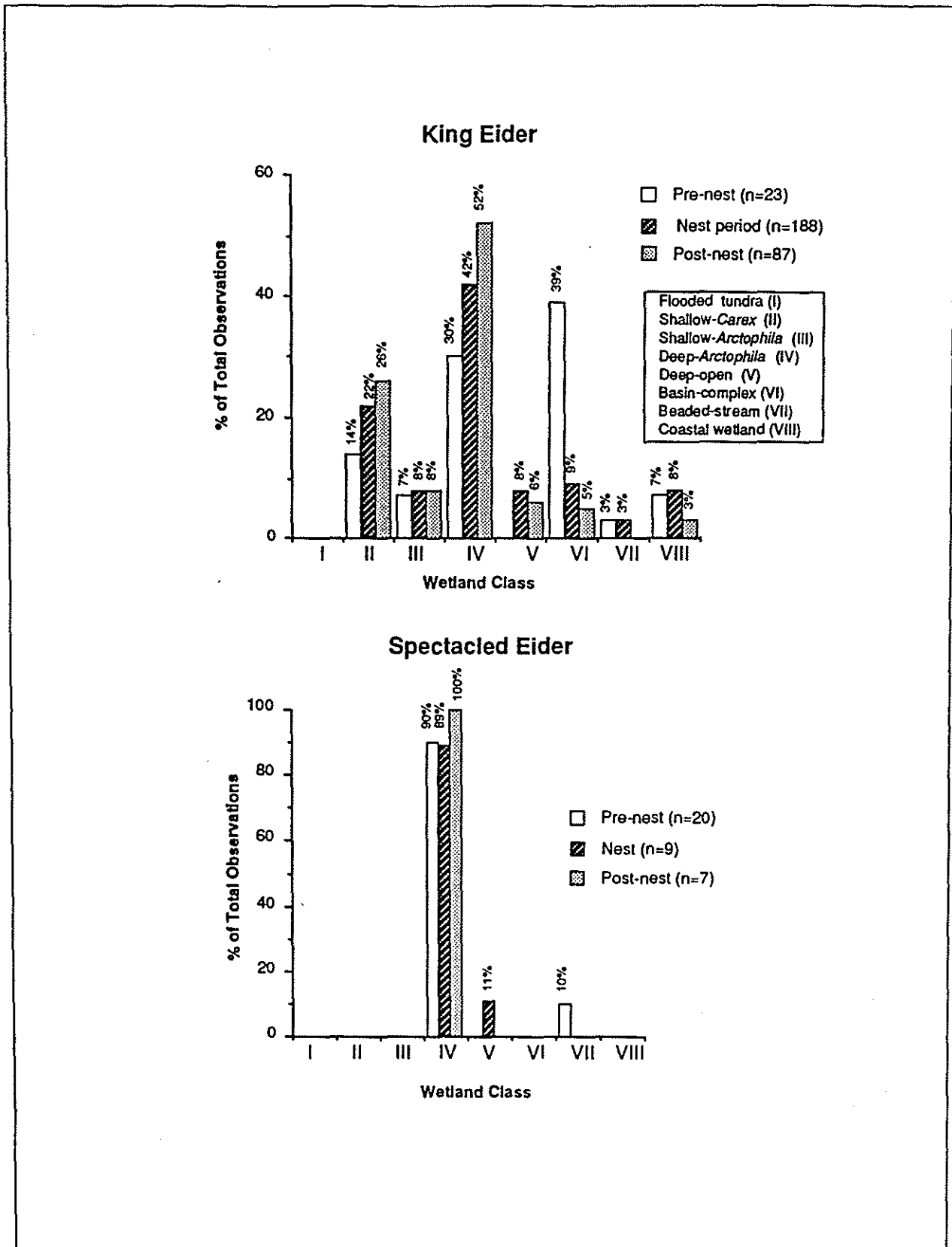


Figure 15. Observations of King and Spectacled eiders (by wetland class) during periods of the summer at Storkersen Point in 1971-1973 (Bergman et al. 1977).

tacted eiders (Fig. 15) used Deep-*Arctophila* (IV) ponds extensively throughout the season (Bergman et al. 1977).

In late summer, female King and Spectacled eiders with broods (Fig. 16) were observed most commonly on Shallow-*Carex* (II) and Deep-*Arctophila* (IV) ponds at both Storkersen and NPR-A study sites (Bergman et al. 1977, Derksen et al. 1979). For example, 64% (n=19) of King Eider broods at Storkersen Point (Fig. 16) were observed on Shallow-*Carex* (II) ponds (Bergman et al. 1977). At NPR-A study sites (Fig. 16), 55% (n=18) of Spectacled Eider broods were on Shallow-*Carex* (II) ponds, and 78% (n=9) of King Eider broods were on Deep-*Arctophila* (IV) ponds (Derksen et al. 1979).

At Storkersen Point, adult King Eiders were seen feeding most frequently on Shallow-*Carex* (II) ponds (46% of 107 observations) and Basin-complex (VI) wetlands (40% of 107 observation) (Bergman et al. 1977). Adult King Eiders fed regularly on chironomids and Trichopterans (caddisfly larvae), while fairy shrimp (Anostracans) and water fleas (Cladocerans) were most important in the diet of young (Bergman et al. 1977). As did Oldsquaws, eiders took oligochaetes in smaller proportions than their occurrence in the habitat, while invertebrates associated with emergent vegetation (in this case, caddisfly larvae) were taken in greater proportions than expected (Bergman et al. 1977). However, Bergman et al. (1977) did not provide detailed information on food use versus availability.

Pacific Loons were most frequently observed in Deep-*Arctophila* (IV) lakes or in Basin-complex (VI) wetlands (Fig. 17) containing *Arctophila* at Storkersen Point during the pre-nest period (Bergman et al. 1977). Deep-*Arctophila* (IV) lakes continued to be important during the nesting and post-nest periods at Storkersen (Fig. 17); however, use of Basin-complex (VI) wetlands declined during these periods. At Square Lake and Teshekpuk Lake (NPR-A), Pacific Loons were observed most commonly in Deep-*Arctophila* (IV) lakes, while at Island Lake they were seen mostly on Deep-open (V) lakes (Derksen et al. 1979). Shallow-*Carex* (II) and Shallow-*Arctophila* (III) ponds (Fig. 17) were also important at Square Lake and Teshekpuk Lake (Derksen et al. 1979). Red-throated Loons were observed most commonly in wetlands with *Arctophila* at both Storkersen and NPR-A study sites (Bergman and Derksen 1977, Derksen et al. 1979).

Nests of Pacific Loons at Storkersen Point (Fig. 18) were located most commonly in Deep-*Arctophila*

(IV) ponds (Bergman and Derksen 1977), and broods were frequently observed in the same wetlands as were used for nesting or in nearby wetlands of the same type [i.e., Deep-*Arctophila* (IV)]. Shallow-*Carex* (II) ponds were used to a much greater extent by Pacific Loons for brood-rearing at NPR-A study sites (Fig. 18) than at Storkersen Point (Derksen et al. 1979). Although Red-throated Loons preferred Shallow-*Arctophila* ponds (III) for brood-rearing at NPR-A study sites (Fig. 18), they also used Shallow-*Carex* (II) ponds (Derksen et al. 1979).

Unlike Red-throated Loons, which feed on fish in nearby marine waters, Pacific Loons eat invertebrate prey, and patterns of brood movement between wetlands reflect the need to provide young with an adequate invertebrate supply. Consequently, Pacific Loons may move their broods from the nest pond to nearby wetlands in response to changes in availability of such preferred invertebrate prey as Tricoptera (caddisflies) and Anostracans (tadpole shrimp) (Bergman and Derksen 1977). Pacific Loons have nested in impoundments with *Arctophila* in the Prudhoe Bay oil field (pers obs.).

#### Surface-feeders

The Northern Pintail is the most common surface-feeding duck occurring at Prudhoe Bay. The large majority (up to 80%) of the Northern Pintails observed at Prudhoe Bay (pers obs.), Storkersen Point (Bergman et al. 1977), and NPR-A study sites (Derksen et al. 1979) were males. Thus, wetland use patterns reported for these areas may reflect summer requirements of males as compared to females.

During the early summer (Fig. 19), Northern Pintails preferred Shallow-*Arctophila* (III) and Flooded tundra (I) wetlands at NPR-A study sites (Derksen et al. 1979) and Shallow-*Arctophila* (III) and Basin-complex (VI) wetlands containing *Arctophila*-rimmed ponds and areas of flooded tundra at Storkersen Point (Bergman et al. 1977). Basin-complex (VI) wetlands accounted for 81% of 423 feeding observations at Storkersen Point and were particularly important to pintails during the molt in July (Bergman et al. 1977). At NPR-A study sites, Northern Pintails shifted increasingly to Deep-*Arctophila* (IV) lakes and Beaded-streams (VII) in July, and Deep-open (V) lakes in August. The majority of Northern Pintail brood sightings at NPR-A study sites (Derksen et al. 1979) were from Deep-*Arctophila* (IV) ponds (Fig. 12).

Northern Pintails made limited use of Shallow-

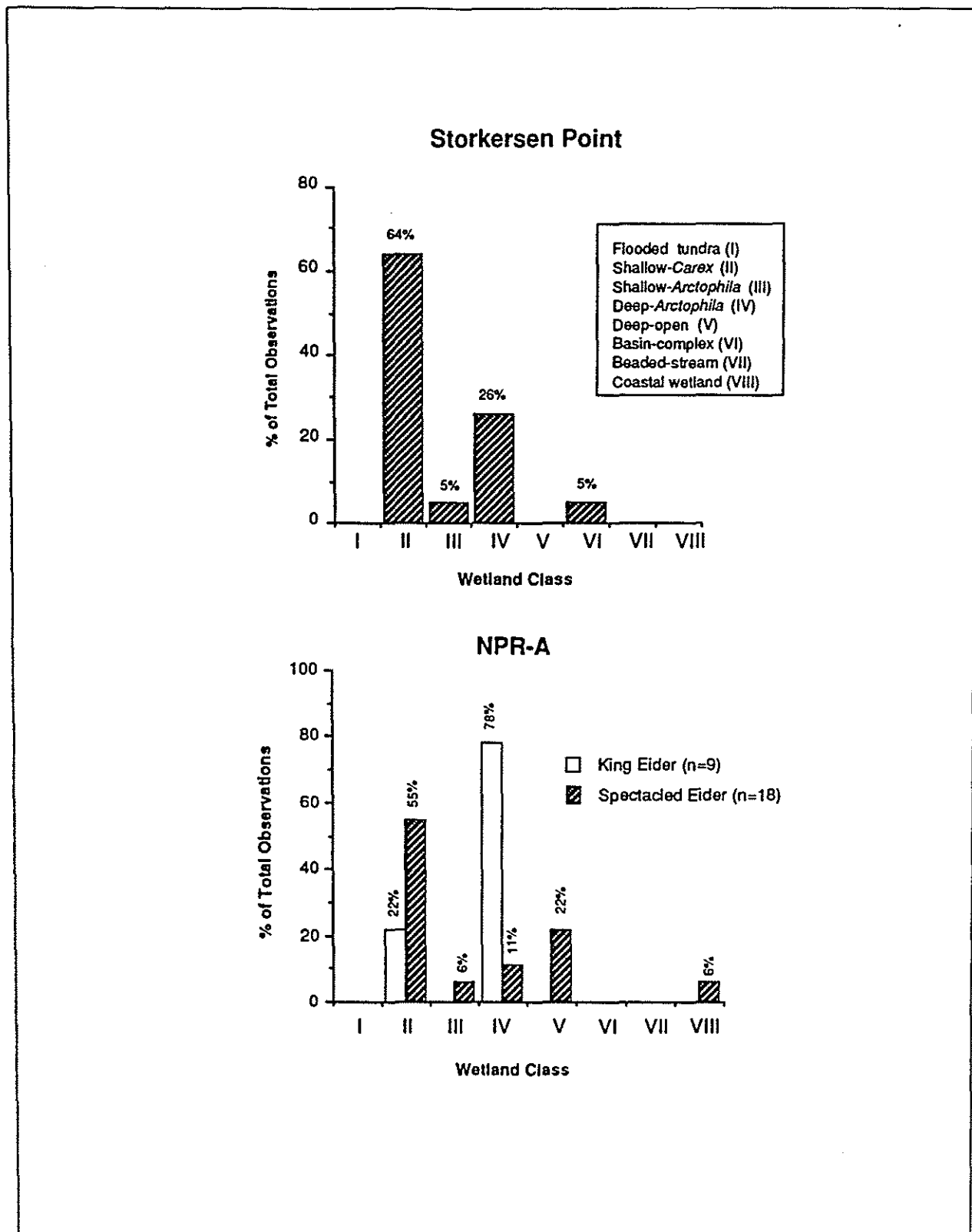


Figure 16. Observations (by wetland class) of King Eider broods (n=19) at Storkersen Point in 1971-1973 (Bergman et al. 1977) and King and Spectacled eider broods at five NPR-A study areas (Island Lake, Teshekpuk Lake, Square Lake, Meade River, and Singiluk) in 1977 and 1978 (Derksen et al. 1979). At NPR-A, Class VIII wetlands refer in this case to Rivers and Upland tundra pools, two wetland types created by Derksen et al. (1979).

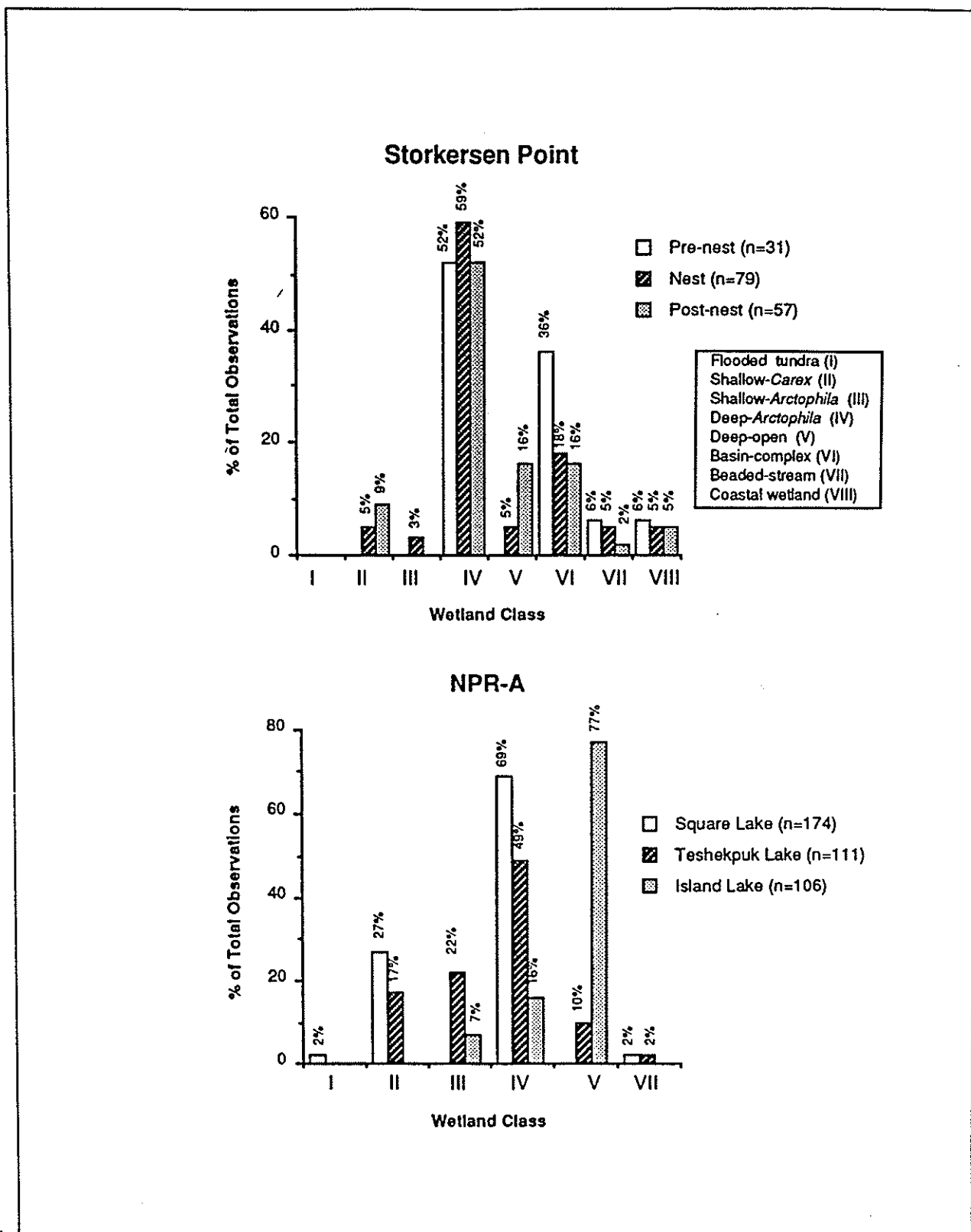


Figure 17. Observations of Pacific Loons (by wetland class) at Storkersen Point in 1971-1973 (Bergman et al. 1977) and at three NPR-A study areas (Square Lake, Teshekpuk Lake, and Island Lake) in 1977 and 1978 (Derksen et al. 1979). At NPR-A, Derksen et al. (1979) did not include Coastal (VIII) wetlands in their classification system, and excluded Basin-complex (VI) wetlands from use by Pacific Loons. Use periods at Storkersen are comparable to those used at the NPR-A.



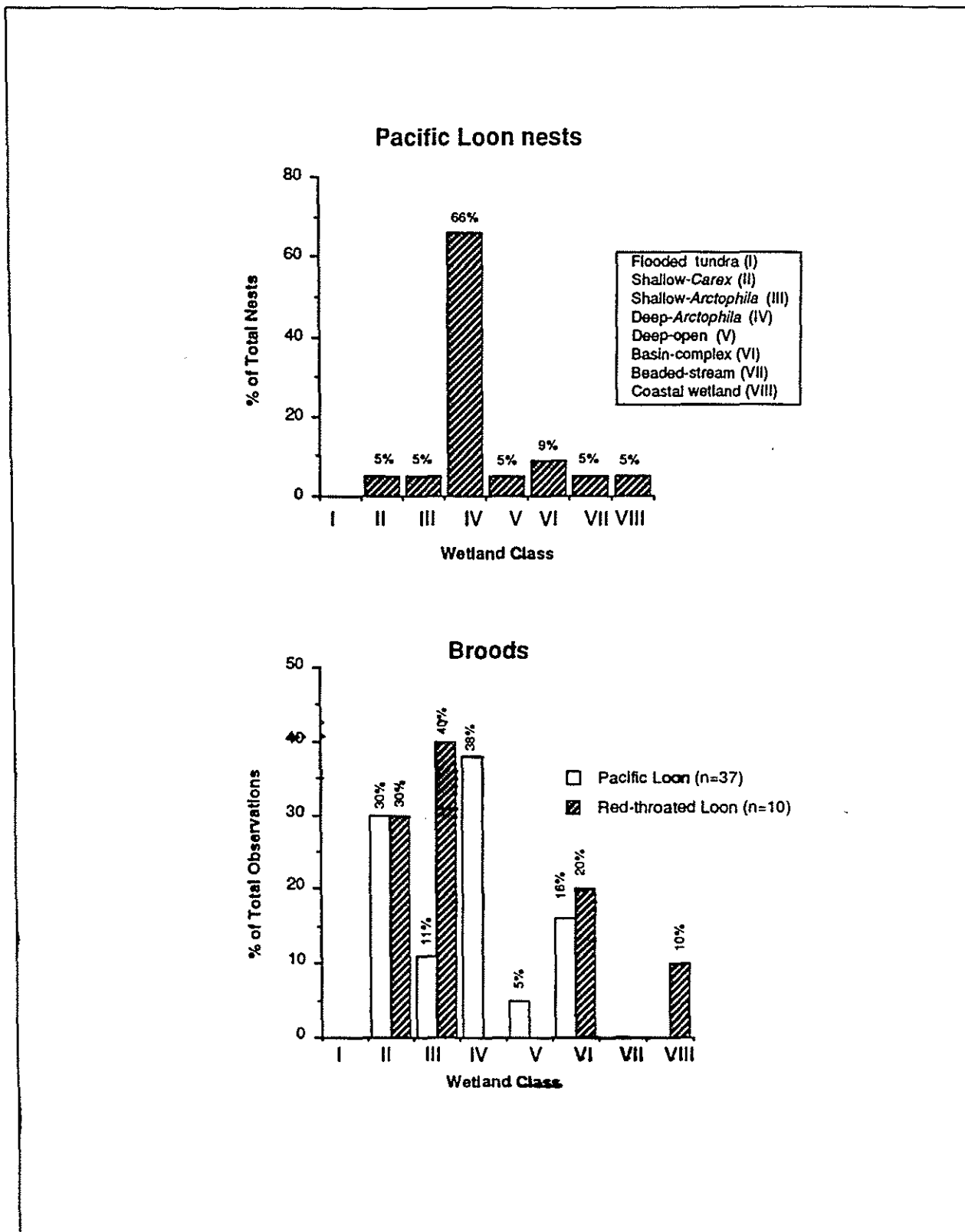


Figure 18. Observations of Pacific Loon nests (by wetland class) at Storkersen Point from 1971 to 1975 (Bergman and Derksen 1977) and observations of Pacific and Red-throated loon broods (by wetland class) at five NPR-A study areas (Island Lake, Teshekpuk Lake, Square Lake, Meade River, and Singluk) in 1977 and 1978 (Derksen et al. 1979). At NPR-A, Class VIII wetlands refer in this case to Rivers and Upland tundra pools, two wetland classes created by Derksen et al. (1979).

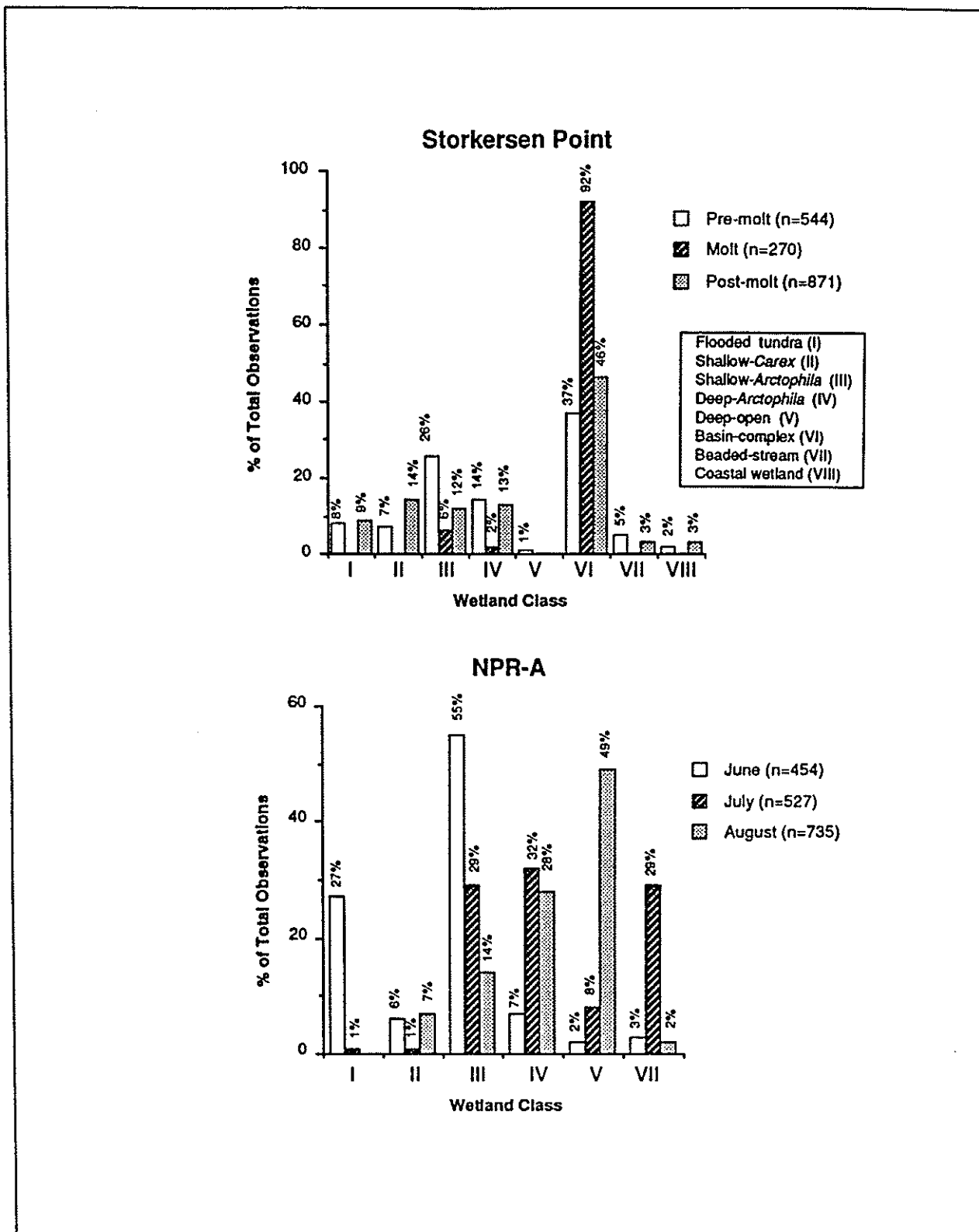


Figure 19. Observations of Northern Pintails (by wetland class) during periods of the summer at Storkersen Point in 1971–1973 (Bergman et al. 1977) and at five NPR-A study areas (Island Lake, Teshekpuk Lake, Square Lake, Meade River, and Singiluk) in 1978 (Derksen et al. 1979). At NPR-A, Derksen et al. (1979) did not include Coastal (VIII) wetlands in their classification system, and excluded Basin-complex (VI) wetlands from use by Northern Pintails. Use periods at Storkersen are comparable to those at the NPR-A.

*Carex* (II) ponds (Fig. 19). During late July and August at Storkersen Point, however, there was increased use of Shallow-*Carex* (II) ponds where fairy and tadpole shrimp were concentrated (Bergman et al. 1977). According to Derksen et al. (1979), concentrations of benthic invertebrates may have also attracted broods to Shallow-*Carex* (II) ponds at NPR-A study sites in late summer.

#### Waders

Derksen et al. (1979) combined observations for several shorebird species to provide an overall impression of wetland use at Teshekpuk Lake and Island Lake. Species included were Lesser Golden-Plover (*Pluvialis dominica*), Black-bellied Plover (*Pluvialis squatarola*), Long-billed Dowitcher (*Limnodromus scolopaceus*), Pectoral Sandpiper (*Calidris melanotos*), Dunlin (*Calidris alpina*), Semipalmated Sandpiper (*Calidris pusilla*), Red Phalarope (*Phalaropus fulicaria*), and Red-necked Phalarope (*Phalaropus lobatus*).

In June, Flooded tundra (I) and Shallow-*Carex* (II) wetlands were used most commonly (Fig. 20) at Island Lake, and Flooded tundra (I) wetlands and Beaded-streams (VII) were used most commonly at Teshekpuk Lake (Derksen et al. 1979). As Flooded tundra (I) wetlands dried in July, shorebirds switched increasingly to Shallow-*Carex* (II) ponds and Deep-open (V) lakes at Teshekpuk and to Deep-open (V) and Deep-*Arctophila* (IV) lakes at Island (Fig. 20), where they often fed along exposed shorelines. Because results were weighted heavily by the large number of phalarope observations relative to observations of other shorebird species, brief summaries of the use patterns of phalaropes and three other common waders (Pectoral Sandpiper, Semipalmated Sandpiper, and Dunlin) are provided below. However, information on percent wetland use by these species was not provided.

The majority of Red Phalaropes at Teshekpuk Lake were recorded on Flooded tundra (I) wetlands during June; but during July and August, use of these wetlands decreased markedly, and birds shifted to exposed shorelines of large water bodies. At Island Lake, Red Phalaropes often used Deep-open (V) lakes in June. Early in the season, Red-necked Phalaropes frequently used Beaded-streams (VII) at both Teshekpuk and Island lakes. In July and August, they used Shallow-*Carex* (II), Shallow- (III) and Deep-*Arctophila* (IV) wetlands, and Beaded-streams (VII). Generally, Red Phalaropes used Deep-open (V) lakes more than

Red-necked Phalaropes, whereas Red-necked Phalaropes used Shallow- (III) and Deep-*Arctophila* (IV) wetlands, and Beaded-streams (VII) more than Red Phalaropes. Flooded tundra (I) and Shallow-*Carex* (II) wetlands were important to both. In the Prudhoe Bay oil field, Red-necked phalaropes are more common than Red Phalaropes.

At Teshekpuk Lake, 99% of Pectoral Sandpiper observations in June and July were on Flooded tundra (I) wetlands. In August, Shallow-*Arctophila* (III) ponds were important at Teshekpuk, whereas shorelines of Deep-open (V) lakes were heavily used at Island Lake just prior to migration.

At Teshekpuk and Island lakes, Dunlin commonly used Flooded tundra (I) and Shallow-*Carex* (II) ponds in June. As Flooded tundra (I) wetland dried in July, Dunlins shifted use to Shallow-*Carex* (II) ponds at Teshekpuk and to Deep-open (V) lakes at Island. Beaded-streams (VII) were also used, particularly in August.

Wetland use by Semipalmated Sandpipers was concentrated on Flooded tundra (I) wetlands, Deep-open (V) lakes, and Beaded-streams (VII) in June. Shallow-*Carex* (II) ponds, Deep-open (V) lakes, and Beaded-streams (VII) were important later in the season.

As mentioned earlier, the Bergman classification system does not include terrestrial habitats. Although phalaropes preyed heavily on invertebrates taken from vegetation at the margins of shallow ponds at Barrow (Connors 1983), larval invertebrates (principally tipulids) found in terrestrial habitats are considered the single most important food for the majority of shorebird species during summer in arctic Alaska (MacLean and Ayres 1982). (Semipalmated Sandpipers, however, preyed heavily on chironomids throughout the season at Barrow; MacLean and Ayres 1982.) The heavy dependence on tipulid larvae by most shorebirds is apparently related to prey size: terrestrial tipulid larvae are often more than 10 mg dry weight compared to less than 1 mg dry weight for the larvae of aquatic chironomids (Connors 1983).

#### Summary

Based on the concept of wildlife guilds, we provide a simplified overview of waterbird use at Shallow-*Carex* (II) ponds (Table 13) and Flooded tundra (I) wetlands (Table 14). The information provides a basis for discussing the potential value of small permanent impoundments to different invertebrate-eating water-

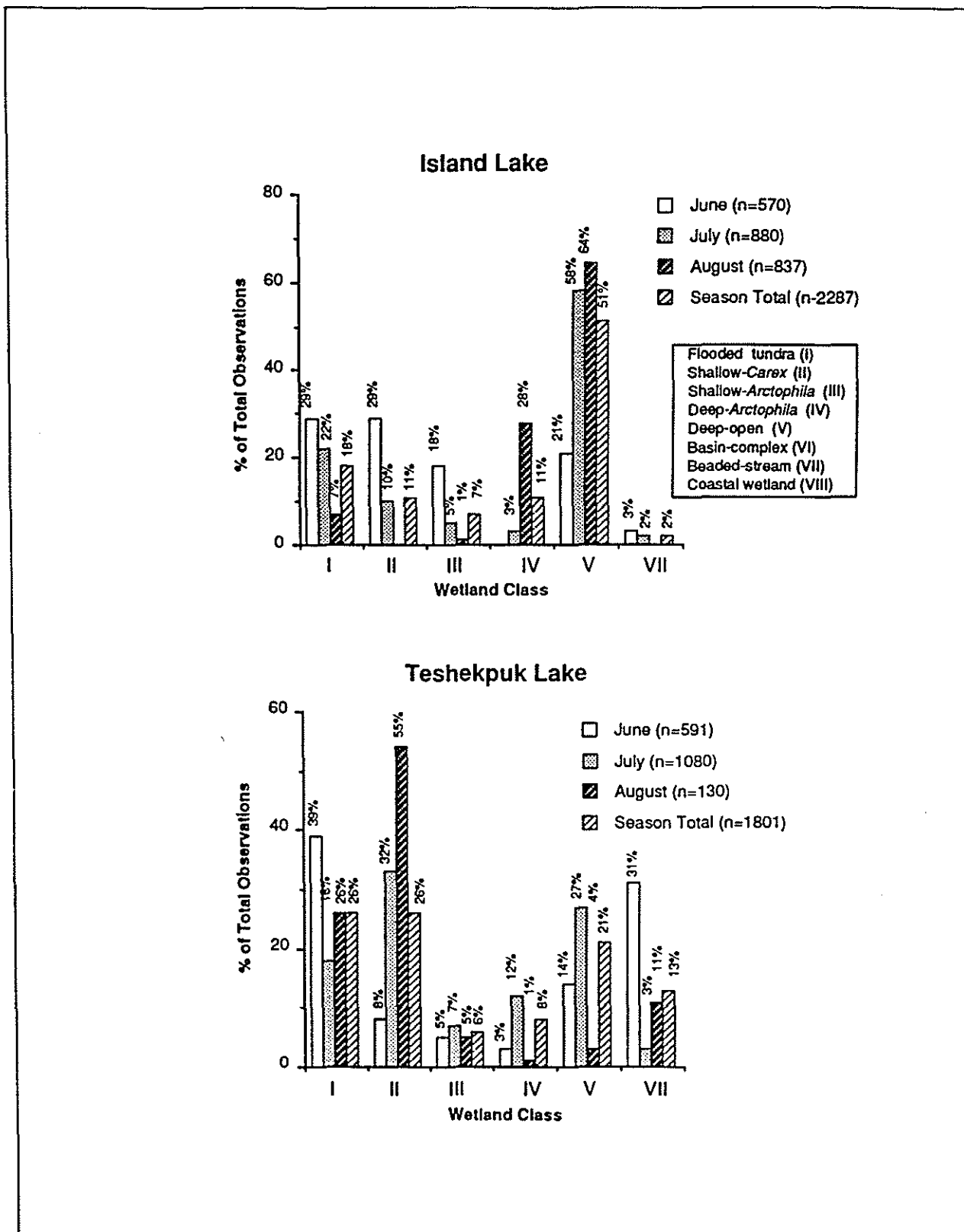


Figure 20. Observations of shorebirds (all species combined) during periods of the summer at two NPR-A study areas (Island Lake and Teshekpuk Lake) in 1978 (from Derksen et al. 1979). Results were weighted heavily by the large numbers of phalaropes relative to other shorebird species. Derksen et al. (1979) did not include Coastal (VIII) wetlands in their classification system, and excluded Basin-complex (VI) wetlands from use by shorebirds.

Table 13. Summary of use patterns at Shallow-Carex (Class II) wetlands by Arctic Coastal Plain waterbirds in relation to season. Based on Bergman et al. 1977, Derksen et al. 1979, and Taylor 1986. See text for details.

Wildlife Guild	Species	Early summer		Mid-summer		Late summer	
		Age & Sex <sup>1</sup>	Activity <sup>2</sup>	Age & Sex	Activity	Age & Sex	Activity
Divers	Oldsquaw	F	N,Fe	F	N,Fe	-	-
	King Eider	F	N,Fe	F	N,Fe,Br	F,Y	Fe,Br
	Spectacled Eider	F	N,Fe	F	N,Fe,Br	F,Y	Fe,Br
	Pacific Loon	-	-	-	N,Fe,Br	F,M	Fe,Br
Surface-feeders	Northern Pintail	F	Fe	-	-	M,F	Fe
Waders	Phalaropes	M,F	N,Fe	M	N,Fe	M,Y	Fe
	Dunlin	-	-	-	-	Y	Fe
	Pectoral Sandpiper	-	-	-	-	Y	Fe
	Semipalmated Sandpiper	-	-	-	-	Y	Fe

<sup>1</sup>F=Female, M=Male, Y=Young

<sup>2</sup>N=Nesting, Fe=Feeding, Br=Brood-rearing

Table 14. Summary of use patterns on Flooded tundra (Class I) wetlands by Arctic Coastal Plain waterbirds in relation to time of season. Based on Bergman et al. 1977, Derksen et al. 1979, and Taylor 1986. See text for details.

Wildlife guild	Species	Early summer		Mid-summer		Late summer	
		Age & Sex <sup>1</sup>	Activity <sup>2</sup>	Age & Sex	Activity	Age & Sex	Activity
Divers	Oldsquaw	-	-	-	-	-	-
	King Eider	-	-	-	-	-	-
	Spectacled Eider	-	-	-	-	-	-
	Pacific Loon	-	-	-	-	-	-
Surface-feeders	Northern Pintail	M,F	Fe	-	-	-	-
Waders	Phalaropes	M,F	Fe	M	Fe	-	-
	Dunlin	M,F	Fe	-	-	-	-
	Pectoral Sandpiper	M,F	Fe	-	-	-	-
	Semipalmated Sandpiper	M,F	Fe	-	-	-	-

<sup>1</sup>F=Female, M=Male, Y=Young

<sup>2</sup>Fe=Feeding

birds. We suggest that small permanent impoundments may be most important to breeding divers and their broods. They may also be important to breeding surface feeders, but too few breeding pintails were identified at the study sites to accurately assess the importance of small shallow ponds. For waders, small permanent impoundments are important primarily to juveniles during mid- and late summer. However, for the most part, shorebirds (with the possible exception of Red-necked Phalaropes) do not depend on small permanent water bodies to as great an extent as do waterfowl. Large seasonal impoundments may be used principally by surface-feeders and waders in early summer prior to breeding, whereas divers appear to make limited use of this wetland type.

## CONCLUSIONS

Results from this single-year study show that small permanent impoundments contain a significantly higher biomass of both chironomids and oligochaetes than similarly sized natural ponds. Results also show that large *Chironomus* larvae are partially responsible for the high invertebrate biomass of some impoundments. Since invertebrate abundance and size are widely recognized as important measures of habitat quality for waterbirds, the high productivity of impoundments in the Prudhoe Bay oil field suggests that they may benefit populations of some waterbird species. However, we do not know when, to what degree,

or if productivity declines over time. Further, although we know that greater invertebrate biomass should be beneficial to waterbirds, we do not know to what extent they use it. Until direct measures of bird use are collected, we can only hypothesize about potential use of impoundments.

Waterbird use patterns presented in Tables 13 and 14 are generalized, and there are exceptions to the estimates made. For example, the greater amount of emergent vegetation in small permanent impoundments compared with analogous Shallow-*Carex* (II) ponds probably benefits divers and surface-feeders, particularly females with broods, by providing cover and a substrate for important foods such as caddisfly and stonefly larvae. By contrast, deeper water and steeper shoreline gradients probably limit access by waders to invertebrate-rich sediments. For waders, impoundments may represent a net loss of habitat quality because waders may benefit from terrestrial habitats (moist or wet tundra) in their unimpounded state. Although we suspect that large seasonal impoundments (which can reach hundreds of hectares in size; Lederer 1984) and analogous Flooded tundra (Class I) wetlands are similar in terms of invertebrate productivity, we know very little about the hydrology of these impoundments compared with similar natural wetlands and how potential differences in drying rates and water level changes might affect waterbirds. Comparisons between impoundments and natural wetland classes are summarized in Table 15.

Table 15. Generalized comparisons between two impoundment types and their analogous natural wetland classes.

Impoundment type	Apparent differences from analogous wetland class	Guilds (age and sex categories) hypothesized to benefit from impoundment	Guilds (age and sex categories) hypothesized to be adversely affected through loss of preferred terrestrial habitat
Impoundment analogous to Shallow- <i>Carex</i> (Class II) pond	<ul style="list-style-type: none"> <li>•Greater biomass of chironomids and oligochaetes</li> <li>•More chironomid taxa</li> <li>•More emergent vegetation</li> <li>•Deeper water</li> <li>•Steeper shoreline gradient</li> <li>•Less exposed sediment</li> </ul>	<ul style="list-style-type: none"> <li>•Divers (breeding females and broods)</li> <li>•Surface-feeders (breeding females and broods)</li> </ul>	<ul style="list-style-type: none"> <li>•Waders (adults and young with exception of phalaropes)</li> </ul>
Impoundment analogous to Flooded tundra (Class I) wetland <sup>1</sup>	<ul style="list-style-type: none"> <li>•No current information on secondary productivity or hydrology of large, shallow impoundments</li> </ul>	<ul style="list-style-type: none"> <li>•Surface-feeders (pre-breeding and non-breeding adults)</li> </ul>	<ul style="list-style-type: none"> <li>•Waders (adults and young with exception of phalaropes)</li> </ul>

<sup>1</sup>Divers appear to make limited use of Class I wetlands; thus, evaluating impacts of analogous impoundments may require information on types and densities of natural wetlands such impoundments replace.

The best use of this report is for designing new impact-assessment research and planning effective habitat mitigation, should such mitigation be required. For mitigation to be effective, however, habitat evaluation needs to be better related to some objective for management (e.g., is habitat for divers more valuable than habitat for waders, and is habitat for breeding birds more valuable than habitat that supports large numbers of non-breeding individuals?). If the mitigation goal is to provide feeding habitat for waders, then it may be necessary to modify impoundments to have

more gradual shoreline gradients and shallower water depths than if the goal is to provide habitat for divers and surface feeders. However, manipulating the shorelines of impoundments may affect productivity. Although we have no assurances that modifying impoundments around guidelines developed from the study of natural wetlands will lead to greater use, we suggest that greater use of these water bodies can best be achieved by emphasizing design features that increase the availability of invertebrates.

## Literature Cited

- Alexander, V., and M.C. Miller. 1978. Effects of the pipeline haul road on nearby ponds and lakes across Alaska's north slope. Unpublished annual progress report, U.S. Energy Research and Development. Admin. Rep. No. RLO-2229-T9-2. 51 p.
- Armstrong, D.P., and T.D. Nudds. 1985. Factors influencing invertebrate size distributions in prairie potholes and implications for coexisting duck species. *Freshwater Invert. Biol.* 4:41-47.
- Belanger, L., and R. Couture. 1988. Use of man-made ponds by dabbling duck broods. *J. Wildl. Manage.* 52:718-723.
- Belant, J.L., and R.K. Anderson. 1991. Common loon, *Gavia immer*, productivity on a northern Wisconsin impoundment. *Can. Field-Nat.* 105:29-33.
- Bergman, R.D., and D.V. Derksen. 1977. Observations on Arctic and red-throated loons at Storkersen Point, Alaska. *Arctic* 30: 41-51.
- Bergman, R.D., R.L. Howard, K.F. Abraham, and M.W. Weller. 1977. Water birds and their wetland resources in relation to oil development at Storkersen Point, Alaska. USDI Fish and Wildl. Serv. Resource Publ. No. 129, Washington, D. C.
- Brown, J., B.E. Brockett, and K.E. Howe. 1984. Interaction of gravel fills, surface drainage, and culverts with permafrost terrain. CRREL Rep. No. 84-11. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.
- Brown, M., and J.J. Dinsmore. 1986. Implications of marsh size and isolation for marsh bird management. *J. Wildl. Manage.* 50:392-397.
- Butler, M.G. 1982a. A 7-year life cycle for two *Chironomus* species in arctic Alaska tundra ponds (Diptera: Chironomidae). *Canadian J. of Zool* 60:58-70.
- Butler, M.G. 1982b. Production dynamics of some arctic *Chironomus* larvae. *Limnol. Oceanogr.* 27:728-736.
- Butler, M.G., and D.H. Anderson. 1990. Cohort structure, biomass, and production of a merovoltine *Chironomus* population in a Wisconsin bog lake. *J. N. Am. Benthol. Soc.* 9:180-192.
- Butler, M., M.C. Miller, and S. Mozley. 1980. Macrobenthos. Pages 297-339. In: J.E. Hobbie (ed). *Limnology of tundra ponds*, Barrow, Alaska. VS/IBP Synthesis Ser. 13. Dowden, Hutchinson, and Ross, Stroudsburg, Penn.
- Connors, P.G. 1983. Prudhoe Bay Waterflood Project: tundra bird monitoring program 1982. Report to U.S. Army Corps of Engineers, Alaska District, Anchorage, by Bodega Marine Laboratory, Bodega Bay, California.
- Custer, T.W., and F.A. Pitelka. 1978. Seasonal trends in summer diet of the Lapland Longspur near Barrow, Alaska. *Condor* 80:295-301.
- Danell, K., and K. Sjöberg. 1982. Successional patterns of plants, invertebrates, and ducks in a man-made lake. *J. of Applied Ecology* 19:395-409.
- Derksen, D. V., W. D. Eldridge, and T. C. Rothe. 1979. Waterbird and wetland habitat studies. Pg. 229-311. In: P.C. Lent (ed). *Studies of selected wildlife and fish and their use of habitats on and adjacent to NPR-A 1977-78*. USDI National Petroleum Reserve in Alaska, Anchorage.
- Driver, E.A., L.G. Sugden, and R.J. Kovach. 1974.



- Calorific, chemical and physical values of potential duck foods. *Freshwater Invert. Biol.* 4:281-292.
- Dzubin, A. 1969. Comments on carrying capacity of small ponds for ducks and possible effects of density on mallard production. Pg. 239-267. In: J.T. Ratti, L. D. Flake, and W.A. Wentz (eds.). *Waterfowl ecology and management: selected readings*. The Wildl. Soc., Inc., Bethesda, Maryland.
- Fredrickson, L.H., and F.A. Reid. 1988. Invertebrate response to wetland management. *Fish and Wildlife Leaflet 13*. USDI Fish and Wildlife Service, Washington, D. C.
- FWS (USDI Fish and Wildlife Service). 1989. Technical guidance to U.S. Army Corps of Engineers on revision of Abbreviated Processing Procedure. 30 p.
- Hershey, A.E. 1985. Littoral chironomid communities in an arctic Alaskan lake. *Holarctic Ecol.* 8:39-48.
- Hobbie, J.E. 1984. The ecology of tundra ponds of the arctic coastal plain: a community profile. USDI Fish and Wildl. Serv. Rep. FES/OBS-83/25. 52 p.
- Hobbs, N.T., and T.A. Hanley. 1990. Habitat evaluation: do use/availability data reflect carrying capacity? *J. Wildl. Manage.* 54:515-522.
- Holmes, R.T. 1966. Breeding ecology and annual cycle adaptations of the red-backed sandpiper (*Calidris alpina*) in northern Alaska. *Condor* 68:41-43.
- Holmes, R.T., and F. A. Pitelka. 1968. Food overlap among coexisting sandpipers on northern Alaska tundra. *Syst. Zool.* 17:305-318.
- Howard, R.L. 1974. Aquatic invertebrate-waterbird relationships on Alaska's Arctic Coastal Plain. M.S. Thesis, Iowa State Univ., Ames. 49 p.
- Hudson, M.S. 1983. Waterfowl production on three age-classes of stock ponds in Montana. *J. Wildl. Manage.* 47:112-117.
- Jackson, J.K., and V.H. Resh. 1989. Sequential decision plans, benthic macroinvertebrates, and biological monitoring programs. *Environ. Manage.* 13:455-468.
- Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 6:65-71.
- Kadlec, J.A. 1962. Effects of a drawdown on a waterfowl impoundment. *Ecol.* 43:267-281.
- Kaminski, R.M., and H.H. Prince. 1981. Dabbling duck and aquatic macroinvertebrate response to manipulated wetland habitat. *J. Wildl. Manage.* 45:1-15.
- Kertell, K. 1991. Disappearance of the Steller's eider from the Yukon-Kuskokwim delta, Alaska. *Arctic* 44:177-187.
- Kertell, K. 1992. Conservation of Steller's and Spectacled eiders. *Alaska's Wildlife* 24(Jan-Feb):21.
- Klinger, L.F., D.A. Walker, M.D. Walker, and P.J. Webber. 1983. The effects of a gravel road on adjacent tundra vegetation. In: Prudhoe Bay Waterflood Project, environmental monitoring program, 1982. U.S. Army Corps of Engineers, Alaska District, Anchorage.
- Klopatek, J.M. 1988. Some thoughts on using a landscape framework to address cumulative impacts on wetland food chain support. *Environ. Manage.* 12:703-711.
- Krapu, G.L., and G.A. Swanson. 1975. Some nutritional aspects of reproduction in prairie nesting pintails. *J. Wildl. Manage.* 39:156-162.
- Kreil, K.Y. 1986. Comparison of waterfowl use and invertebrate abundance on constructed and natural wetlands in North Dakota. M.S. Thesis, Univ. of North Dakota, Grand Forks.
- Lederer, N.D., D.A. Walker, and P.J. Webber. 1984. Cumulative development of the Prudhoe Bay field. Map prepared at Institute of Arctic and Alpine Research, Boulder, Colorado, in cooperation with the USDI Fish and Wildl. Serv.
- Lokemoen, J.T. 1973. Waterfowl production on stock-watering ponds in the northern plains. *J. Range Manage.* 26:179-184.
- Lokemoen, J.T., H.F. Duebbert, and D.E. Sharp. 1984. Nest spacing, habitat selection, and behavior of waterfowl on Miller Lake Island, North Dakota. *J. Wildl. Manage.* 48:309-321.
- MacLean, S.F., and M.P. Ayres. 1982. Prudhoe Bay Waterflood Project: insect monitoring program. Report to U.S. Army Corps of Engineers, Alaska District, Anchorage, by Institute of Arctic Biol., Fairbanks.
- MacLean, S.F., Jr., and F.A. Pitelka. 1971. Seasonal patterns of abundance of tundra arthropods near Barrow. *Arctic* 24:19-40.
- Martin, P.D. 1983. Bird use of arctic tundra habitats at Canning River delta, Alaska. M.S. Thesis, Univ. of Alaska, Fairbanks. 117 p.
- Merritt, R.W., and K.W. Cummins (eds). 1984. An in-

- roduction to the aquatic insects of North America. 2nd Edition. Kendall/Hunt, Dubuque, Iowa. 722 p.
- Miller, M.C., R.T. Prentki, and R.J. Barsdate. 1980. Physics. Pg. 51–75. In: J.E. Hobbie (ed). Limnology of tundra ponds, Barrow, Alaska. VS/IBP Synthesis Ser. 13. Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania.
- Murphy, S.M., B.A. Anderson, C.L. Cranor, and M.T. Jorgenson. 1989. Lisburne terrestrial monitoring program—1988. The effects of the Lisburne Project on geese and swans. Report to ARCO Alaska, Inc., Anchorage, by Alaska Biological Research, Fairbanks.
- Nelson, J.W., and J.A. Kadlec. 1984. A conceptual approach to relating habitat structure and macroinvertebrate production in freshwater wetlands. Trans. N. A. Wildl. and Nat. Res. Conf. 49:262–270.
- Patterson, J.H. 1976. The role of environmental heterogeneity in the regulation of duck populations. J. Wildl. Manage. 40:22–32.
- Pequegnat, W.E., B.J. Gallaway, and T.D. Wright. 1990. Revised procedural guide for designation surveys of ocean dredged material disposal sites. Tech. Rept. D-90-8, U.S. Army Engineer Waterways Exp. Station, Vicksburg, Mississippi. 262 p. + Appendices.
- Pinder, L.C.V. 1986. Biology of freshwater chironomidae. Annu. Rev. of Entomol. 3: 1–23.
- Pollard, R.H., R. Rodrigues, and R.C. Wilkinson. 1990. Wildlife use of disturbed habitats in arctic Alaska: 1989 final report. Report to BP Exploration (Alaska) Inc., Anchorage, by LGL Alaska Research Associates, Inc., Anchorage. 111 p. + Appendices.
- Prentki, R.T., M.C. Miller, R.J. Barsdate, V. Alexander, J. Kelley, and P. Coyne. 1980. Chemistry. Pg. 76–178. In: J.E. Hobbie (ed). Limnology of tundra ponds, Barrow, Alaska. VS/IBP Synthesis Ser. 13. Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania.
- Root, R.B. 1967. The niche exploitation pattern of the blue-gray gnatcatcher. Ecol. 37:317–350.
- Rosenberg, D.M., H.V. Danks, and D.M. Lehmkuhl. 1986. Importance of insects in environmental impact assessment. Environ. Manage. 10:773–783.
- Rossiter, J.A., and R.D. Crawford. 1983. Evaluation of artificial wetlands in North Dakota: recommendations for future design and construction. In: Wetlands, floodplains, erosion, and storm water pumping. Transportation Research Record 948, Natl. Acad. of Sc., Washington, D.C.
- Rumble, M.A. 1989. Surface mine impoundments as wildlife and fish habitat. General Technical Report RM-183. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 6 p.
- Rumble, M.A., and L.D. Flake. 1983. Management considerations to enhance use of stock ponds by waterfowl broods. J. Range Manage. 36:691–694.
- Rundle, W.D., and L.H. Fredrickson. 1981. Managing seasonally flooded impoundments for migrant rails and shorebirds. Wildl. Soc. Bull. 9:80–87.
- Ruwaldt, J.J., Jr., L.D. Flake, and J.M. Gates. 1979. Waterfowl pair use of natural and man-made wetlands in South Dakota. J. Wildl. Manage. 43:375–383.
- Senner, R.G.B. 1989. Effects of petroleum operations in Alaskan wetlands. Report to ARCO Alaska, Inc., and BP Exploration (Alaska) Inc., Anchorage, by Robert Senner and Company, Anchorage, Alaska. 138 p.
- Serie, J.R., and G.A. Swanson. 1976. Feeding ecology of breeding gadwalls on saline wetlands. J. Wildl. Manage. 40:69–81.
- Sugden, L.G. 1973. Feeding ecology of pintail, gadwall, American widgeon and lesser scaup ducklings. Can. Wildl. Serv. Rep. Ser. 24. 44 p.
- Swanson, G.A., G.L. Krapu, and J.R. Serie. 1979. Foods of laying female dabbling ducks on the breeding grounds. Pg. 47–57. In: T.A. Bookhout (ed). Waterfowl and wetlands: an integrated review. Proceedings of 39th Midwest Fish and Wildl. Conf., Madison, Wisconsin.
- Taylor, E.J. 1986. Foods and foraging ecology of Oldsquaws (*Clangula hyemalis* L.) on the Arctic Coastal Plain of Alaska. M.S. Thesis, Univ. of Alaska, Fairbanks. 130 p.
- Troy, D.M. 1982. Prudhoe Bay Waterflood Project: tundra bird monitoring program. Report by LGL Alaska Research Associates, Inc., Anchorage.
- Troy, D.M. 1983. Prudhoe Bay Waterflood Project: tundra bird monitoring program 1982. Report by LGL Alaska Research Associates, Inc., Anchorage.
- Troy, D.M. 1985. Prudhoe Bay Waterflood environmental monitoring project. Report to

- Envirosphere Company, Anchorage, by LGL Alaska Research Associates, Inc., Anchorage, Alaska.
- Truett, J.C., and K. Kertell. 1989. Effects of habitat disturbance on arctic wildlife: a review and analysis. Report to BP Exploration (Alaska) Inc., Anchorage, by LGL Alaska Research Associates, Inc., Anchorage.
- Truett, J.C., and K. Kertell. 1992. Tundra disturbance and ecosystem production: implications for impact assessment. *Environ. Manage.* 16(3).
- Uresk, D.W., and K. Severson. 1988. Waterfowl and shorebird use of surface-mined and livestock water impoundments on the Northern Great Plains. *Great Basin Nat.* 48:353-357.
- Van Horne, B. 1983. Density as a misleading indicator of habitat quality. *J. Wildl. Manage.* 47:893-901.
- Verner, J. 1984. The guild concept applied to management of bird populations. *Environ. Manage.* 8:1-14.
- Walker, D.A., P.J. Webber, K.R. Everett, and J. Brown. 1980. Geobotanical atlas of the Prudhoe Bay region, Alaska. CRREL Report No. 80-14. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. 73 p.
- Walker, D.A., E.F. Binnian, N.D. Lederer, E. A. Nordstrand, M.D. Walker, and P.J. Webber. 1986. Cumulative landscape impacts in the Prudhoe Bay Oil Field, 1949-1983. Final report to USDI Fish & Wildl. Serv., Habitat Resources Section, Anchorage, Alaska, by Inst. of Arctic and Alpine Res., Univ. of Colorado, Boulder.
- Walker, D.A., P.J. Webber, E.F. Binnian, K.R. Everett, N.D. Lederer, E.A. Nordstrand, and M.D. Walker. 1987. Cumulative impacts of oil fields on northern Alaskan landscapes. *Science* 238:757-761.
- Weller, M.W. 1988. Issues and approaches in assessing cumulative impacts on waterbird habitat in wetlands. *Environ. Manage.* 12:695-701.
- Weller, M.W. 1990. Waterfowl management techniques for wetland enhancement, restoration, and creation useful in mitigation procedures. Pg. 517-528. In: J.A. Kusler, and M.E. Kentula (eds). *Wetland creation and restoration: the status of the science*. Island Press, Washington, D. C. 594 p.
- Wetzel, R.G. 1983. *Limnology*. Saunders College Publishing, Philadelphia, Pennsylvania.
- Whitman, W.R. 1976. Impoundments for waterfowl. Canadian Wildl. Serv., Occ. Paper Number 22.