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Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

Volume 23

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OUTER CONTINENTAL SHELF
ENVIRONMENTAL ASSESSMENT PROGRAM

FINAL REPORTS OF PRINCIPAL INVESTIGATORS

VOLUME 23

OCTOBER 1984

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE
OFFICE OF OCEANOGRAPHY AND MARINE ASSESSMENT
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Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

VOLUME 23 OCTOBER 1984

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SELECTED ECOLOGICAL STUDIES ON CONTINENTAL SHELF BENTHOS AND SEA ICE FAUNA IN THE SOUTHWESTERN BEAUFORT SEA

by

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with

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Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 6

31 May 1984

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A. Objectives

The research undertaken for OCSEAP and reported here covers two main scientific areas: (1) the trends in benthic fauna community structure with increasing depth and distance from shore and (2) the structure and dynamics of the nearshore sea ice faunal assemblage and its relationship to the benthos and zooplankton. Additional objectives include the characterization of organic flux to the sediments beneath the sea ice and the submittal of appropriate voucher specimens to the California Academy of Sciences.

B. Conclusions

Major components of the invertebrate fauna have been analyzed for cross-continental shelf trends in distribution, taxonomic composition, species richness and abundance. The macrobenthos (>1.0 mm) and megabenthos (>1.3 cm) exhibit opposite patterns in numerical density seaward of 5 m depth. The macrofauna are most abundant nearshore, while the megafauna are most numerous at the shelf edge and the upper part of the continental slope. The macrofaunal biomass peaks on the upper slope. The major components of the increased densities and biomass are polychaete worms, mainly Minuspio cirrifera for the macrofauna, and several species of ophiuroids for the megafauna. Species richness for five 0.1 m^2 grab samples for the polychaete worms and bivalve molluscs is maximum on the inner shelf. Species richness and total numerical density of polychaetes are high in shallow water in contrast to temperate open coastal environments. The low wave turbulence which is the result of damping effects of sea ice is suggested as the cause. The numerical density and biomass of the macro- and megafauna of the SW Beaufort Sea are similar to those found in rich environments in temperate environments.

As a number of the amphipods are abundant in coastal waters and are prominent members of the prey consumed by arctic cod and many fishes, this segment of the Beaufort food web is probably an important part of the food chain of key species of fish, birds and mammals. Assessments of this community provide a foundation upon which to base industrial decisions that impinge on the Beaufort Sea environment.

The flux of organic carbon to the shallow inner continental shelf communities is sufficiently high to provide an early source of newly-fixed carbon. The flux rates remain high throughout the spring period. Fecal pellets, particularly from the ice amphipod Pseudalibrotus (=Onisimus) litoralis, consist almost entirely of ice diatom fragments. Though several large particles can be identified and flux rates estimated, much of the organic material is of an unidentifiable detrital nature.

The benthic macrofauna is distributed roughly into a nearshore group (5-15 m depth) and a more widely spread shelf group of species. There are also outer shelf species at the edge of the continental shelf at depths of 70 to 100 meters. A study of the patterns of numerical densities of dominant species demonstrates that most broadly distributed species of bivalve molluscs, gammarid amphipods and polychaete worms have an optimum depth zone within which they are markedly more abundant. A number of species exhibit a bimodel pattern in abundance with the minimum centered at the region of the sea ice shear zone indicating that the ice gouging itself or secondary effects arising from this process causes a detrimental environmental stress.

The sea ice algal community appears to be an important source of carbon to the Beaufort Sea food web. Studies on the fauna associated with the undersurface of the sea ice during the spring months indicate that both meiofauna (63 µm-500 µm) and macrofauna (>500 µm) are present. In shallow oceanic waters, the meiofaunal groups increase significantly in numbers during May-June while benthic species of amphipods are twice as abundant at the ice-water interface as on the sediments. Evidence indicates these animals are grazing on the pennate diatoms growing there.

Although the density of meiofauna within the ice is low compared to that typically found in sediments, it is much higher than had previously been reported from sea ice. Nematodes are the numerically dominant group, but copepods and turbellarians are also abundant. The life-histories of the two most numerous copepods have been examined and found to be very different. Cyclopina gracilis appears to reproduce continuously during the study, while Harpacticus sp. mates in the ice but does not appear to undergo a complete reproductive cycle there. An experiment was carried out to test the hypothesis that pelagic organisms prey on ice fauna, but the results are inconclusive.

C. Implications

Extensive exploratory and production drilling for petroleum on the Alaskan and Canadian continental shelf has the potential to significantly influence the marine benthic environment and its associated biota. Although it is not possible to accurately predict the specific consequences of oil and gas development on the invertebrate species and the benthic food web, the addition of descriptive baseline data on species distribution, composition and abundance now permits refined estimates of the variability occurring within the benthic community through both space and time. It is these estimates which are necessary in sorting out the naturally-occurring changes in the biota from those induced by the future development of the petroleum industry.

The benthos of the Beaufort Sea continental shelf represents large concentrations of biomass that are potential food for many predatory organisms. As the benthic food web leads to many critical marine vertebrate species and to man, a determination of the distributional ecology and of biological rates is necessary for an understanding and modelling of the food webs of the sensitive species. Though environmental assessment decisions based on biological concerns may be made primarily on the species critical to man's food supply or to the environmentally concerned public, the benthos must also be considered in their role as a food source for many of these species. The distribution and abundance of benthic invertebrate prey may well affect the distribution, abundance, reproductive rates, growth rate and mortality rate of the critical vertebrate predators.

Biological rates dictate how much biomass is produced and, therefore, how much food will be available to predators. So little is known about the basic biology of marine organisms in the Arctic that static data based only on standing stocks does not reveal the level of available food supply. Large standing stocks of benthos could be comprised of old, slowly growing and slowly reproducing species. The time-series of benthic macrofaunal samples taken across the continental shelf along the standard OCS Pitt Point Transect now provides excellent material with which to explore some of these problems pertinent to the benthic food web. By determining the recruitment pattern of dominant species of a number of taxonomic groups across the shelf, estimates can be made of the reproductive rate of these species populations. Analyses of growth and mortality rates provide data on the biological activity and secondary production rates of dominant species. For instance, such analyses of gammarid amphipods that are known to be primary food sources for arctic cod yield basic data on the food supply to that fish under Beaufort Sea conditions.

The work on the epontic community has been a necessary step in understanding the role of the benthos in the arctic ecosystem. The degree of linkage between the under-ice and sedimentary communities has been examined to determine potential energy pathways and possible reproductive cues to the underlying benthic communities. The gammarid amphipods, the dominant members of the ice macrofauna, are important sources of food for arctic cod and other critical species, and these analyses add to our understanding of repopulation rates for benthic communities decimated by predators or by pollution events.

II. INTRODUCTION

A. General Nature and Scope of Study

Fundamental questions in the field of marine benthic ecology continue to involve causes for the spatial and temporal patterns of the distributions and abundance of species and species groups. While answers lie in both the processes involved with species interactions and in species-environmental relationships, correlative studies of species distributions and abundances along environmental gradients are a basic step in the initiation of such research. Insight into the relative importance of environmental and biological interactions can be obtained by contrasting similar data from differing environments and ecosystems.

Many such distributional studies have been undertaken in temperate waters, and sediment type, temperatures, depth, food input, currents and other environmental features have been implicated as basic physical and chemical influences on benthic ecological patterns in particular regions. However, there are few results reported in the literature contrasting data from markedly different environments that allow an evaluation of the relative importance of various aspects of the benthic environment. Over the last decade the benthic macrofauna has been studied extensively and aspects of the taxonomic composition and abundance are fairly well known in the southern Beaufort Sea (MacGinitie, 1955; Carey et al., 1974; Wacasey, 1974; Carey and Ruff, 1977; Bilyard and Carey, 1980). However trends in the benthos from the coastal zone to the deep-sea or of size classes other than the macrofauna are generally lacking. Trends in the abundance and species richness of the benthic macrofauna (1.0-13 mm) and megafauna (>1.3 cm) across a broad spectrum of bottom environments can provide insight into species environmental interactions.

The ability to predict benthic faunal distribution and abundance patterns provides a useful approach to estimating potential pollution problems associated with oil exploration and production on the Alaskan continental shelf. These patterns assume different scales depending on the size of animals, the degree of environmental disturbance, and the patchiness of the environment. Therefore, when possible the organisms from the width of the size spectrum should be studied for determination of ecological patterns for the community.

Benthic ecological studies on the Beaufort Sea continental shelf have included functional process-oriented research that is built upon an accumulated base of descriptive information on the invertebrate organisms and environmental measurements. Changes in the numerical abundance and biomass of the macrobenthos (1.0-13 mm) and megabenthos (>13 mm) have been examined at stations across the shelf. Research on the interrelationships between the underice epontic community and the associated sedimentary biota has been undertaken.

Concentrated study of the Beaufort Sea continental shelf benthic invertebrates was not initiated until the early 1970's. As very little was known about the fauna at the beginning of the exploration and developmental phases of the petroleum fields on the Alaskan North Slope, the early research involved basic survey work on the 1971 and 1972 US Coast Guard oceanographic cruises (WEBSEC-71 and WEBSEC-72). Detailed analysis of benthic communities and identification of the total polychaete worm fauna over a wide range of depths was accomplished. Further continental shelf survey sampling was then continued under the OCSEAP with the cooperation of the Coast Guard and their Beaufort Sea icebreaker program. With NOAA's interest and logistics support, seasonal sampling and study of temporal changes in the continental shelf communities was accomplished for the first time.

During the first year of operation a major objective was the summarization of literature and unpublished data pertinent to the Beaufort Sea. A significant amount of this information came from the work-up of the samples and the analysis of the data already on hand at Oregon State University as a result of the WEBSEC investigations. The objectives under the present research contract emphasize the delineation of the benthic food web and the description of the coastal benthos.

Much of the Beaufort Sea fauna has now been characterized at the species level, and detailed studies on temporal changes in the continental shelf benthic communities are underway.

Research has been undertaken in cooperation with other scientists which is oriented toward understanding the processes that maintain the nearshore and lagoonal ecosystems. Of particular interest is the source of carbon that fuels the heterotrophic organisms living within the system. In lower latitude oceanic waters most of the carbon fixed by photosynthesis is ultimately derived from the phytoplankton, but in coastal waters much of the organic material may be land-derived. Water acts as a three-dimensional reservoir and transporter of organic carbon through a complex cycle that involves the interactions of numerous marine organisms. The benthos as an ecological group depend to a large extent on detritus that falls down to them. In the ice-covered waters of the Arctic, the epontic diatoms on the undersurface of the sea ice are an added source of carbon to the system (Horner, 1976), and in shoal waters benthic algae add to the primary production (Matheke and Horner, 1974).

The underice diatom bloom has been documented in coastal waters in the Chukchi Sea off Barrow, Alaska (Horner and Alexander, 1972), in the Eskimo Lakes region (Grainger, 1975), and in Stefansson Lagoon (Horner and Schrader, 1982). Though its areal extent either in coastal waters or offshore over the continental shelf is not known, it has been suggested that these epontic diatoms could be an important energy source within the southern Beaufort Sea ecosystem (Clasby et al., 1973). It is most pertinent to note that Schell (RU #537) recently measured substantial concentrations of chlorophyll on the undersurface of Beaufort Sea ice to a distance of 100 n.m. offshore (Schell, personal communication). The existence of the algal epontic community in oceanic waters suggests that primary production in this community is indeed energetically important to the total Beaufort Sea ecosystem. Although no direct measurements have been made, the pennate diatoms may fall to the sea floor upon ice melt in June (Matheke and Horner, 1974) thus providing a supplementary route for organic carbon to reach the benthos.

Numerous organisms have been sampled in association with the ice-sea water interface as the diatom bloom progresses through the months of April, May and June. Nematode worms are the most abundant, but harpacticoid copepods, amphipods and polychaete larvae have also been observed on the underice surface. The coastal amphipod Onisimus affinis, an important member of the demersal fish food chain, has been reported as migrating up to epontic community presumably to feed (Percy, 1975). Although the degree of linkage between the underice epontic community and the benthic community beneath is not known, it has been hypothesized that the sinking of detritus and diatom cells could provide a sizeable downward organic input to the underlying benthos. The vertical migration of benthic fauna up to the ice undersurface could provide these invertebrates with a significant source of energy-rich organics.

B. Specific Objectives

1. Analysis of the cross-shelf trends in the large macrofauna (>1.0 mm) and the megafauna (>1.3 cm) offshore of Harrison Bay.
    a. Determination of the patterns of distribution, numerical density, biomass and feeding type of the benthic invertebrate fauna across the Alaskan arctic continental shelf.
    b. Comparison of the ecological patterns of the arctic macrofauna (>1.0 mm) with those of the mega-epifauna (>1.3 cm) .
    c. Comparison of the ecological patterns of the arctic benthos with those from temperate regions.
    d. Evaluation of the controlling features of the arctic benthic environment.

2. Time-series laboratory studies on the meiofaunal (>63 μm) samples and large macrofaunal (>1.0 mm) samples from seasonal sea ice off Narwhal Island (1980).
   a. Definition of the species composition and abundance of the ice meiofaunal community for the period 1 April through 10 June 1980.
   b. Determination of the life histories of dominant ice harpacticoid and cyclopoid copepods for the period of study, April through 10 June 1980.
   c. Description of the temporal changes in the ice macrofauna.
3. Analysis of organic particles collected at the benthic boundary during the 1980 sea ice faunal studies.
   a. Identification and quantification of the particles.
   b. Determination of the total flux of mass, carbon and nitrogen for the particle trap experiments.
4. Provide the California Academy of Science with a well-labelled, representative collection of benthic invertebrate species.

C. Relevance to Problems Associated with Petroleum Development

1. Cross-shelf Trends

Extensive exploratory and production drilling for petroleum on the Alaskan and Canadian continental shelf has the potential to significantly influence the marine benthic environment and its associated biota. Although it is not possible to accurately predict the specific consequences of oil and gas development on the invertebrate species and the benthic food web, the addition of descriptive baseline data on species distribution, composition and abundance now permits refined estimates of the variability occurring within the benthic community through both space and time. It is these estimates which are necessary in sorting out the naturally-occurring changes in the biota from those induced by the future development of the petroleum industry.

Detrimental impact on the marine environment and its associated biota is a major concern in offshore petroleum exploration and production. Potential environmental problems are very real in the southern Arctic Ocean (Beaufort Sea) where initial discoveries indicate significant oil concentrations under the inner continental shelf. The immense forces of the moving pack ice and the extremely cold temperatures accentuate the dangers of acute and chronic oil spills. These potential impacts cannot be sufficiently evaluated until the roles of various biological production processes in the polar ecosystem are known.

The benthos concentrated at the lower boundary of the oceans represents a potential source of food in the Beaufort Sea for a range of predators. Large standing stocks of benthic biota are found at the edge of the continental shelf (Carey and Ruff, 1977). Though many aspects of the benthic food web are unknown it is evident that the epibentic crustaceans on the inner shelf are a segment of the benthic community that are pivotal in the food web leading to critical marine vertebrate species and to man (Griffiths and Dillinger, 1981). As the numerical density and standing stocks of organisms are the resultant of many biological processes, the determination of biological rates is also mandatory for a realistic energetic model of an ecosystem. Furthermore, the benthic food web may indirectly as well as directly influence the secondary production of marine animal species that are important to man. It is likely that the distribution and abundance of some of these critical species are influenced by the distribution and abundance of benthic prey species. Ultimately growth and mortality rates control biological secondary production rates of the dominant species. Such analyses of gammarid amphipods that are known to be primary food sources for arctic cod can yield basic data on the food supply to that fish under Beaufort Sea conditions.

Life history information is relevant to management decisions concerned with environmental disturbance and the repopulation rates of the benthic communities in disturbed areas. If the nearshore fauna is reproductively already adapted to frequent environmental disturbance caused by storm wave turbulence or by ice gouging, an area subjected to an oil spill or other man-caused event might be expected to repopulate rapidly. Major changes in the benthic communities associated with a pollution event may therefore be found to fall within the limits of natural variability for these invertebrate populations.

2. Ice Fauna

Research on the underice epontic community in the Beaufort Sea has great relevance to environmental assessment decisions before, during and after exploratory and production phases of petroleum development. This potentially significant source of plant production and possible significant portion of the marine food web is open to large-scale and direct degradation by any under-ice oil spill. Specifically, it is evident from our 1980 spring studies seaward of Narwhal Island at a water depth of 9 meters that vagile benthic crustaceans such as the gammarid amphipod Pseudalibrotus litoralis swim up to the ice algal layer for grazing. Epibenthic crustaceans such as the gammarids are an important source of food for the young arctic cod (Sekerak, unpublished manuscript). It has been suggested by many authors (Clasby et al., 1973; Horner, 1976; Hameedi, 1978) that there is a downward flux of ice diatoms and detritus that provides food for the benthic fauna below. Indications point to a productive under-ice diatom community (Clasby et al., 1973; Horner, 1976; Dunbar and Acreman, 1980) that is widespread (Schell, personal communication) in Beaufort Sea waters and that may be a major link in the food web of many species of marine vertebrates and of man. Assessments of this community provide a foundation upon which to base industrial decisions that impinge on the Beaufort Sea environment.

In the hazardous arctic environment an oil well blowout or subsea pipeline rupture by a grounded ice ridge during the nine month ice-covered season could endanger the local ice biotic community and its associated food web. As the food web extends to marine mammals, birds and other top predators in the Beaufort Sea, the ramifications of detrimental pollution at the ice-water interface are essential to consider. Knowledge of the structure, function and ecology of the sea ice biotic community will aid in estimating possible damage and in developing techniques and technology to diminish such problems.

3. Particle flux

The falling of large particles provides the major mechanism for significant fluxes of organic materials, sediments, elements and contaminants. Large particle fluxes are significant in shallow waters in the Arctic (Carey, unpublished; Pett et al., 1983) and in temperate waters (Smetacek, 1980) and even to deep-sea depths (Honjo and Roman, 1978; McCave, 1975). Pollutants incorporated in, or adsorbed to, large particles could be rapidly transported to the sea floor and to the associated benthic communities. As amphipod and mysid crustaceans and other epibenthos are integral links in the arctic food web (Griffiths and Dillinger, 1981), oil spills and other man-caused pollution could be transported to the benthic food web via large particles. This is particularly likely for the particle link between the underice biotic community and the benthos beneath in shallow water. Pipeline ruptures and oil well blowouts during the ice-covered periods of the year would concentrate under the ice and be susceptible to bio-transport to the bottom during the growth phases of the ice community in the latter parts of the arctic spring.

D. Acknowledgements

The results included in this final report for RU #006 (NOAA/BLM Contract no. NA81RAC00061) represent the work of many in the field and laboratory. The results are derived from the 1976 R/V ALUMIAK, 1976-1977 USCGC GLACIER, and 1978 USGC NORTHWIND cruises in the SW Beaufort Sea and the 1980 fieldwork at the Narwhal Island ice station off Prudhoe Bay. R. E. Ruff was the mainstay in all phases of research; without him the research could not have been accomplished. On shipboard and at the Narwhal Island Ice Station, P. A. Montagna and P. H. Scott were indispensable during field operations. J. C. Kern and K. R. Walters worked hard and long at the ice station and OCSEAP Prudhoe Bay field lab. SCUBA diving services were provided by G. F. Smith of Coastal Environmental, Bellingham, Washington; J. Dougherty and R. Poirot undertook the long and strenuous dives for the ice fauna projects. K. Persons and S. Petersen provided logistic support at Prudhoe Bay for the project Sea Ice-80. Personnel from RU #359 were also a significant help during the April-June study period at the ice station. The NOAA helicopter pilots and mechanics are to be commended for their fine logistic support to the Narwhal Island Sea Ice-80 station. For shipboard operations we wish to thank the captain of the R/V ALUMIAK and the captains and crew of the USCGC GLACIER and USCGC NORTHWIND.

In the Marine Benthic Ecology Laboratory on the Oregon State University campus many individuals also provided valuable services. M. A. Boudrias, P. A. Montagna, R. E. Ruff, P. H. Scott, J. Trautman and W. Savidge generated the high quality quantitative ecological and taxonomic data; K. R. Walters, J. Gish and E. W. Hogue analyzed and managed the numerous data. R. E. Ruff also was indispensible in data summary, editing and drafting services. The report was typed by P. Wegner and J. Sharpe.

K. H. Dunton provided samples of macro-algae, and G. Heron helped with copepod taxonomy. D. Schneider identified the mysid and amphipod fecal pellets.

III. Current State of Knowledge

A. Benthic Fauna

With the discovery of large oil reserves on the North Slope of Alaska, fundamental ecological studies have provided extensive knowledge since 1971 of the benthic fauna of the southwestern Beaufort Sea. Numerous collections have been made of the littoral and shallow sublittoral fauna by Broad (1977), of the lagoon fauna (Griffiths and Craig, 1979), of shallow nearshore environments (Feder et al., 1976) and offshore environments (Carey, 1981; Frost and Lowry, 1983). This review concentrates on the offshore fauna.

Ecological patterns of distribution and abundance of the benthos have been synthesized as a result of surveys of infauna and epifauna across the southwestern Beaufort Sea continental shelf and slope (Carey, quarterly and annual reports 1976-1981, RU #006). The analysis of the distribution and abundance of the benthic macrofauna species was undertaken to define possible limits and zones of abundance of coastal shelf and outer shelf fauna. The shelf data were compiled from three OCS cruises from the summers of 1976-78 and the slope data from a 1971 WEBSEC cruise and the 1978 OCS cruise. From extensive studies of polychaete worms, gammarid amphipods and bivalve molluscs there are nearshore, outer shelf and upper slope faunal groups (Carey, 1981; Carey et al., 1984). The benthic macrofauna appear to be depressed in the 20-25 m depth range, probably caused by the direct and indirect effects of ice gouging into the bottom sediments. There is a maximum of numerical abundance and biomass of the macrofauna in much of the southwestern Beaufort Sea at the edge of the continental shelf and the upper continental slope (Carey and Ruff, 1977).

The degree of temporal variability of the benthic communities across the shelf is correlated with depth. The fauna at the shelf edge appear to undergo seasonal changes, though many dominant species of macrofauna reproduce at a low rate over a long period of time (Carey, 1981). Over a three-year period, a preliminary analysis of summer abundance of 25 species of bivalve molluscs and 24 species of polychaetous annelids indicates no marked changes in community structure. Rank order of abundance analysis demonstrates changes in the dominant species during the three-year period, but generally the dominant species tend to remain in the top three or four.

B. Ice Fauna

Detailed quantitative studies focused on arctic and subarctic ice fauna have been undertaken only in the last decade. Explorers and scientists on early expeditions to the Arctic observed amphipods and other organisms associated with ice and ice edge environments, but these observations were often incidental and vague (e.g., Nansen, 1906). Early taxonomic works (MacGinitie, 1955) and more recent quantitative and process-oriented studies on ice algae (Apollonio, 1965; Horner, 1977) also noted the types of fauna associated with ice living on the ice undersurface. Research on these faunal assemblages was first undertaken in the Arctic during the summer and fall of 1970 and 1973 by Golikov and Averincev (1977) along the coasts of Heve Island, Alexandra Land, Rudolph Island and Victoria Island in the Franz Josef Land Archipelago in the Barents Sea. This extensive work utilized SCUBA diving to study the benthic and ice faunal assemblages on the shallow shelf.

Because Russian and Polish scientists were among the early workers in Antarctic ice faunal research (Gruzov et al., 1968; Rakusa-Suszczewski, 1972), it is not surprising that they also pioneered ice faunal research in the Arctic. Research on ice fauna began in Canadian and US waters in 1979 when Cross (1982) and Bradstreet and Cross (1982) undertook extensive studies of the marine ecosystem in Pond Inlet, Baffin Bay in the eastern Canadian Arctic. In 1979 Carey and Montagna (1982) also initiated ice faunal research in Stefansson Sound near Prudhoe Bay, Alaska in the southern Beaufort Sea. Additional research was undertaken on the inner shelf seaward of Narwhal Island in the Prudhoe Bay region of Alaska (Kern and Carey, 1983; Carey, 1982; Boudrias and Carey, unpublished). Research on the animals associated with the undersurface of sea ice has continued in McKinley Bay on the Tuktoyaktuk Peninsula, southeastern Beaufort Sea (Pett et al., 1983), in Frobisher Bay 1979-1981 (Grainger and Hsiao, 1982) and at the pack ice edge in the Barents Sea (Gulliksen, in press). A more southern study was undertaken by Dunbar and Acreman (1980) in the Gulf of St. Lawrence; though the research was oriented toward the ice algae, observations were also made on the fauna. Dunbar had worked on arctic and subarctic zooplankton earlier and had summarized data on amphipod species known to associate with the sympagic environment (Dunbar, 1946, 1964).

Some of the earliest observations on animals associated with sea ice came from MacGinitie's extensive year-round systematic and natural history research on marine invertebrates in the Point Barrow, Alaska region from 1948 to 1950 (MacGinitie, 1955). He reported that numerous amphipods (Apherusa glacialis) lived under ice floes during the summer months in the northeast Chukchi Sea in the vicinity of the US Naval Arctic Research Station.

Other early observations on ice fauna came from workers involved in the multidisciplinary research conducted on the floating ice island research station T-3 (Mohr and Tibbs, 1963; Barnard, 1959) and from ice algal studies. Barnard (1959) reported on numerous amphipods captured beneath pack ice adjacent to the ice island by baited traps, but no direct observations were made on their in situ behavior and ecology at the ice undersurface. Data were not available from these early studies on absolute abundance, feeding behavior or thigmotactic affects of ice. Apollonio (1965) observed abundant gammarid amphipods that were "undoubtedly feeding on algae" while he was making collections on the ice undersurface near Devon Island in the Canadian Arctic for determinations of chlorophyll concentrations. Horner and Alexander (1972), Clasby et al. (1976) and Horner (1977) reported flagellates, heliozoans, hypotrichous ciliates, abundant nematodes, polychaete larvae, turbellarians, harpacticoid copepods and amphipods as part of the ice community. The amphipods were observed living on the undersurface of nearshore ice, and it was noted that their fecal pellets contained fragments of ice diatoms.

Once SCUBA diving in polar ice-covered waters was proven to be feasible (Peckham, 1964), quantitative studies on the structure and function of the sea ice communities became possible. The scientific field rapidly developed (Gruzov et al., 1968; Clasby et al., 1973) as the use of this diving technology permitted direct observation, quantitative sampling, and in situ experimentation. A number of specialized sampling devices have been utilized to sample the ice under-surface from above through holes augered in the ice (Gruzov et al., 1968; Rakusa-Suszczewski, 1972; Grainger and Hsiao, 1982). However, the ice-water interface consists of soft ice and fragile open crystalline structures (Kovacs and Mellor, 1974) that often cannot be effectively sampled or studied from above with standard coring devices (Clasby et al., 1973). The study of the arctic ice faunal community has developed so rapidly that much of the information collected remains unpublished and is available only in a variety of data reports, particularly those recently compiled for environmental impact assessment research oriented toward the oil industry for their oil exploration in offshore waters.

The true ice macrofauna (>0.5 mm) is almost entirely composed of gammarid amphipods (Griffiths and Dillinger, 1981; Carey, 1982). There appear to be four main macrofaunal sympagic communities: (1) the protected lagoon/bay fast ice community dominated by Gammaracanthus loricatus, (2) the shallow coastal fast ice community dominated by Pseudalibrotus litoralis, (3) the deeper seasonal sea ice zone fast ice community dominated by Apherusa glacialis, and (4) the old ice community dominated by Apherusa glacialis and Gammarus wilkitzkii.

The Apherusa community over deeper water contains larger numbers of amphipod individuals. The shallow fast ice sympagic community in the Beaufort Sea had a mean of 10.4 amphipods per m^2 (Carey, 1982; Boudrias and Carey, unpublished). The deeper fast ice community had a mean of 30.9 amphipod individuals per m^2 in the Canadian Arctic (Cross, 1982). In the old ice community characterized by the amphipod species *Apherusa glacialis* and *Gammarus wilkitzkii* and studied in the Barents Sea by Gulliksen (in press), both numbers and biomass of the ice amphipods decreased significantly from the ice edge into the pack ice.

Both permanent and temporary meiofaunal organisms in the size range 63-500 µm occur within the lower layers of the sea ice habitat. Meioplanktonic larvae of benthic polychaetes, pelecypods, gastropods, tunicates, turbellarians and cirripedes have been reported within the lower sea ice in the Arctic Basin (Grainger and Hsiao, 1982; Horner, 1977; Pett et al., 1983). Pett et al. (1983) reported spinoid polychaete larvae in the Canadian Beaufort Sea ice. Carey and Montagna (1982) found hesionid polychaete larvae in Beaufort Sea ice, including nectochaete larval stages that are probably capable of feeding on diatoms. Blake (1975) found that the juveniles of a similar hesionid species fed upon diatoms in the laboratory.

Permanent meiofauna including nematodes, harpacticoid and cyclopoid copepods, calanoid copepods, and rotifers have been reported as members of the sympagic community (Pett et al., 1983; Carey and Montagna, 1982; Kern and Carey, 1983; Cross, 1982). These organisms often occur in large numbers in most environments except in the ice in protected lagoons where the environment is highly variable (Carey and Montagna, 1982). In Stefansson Sound meiofaunal densities ranged from 4,500 to 8,000 m^{-2}, whereas offshore in the fast ice the range was 36,000-320,000 m^{-2} (Kern and Carey, 1983).

Nematodes are the dominant members of the ice meiofauna. In Pond Inlet, Baffin Bay, nematode worms accounted for 58.8% of the meiofauna (<1.0 mm) by number (Cross, 1982). In the shallow Beaufort Sea their numerical density exhibited an increase through the spring of 1980, and they ranged from 3,590 m^{-2} in April to 62,360 m^{-2} in June. Nematodes averaged 47.0% of the meiofauna during the study (Kern and Carey, 1983). There is little information available on the biology and ecology of the sympagic Nematoda. The strong trend in increasing population size through the spring suggests that these organisms are viable components of the ice community.

Copepods, mostly harpacticoids and cyclopoids, were the second most abundant group within the meiofauna in the lower ice environment. In the southern Beaufort Sea, these copepods comprised 28% of the meiofauna population by number (Kern and Carey, 1983), while in the eastern Canadian Arctic, they accounted for 39.7% of the small animals (Cross, 1982).

C. Particle Flux

It has been conjectured that the downward transport of organic detritus, fecal pellets, crustacean molts and pennate diatom cells from the ice undersurface provides a food source for the pelagic and benthic faunas (Alexander, 1980, 1981; Golikov and Scarlato, 1973; Bradstreet and Cross, 1982; Horner and Schrader, 1982; Hameedi, 1978). The organic matter not consumed while sinking through the water column would be available to the benthos as food. The depth of water, the temporal pattern, and the flux rate of detrital sinking would influence the availability of degradable organics to the two faunas (Green, 1976). The supposition has been stated that during the melt season beginning in late May-early June, particles and algae slough off the bottom surface of the ice. In shallow water this sudden flux would provide an impulse of food materials to the sea floor as well as to the water column. In deep water less utilizable organic matter would reach the benthos. If the flux from the sympagic community takes place at a low rate over an extended period of time, more food could be utilized by the zooplankton on its way down to the bottom than if there was a sudden influx from the ice during accelerated ice melt in early summer.

Particles from the sympagic community reach the sea floor in shallow water throughout the winter and spring. In the Canadian Beaufort Sea pennate diatoms from the epontic algal assemblages were captured in near-bottom sediment traps in 6 to 19 m of water on the shelf offshore of the Mackenzie River and in McKinley Bay, a shallow coastal embayment in the ecological transition zone (Pett et al., 1983). Algal cells increased from 4 x 10^6 cells $m^{-2}day^{-1}$ to 28 x 10^6 cells $m^{-2}day^{-1}$ in May-June. However, total particulate flux of carbon and nitrogen does not seem to be affected by the accelerated loss of the ice algal community from the ice undersurface in early June (Pett et al., 1983; Carey, unpublished). The carbon flux to the sediments through a 7 m water column in the southern Beaufort Sea off Narwhal Island varied between 29 and 48 mgC $m^{-2}day^{-1}$ with no significant trends or correlations with environmental events. Nitrogen flux was low, 1.5 to 6.2 mgN $m^{-2}day^{-1}$ and erratic throughout the spring season. Fecal pellets from the grazing sympagic amphipod Pseudalibrotus litoralis contained high concentrations of pennate ice diatom frustules; their flux to the bottom increased from April through May, 1980 and then fell almost to zero in early June. The carbon and nitrogen data indicate that there is no sudden influx of organic materials to the benthic environment during the melting period but rather there is generally a high and continual rain of organic matter to the bottom throughout the spring growing season.

IV. Study Area

As part of the Arctic Ocean, the Beaufort Sea along the Alaskan north slope is subject to extensive ice cover during much of the year. Normally the sea ice melts and is advected seaward in July and August in response to regional wind stresses, but in some years the polar pack can remain adjacent to the coastline throughout the entire season. The extent of ice cover during the sunlit summer months affects wind mixing of surface water and the penetration of light into the water column. These factors affect the onset and intensity of phytoplankton production which is highly variable and generally of low magnitude (Horner, 1976; Clasby et al., 1976). The keels of sea ice pressure ridges cause significant disturbance to the benthic environment by plowing through the bottom sediments as they are transported across the inner shelf by the currents and prevailing winds (Barnes and Reimnitz, 1974; Reimnitz and Barnes, 1974).

Generally, the bottom water masses of the southwestern Beaufort Sea are stable, and except for the shallow coastal zone, differ little in thermohaline characteristics throughout the year (Coachman and Aagaard, 1974). However, the outer shelf region from Point Barrow to about 150°W is influenced by Bering-Chukchi water that is advected as a subsurface layer and moves around Point Barrow throughout the year in pulses controlled in part by atmospheric pressure gradients (Hufford et al., 1977). Coastal upwelling has also been observed in the Barter Island region during a summer when the pack ice had moved relatively far offshore (Mountain, 1974).

A unique habitat exists within the lower layers of polar and subpolar sea ice. The bottom ice layer has been described as being soft (Horner, 1976), or loose (Andriashev, 1968) in composition, in contrast to the hard ice above. It has relatively constant temperatures (-3 to 0°C), enough nutrients to support algal growth, variable osmotic pressure, and a probable abundance of organic material (Meguro et al., 1967). Seasonal ice is generally 2.0 to 2.5 m thick, yet sufficient light of adequate quality passes through it to support photosynthesis within the ice habitat (Maykut and Grenfell, 1975). Multi-year (pack) ice is generally thicker, but the presence of chlorophyll within the lower ice layers (English, 1961) is evidence that photosynthesis also occurs in this ice. Pack ice is present all year, and therefore provides a permanent environment in which ice organisms can survive. Seasonal ice breaks up each year in late spring, so that organisms within the lower layers of this ice exist in an ephemeral habitat. Despite the temporary nature of the seasonal ice environment, an abundance of life can be found there.

During most of the year in oceanic waters, arctic ice generally exists as a mixture of old and new ice. Because of the dynamic forces involved, newly formed thin pack ice can exist adjacent to multi-year ice floes and pressure ridges tens of meters thick (Zubov, 1943). As age and thickness of the ice increase, its crystalline structure, salinity and light transmissivity change. Age and deformation of ice, therefore, are other characteristics necessary for consideration in defining ice habitats.

The specific study areas in the southwestern Beaufort Sea reported upon in the following results sections include: (1) a broad transect line of stations in the vicinity of Harrison Bay, SW Beaufort Sea (Figure 1), and (2) a shallow diving station occupied in the frozen spring months offshore of Narwhal Island (Figure 2). The Pingok Island Cross-Shelf Transect includes a range of environments from the inner continental shelf at 5 m depth to the deep-sea at 1800 m depth on the continental slope. The Narwhal Island Ice Station is an oceanic environment just seaward of the barrier island. It is in the seasonal sea ice zone and is within the depth range directly influenced by sea ice gouging.

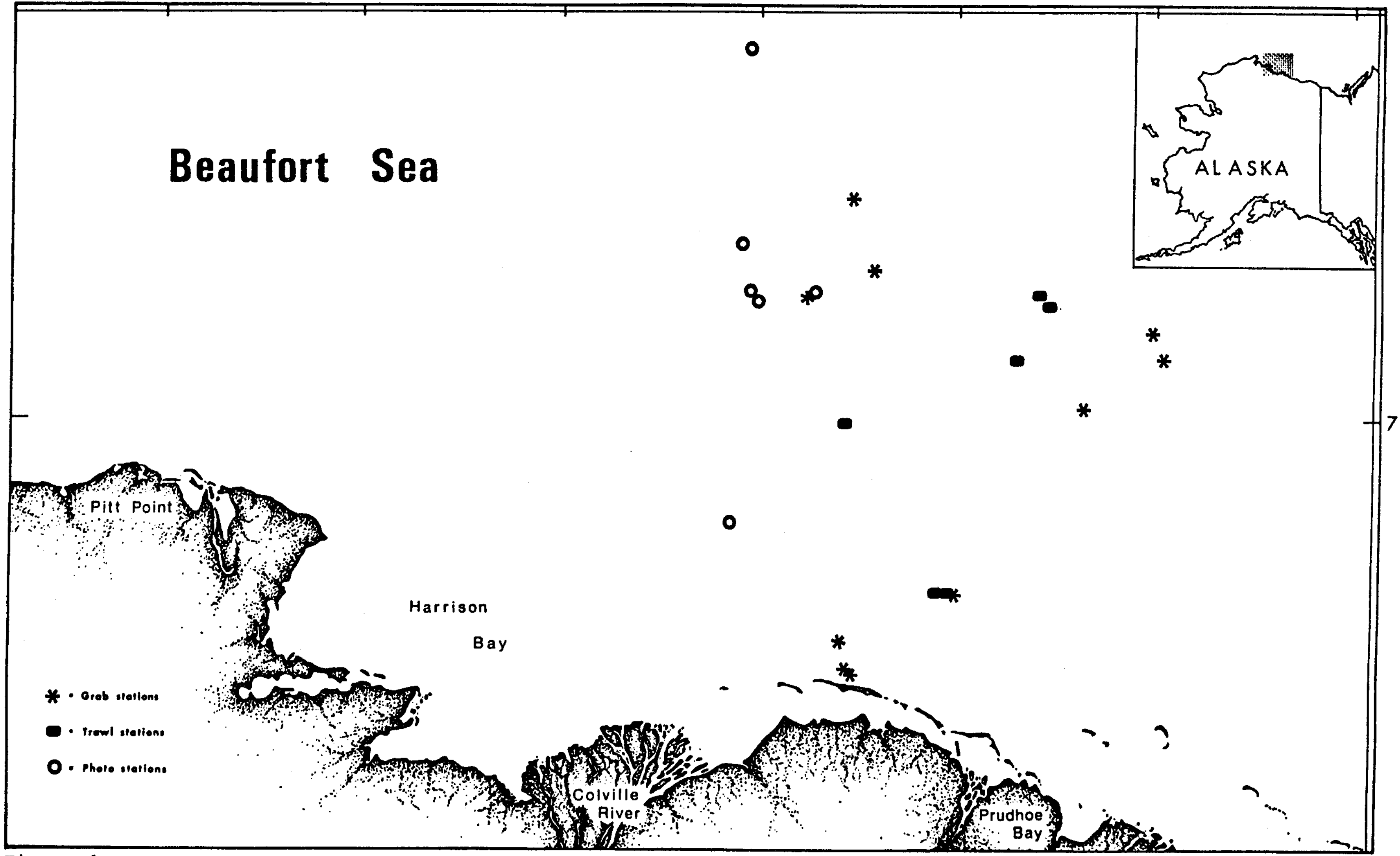

Figure 1. Location map for grab, trawl and photographic stations on the cross-shelf transect in the SW Beaufort Sea.

V. Sources, Rationale and Methods of Data Collection

A. Sources and rationale

1. Benthic continental shelf fauna

There has been a need to define cross-shelf trends of benthic fauna with as complete a description of the community as possible to include major components of the benthic food web. As much data as possible has been put together to synthesize faunal changes along environmental gradients. By combining data from otter trawls, stereo bottom photography and bottom grabs, trends across the shelf in both the macrofauna and megafauna have been synthesized. Without this combined approach data from various depth zones would have been incomplete because of sampling problems caused by sea ice during the summer cruises.

2. Ice fauna (Narwhal Island)

The epontic (sympagic) sea ice faunal community has been examined in detail because of its importance in the Beaufort Sea ecosystem during the spring months. Gammarid amphipods are the major component of the ice macrofauna and these organisms are important prey for the arctic and glacial cod, pivotal higher carnivores in the oceanic food web. The Sea Ice-80 fieldwork off Narwhal Island in conjunction with RU #359 provided an extensive collection of meiofaunal and macrofaunal samples that form the basis of an intensive time series study of the ice, midwater and sea floor fauna.

3. Particle flux

Because the role of the spring ice community in the arctic oceanic ecosystem is unknown, energetic links between the ice subsurface and the sea floor have been investigated. As detailed by such researchers as Honjo (1980) and Suess (1980) large particles account for a significant portion of the downward flux of sediments and organic carbon and nitrogen. Collection of large particles at the benthic boundary beneath the ice by sediment trap at the Narwhal Island ice station provides data to assess the input of detrital carbon and nitrogen to the benthic community.

B. Field and Laboratory Methodology

1. Benthic continental shelf fauna

a. Macrofauna

The macrofauna were collected by 0.1 m^2 Smith-McIntyre bottom grab (Smith and McIntyre, 1954) at 10 stations from 5 to 1800 m depth in a broad transect across the continental shelf and upper continental slope (Appendix I: Table 4). Five quantitative samples were obtained from each station; only those samples with an unwashed appearance and with a minimum of 3.5 liters of sediment were retained for analysis.

Grab samples were washed on board ship through 1.00 and 0.42 mm screens, and the material retained on the sieves preserved in 10% formalin neutralized with sodium borate. Rigorous procedures for field sample collections were maintained during all phases of the project to ensure sample integrity. Field data sheets were completed at the time of collection to record observations on sampling conditions, sample quality, and biological information of note. The samples were routinely double labelled to minimize confusion, and complete field as well as laboratory log books were maintained. Careful preservation techniques were followed for proper fixation of the tissues, and the samples were shifted to 70% ethanol in the laboratory for long-term storage. Sampling adequacy was addressed through accumulation curves for total number of species, absolute number of specimens, and total biomass. Five 0.1 m^2 grab samples now appears to be the minimum number at most shelf depths to adequately describe the benthic macrofaunal species composition.

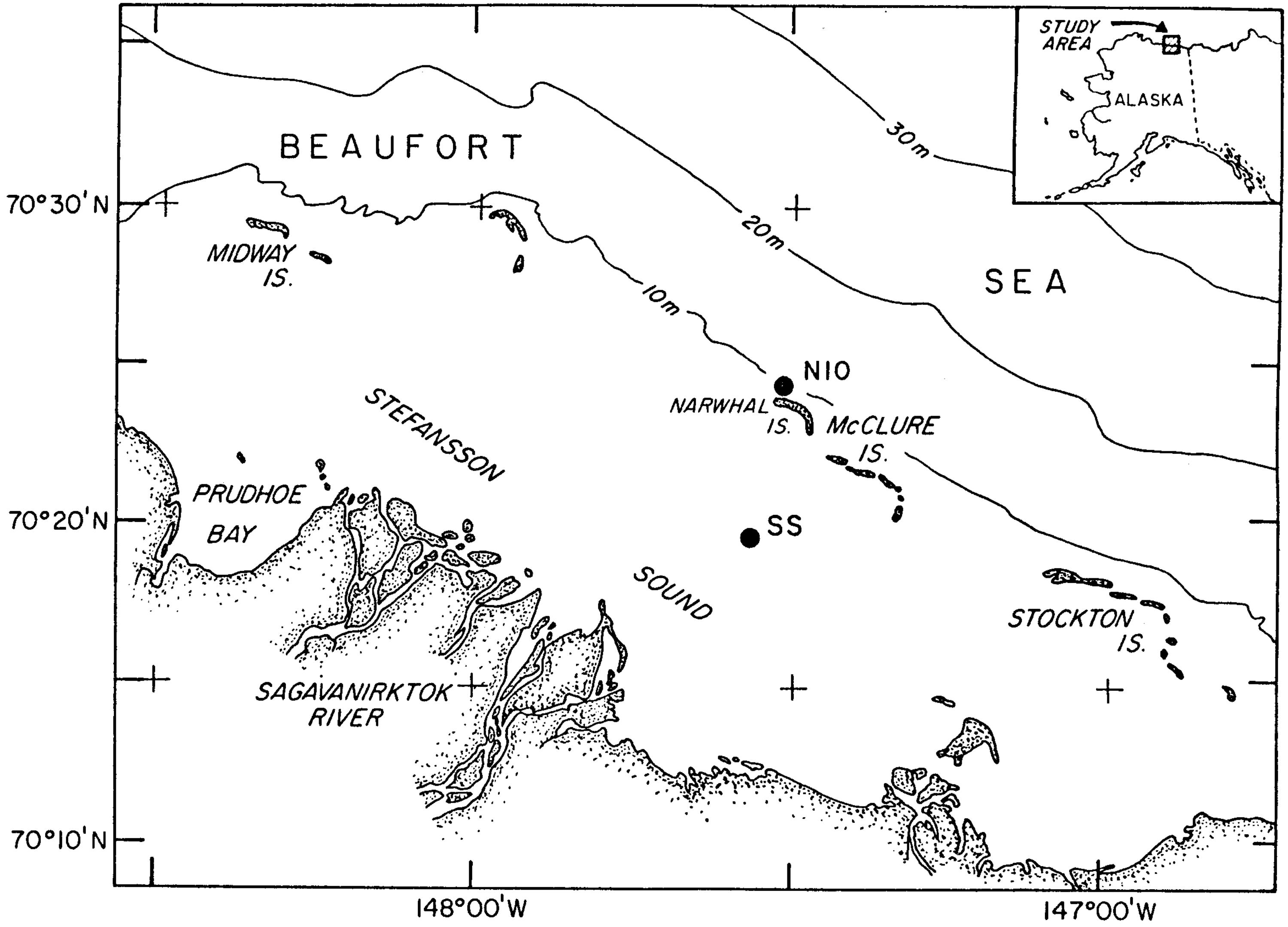

Figure 2. Location map for the Narwhal Island ice station (NIO) for Project Sea Ice-80. Station SS designates the location of the 1979 pilot study on ice fauna at the Boulder Patch.

Standard analytical methods were employed to process the Smith-McIntyre grab samples in the laboratory. The quantitative samples were sieved into two fractions, including the large macro-infauna (>1.00 mm) and the smaller macro-infauna (0.5-1.00 mm). The organisms in the larger fraction were picked from the sediment particles and organic debris under a dissecting microscope, and sorted to major taxonomic category. The organisms were then enumerated, wet-weighed, and the dominants were identified to the species level as far as possible. Verification of species identifications were solicited from taxonomic specialists whenever necessary. For selected stations the small macro-infauna organisms (0.5-1.00 mm) were also picked, sorted, identified and enumerated to provide essential life history data on the juveniles of the dominant species.

b. Megafauna

1) Trawl collections

The megafauna were sampled by qualitative 4 m semi-balloon Gulf of Mexico shrimp trawls with stretch mesh, used when possible with a 1.3 cm stretch mesh liner. Summer sea ice conditions dictated the length and direction of each tow, and prevented the collection of standardized net tows for comparative purposes or abundance estimates. Samples were obtained, however, from each of 6 stations from depths of 28 to 360 m during the summers of 1971 and 1972 (Appendix I: Table 5).

2) Bottom photography

Photographs were taken with an Edgerton stereo deep-sea camera system during the summer of 1972 (Appendix I: Table 6) during the US Coast Guard WEBSEC field work. Bottom photography was utilized as an ultimate approach for the aquisition of quantitative data for visible mega-epifauna. When ice conditions excluded the use of towed trawls, quantitative abundance data were obtained for the visible megafauna. An Edgerton stereo deep-sea camera system (Model 205) on automatic tuned sequence was flown within 1.0 to 12.0 meters of the sediment surface. Visible fauna in the photographs were identified to major groups when further definition was not possible and to species when positive identification could be made based upon the otter trawl collections from the same area.

2. Ice fauna (Narwhal Island)

a. Meiofauna

1) Ice undersurface

Ice meiofaunal samples were collected on nine occasions between 14 April and 5 June, 1980 (Appendix II: Table 17). A 36 m^2 area, approximately 18 m from a tent-covered dive hole, was staked out on the undersurface of the ice with a rope marked in 0.5 m increments. This divided the study area into a grid containing 144 0.25 m^2 quadrats. Sampling locations within this area were assigned using coordinates taken from a random numbers table. Samples from 24 April and 11 May were taken slightly outside the study grid. Ice samples collected on 14 April and 5 June were taken an unknown distance within 40 m of the study area (Kern, 1981).

Quadrats were sampled by a diver, using SCUBA, with a corer of 10.5 cm i.d. This sampled an 86.6 cm^2 area of the undersurface of the ice. One end of each corer was covered with 64 micron mesh. The open end was pushed into the undersurface of the ice until hard ice was reached. Cores were contained by sliding a spatula into the ice over the end of the corer, and then capped while underwater; quadrats were never sampled more than once. Samples from 14 April and 5 June were collected using an ice scraper (Carey, 1981), rather than a corer, and could not be compared quantitatively with the cores.

Samples were placed in jars and transported to the lab where they were washed on a 64 micron sieve. Animals were preserved in 10% buffered formalin and stained with rose bengal. Core samples were sorted into major taxonomic groups and enumerated under a dissecting microscope. Only taxa of sizes large enough to be consistantly retained on a 64 micron mesh were enumerated since the sample could not be regarded as being quantitative for smaller organisms. Calanoid copepods, which were found infrequently in cores and always in low numbers, were also not counted since it was unclear whether they were present in the ice or caught in the corers prior to being inserted into the ice. Cyclopoid and harpactiocid copepods were identified to the species level. It was not possible in the time available to identify each copepodite stage. Instead, all undamaged individuals belonging to the two dominant copepod species were measured to the nearest 24 microns using an ocular micrometer. Total length, excluding the terminal setae, of these organisms was measured. One hundred individuals of each of these species were randomly chosen from the ice scraper samples and measured. The presence of egg sacs and pre-copulatory clasping pairs was recorded for these species on all sampling dates. The gender of all individuals large enough to be sexed was recorded.

Cores taken from the ice undersurface were used for density estimates of the fauna, for collection of species used for life-history studies, and as controls for comparison with cores from caged areas of the ice (Kern, 1981). Ice scraper samples were used only for the copepod life-history studies.

A one-way analysis of variance was used to test for changes over time in the density of major taxa and copepod species. A multi-variate analysis of variance (Cohen and Burns, 1977) was used to test for differences in the density of major taxa and copepod species between caged and uncaged ice. Data were $\log_{10}(x+1)$ transformed before the above tests were performed. The Kolmogorov-Smirnov test (Tate and Clelland, 1957) was employed to test whether the population size structures of the dominant copepod species changed over time. The size-frequency distribution at each sampling date was compared separately with the distribution of the preceding date, as well as the following date. Since the same data set was tested several times, the chance of making an error by incorrectly rejecting the null hypothesis of no difference in population structure was increased. Therefore, to be conservative, the level of significance used to reject the null hypothesis was preset at 0.01.

2) Midwater collections

Quantitative collections were made of the large meiofauna in midwater with a 0.75 m ring net on a pulley and line arrangement (Horner and Schrader, 1981). Replicate tows were made with a technique which standardized the time, speed, depth, distance and net orientation. The mesh of the zooplankton net was 308 µm; therefore, only the largest of the permanent meiofauna were retained quantitatively by the net.

b. Macrofauna

1) Ice undersurface

The underice macrofauna were collected by SCUBA divers with hand-held open-mouth nets. The mesh size was 0.5 mm, and the net width 10 cm. The net was pushed along the undersurface of the ice in a straight transect 10 m in length. The area sampled per haul was 1.0 m^2. Five replicates were taken during six sampling dates- 13 April, 19 April, 5 May, 17 May, 31 May and 9 June, 1980 (Appendix II: Table 18).

The samples were washed into jars in a heated tent at the field station and brought back to the OSCEAP field laboratory at Prudhoe Bay, Alaska. The samples were washed through a 0.5 mm sieve, and 10% formalin buffered with sodium borate was added. Crustaceans were later identified (Appendix II: Table 19) using the following references: Barnard, 1969; Sars, 1895 and 1918; Stephensen, 1923, 1925, 1931 and 1944; and Gurjanova, 1951.

2) Midwater collections

Macrofauna (>0.5 mm) were quantitatively collected by 0.75 m ring zooplankton net with 308 µm mesh. The ring was attached to a line and pulley system anchored to a wooden post mounted through the ice 14 m away from the dive hole (Horner and Schrader, 1981). Net tows were standardized to sample at 3 m depth at a speed of about 0.15 $msec^{-1}$. The samples were washed into jars at the field tent. At the OCSEAP lab in Prudhoe Bay the samples were washed on a 0.5 mm sieve and preserved in 10% formalin buffered with sodium borate. Sample tows were made in pairs. On four occasions the standardized tows were made every two hours over a 24 hour period to determine the temporal pattern of amphipod abundances in the water column. These time series studies were made 30 April-1 May, 7-8 May, 19-20 May, and 2-3 June, 1980.

3) Sediments

Macro-epibenthic fauna were collected by SCUBA diver with the same 10 cm flat bottomed nets as those used on the undersurface of the sea ice (Appendix II: Tables 20-23). Five net hauls were made per sampling period over 10 m long transects; each transect haul covered 1.0 m^2. At the end of each transect run the net was folded over the metal frame to retain the sample. The samples were washed on a 0.5 mm seive and were preserved in 10% formalin neutralized with sodium borate.

3. Particle Flux (Narwhal Island)

Large particles were collected as close as possible to the sediment-water interface with cylindrical particle traps with an inside diameter of 13.1 cm and a height of 39 cm above the collecting surface. The traps, therefore, had an aspect ratio of 3:1. This has been determined as the correct configuration to minimize resuspension by water turbulence within the sampling cylinder (Gardner, 1980). A prefired and preweighed glass fiber filter was placed at the bottom of each cylinder over a porous filter bed, through which the water retained in the cylinder could be drained.

Eight traps, four in each of two weighted frames were deployed seven times from 17 April through 5 June, 1980. SCUBA divers placed the two trap arrays on the sediment surface with the aid of spongex flotation. They were located to the south of the dive hole in a sector of the study site chosen to have minimal disturbance from the other diving operations undertaken for the Sea Ice-80 studies (Figure 3). The cylinders contained filtered seawater and were capped during deployment. Upon retrieval the caps were replaced on the cylinders by the divers before moving them to minimize contamination problems.

In the field laboratory, the inside of the cylinders was washed down with filtered fresh water, and the remaining moisture was pulled through the glass-fiber filter pad by gentle suction. The cylinders were disassembled and the filters removed in a protective work hood made of plastic sheeting to minimize contamination. With the aid of forceps, each filter sheet was carefully placed in a separate prelabelled, sterile, plastic petri dish for transport to Oregon State University. Upon removal from each cylinder the filters were stored in a deep-freezer and kept frozen during shipping and later storage.

Laboratory analyses included particle counts, particle weights with a correction for NaCl, measurement of organic carbon and nitrogen, and identification of particle type and particle qualitative composition by scanning electron micrography. These data were then used to calculate the flux of carbon, nitrogen and identifiable particles to the sea floor beneath the ice.

Counts of particles were made on each thawed filter with 6x magnification under a dissecting microscope without removing the filter from its sterile petri dish (Appendix III: Table 29). Selected recognizable particles were counted and measured with an ocular micrometer.

The total mass of particles on each filter was measured by drying the filters in a drying oven at 65°C to constant weight. Weights were then measured to the nearest ±0.001 g. For the salt correction three 1.629 cm^2 subsamples were removed from each of the filters and soaked in 10 ml of 0.3N HCl. Magnesium concentrations in the subsamples were measured against dilute seawater standards with a flame spectrophotometer. The weight of sea salt for each sample was then calculated.

The amount of carbon and nitrogen contained on the collection filters was measured in four 1.629 cm^2 subsamples removed from each filter. The subsamples

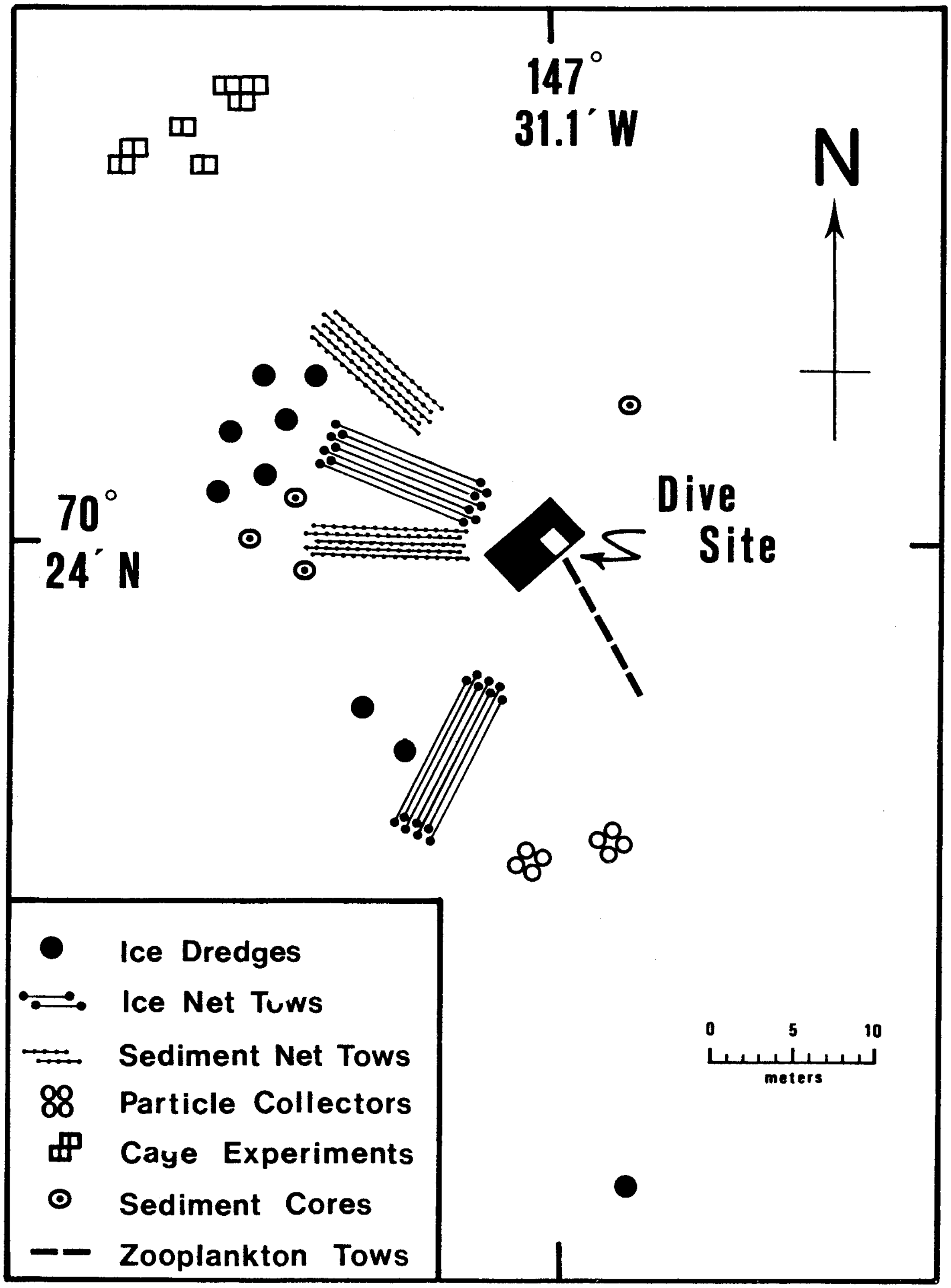

Figure 3. Narwhal Island ice station for Project Sea Ice-80. Note the dispersion of locations to minimize inter-project disturbance. RU #359 utilized the northwestern sector for ice algal studies.

were burned in a CHN Analyzer to determine the weights of the contained carbon and nitrogen in μg.

Subsamples (0.595 cm^2) were removed from areas of interest on the filters for scanning electron microscope study. These were dried, mounted and sputter-coated with Au/Pd, and then examined and photographed at a range of appropriate magnifications (see Appendix III: Figures 57-63).

Calculations were then made to determine the flux per unit area and per day for the recognizable particles, carbon, nitrogen and total mass.

4. Environmental data (Narwhal Island)

Temperature and salinity were measured throughout the study period with a Kahl Scientific Company electrodeless salinometer (Model RS5-3). The salinometer was modified to measure temperatures down to -2.0°C, though minimum temperatures below this value were probably reached. The sensor unit was lowered to depths about 30 cm below the ice-water interface and the same distance above the sediments to minimize interference with the inductive salinometer functioning (Kahlsico, 1975). Measurements were made at 1 m increments down to the sediment (Appendix II: Table 24).

VI. Results

A. Benthic continental shelf fauna: cross-shelf trends.

The total numerical density of macrofauna (means ± standard deviation) demonstrate a bimodal pattern (Figure 4 and Appendix I: Tables 7-10). The maxima at 10 m and 700 m depth and the minima at 5 m and 1800 m depth are statistically significant. The 10 m peak is significant at the .001 level. The annelids are the dominant taxonomic group at most stations, though the molluscs predominate at 3 stations at 23, 100 and 1800 meters depths (Figure 5).

The macrofaunal biomass generally follows an increasing trend of abundance with depth to the outer shelf and upper slope with a subsequent decrease to low standing stocks at 1800 m (Figure 6 and Appendix I: Tables 11-13). The high biomass at 15 m depth is an artifact directly attributable to the thick shells of the bivalve mollusc Astarte montagui.

Polychaete species generally have broad distributions across the southwest Beaufort Sea continental shelf, with one or more maxima of numerical abundance (Figure 7 and Appendix I: Table 14). For example Minuspio cirrifera is very abundant at both the 10 m and 700 m depth, while Chone nr C. murmanica is most abundant at 47 m. The 15 m depth station appears to have depressed polychaete populations which may be caused by severe ice grounding in this zone. Such variability also indicates the patchiness of the fauna, environment, or both. Note that Capitella capitata, a species indicative of environmental disturbance, is found in the nearshore zone. Pelecypod mollusc species are also found across broad areas of the shelf, though the species populations are generally abundant only in a narrow depth zone (Figure 8). Dominant species of polychaetes and bivalves can, therefore, be used to characterize portions of the shelf and upper slope environments.

Species richness (number of species per station) is highest at the intermediate depths (10-100 m) for both the Polychaeta and Pelecypoda with minimal diversities at the shallowest station (5 m) and the deeper stations (200 to 1800 m) (Figure 9).

A study of feeding types of polychaete worms emphasizes the increasing importance of subsurface deposit feeding species with increasing depth (Figure 10). Surface deposit feeders are most abundant at the shelf edge and decrease down to the 1800 m depth.

Megafaunal invertebrates are most abundant on the outer continental shelf and uppermost part of the Beaufort Sea continental slope (Figure 11). Though these quantitative data are limited to the visible fauna seen in bottom photography, otter trawl collections indicate that these fauna are the predominant grazers in the megabenthic community. Ophuiroids are the dominant group and compose a large proportion of the large fauna (Figure 12 and Appendix I: Figures 44-54). Ophiacantha bidentata can be identified from the photographs because of its unique appearance, though the genera Ophuira and Ophiocten could not be differentiated in the photographs. Note the abundance estimates of ophuiroids from both the photographic counts and the grab data characterize the outer shelf-upper high slope standing stocks. Grab and photographic ophuiroid abundance estimates for the shallowest station (25 m) may differ because of the increased turbidity in onshore waters that lowers photographic contrast and definition due to light backscatter from suspended particles. This band of high ophuiroid abundance is correlated with areas of postulated higher sedimentation rates (Carey et al., 1974).

The depth distributions of mega-epifauna are generally broad (Figure 13). Species distribution data compiled from both the trawl collections and the bottom photographs demonstrate these trends. The shallow stations support few species of megafauna; the distribution of this ecological group tends to be shifted toward deeper water.

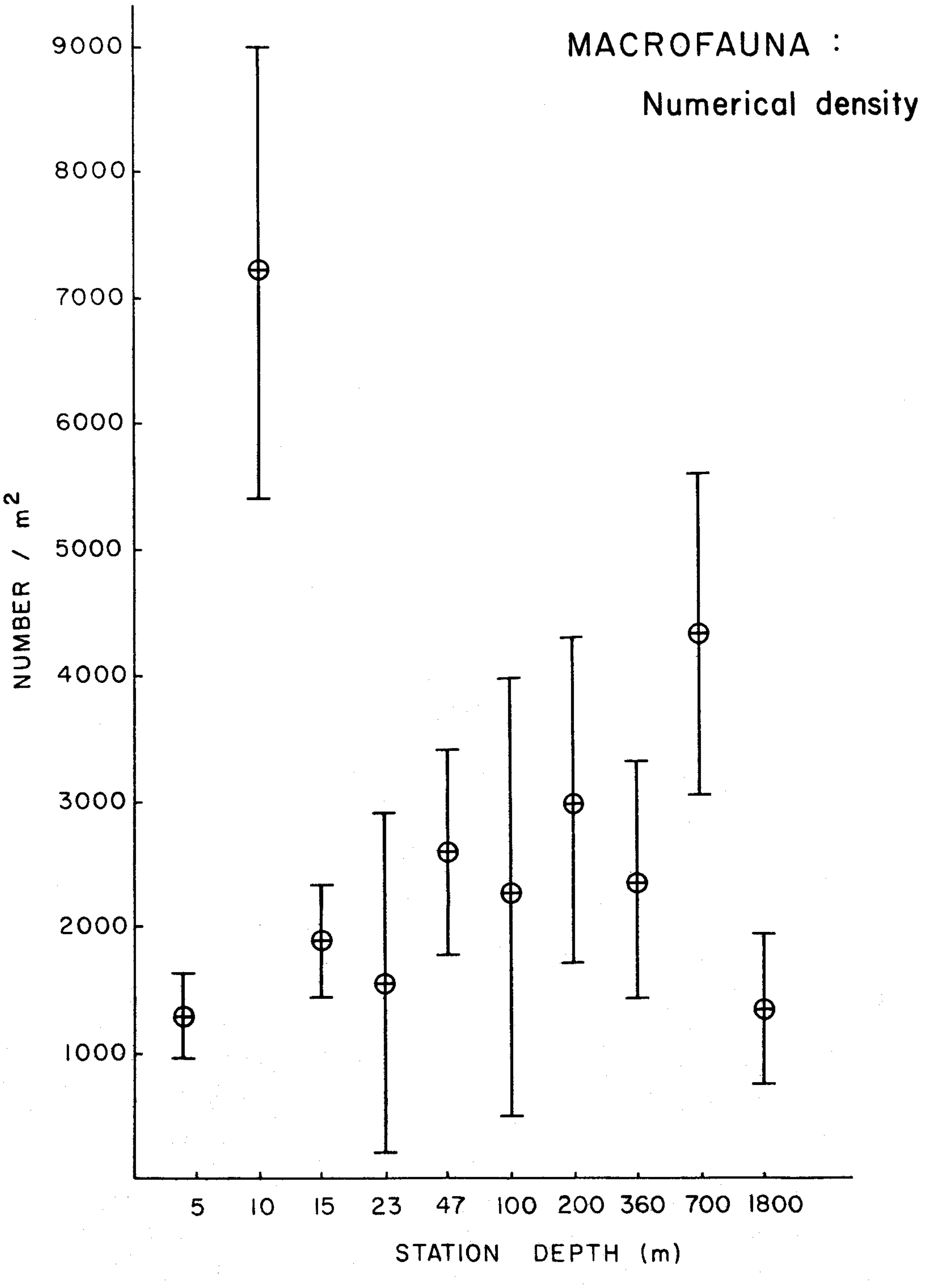

Figure 4. Numerical density of benthic macrofauna (>1.0 mm) on the Pingok Island cross-shelf transect. Means ± 1 standard deviation. N = 5 per station.

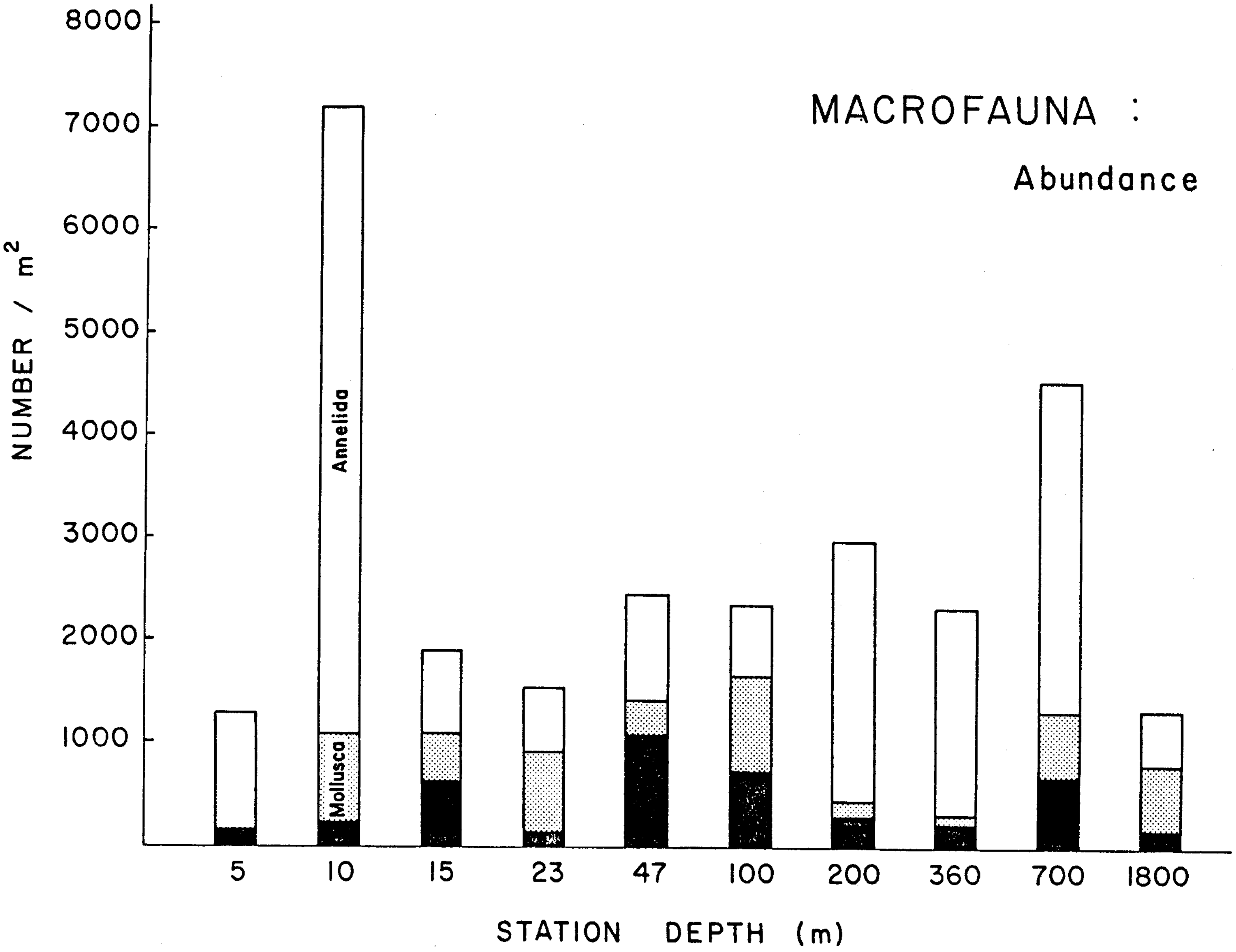

Figure 5. Abundance of benthic macrofauna on the Pingok Island transect to demonstrate cross-shelf trends of the two dominant major taxa, Annelida and Mollusca.

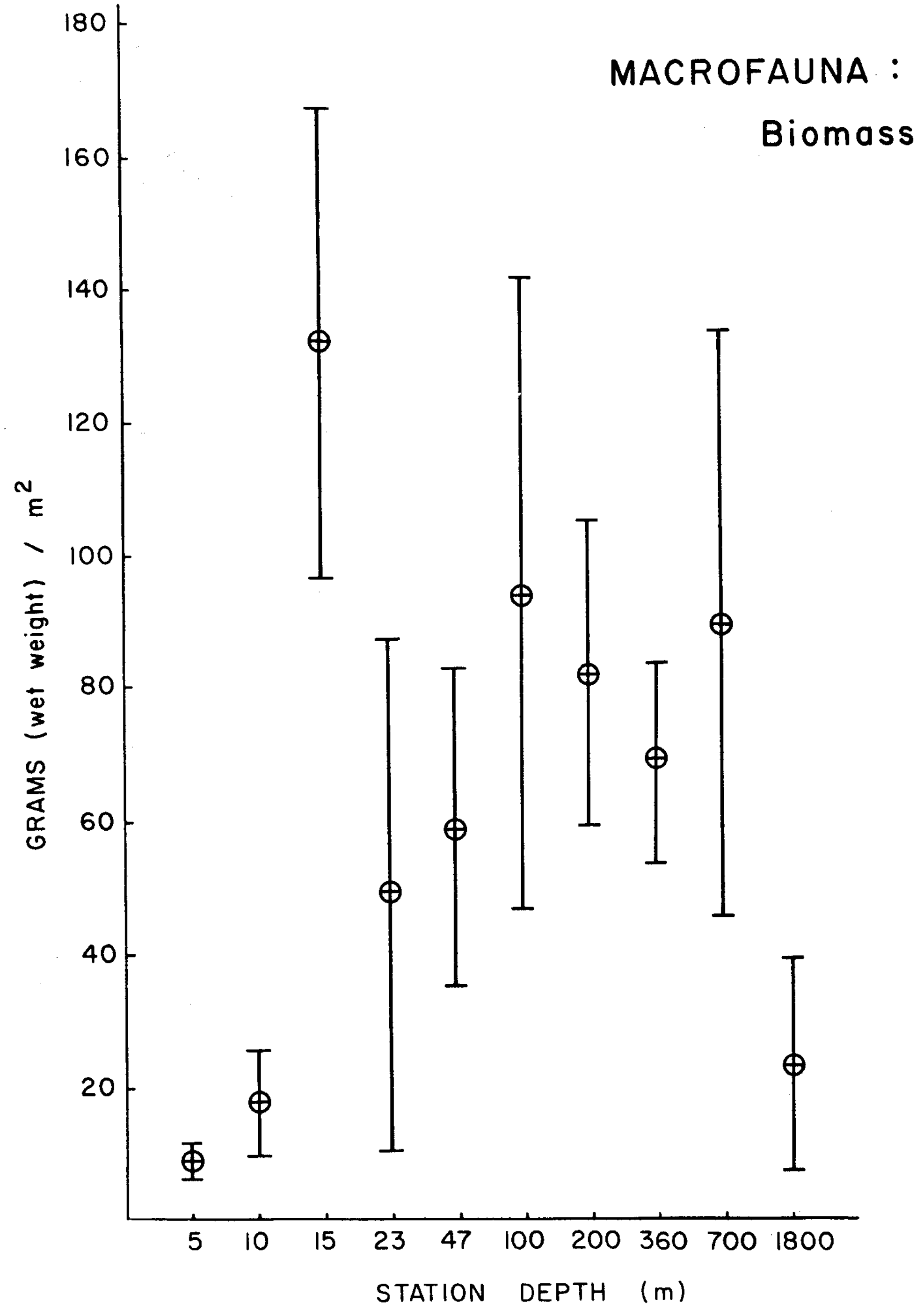

Figure 6. Standing stock biomass (wet-preserved weight) of benthic macrofauna on the Pingok Island cross-shelf transect. Means ± 1 standard deviation. N = 5 per station.

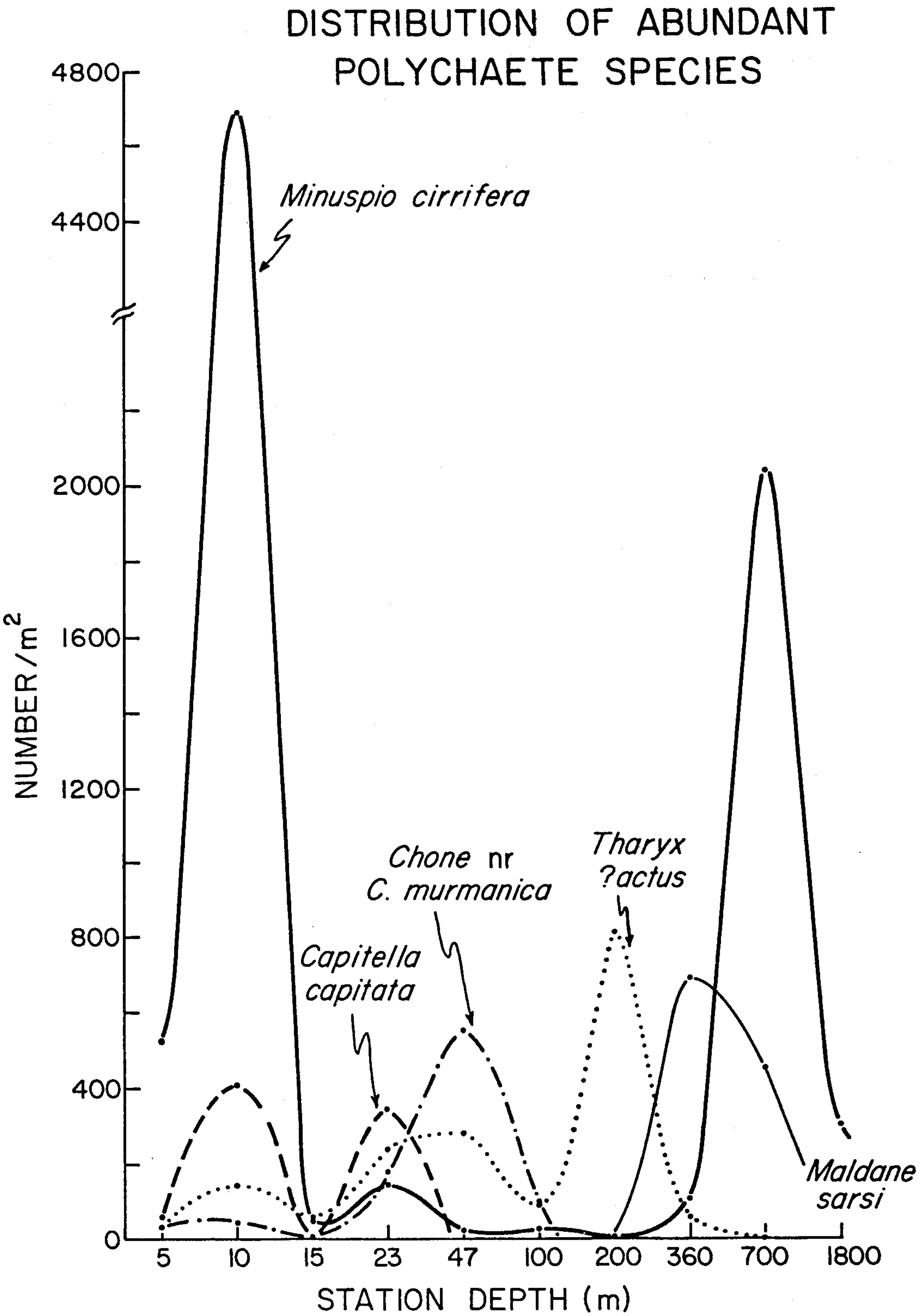

Figure 7. Patterns of distribution and abundance of dominant polychaete species on the Pingok Island cross-shelf transect. Means of 5 samples per station.

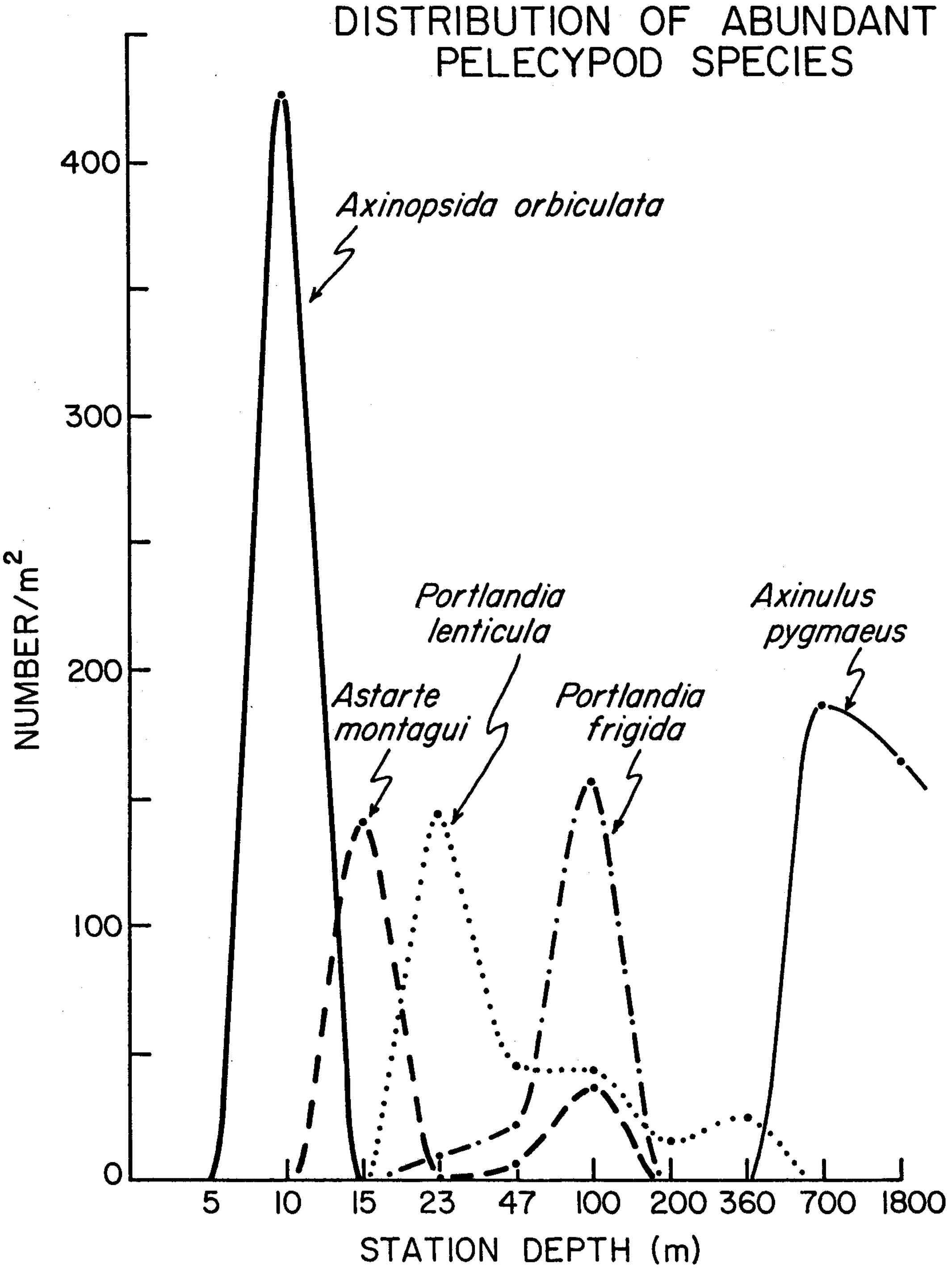

Figure 8. Patterns of distribution and abundance of dominant pelecypod species on the Pingok Island cross-shelf transect. Mean of 5 samples per station.

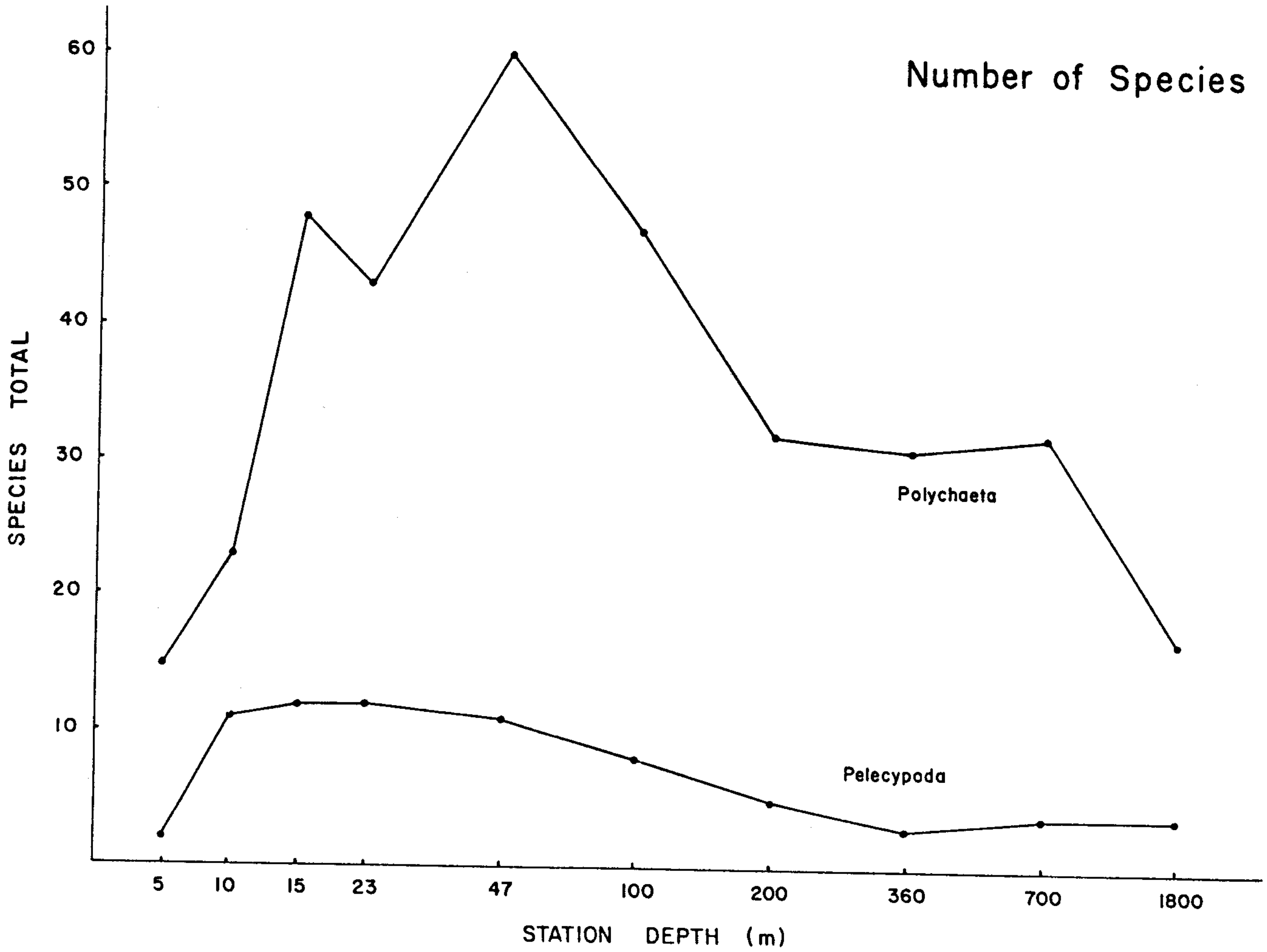

Figure 9. Number of species of Polychaeta (Annelida) and Pelecypoda (Mollusca) on the Pingok Island cross-shelf transect. Total of 5 samples per station.

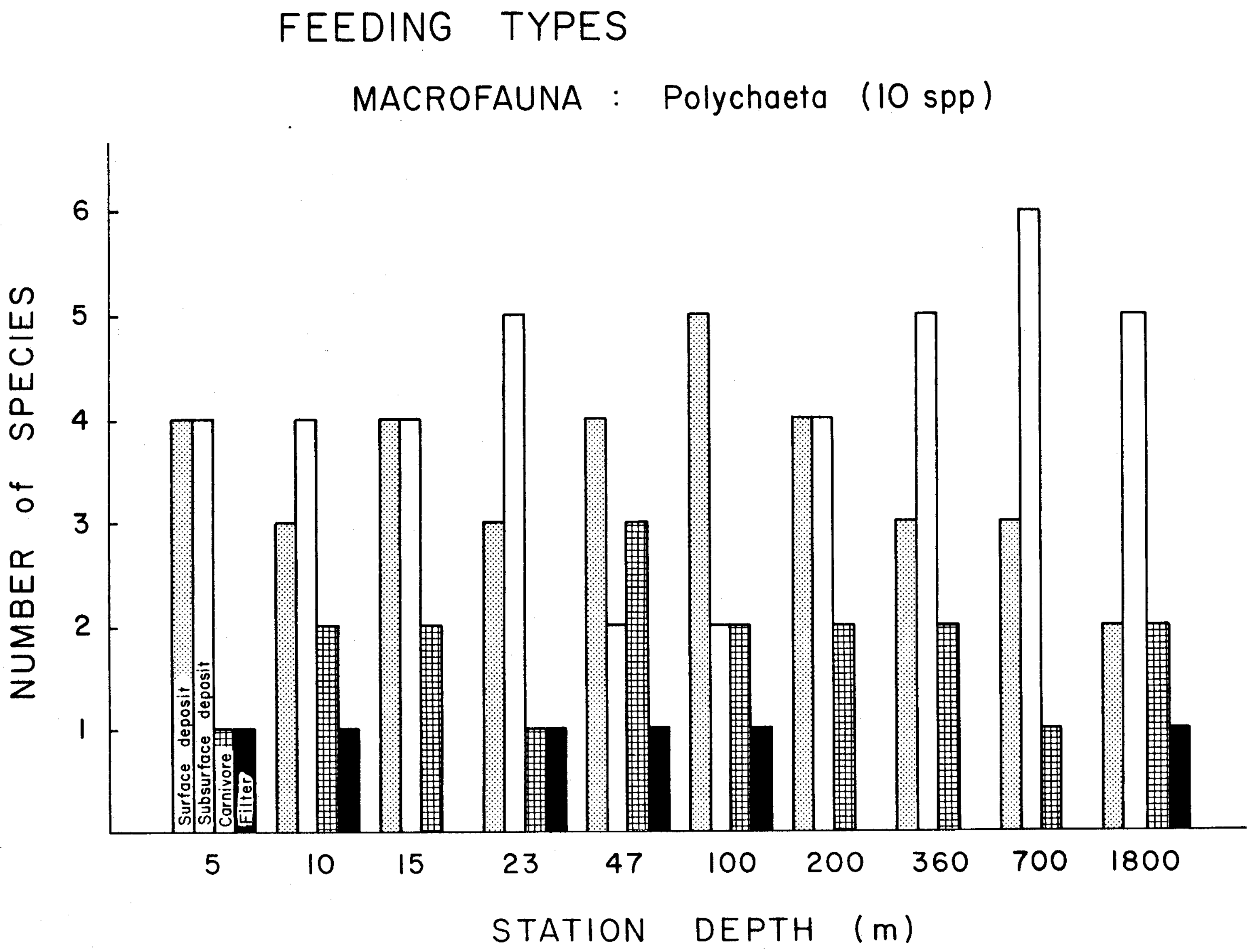

Figure 10. Feeding types of the 10 most abundant polychaete species on the Pingok Island cross-shelf transect.

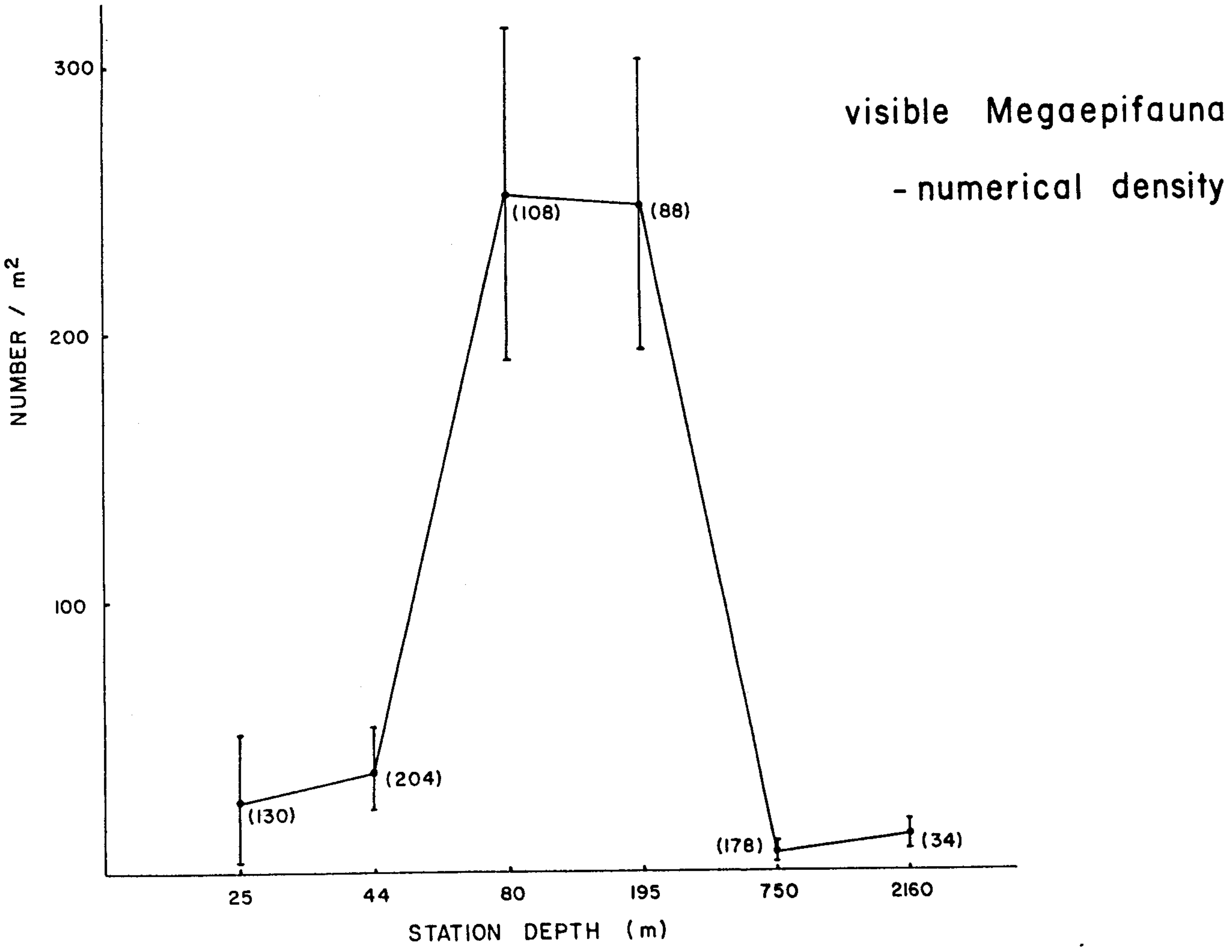

Figure 11. Abundance of visible mega-epifauna (>1.3 cm). Estimates derived from stereo bottom photography. Numbers in parantheses indicate the photographic aerial coverage (m^2) at each station.

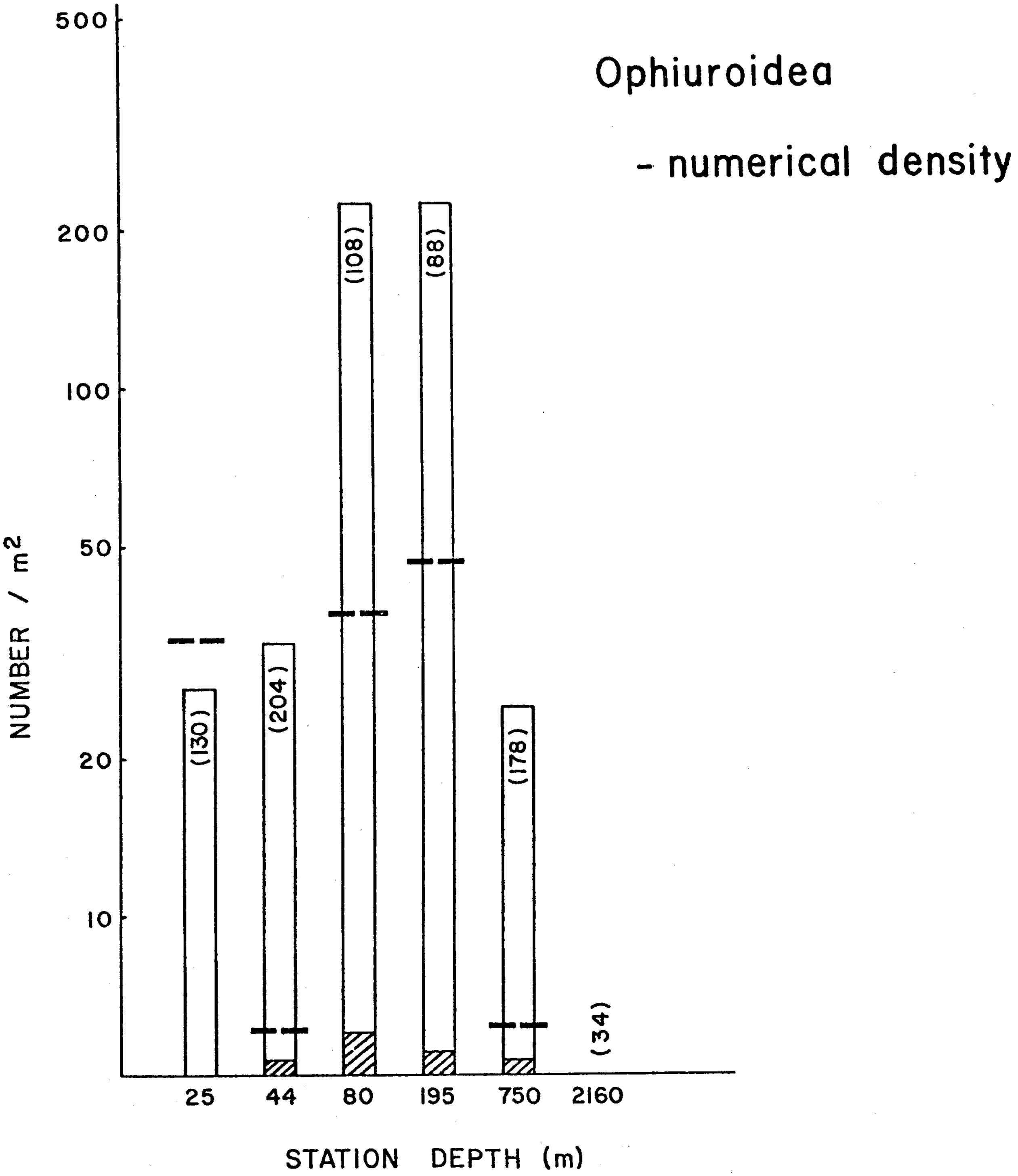

Figure 12. Numerical density of the total ophiuroid fauna characterized by bottom photography (bars) and from grab samples (dashes). Numbers in parentheses indicate the photographic aerial coverage (m^2) at each station. Grab sample estimates derived from five replicates (0.5 m^2) at each station. Shaded areas indicate the ophiuroid species Ophiacantha bidentata.

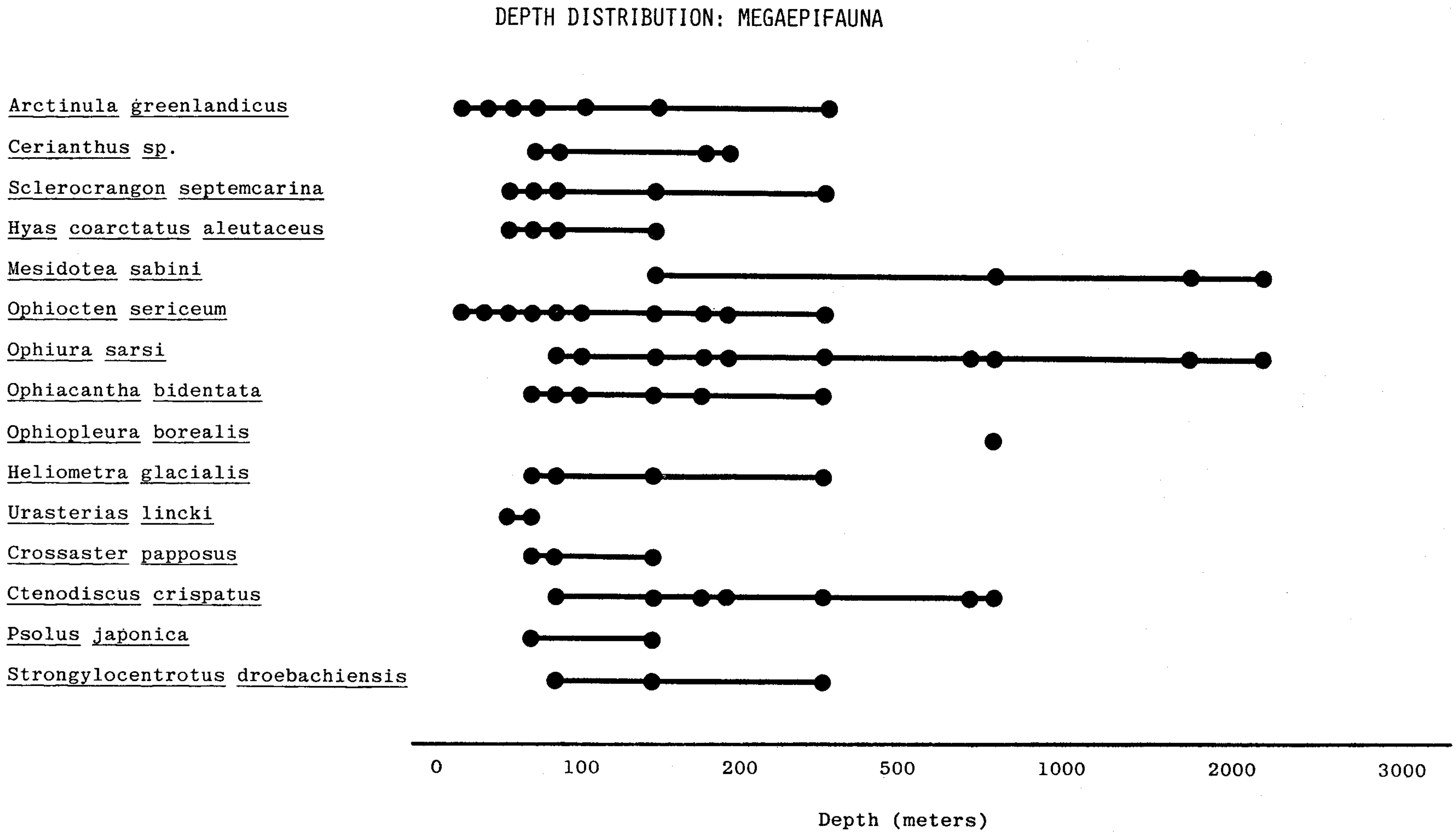

Figure 13. Distributional pattern of mega-epifauna (>1.3 cm) on the Pingok Island cross-shelf transect. Data derived from both otter trawl collections and bottom photography.

B. Ice fauna (Narwhal Island ice station)

1. Ice meiofauna (Kern, 1981)

Nematodes, copepods, turbellarians, polychaetes, and amphipods were collected from the undersurface of the ice. The mean number of individuals collected per 100 cm^2 for each group at all dates when corers were used, with the associated standard deviations, is given in Appendix II: Table 25. Nematodes dominated, comprising 47.0% of the fauna collected throughout the study (Figure 14). Copepods and turbellarians made up 28.8% and 16.1% of the fauna, respectively. Polychaetes and amphipods were minor members of the ice fauna, together representing less than ten percent of the total.

Each group showed a significant change in abundance over time. In general, the number of individuals within each taxon increased as the ice algal bloom progressed. Polychaetes were the only exception to this pattern, with their greatest density occurring on 24 April. Nematode and turbellarian abundance increased rapidly from minimum values at 24 April to maximum on 2 June. Copepods exhibited a different trend in abundance (Figure 15), appearing to decrease initially, then increase, and finally decrease again. Since the standard deviations are high, it is possible that this pattern is not real.

Seven species of cyclopoid and harpacticoid copepods were identified from the ice. The mean number of individuals collected per 100 cm^2 for each of the five dominant species, and the associated standard deviation, is given for each date on which cores were taken (Appendix II: Table 26). *Cyclopina gracilis*, a cyclopoid, was the dominant species, making up 55.0% of the ice copepod fauna. *Harpacticus* sp. and *Halectinosoma* sp., two harpacticoids, comprised 23.0% and 19.8% of the copepods, respectively. The cyclopoid *Oncaea* sp. represented 1.5% of all copepods and *Dactylopodia signata*, a harpacticoid, less than one percent. Two copepodites were collected that probably belonged to the species *Cyclopina schneideri*. The seventh species was represented by a single individual that was too young to identify.

Although there was a significant change in abundance over time for total copepods, densities of two species, *Halectinosoma* sp. and *Dactylopodia signata*, did not change significantly. The abundance of *Cyclopina gracilis* and *Harpacticus* sp. did change significantly through the study ($P<.002$), as well as that of *Oncaea* sp. ($P<.05$). The three dominant species displayed similar patterns in abundance over time (Figure 15). Densities appeared to decrease initially, reach a maximum in the second half of May, and then decrease toward the end of the study.

Data on the life-history characteristics recorded for the two dominant copepods, *Cyclopina gracilis* and *Harpacticus* sp., are given in Appendix II: Table 27. *Cyclopina gracilis* adults were present at all dates. Only copepodites of *Harpacticus* sp. were collected before 11 May. *Harpacticus* sp. males were more abundant than females until the final three sampling dates. The reverse trend occurred with *C. gracilis* where females outnumbered males initially, but were generally less numerous after 5 May. Gravid *C. gracilis* females were collected on five of the sampling dates, but were never a large percentage of the adult female population. No gravid *Harpacticus* sp. females were found in the ice, but pre-copulatory clasping pairs were present on 26 May and 2 June. Adult males clasped late copepodite females on the prosome with their modified antenules.

The size-frequency distribution of *Harpacticus* sp. indicates that the population structure changed greatly during the course of the study (Figure 16). Over 95% of the *Harpacticus* sp. individuals could be measured. Initially the population was composed entirely of copepodites. By 15 May, however, a mode appeared at approximately 840 microns that was composed of adult males and late copepodite females. This feature remained in later samples because the adult males had reached their maximum size. Females continued to grow and a broad mode corresponding to adult females was seen beginning 19 May. Significant differences in population

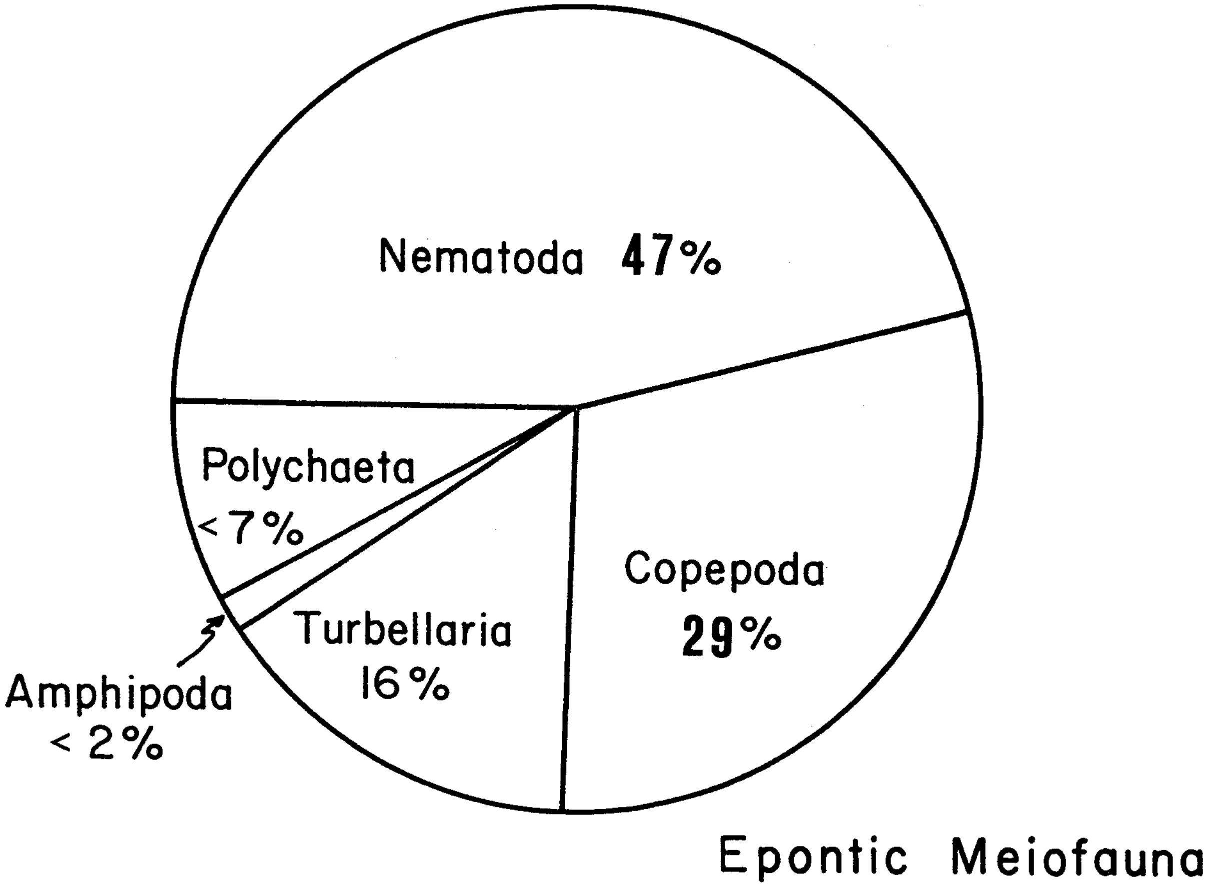

Figure 14. Composition of sea ice meiofauna by major taxa at the Narwhal Island ice station, spring, 1980.

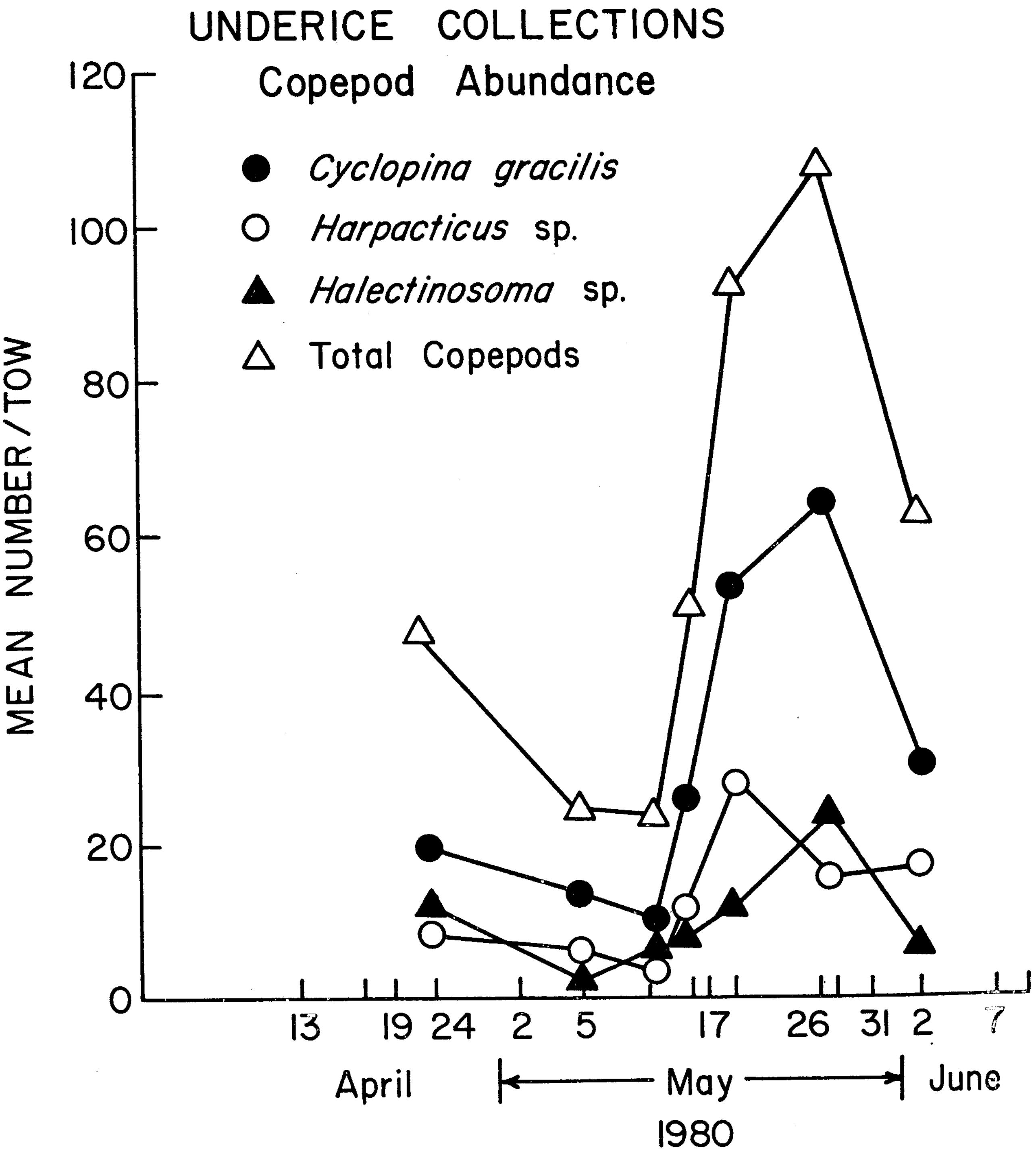

Figure 15. Abundance of underice copepods during the spring, 1980, at the Narwhal Island ice station.

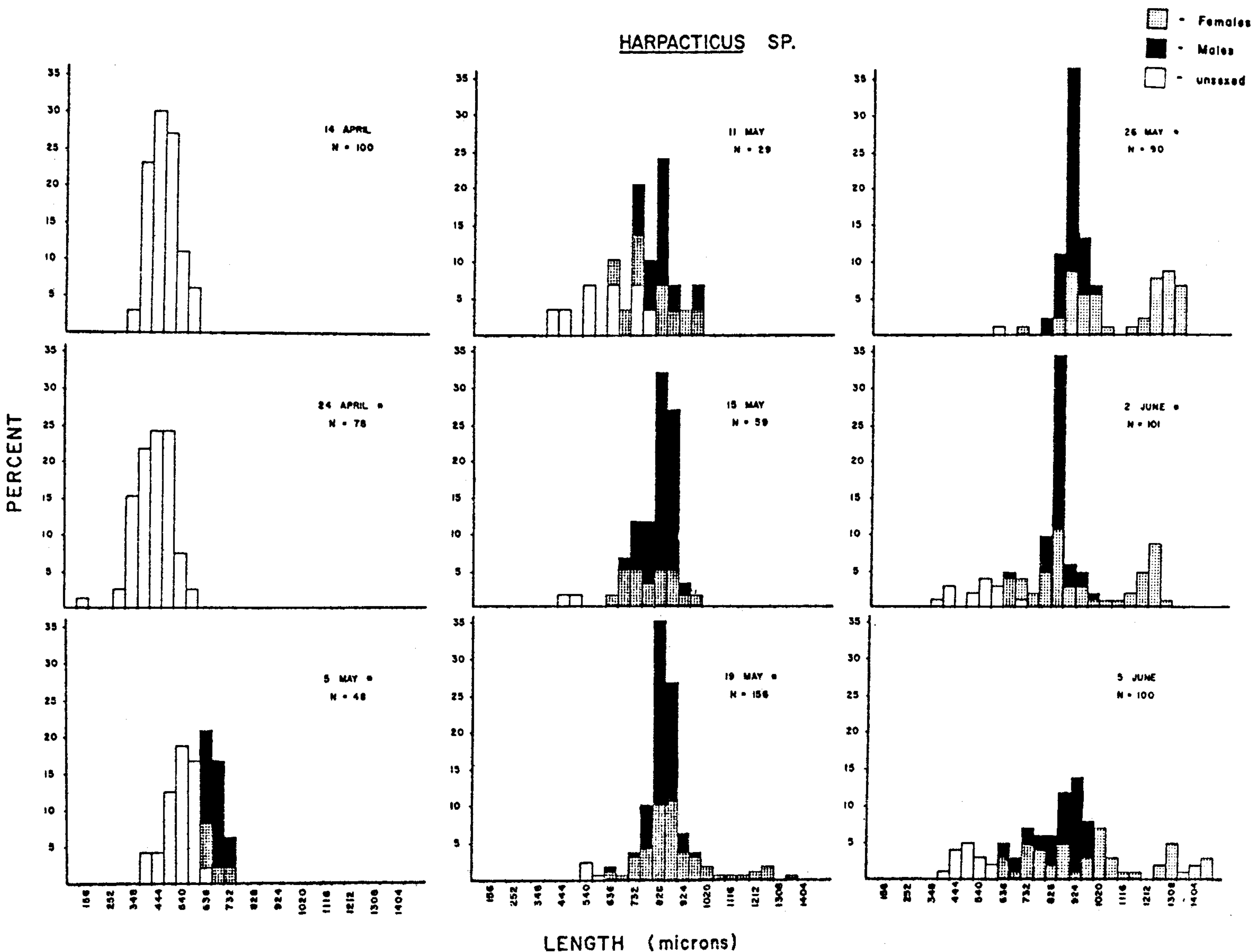

Figure 16. Size-frequency distribution of Harpacticus sp. collected from the underice surface during the spring, 1980, at the Narwhal Island ice station.

structure were indicated by the Kolmogorov-Smirnov test in the second and third comparisons (24 May-26 May, 26 May-2 June, and 2 June-5 June). Only 29 individuals were measured from 5 May and this sample size is inadequate to calculate the test statistic where the sample sizes are unequal (Tate and Clelland, 1957). To make comparisons between this date and the preceding and following sampling dates, the smaller sample size was used alone to determine the test statistic.

The population structure of Cyclopina gracilis (Figure 17) changed greatly during the study, but most of the change occurred in the early samples. Over 92% of all individuals could be measured. The Kolmogorov-Smirnov test indicates that significant changes in the size-frequency structure of the population occurred between the first two sampling dates (14 April-24 April), the second and third dates (24 April-5 May), the fifth and sixth dates (15 May-19 May), and the eighth and ninth dates (2 June-5 June). The earliest samples contained mostly juveniles. In the cores taken 15 May, and in all following samples, three major modes were evident in the size-frequency distributions. The first mode, centered at around 260 microns, was composed of young copepodites. The second, located at approximately 520 microns, was largely made up of adult males and late female copepodites. Adult females had a much greater size range than males, and had a broad peak centered near 700 microns. The size-frequency distributions of C. gracilis on 5 June had these three modes, but they were broader and had shifted to larger sizes relative to the previous dates.

Data from the time-series midwater collections with the 0.75 m ring net demonstrate that harpacticoid copepods are present in the water column only at the end of the season (Figure 18). At the end of May and early June the harpacticoids appear in the collections and increase in abundance up to the very end of the study.

2. Ice macrofauna - sources and seasonal trends

The epontic macrofauna (>0.5 mm) is predominantly comprised of gammarid amphipods. A mean of 99.3% of the macrofauna caught on the ice undersurface with the SCUBA diver-operated ice net sampler were amphipods (Figure 19). The remaining 0.7% of the sea ice macrofauna were miscellaneous arthropods, cnidarians, and polychaetes.

The gammarid amphipods are the dominant taxonomic group associated with the sediments in the study area. A mean of 53.5% of the macro-epifaunal organisms were amphipods while arthropods, i.e., cumaceans, mysids and ostracods represented 45.2% of the fauna captured by the standardized net tows, and miscellaneous species, i.e., nemerteans, annelids and molluscs made up the remaining 1.3% of the epifauna.

During the latter part of the study period there is a significant increase in the number of amphipods per unit area at the ice-water interface (Figure 20), increasing from 25 m^{-2} to 340 m^{-2} ($p = <.005$, Kruskal-Wallis rank analysis). The increase in numerical abundance is caused by juvenile amphipods released from adult female broad pouches at the ice undersurface in early June during the ice melting period (Figure 21). To a large degree the adult Pseudalibrotus litoralis and their offspring form most of the ice assemblage. Therefore, it is not surprising that the pattern of the release of P. litoralis juveniles is the same as for the total amphipod fauna on the ice undersurface ($P = <.005$, Kruskal-Wallis rank analysis). In contrast, the number of gammarids associated with the sediment remained low throughout the total study period (Figure 22). At the end of the spring season the benthic P. litoralis population was 2% of ice population off Narwhal Island.

Excluding juveniles the benthic Pseudalibrotus litoralis population was 6% of the ice faunal abundance. However, additional data from an unpublished report demonstrates that during the latter part of the summer P. litoralis is abundant on the inner Beaufort Sea continental shelf (Carey, 1981). During August 1976, there were 24 individuals per m^2 at 10 m depth, 294 at 15 m and 16 at 20 m.

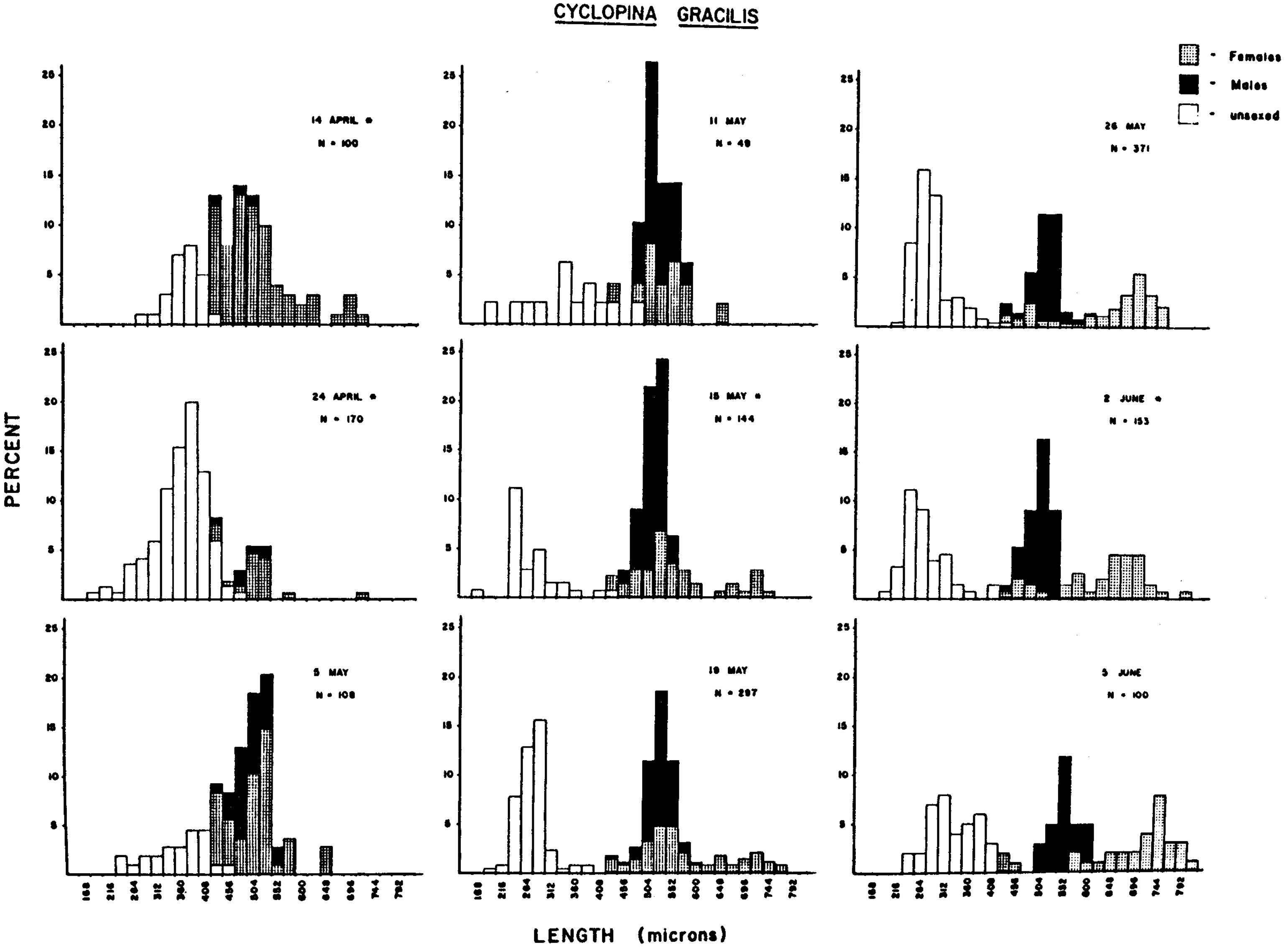

Figure 17. Size-frequency distribution of *Cyclopina gracilis* collected from the underice surface during the spring, 1980, at the Narwhal Island ice station.

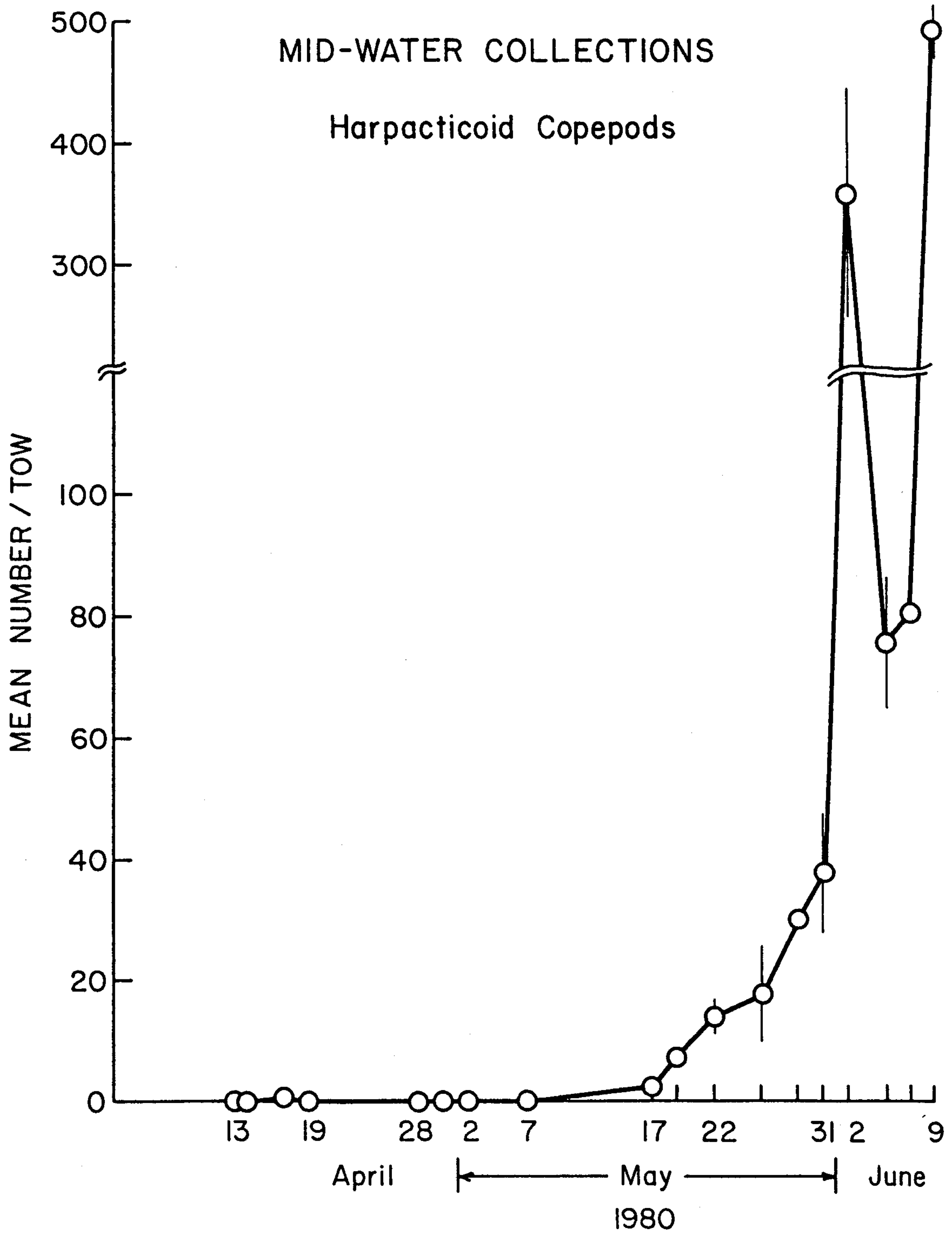

Figure 18. Mid-water collections of harpacticoid copepods by 3/4 meter ring net at Narwhal Island ice station, spring 1980. The mean and total range is indicated for the sample pairs.

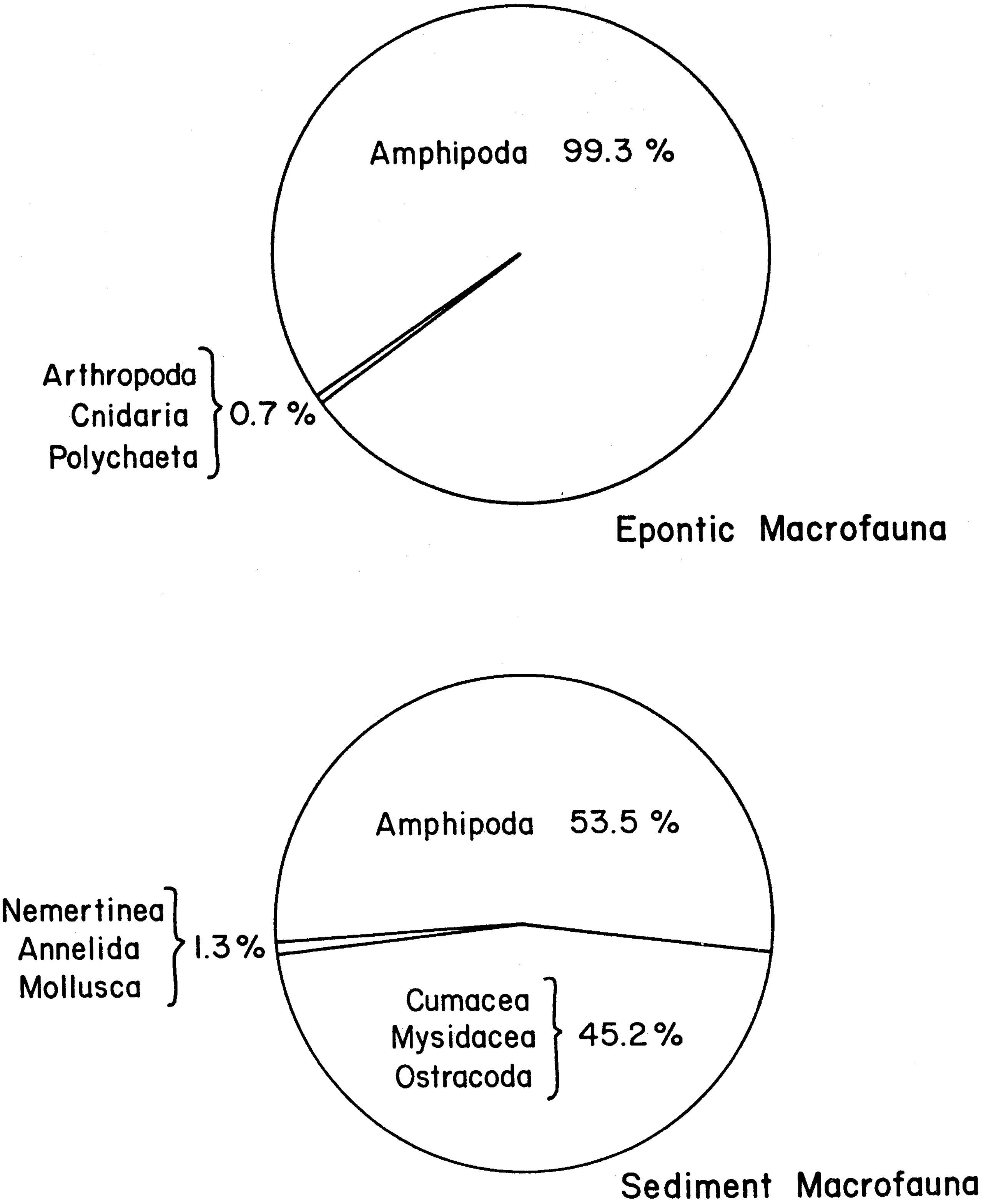

Figure 19. Comparison of major taxonomic composition of ice (epontic) macrofauna and benthic macrofauna at the Narwhal ice station, spring, 1980.

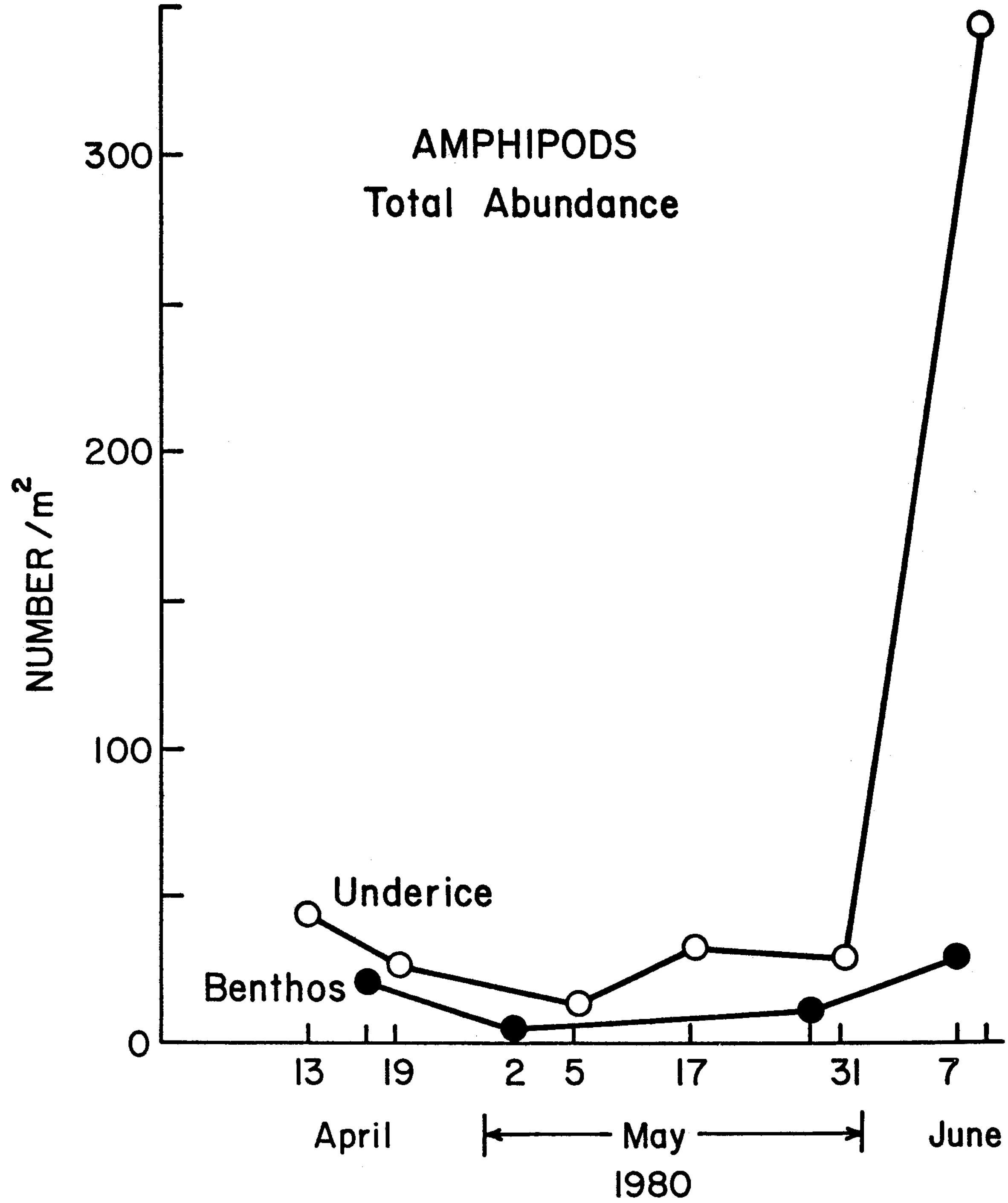

Figure 20. Comparison of the abundance of amphipods on the ice undersurface and the sediment surface at the Narwhal Island ice station, spring 1980.

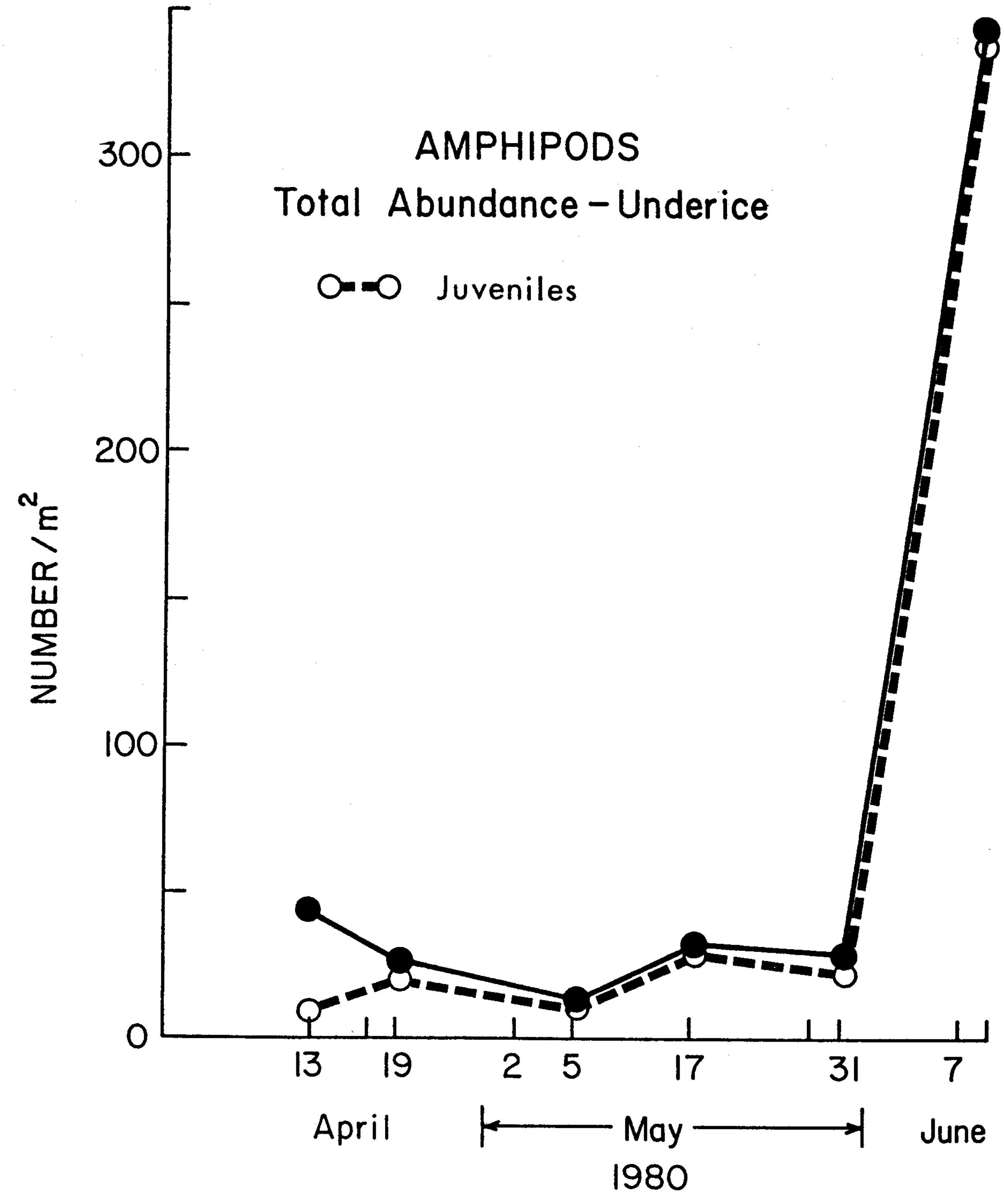

Figure 21. Abundance of underice gammarid amphipods at the Narwhal Island ice station, spring 1980. Note the predominance of juveniles and the major recruitment in early June.

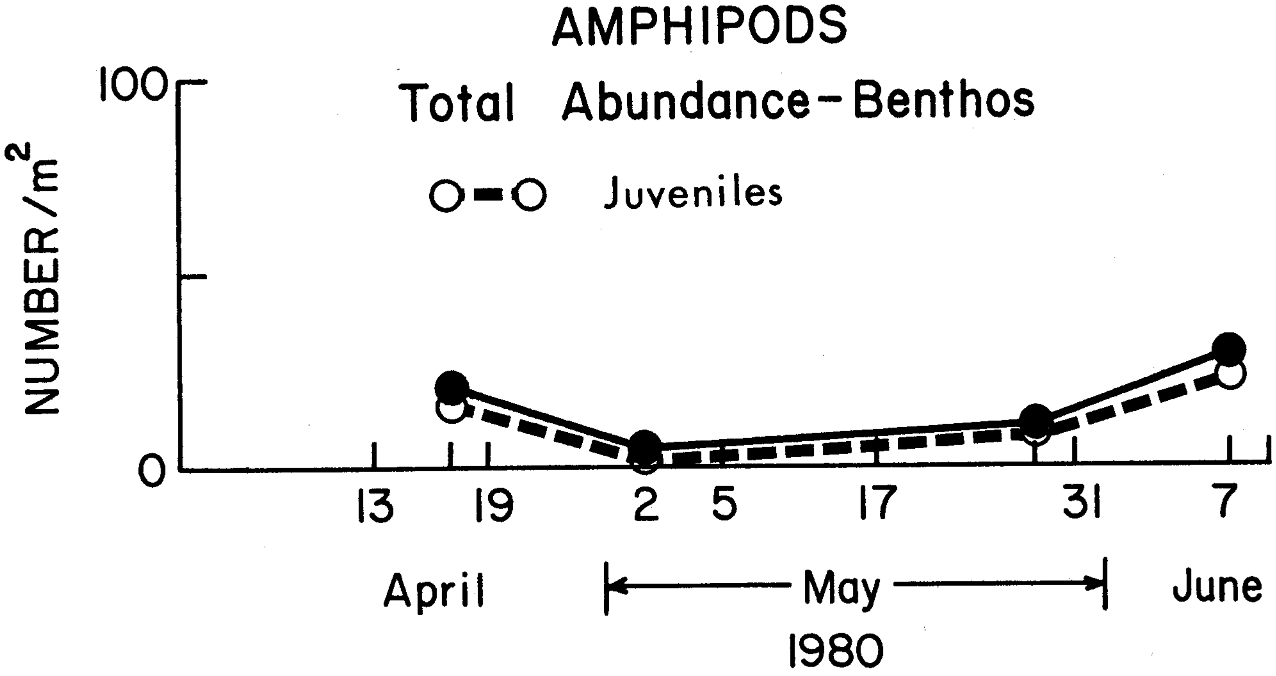

Figure 22. Abundance of benthic gammarid amphipods at the Narwhal Island ice station, spring 1980. Note the predominance of juveniles.

Five species of gammarid amphipods were collected from the ice undersurface, nine from the water column and thirteen from the sediments (Appendix II: Table 28) Though *Pseudalibrotus litoralis* dominates the amphipod ice assemblage with a mean of 9.1 per m^2, it is also found as the numerically important member of the water column and sediment macrofaunal assemblages. Because *P. litoralis* is the only species dominant in all three enviroments, its affinities are widespread during the ice-covered months on the Beaufort Sea shallow continental shelf (Figure 23). The affinities of the abundant species can be assigned to one or two of the environments. Four species, i.e., *Onisimus affinis*, *Onisimus plautus*, *Acanthostepheia malmgreni* and *Onisimus* cf. *aderjugini* were found only associated with the bottom. *Weyprechtia pingius* came from only the ice and water column, and the five ice species were all collected from other environments in addition.

The relationship of the ice, water and sediment populations of *Pseudalibrotus litoralis* was studied by sampling all three environments during the spring study period. The midwater collections demonstrate that some *P. litoralis* were present in the water column at all times during the spring (Figure 24), though during April there were more individuals caught mid-water in the early morning hours (Figure 25). As the sun-lit day length increased during the spring this tendency weakened and disappeared. At the end of the season before ice break-up there appears to be a tendency for maximal activity in the water column also during the early morning hours. Perhaps the decreasing salinity at the ice-water interface (Figure 26) coupled with the dim morning light entrain the movement of the amphipod away from the ice. Though these data indicate the seasonal and diurnal activity of *P. litoralis* in the water column, they do not prove vertical migrations between the ice and the sediments per se. Because of the patterns observed it is likely, however, that the movement of the amphipod between the two surfaces is fairly continuous during the spring.

The population characteristics of *Pseudalibrotus litoralis* change throughout the season at the underice surface (Figures 27 through 32) (Boudrias and Carey, unpublished). The mean length of the adults demonstrates a general trend of growth from April through early June, 1980 (Figures 33 through 35). Though each data point does not represent a significant change in size from one sampling date to the next, the overall trend appears real. In addition, the mean weights of *P. litoralis* adults and immatures also tend to increase during the season (Figures 36 and 37). Again, the individual data points are not significantly different from the others, but the overall trends seem real. Part of the variability of these data is caused by continual recruitment of juveniles into the ice populations of *P. litoralis* (Figure 38). The length-frequency structure of the ice population demonstrates the appearance of young at the ice undersurface throughout the spring.

C. Particle flux to sediments (Narwhal Island)

The overall result of the organic flux studies at the Narwhal Island Ice Station during the Sea Ice-80 project is that the particle flux is relatively high throughout the entire period. There is no significant temporal variability in the total flux of mass, nitrogen, or carbon (Figures 39 through 41, and Appendix III: Tables 30 through 37). The total particle flux by weight is as high at the initial stages of the development of the ice biotic community as it is at the end in early June, 1980. The collections on May 3 and 11 are highly variable with larger mean mass and may be affected by large, rare particles such as crustacean molts and large fecal pellets (Figure 39). The organic carbon and nitrogen flux under the sea ice also exhibit no significant trends with time. In fact, the striking result, particularly for carbon is that the flux starts, remains and ends at relatively high levels.

A few particle types were distinctive and could be identified and the source determined. These included fecal pellets and crustacean molts. Much of the mate-

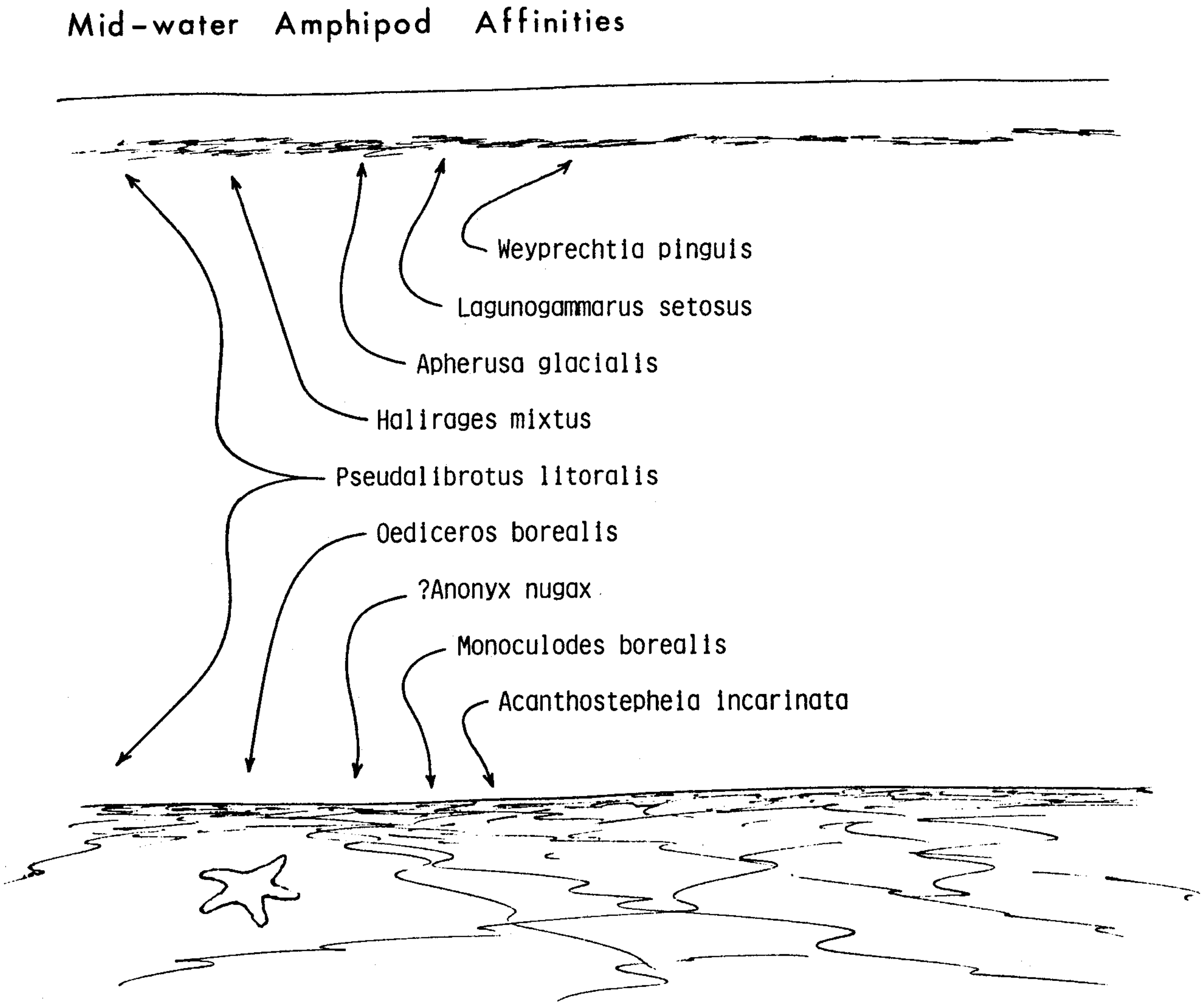

Figure 23. Affinities of gammarid amphipod species in the shallow Beaufort Sea. *Pseudalibrotus litoralis* is abundant in the underice, mid-water, and benthic environments.

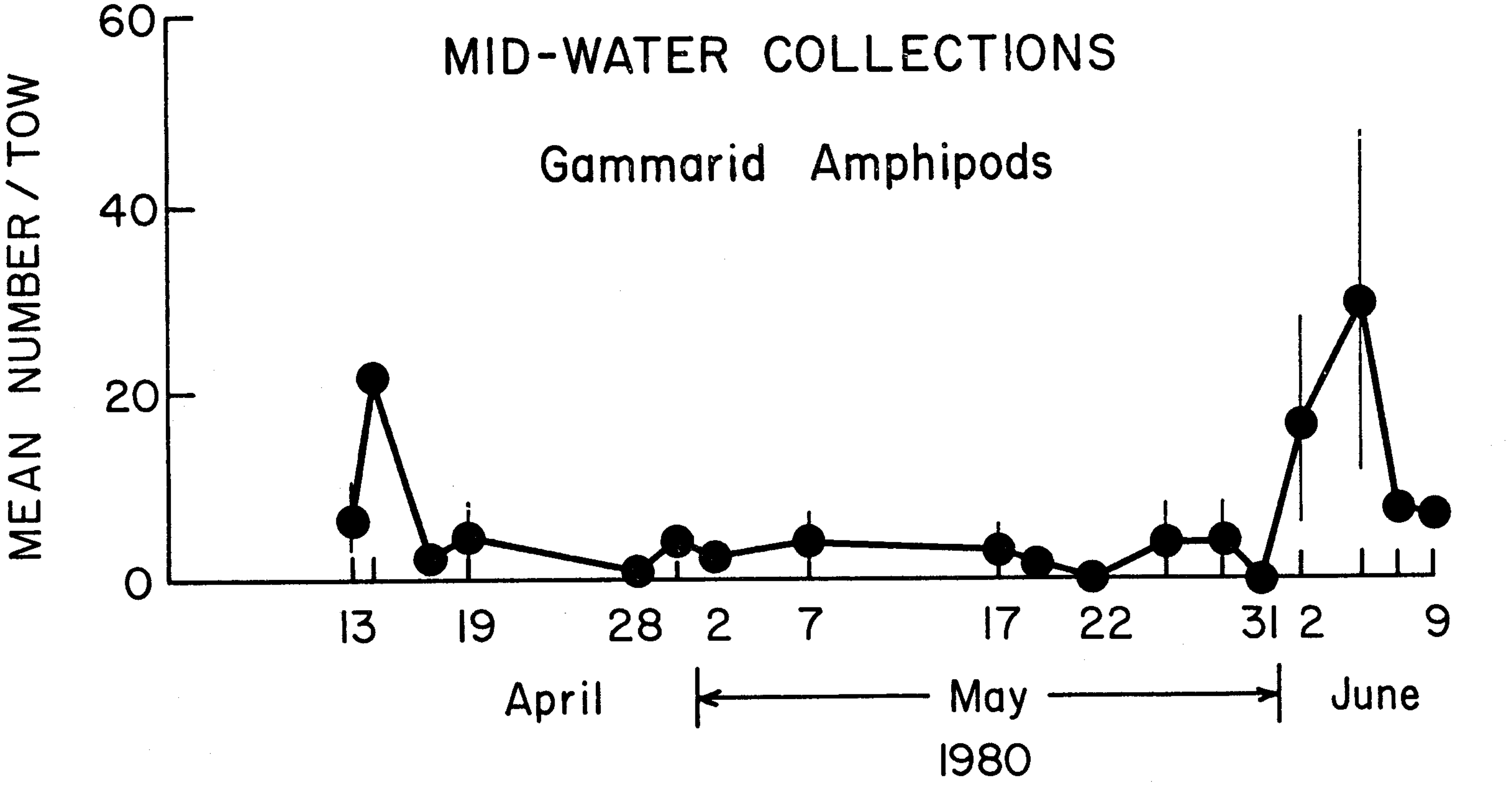

Figure 24. Mean abundance of gammarid amphipods collected by 3/4 meter ring net during the spring, 1980 at the Narwhal Island ice station. Collections made between 1000 and 1200 hrs. The samples were dominated by the amphipod species *Pseudalibrotus litoralis*.

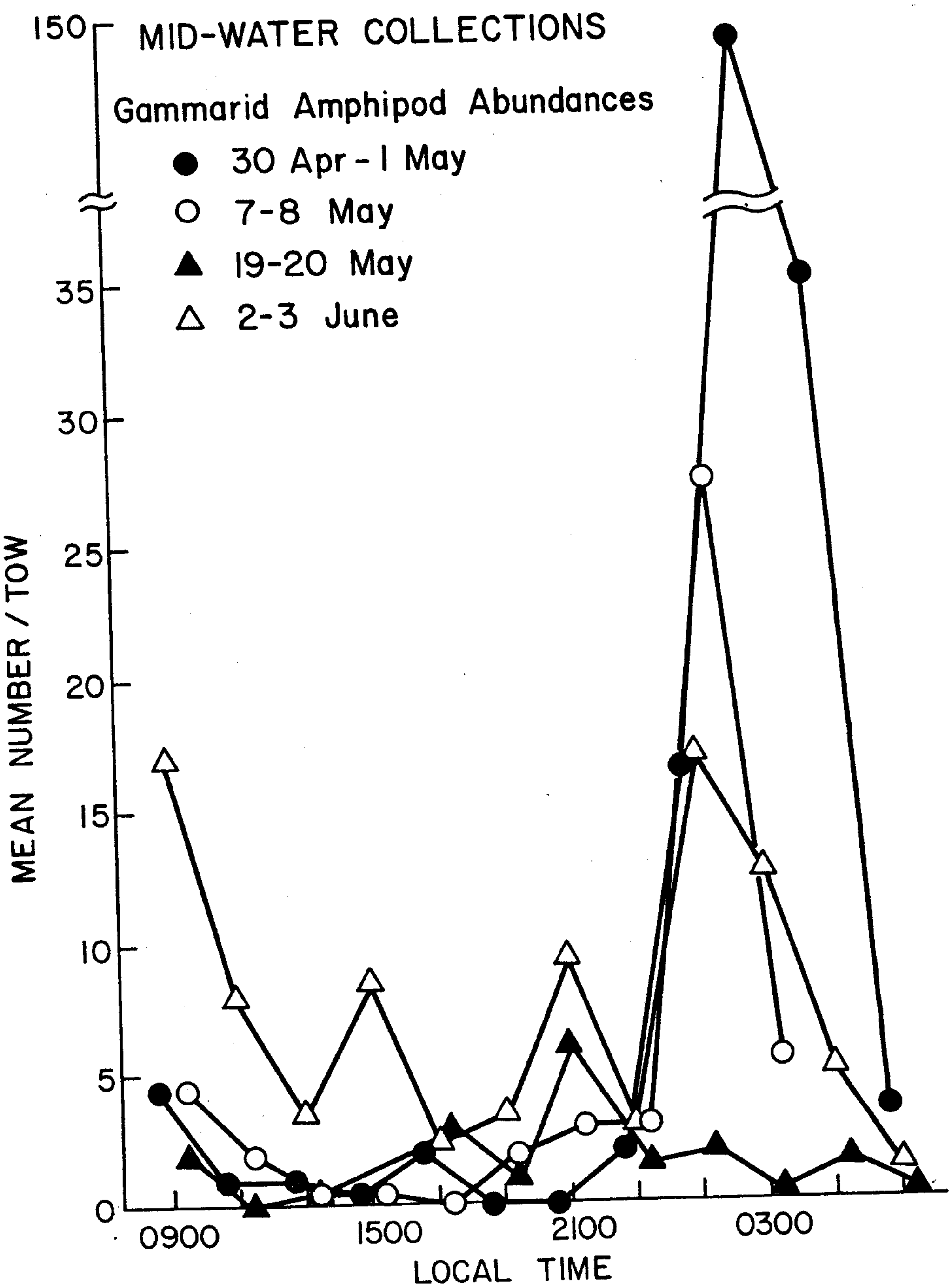

Figure 25. Mean abundance of gammarid amphipods per 3/4 meter net haul during 24 hrs. throughout the spring (1980) at the Narwhal Island ice station. The samples were dominated by the amphipod species *Pseudalibrotus litoralis*.

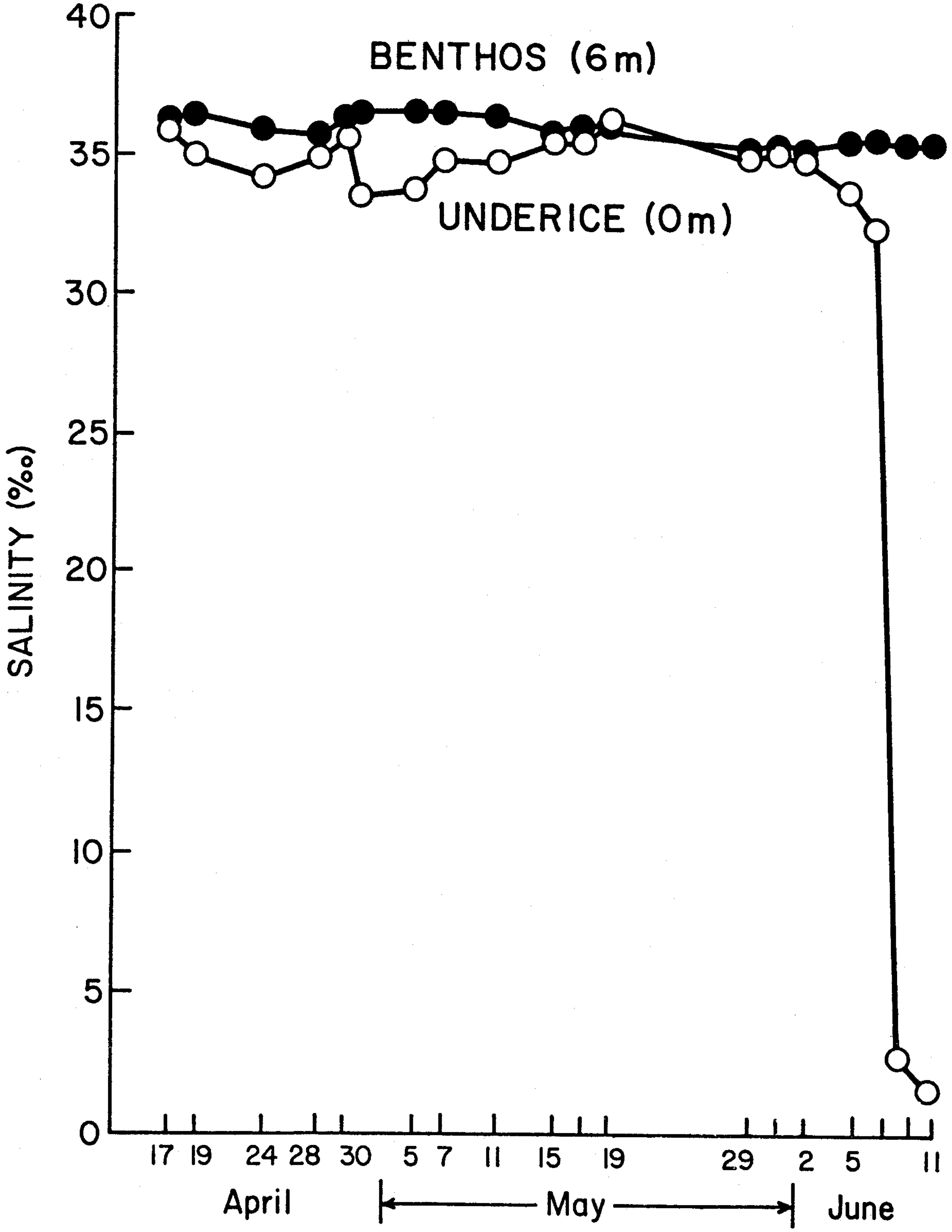

Figure 26. Salinity of water adjacent to the ice undersurface and the sediment surface during the Spring, 1980 at the Narwhal Island ice station during Project Sea Ice-80.

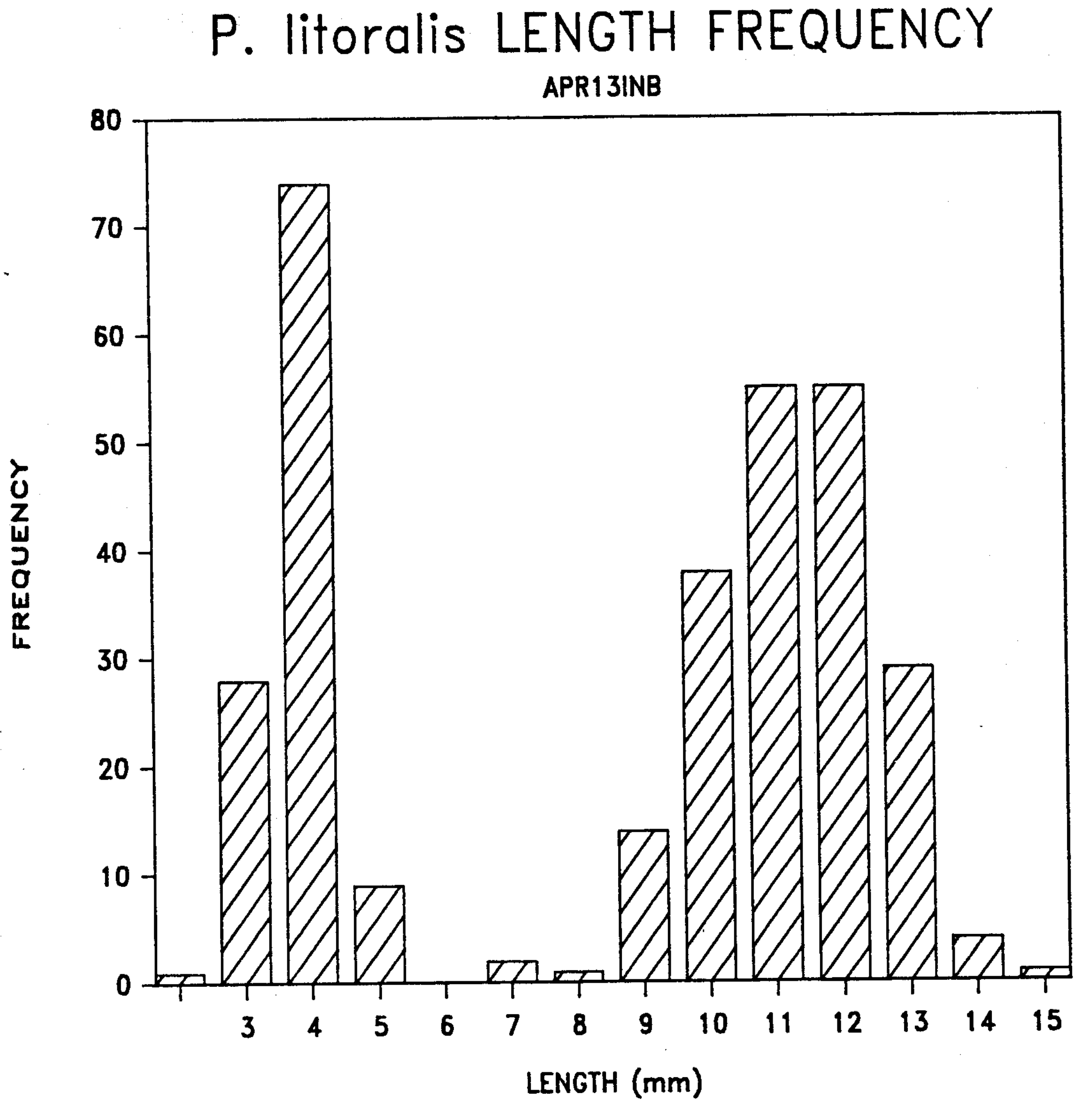

Figure 27. Length-frequency structure of the Pseudalibrotus litoralis populations in the ice environment at the Narwhal Island ice station, 13 April 1980.

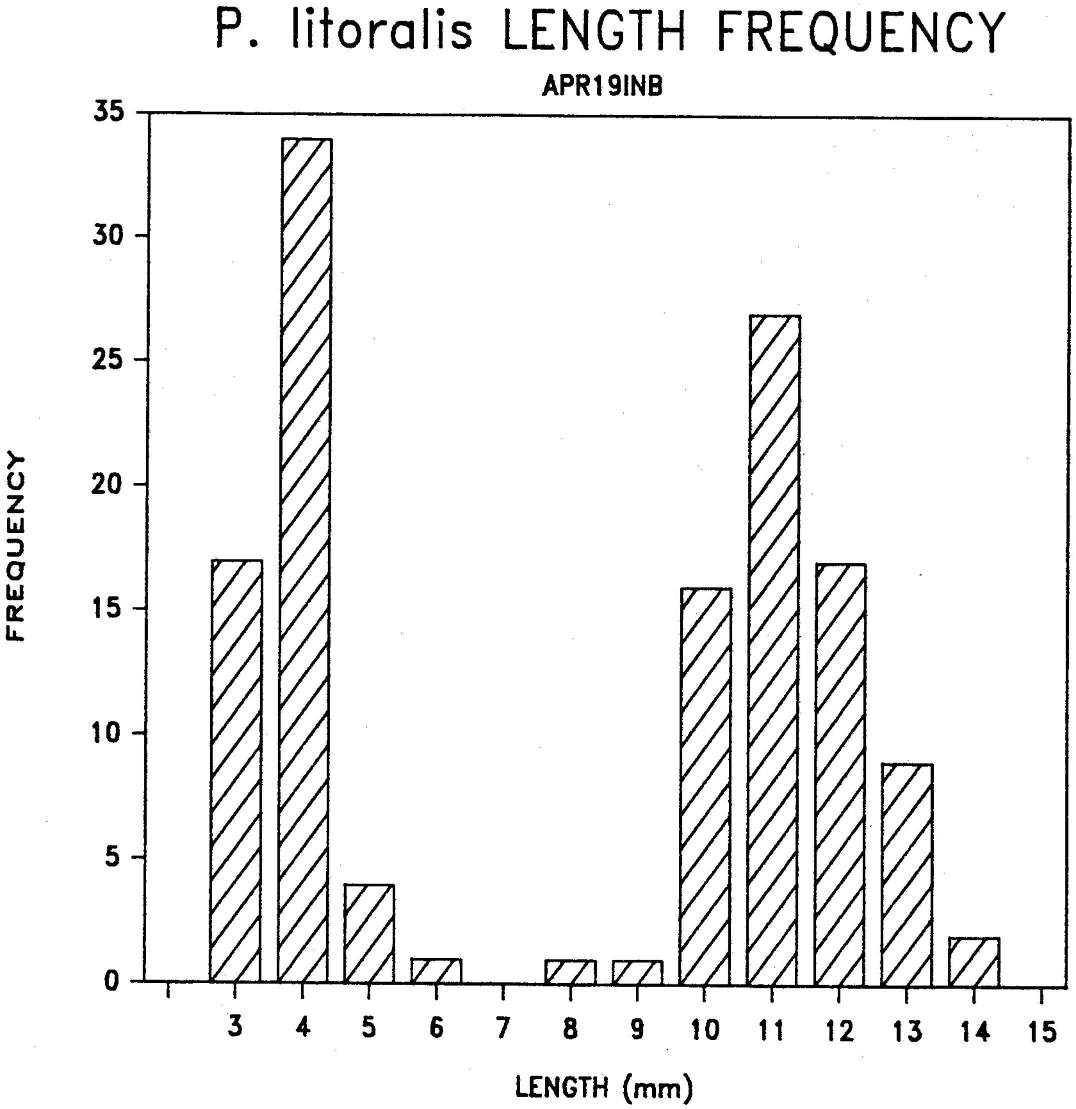

Figure 28. Length-frequency structure of the Pseudalibrotus litoralis populations in the ice environment at the Narwhal Island ice station, 19 April 1980.

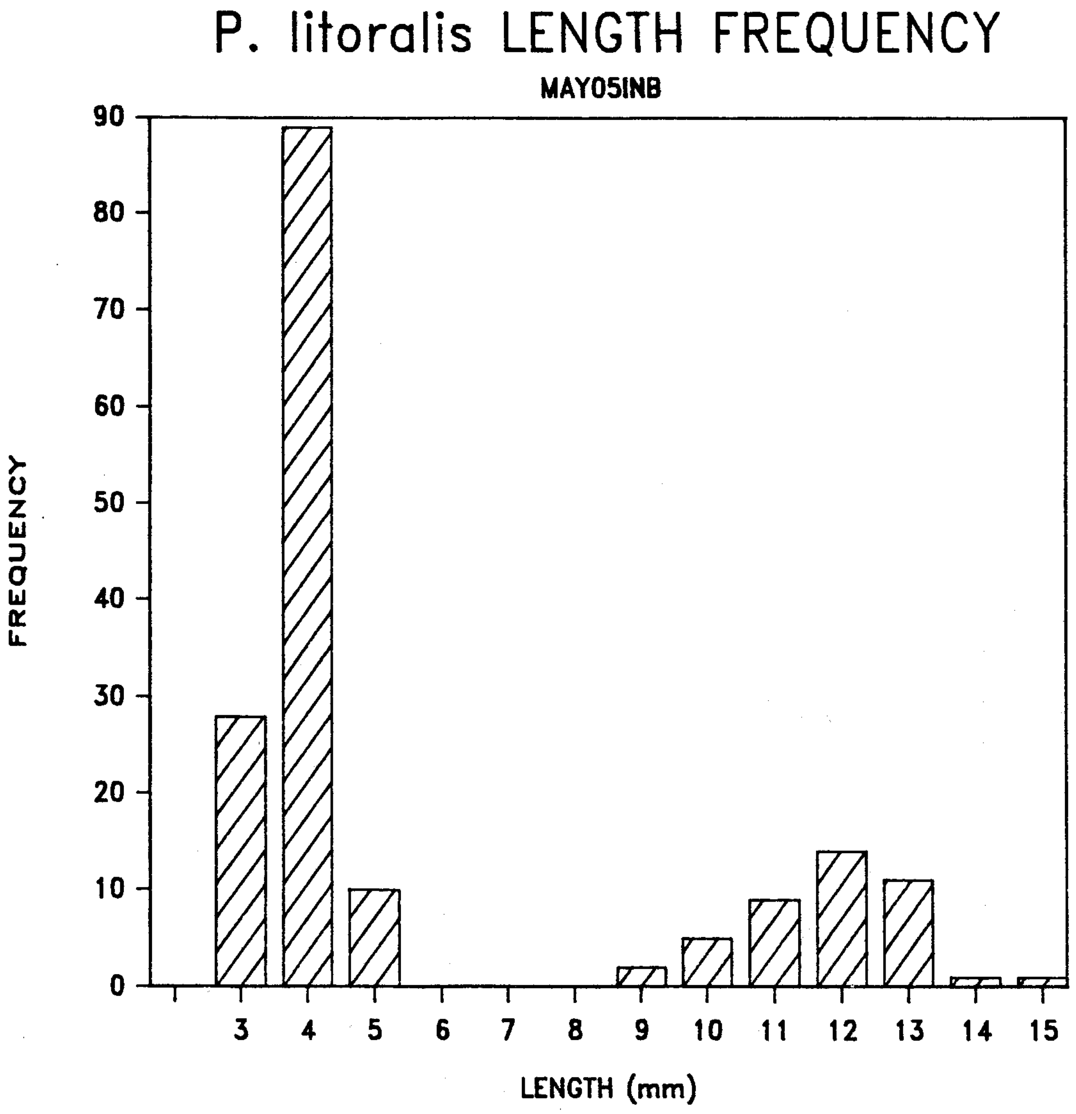

Figure 29. Length-frequency structure of the *Pseudalibrotus litoralis* populations in the ice environment at the Narwhal Island ice station, 05 May 1980.

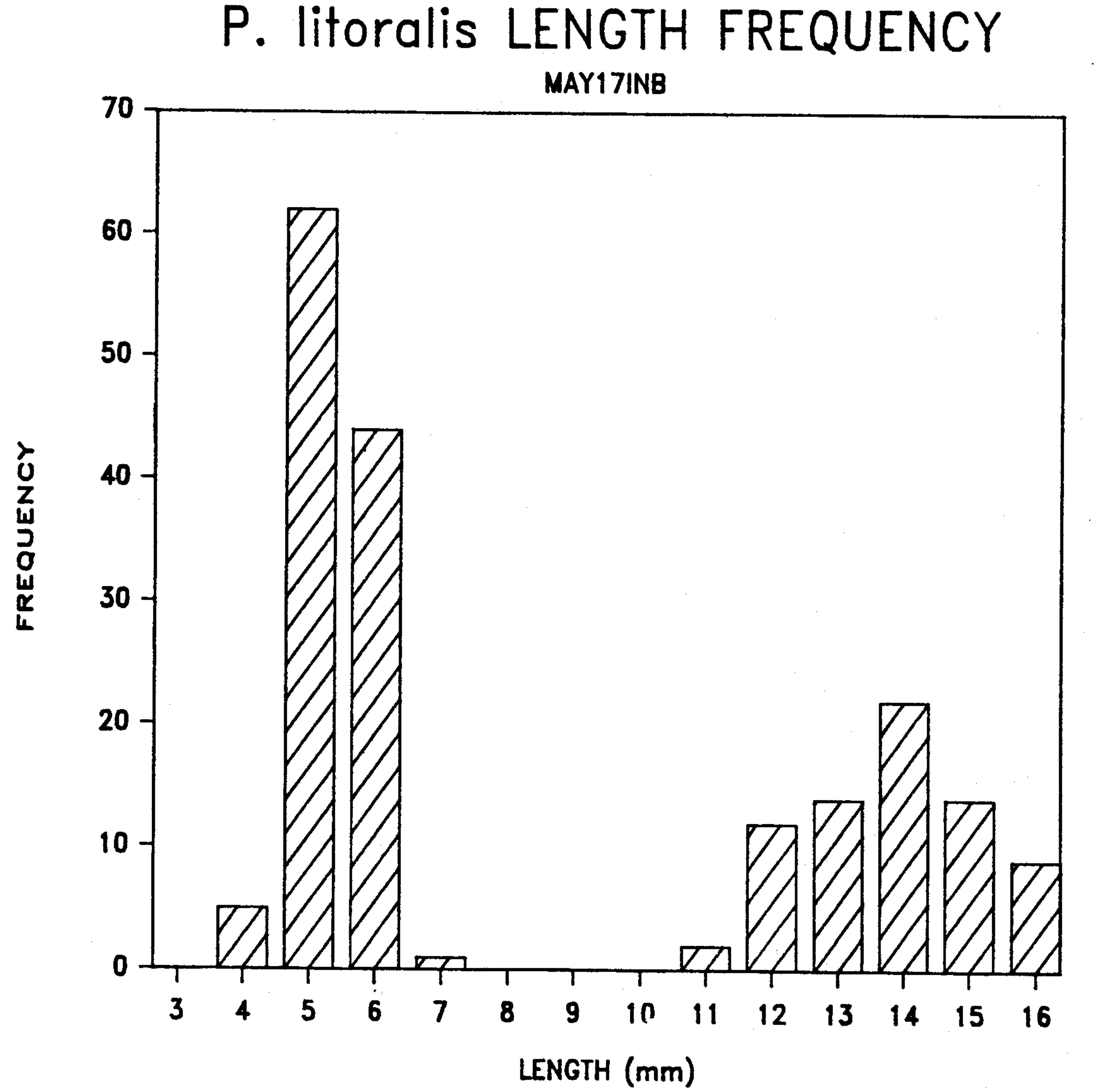

Figure 30. Length-frequency structure of the Pseudalibrotus litoralis populations in the ice environment at the Narwhal Island ice station, 17 May 1980.

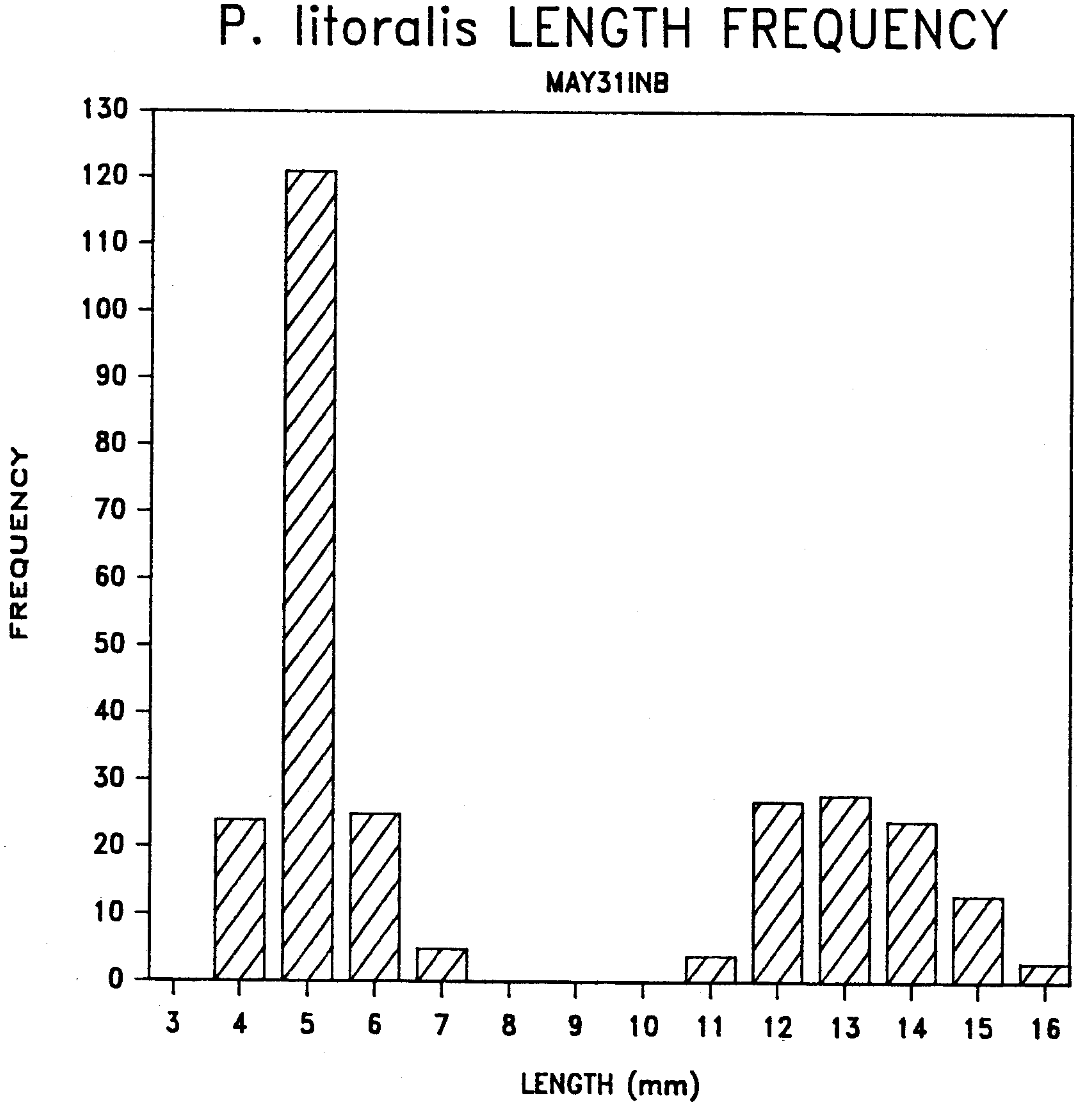

Figure 31. Length-frequency structure of the Pseudalibrotus litoralis population in the ice environment at the Narwhal Island ice station, 31 May 1980.

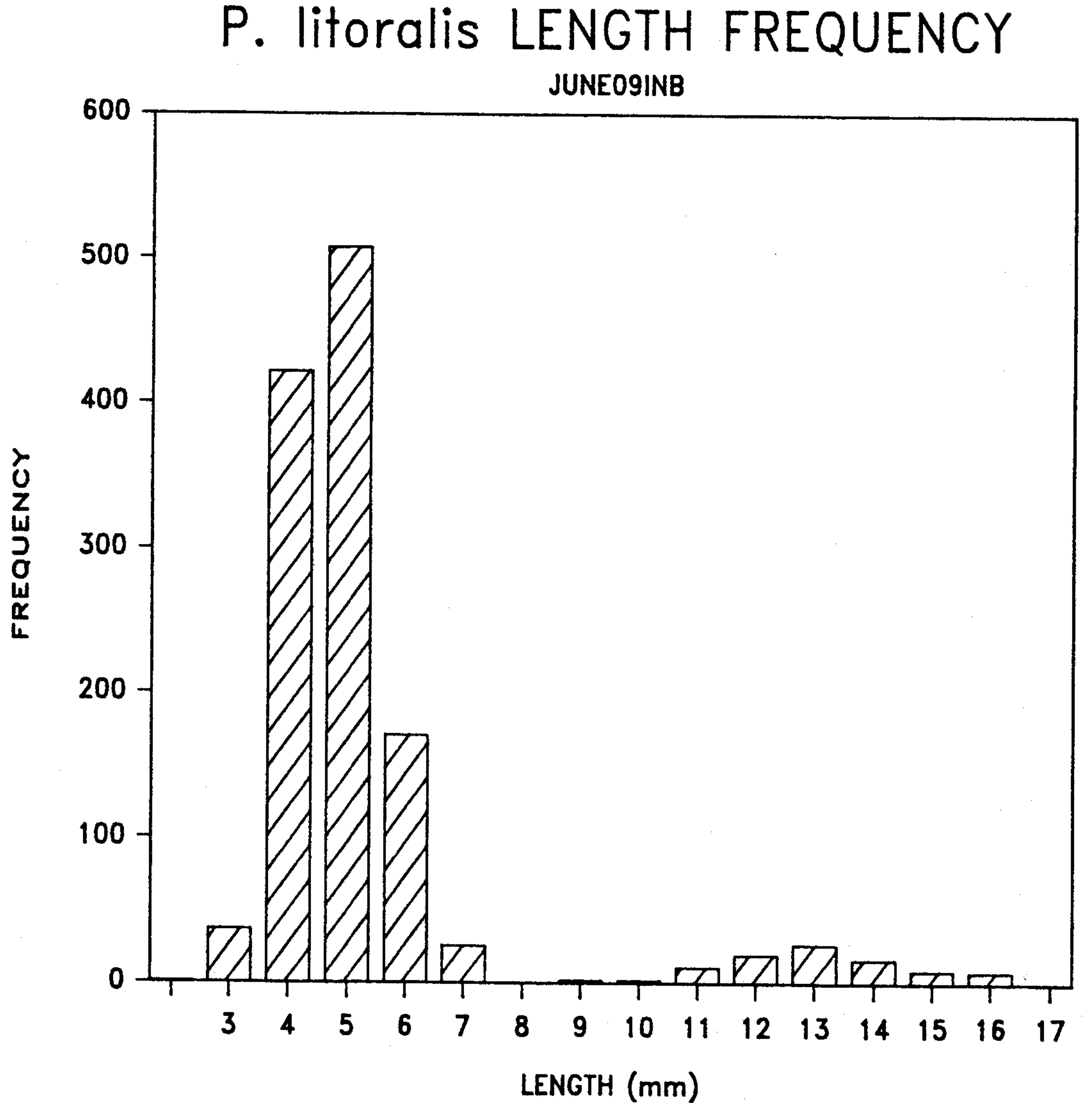

Figure 32. Length-frequency structure of the Pseudalibrotus litoralis population in the ice environment at the Narwhal Island ice station, 09 June 1980.

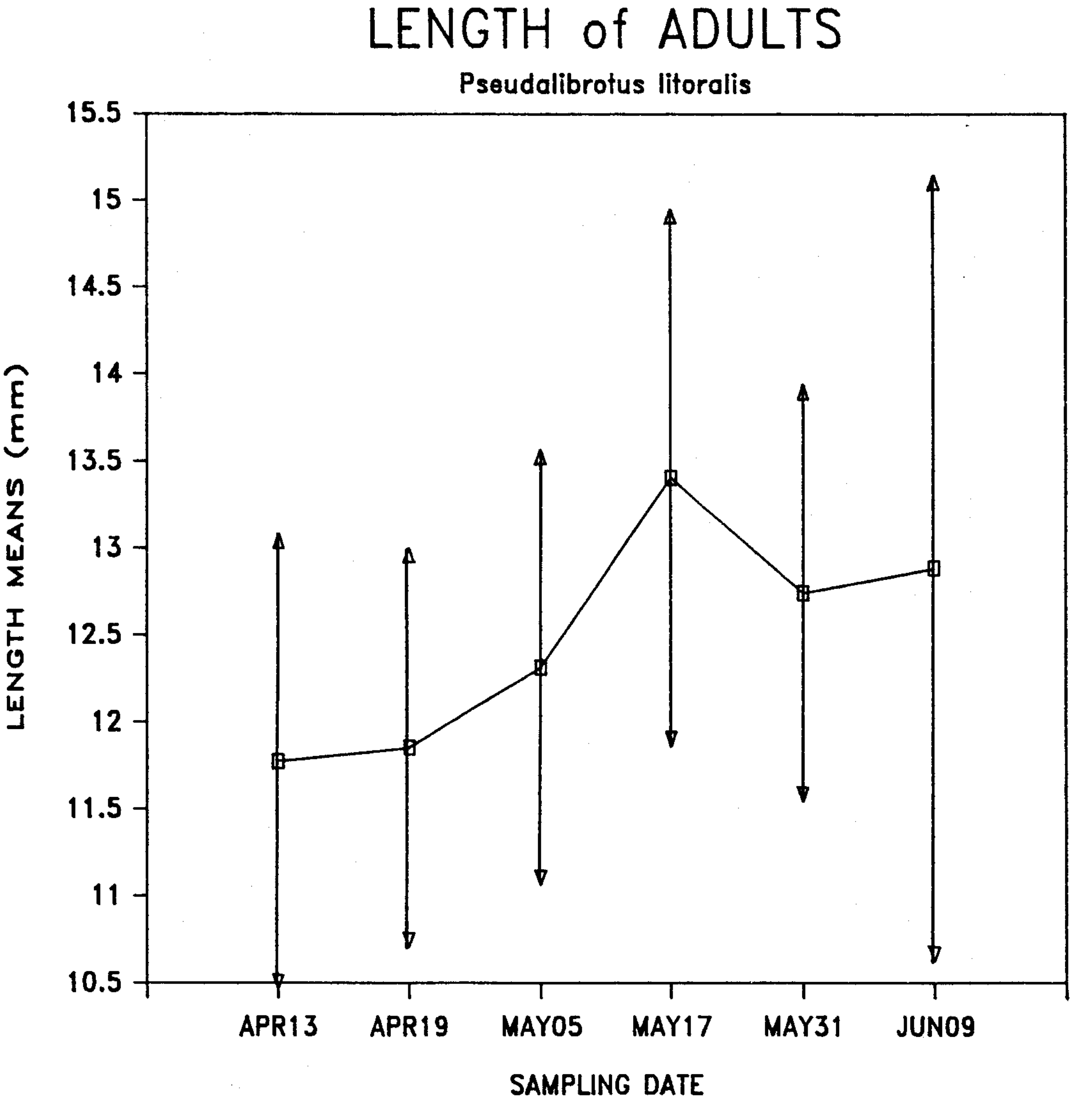

Figure 33. Length of adult Pseudalibrotus litoralis populations in the ice environment at the Narwhal Island ice station, 1980. Means ± 1 standard deviation.

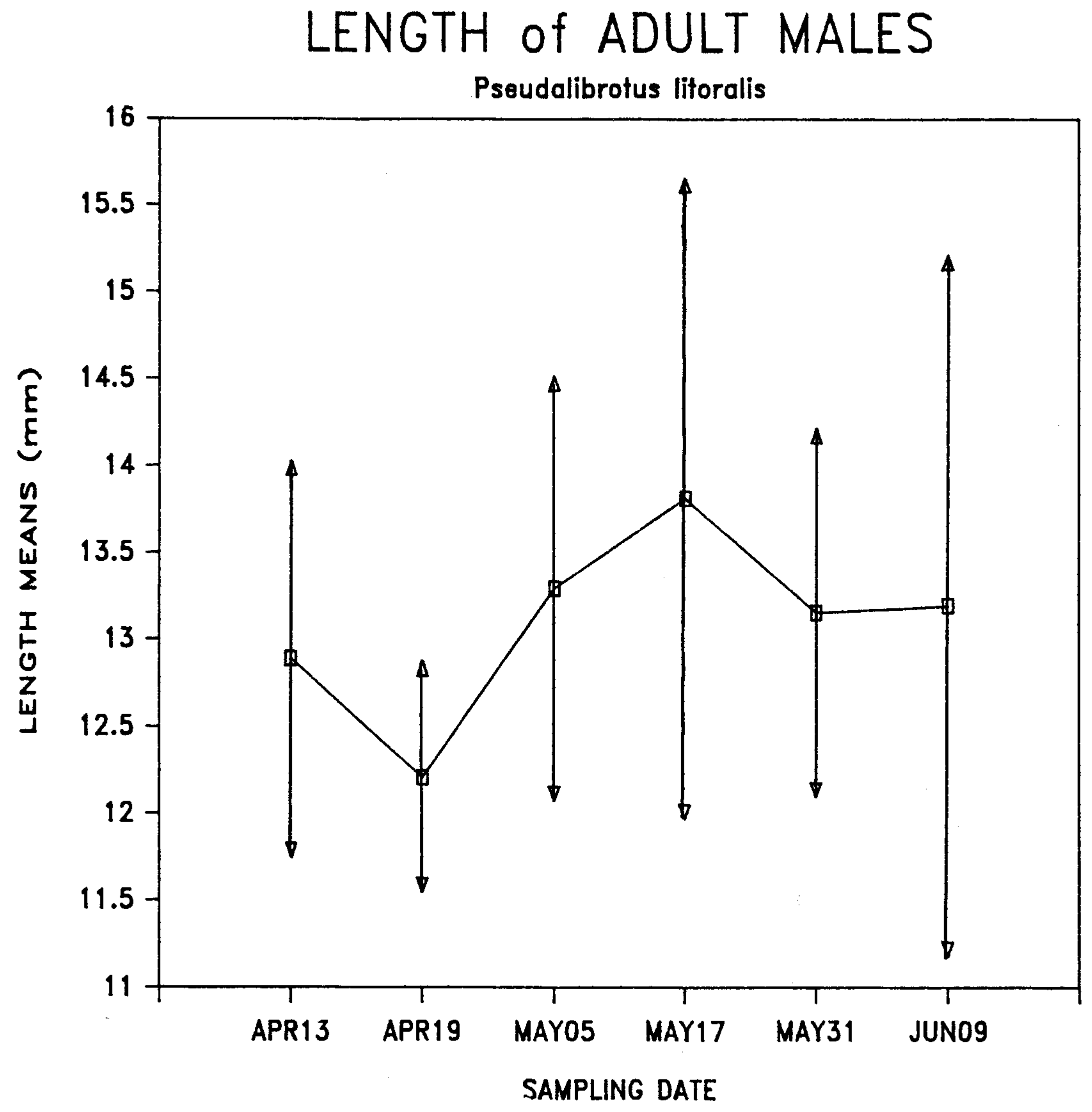

Figure 34. Length of adult male Pseudalibrotus litoralis populations in the ice environment at the Narwhal Island ice station, 1980. Means ± 1 standard deviation.

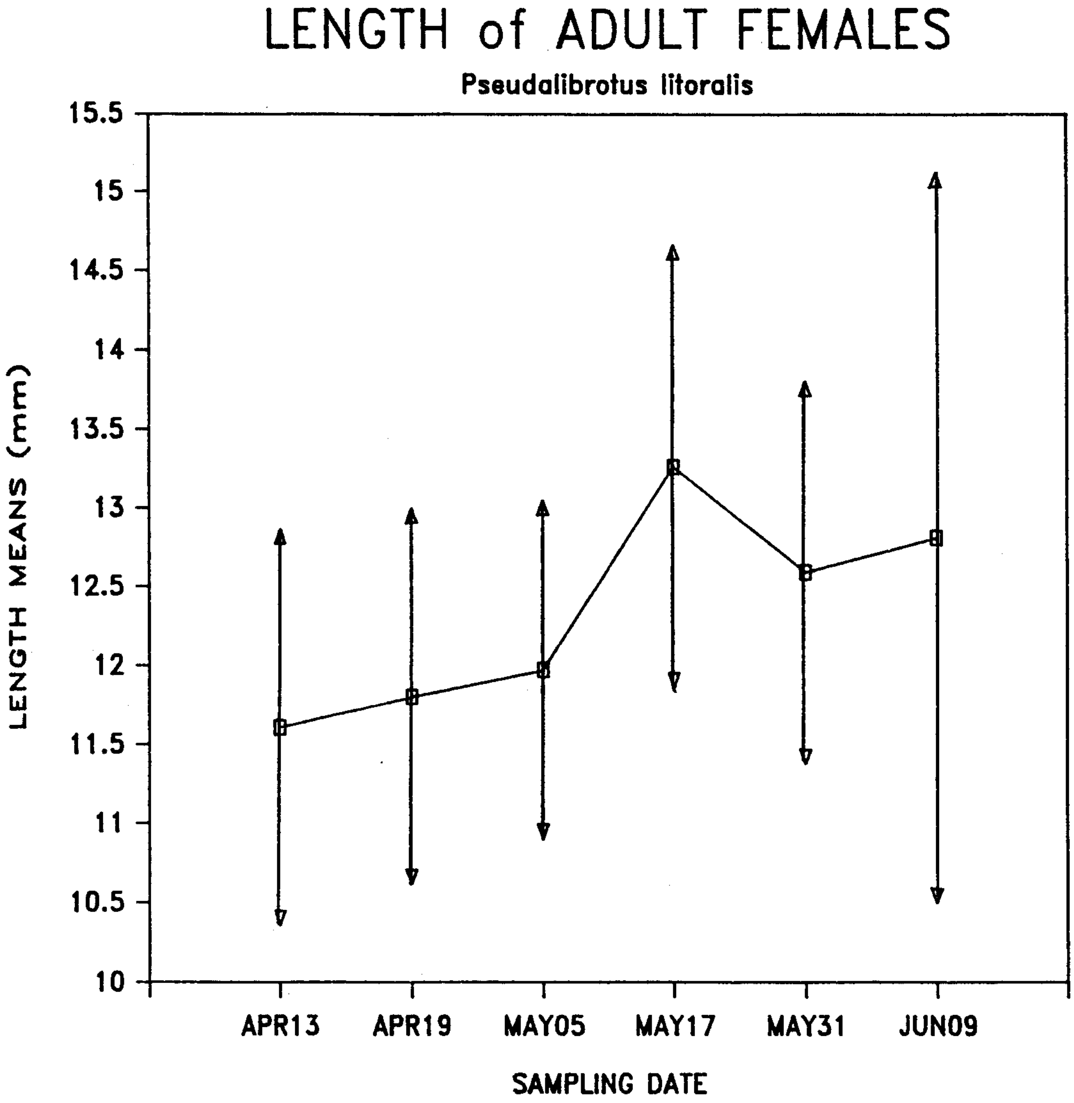

Figure 35. Length of adult female <u>Pseudalibrotus litoralis</u> populations in the ice environment at the Narwhal Island ice Station, 1980. Means ± 1 standard deviation.

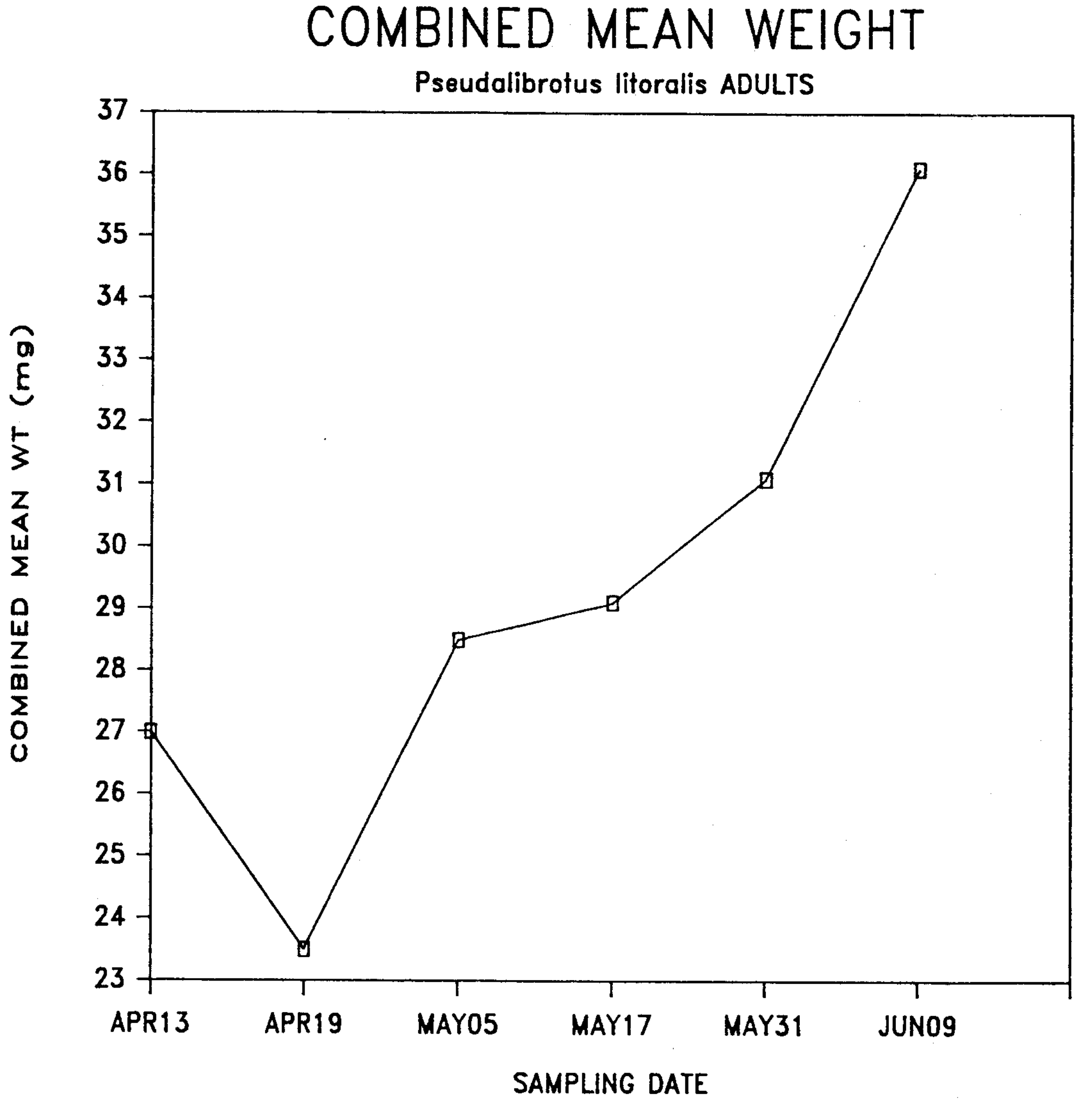

Figure 36. Combined mean weight (wet preserved) of Pseudalibrotus litoralis adults in the ice environment at the Narwhal Island ice station, 1980.

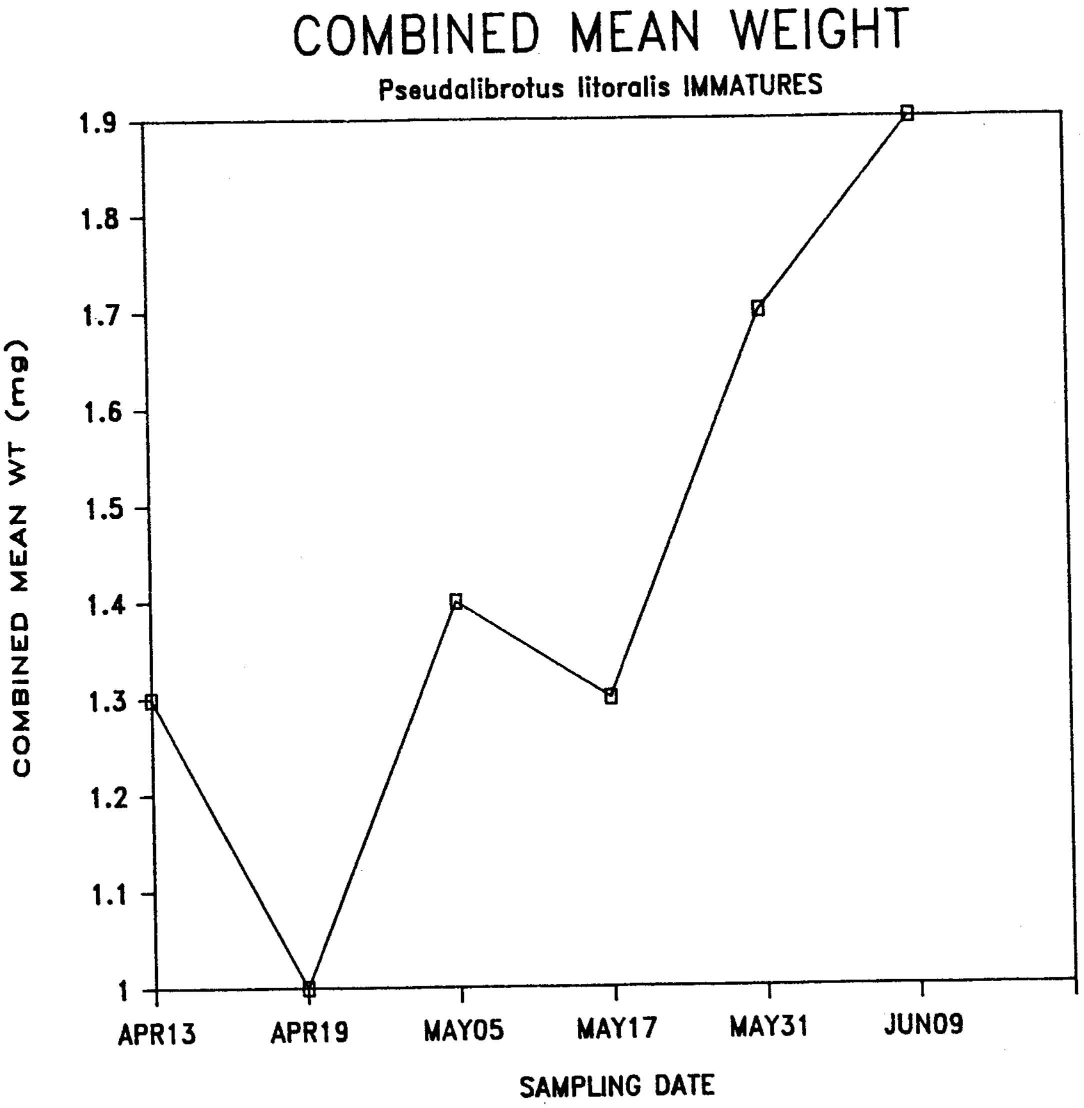

Figure 37. Combined mean weight (wet preserved) for *Pseudalibrotus litoralis* in the ice environment at the Narwhal Island ice Station, 1980.

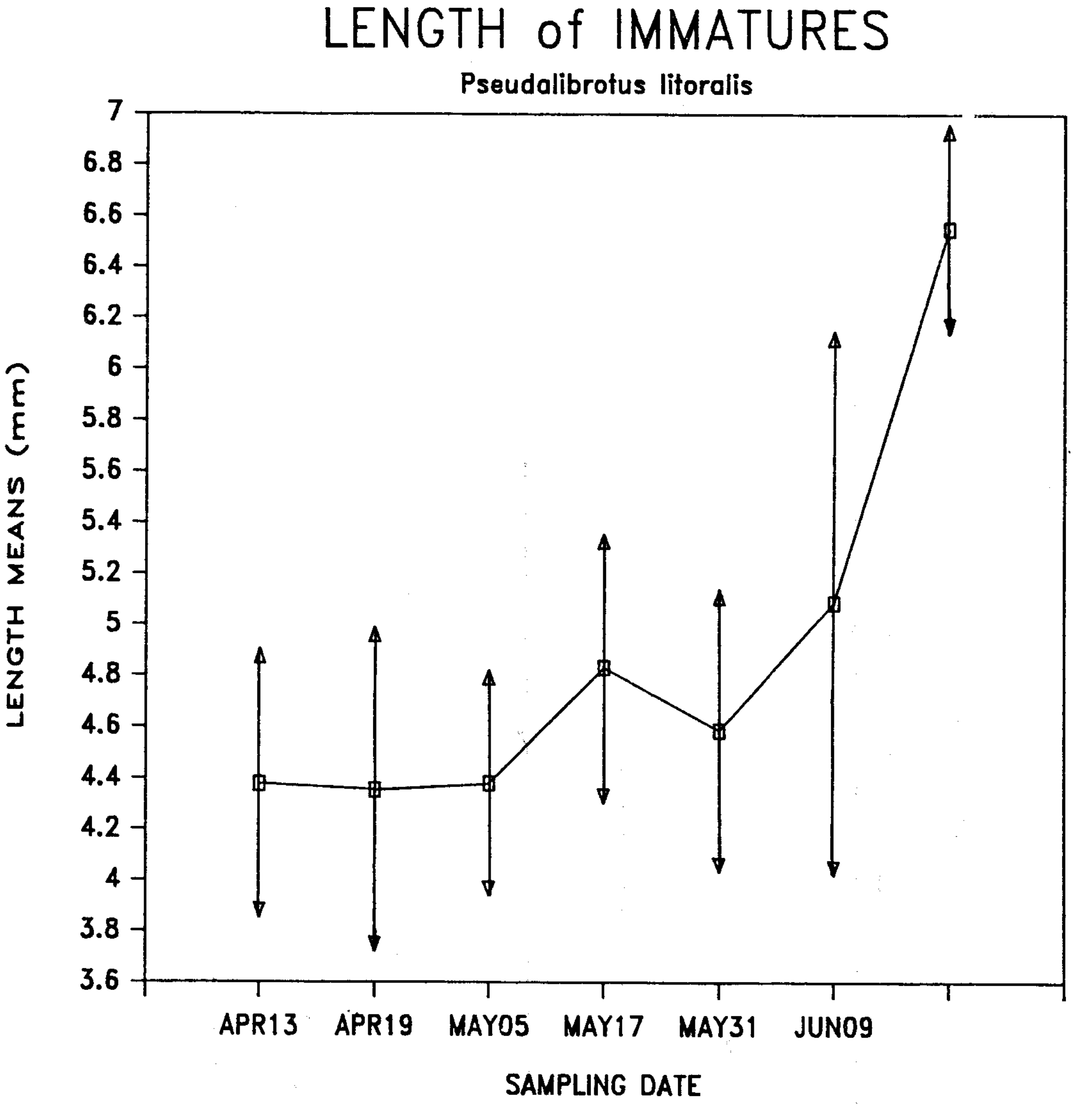

Figure 38. Length of immature Pseudalibrotus litoralis populations in the ice environment at the Narwhal Island ice station, 1980. Means ± 1 standard deviation.

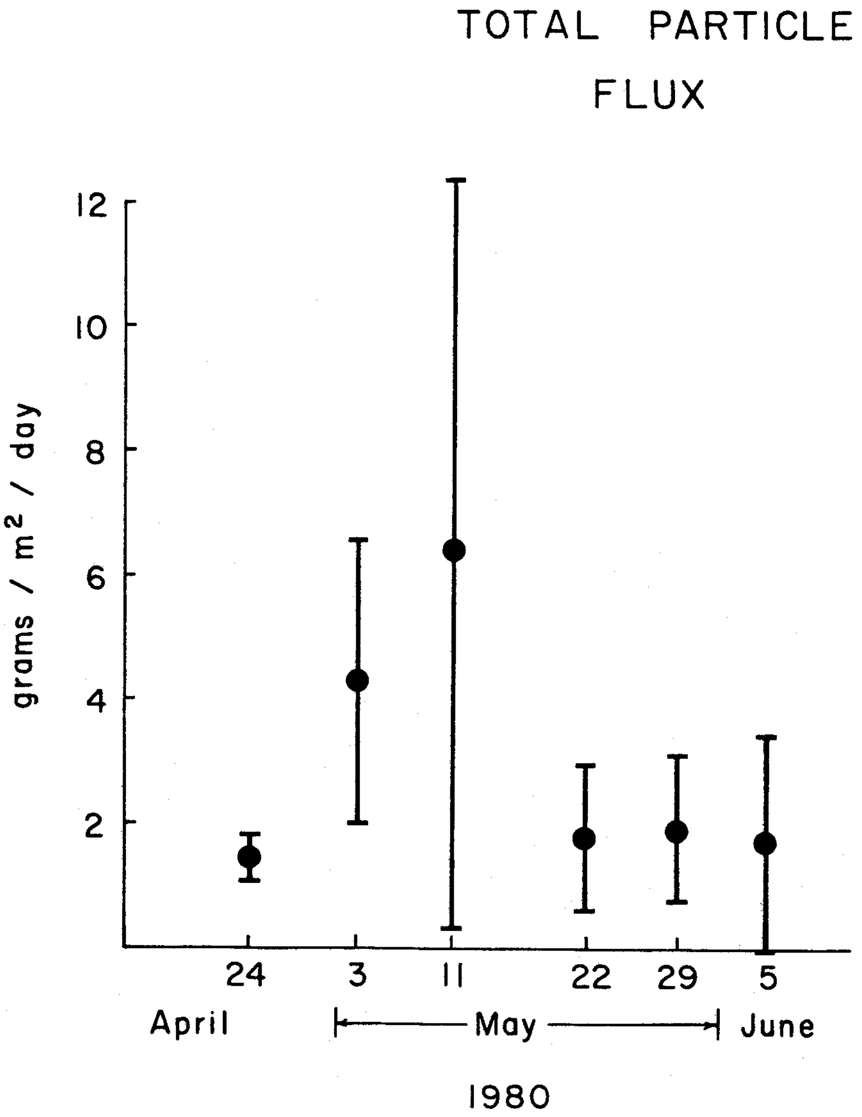

Figure 39. Total mass flux in grams to the sediment surface during spring, 1980, at the Narwhal Island ice station.

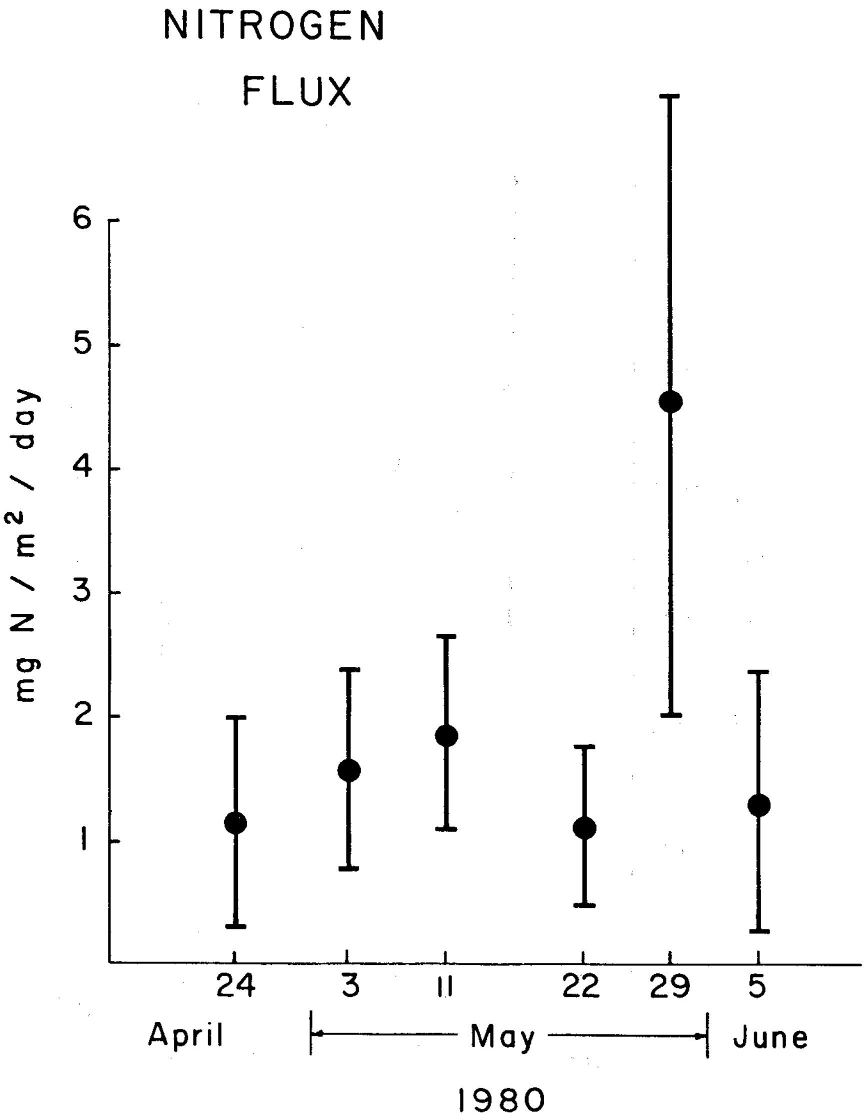

Figure 40. Flux of nitrogen to the sediment surface during spring, 1980, at the Narwhal Island ice station.

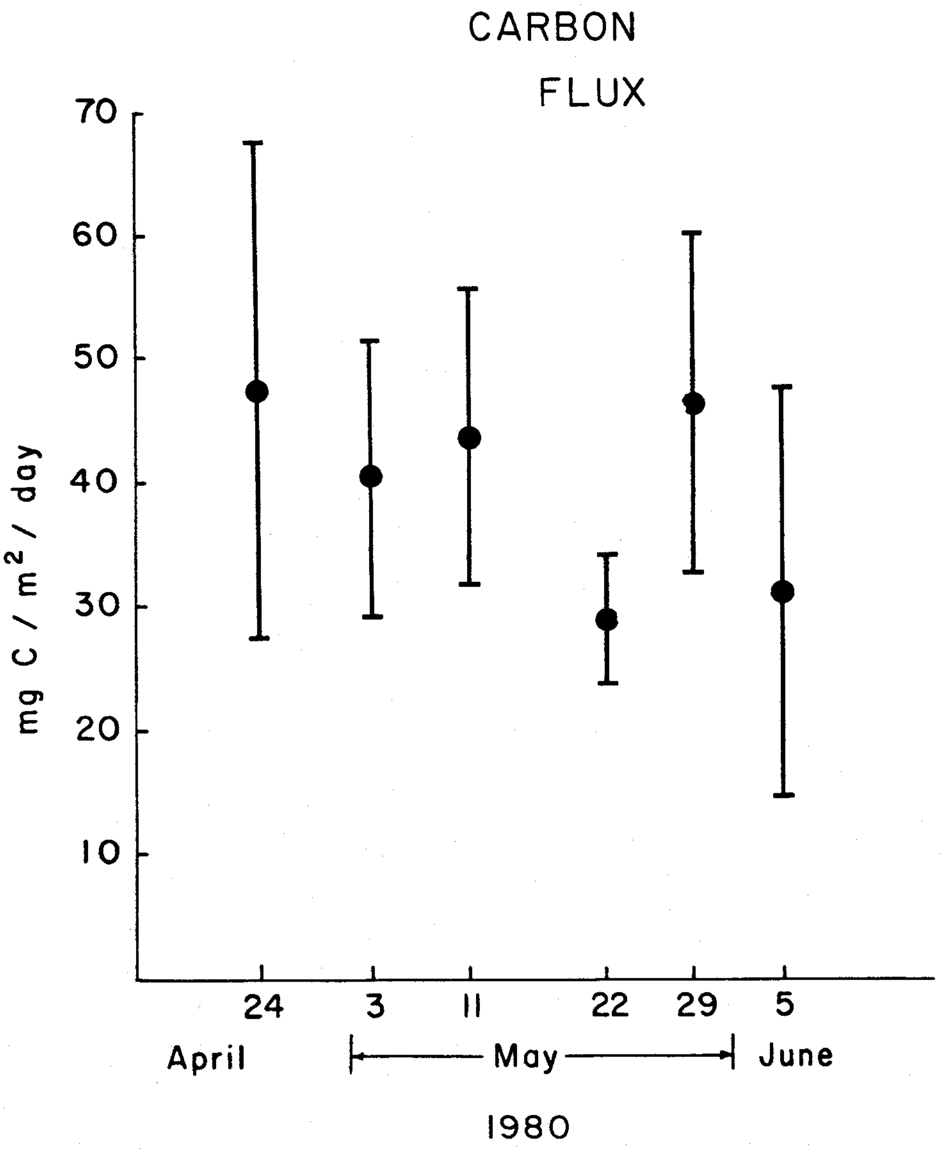

Figure 41. Flux of carbon to the sediment surface during spring, 1980, at the Narwhal Island ice station.

rial appeared as pigmented areas on the glass-fiber filter surface that consisted of generally amorphous matter. Individual diatom tests could be recognized by examination with the scanning electron microscope. Two recognizable fecal pellet types varied over the spring months with contrasting patterns of abundance (Figure 42). The larger pellets formed by the epibenthic mysid *Mysis relicta* were most abundant at the beginning of the collection series and then steadily declined. On the other hand, the smaller fecal pellets, from the amphipod *Pseudalibrotus litoralis*, rose in abundance to a peak on May 19, 1980, and then rapidly declined. A series of photomicrographs and scanning electron micrographs illustrate these pellets and their contents (Appendix III: Figures 55-63). The *M. relicta* pellets contained a complex matrix of generally unidentified material, though some diatom tests and possible crustacean fragments are present. The *P. litoralis* pellets are comprised almost entirely of numerous ice diatom tests.

D. Voucher collections

Species of polychaete worms and pelecypod molluscs encountered during the OCSCEAP studies of RU #006 in the southwest Beaufort Sea have been submitted to the Marine Invertebrate Zoology section, California Academy of Sciences (Appendix IV: Tables 38 and 39).

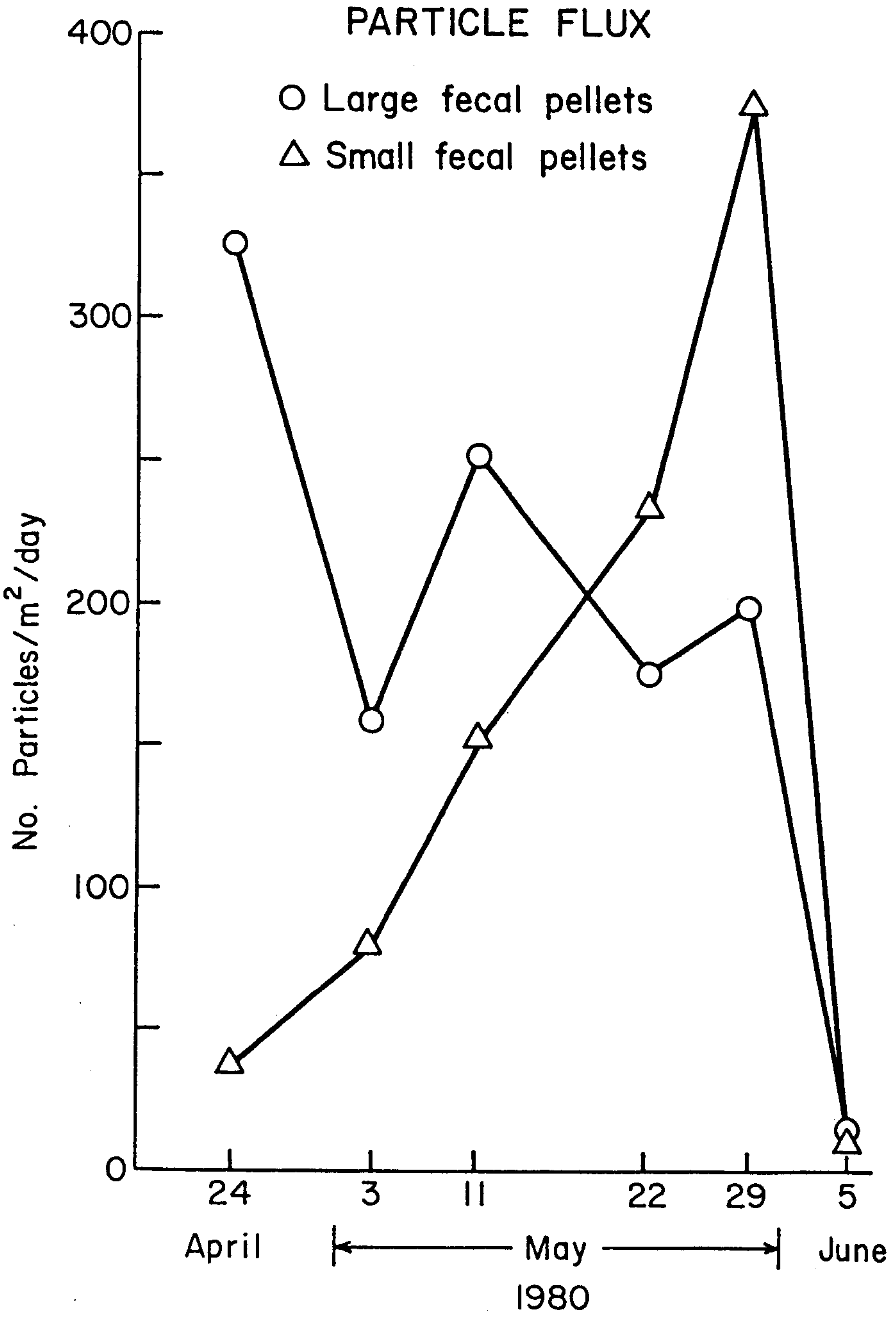

Figure 42. Flux of fecal pellets to the sediments during the spring, 1980 at the Narwhal Island ice station. The large pellets are formed by the epibenthic mysid Mysis relicta and the small pellets by Pseudalibrotus litoralis.

VII. Discussion

A. Benthic continental shelf fauna: cross-shelf trends

Low faunal abundance, species richness, and biomass at the 5 m station indicate an inhospitable environment for biological or physical reasons. In the arctic coastal zone the sea ice appears to be the most important controlling factor. The deeper drafts of pressure ridge keels rest on the sediments at the shallowest depths. Highly saline water forms beneath the ice as salt is excluded and drains downward through the ice during the winter months (Gade et al., 1974). This bottom water layer can become very cold, adding to the stress encountered by the benthic organisms in this zone. There also can be direct mechanical effects of the sea ice on the sediment cover in areas where ice-push builds ridges, levees or jumbled terrestrial fields of ice blocks (Wadhams, 1980). In some areas ice-push can drastically alter the character of the shallow sea floor and presumably damage the benthic fauna. Benthos from several 5 m stations along the coast (Carey et al., unpublished ms) exhibit depressed levels of abundance in areas of known ice override of adjacent low-lying gravel barrier islands.

Lowered summer salinities at these shallow depths, caused both by ice melt and the summer river runoff probably also create a harsher environment by increasing the total salinity range over which the animals must survive (Appendix I: Table 15).

It is also possible that high predation pressure from several of the benthic-feeding migratory waterfowl deplete these shallow water standing stocks. Eider and old squaw ducks are extremely plentiful during their summer feeding and breeding season and feed on shallow benthos, particularly bivalve molluscs (Divoky, 1978).

The inner continental shelf of the Beaufort Sea (5-25 m depth) is subject to strong environmental disturbances in salinity, turbulence, turbidity and ice gouging. These are strongly seasonal, and several are zoned by depth in spite of the narrow range studied. Most of the bivalve distributions, faunal abundances and functional group compositions (feeding type, reproductive pattern, and substrate orientation) tend to be homogenous along the length of the Alaskan Beaufort coast (Carey et al., 1984). At the deepest stations, however, there seems to be a selection for the deposit feeding mode of existence in the siltier sediments. These results suggest that the fluctuating environment has selected for a generalized assemblage of animals.

Polychaetous annelids, collected in coastal waters (5-25 m) along the length of the Alaskan Beaufort Sea coastline, represent a relatively uniform and speciose fauna (105 species) (Carey et al., unpublished ms). Species richness and total numbers vary little with depth and longitude. Generally there are few dominant species; a large species group (39) is widely distributed throughout the environment studied. At the shallowest depths, however, selective surface deposit feeders predominate in the sandy sediments found there. Predators and non-selective deposit feeders are relatively uniform and low in abundance through the region. In spite of a physically structured environment, compositional similarity of the fauna is greater than expected by chance from Point Barrow to Barter Island (Appendix I: Table 16). Several processes disturb the environment, probably selecting for an environmentally tolerant fauna.

On the average, the total benthic macrofaunal community varies in numerical density and biomass over a year's period (Carey, unpublished ms). These changes are more marked on the outer half of the shelf than on the inner shelf at 25 m depth. Small organisms increase in total numbers during the late summer indicating an increase of the population size of small species and perhaps the recruitment of juveniles of the macrofauna to the benthic community. An analysis of population size structure of three species of bivalve molluscs and four species of polychaete worms does not, however, demonstrate a seasonal and discrete burst of recruitment to these populations. It appears that most benthic invertebrate species reproduce throughout much of the year by producing small numbers of yolky lecithotrophic eggs.

The mega-epifauna species distributions, derived from both the photographs and trawl collections, demonstrate a general trend toward very broad depth distributions (Figure 11). These data also illustrate that the shallowest, more variable stations support few species of mega-epifauna.

Comparisons of the abundances of the benthic megafauna and macrofauna demonstrate a general negative correlation between the two groups (Figure 43). Where the megafauna are most abundant, the macrofauna tend to be depressed in numerical density. This relationship could be caused by direct predation on the larvae, juveniles or adults of the macrofauna, or an environment feature such as detrital food supply could have a differential effect on the two faunas.

B. Ice fauna (Narwhal Island)

During the last ten years the primary production of the ice algae has been reported to contribute up to 40% of the total carbon fixed by marine plants in the arctic ecosystem (Alexander, 1974; Horner, 1977; Horner and Schrader, 1982). Because this late spring ice algal production on the undersurface of sea ice occurs before plant production can be supported in the water column or on the sediments, this early source of carbon significantly extends the arctic growing season (Alexander and Chapman, 1981). The undersurface of the ice supports an abundant invertebrate fauna, and the algal community is an important source of energy for these organisms migrating to this interface (Cross, 1982; Carey and Montagna, 1982; Kern and Carey, 1983). These animals in turn form the basis of an abbreviated food web that links the underice fauna to fishes and to seabirds and seals (Bradstreet, 1982; Bradstreet and Cross, 1982).

SCUBA observations and sectioned ice core samples indicate that the sympagic amphipod species occupy a variety of sub-habitats. Generally the macrofauna occupy the lower 5 to 10 cm of ice (Pett et al., 1983), though individuals were observed living in brine channels (Lewis and Milne, 1977; Cross, 1982; Newbury, 1983) and partially or fully embedded within the ice (Gulliksen, in press). Green and Steele (1975) report that Gammaracanthus loricatus is the only amphipod species associated with ice stalactites and may at times be frozen within them. On occasion Apherusa glacialis occupy the brine channels, though they are mostly on the ice undersurface (Cross, 1982). A. glacialis tends to be patchy in distributions with aggregations of juveniles concentrated on clumps and strands of ice algae.

In contrast to the species composition of the ice macrofauna in deeper and offshore waters, whether in fast ice or pack ice, the gammarid amphipod Pseudalibrotus litoralis dominates the ice macrofaunal community on the inner shelf in water depths of about 10 m (Green and Steele, 1975; Carey, 1982).

The large numbers of animals found within the ice of the Beaufort Sea is surprising. Andriashev (1968) provided the only data in the literature that can be used for quantitative comparisons, and his data were from the Antarctic. He found solitary polychaete individuals, cyclopoids up to several hundreds/m^2, harpacticoids (including species of Harpacticus and Dactylopodia) up to hundreds/m^2, and amphipods up to 3040/m^2. No information was given for turbellarians, or for nematodes which was the dominant group in the arctic samples. Comparing the data sets on a per unit area basis (Table 1), it is apparent that the overall abundance of the ice fauna is much greater in the samples collected from the Arctic. Amphipods were the only group which had a greater density in the Antarctic. It is possible that the Beaufort Sea site was an unusually productive one, but there is no evidence to support this idea. The study area was visually indistiguishable from surrounding ice pans when viewed from a helicopter. Chlorophyll a values measured in the ice close to the Narwhal Island study grid (Horner and Schrader, 1981) are similar to those recorded elsewhere (Apollonio, 1965), although further sampling in other areas should be performed.

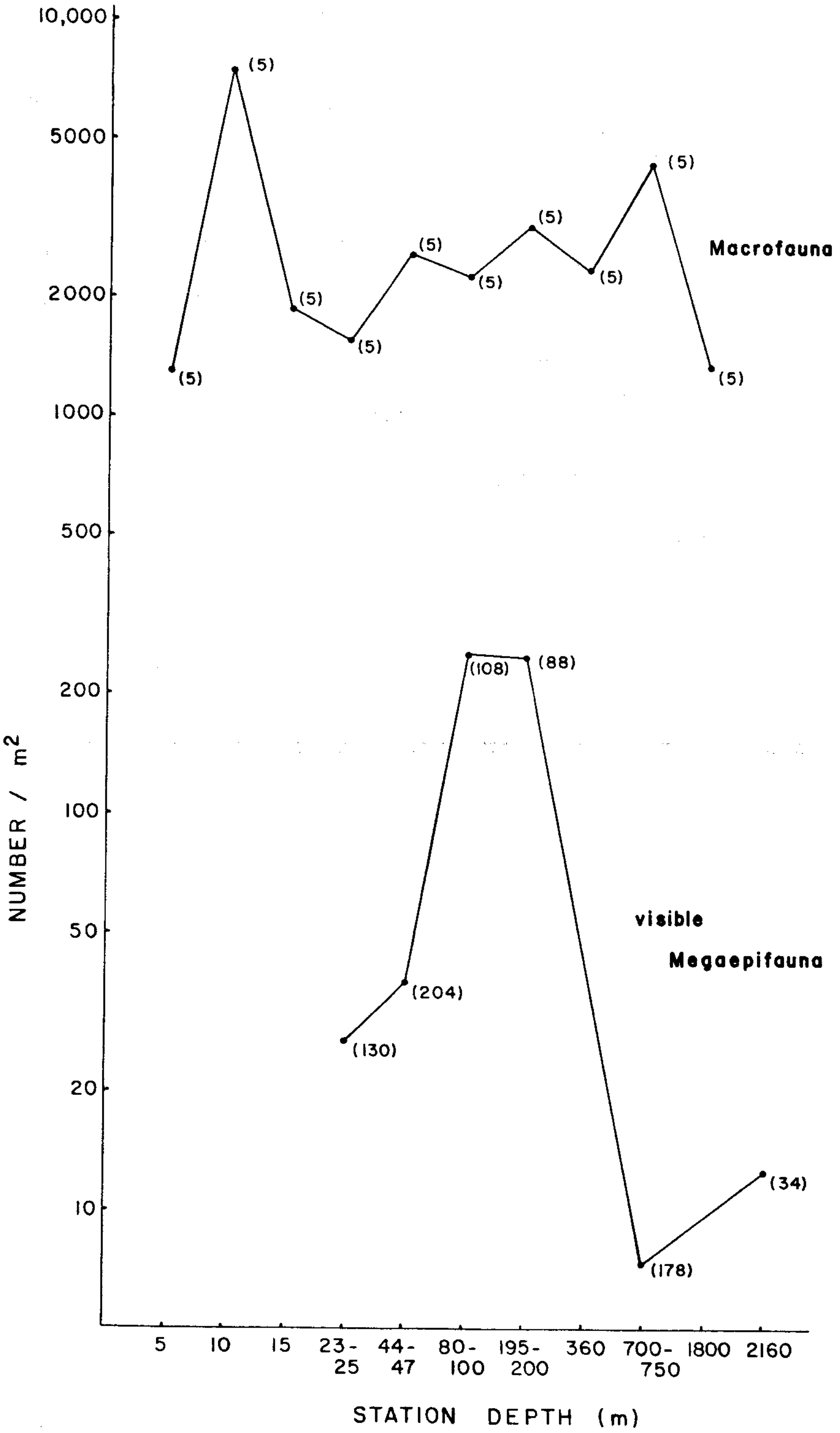

Figure 43. Comparison of the numerical density (means) of the macrofauna (>1.0 mm) and mega-epifauna (>13 mm) on the continental shelf - upper slope on the Pingok Island cross-shelf transect. The numbers of grab samples and photographic aerial coverage (m^2) are indicated in parentheses.

Table 1. Abundance of major taxa collected from sea ice in the Antarctic (Andriashev, 1968) and the Beaufort Sea. Values given are number per m^2. No values for Nematoda or Turbellaria were available from the Antarctic. The minimum densities for taxa collected from the Beaufort Sea were calculated using the lowest mean number per core; the maximum using the highest mean number per core.

Group	Antarctic	Beaufort Sea Minimum	Beaufort Sea Maximum
Polychaeta	Solitary Individuals	135	5,107
Cyclopoida	Up to Several Hundreds	1,058	7,737
Harpacticoida	Scores to Hundreds	1,079	4,638
Amphipoda	Up to 3040	218	1,193
Nematoda	-----------	359	25,022
Turbellaria	-----------	206	15,167

While the density of the ice fauna was greater than expected (Table 2), it was only around five percent of typical benthic meiofaunal density (Coull and Bell, 1979). This may be due to the ephemeral nature of the fast ice habitat. Seasonal ice is only present in the Beaufort Sea from September or October until around June (Barnes and Reimnitz, 1974), and populations must recolonize the lower layer of this ice each year. There is evidence, using artificial substrates suspended over the bottom, that some meiofaunal groups can rapidly develop large populations in abiotic sediments (Scheibel, 1974). Nematodes and copepods, the most abundant taxa in Beaufort Sea ice, were also the dominant groups colonizing the suspended substrates. This is not surprising since these two groups are typically the most abundant in normal sediments (McIntyre, 1969). At least some of the increase in density in Scheibel's study was due to continued immigration of animals after the sediments had initially been colonized. It is also possible that animals migrated to the ice from underlying sediments during the sampling period. However, nematodes are not able to swim large distances (Scheibel, 1974), and continued movement of these organisms to the ice would depend on passive transport from the bottom by advection. Reproduction was responsible for at least part of the increase in abundance observed in the ice. Gravid females were noted in the ice copepod species Cyclopina gracilis, Halectinosoma sp. and Dactylopodia signata. A few nematodes were examined, and gravid individuals were observed (E. W. Hogue, personal communication). Laboratory studies have shown that the time required for marine nematodes to complete one life cycle varies greatly, and can be as short as less than two weeks (Gerlach and Schrage, 1971). It may be possible that the rapid increase in abundance found for nematodes could largely be due to reproduction rather than passive transport, if the ice species have short life cycles.

Grazing by ice fauna may be important in regulating standing stocks of ice algae. It had previously been suggested that ice algae were free from grazing and that tha entire season's reproduction was released into the water column at breakup (Meguro et al., 1967). Nematodes collected from fast ice in the Beaufort Sea had guts filled with diatoms. Most benthic harpacticoids have been found to feed extensively on diatoms (McIntyre, 1969). The large densities of these organisms in the ice suggests that at least some of the algal production may be utilized in situ. Further work is required to determine the extend of grazing by ice fauna.

Environmental conditions within the ice were not recorded in this study so it is not possible to try to relate variations in faunal density between sampling dates to changes in their environment. One interesting finding was the similarity in the abundance trends exhibited by the three dominant copepod species (Figure 15). These species displayed the same relative changes in density throughout the study, suggesting that the same factor or factors might be affecting the populations in similar ways. Total copepod and amphipod abundance appeared to decline around 2 June. They might have been responding before other groups to changes in the ice associated with breakup. By 9 June, although the ice remained solid, there was a layer of low salinity (2.8 ppt) just below the water-ice interface, where no salinities lower than 28.9 ppt were recorded before (Figure 26).

There was a large amount of spatial variability in the ice fauna. Standard deviations were commonly greater than 50% of the mean for some taxa. Ice fauna apparently had a patchy distribution. Although determining the scale of aggregations was not a goal of this study, and the sampling program was not designed to examine this problem, it is evident that the size of faunal patches varied in the study area. Some pairs of cores were virtually identical in the abundance of each of the major taxa, and of copepod species. The patch size in these instances must have minimally been larger along one axis than twice the core diameter (21 cm). Other pairs of cores differed greatly, indicating that these patches were smaller. Patchiness of ice flora has been found to be correlated with light attenuation due to snow depth (Clasby et al., 1976). This could not have been a factor in deter-

Table 2. Densities of meiofauna sampled from underice habitats in different areas in the Beaufort Sea. Values are given in number per m^2. A typical value for the sediments beneath the ice station is presented for comparison.

MEIOFAUNAL DENSITIES

	$\bar{x}m^{-2}$ (ranges)	REFERENCE
EPONTIC:		
STEFANSSON SOUND	4,500 - 8,000	CAREY & MONTAGNA, 1982
NARWHAL ISLAND	36,000 - 320,000	KERN & CAREY, 1983
CANADIAN ARCTIC	300 - 53,000	CROSS, 1982
BENTHIC:		
STEFANSSON SOUND	60,605,000	CAREY & MONTAGNA, 1982

mining the patchiness of the ice fauna in this study since the snow cover over the sampling site was of uniform thickness at any one time.

Life-history studies of offshore marine benthic copepods are rare, and most of the work has been done on harpacticoids living in tide pools (Fraser, 1936; Harris, 1973), in littoral sediments (Rao, 1967; Barnett, 1970; Lasker et al., 1970; Harris, 1972; Jewett and Feder, 1977; Fleeger, 1979; Feller, 1980a), and on algae (Hicks, 1977). These studies have shown that there are many reproductive patterns in harpacticoids, and that even closely related, sympatric species may have markedly different life-histories. Barnett (1970) investigated the life cycles of two congeneric species inhabiting the same mudflat and found that each species had a distinct life-history. Despite these variations, Hicks (1979) has shown that reproductive strategies of harpacticoid copepods tend to differ more between habitats than within habitats. He suggests that factors such as food resource availability and environmental stability are important in determining the evolution of specific life-history strategies. Therefore, it might be expected that copepods inhabiting the ephemeral ice environment would show a different life-history pattern from those of copepods studied elsewhere.

It is evident that Harpacticus sp. and Cyclopina gracilis have different life-history strategies (Figures 16 and 17, and Appendix II: Table 27). C. gracilis appears to reproduce continuously during the ice algal bloom. Gravid females were found on five of the nine sampling dates. Since the number collected on any sampling date tended to be low, it is possible that there were gravid females in the ice throughout the sampling period, but not collected on some occasions because of their low density. Egg sacs may also have been shaken loose before the samples were examined in the laboratory. Continuous recruitment to the population is also indicated by the presence of young copepodites on all sampling dates. The location of modes in the size-frequency distributions of C. gracilis was similar from 15 May to the end of the study (Figure 17). Fleeger (1979) gave size-frequency distributions of Enhydrosoma propinquum that showed a pattern of constant peak locations for an extended period. He suggested that the stable population structure was brought about by continuous recruitment of nauplii. Cyclopina gracilis has been found associated with macro-algae (Sars, 1918) and described as a phytophile (Ceccherelli, 1976). Its continual reproduction, at least while in the ice, fits the strategy of continual or protracted reproduction utilized by most phytal harpacticoids (Hicks, 1979).

Harpacticus sp. did not appear to reproduce in the ice. Since the sampling period coincided with the annual ice algal bloom (Horner and Schrader, 1981) when food resources are highest, the lack of gravid females is surprising. Pre-copulatory clasping, which is typical of harpacticoids, occurred among individuals collected on 26 May and 2 June. Fraser (1936) suggested that the clasping of females, usually copepodites, by adult males precedes spermatophore transfer. The reproductive cycle of Harpacticus sp. could be similar to that of some sediment-dwelling copepods. Jewett and Feder (1977) showed that Harpacticus uniremis around Port Valdez, Alaska had a single distinct reproductive period. Males clasped females most often in April and gravid individuals began to appear approximately nine months later. The intertidal copepod Platychelipus laophontoides had one generation per year and a distinct reproduction period with gravid females being absent for half of the year (Barnett, 1970).

No life-history data for Harpacticus sp. are available for the rest of the year so it is not possible to describe the complete life-history of the organisms. Mating evidently takes place on the ice since clasping, which precedes spermatophore transfer, was observed there. Data from other habitats suggest that Harpacticus sp. probably has one or two generations per year (Jewett and Feder, 1977). The inseminated females probably migrate to the bottom when the ice breaks up in late May or early June. It is not known whether copepods recolonize the ice immediately after it reforms around October or later in the ice season. Low densities of diatoms are present in the ice from its formation and through the winter until around April (Clasby et al., 1973), so little food is presumably available at that time. No Harpacticus sp. adults were present in the April and early May samples indicating that either colonization occurred shortly before by copepodites, or that gravid females had migrated to the ice earlier. There are two possible explanations as to how gravid females could colonize the ice during the winter, in the near-absence of food, resulting in the population structure observed in the samples. First, they may produce resting eggs that could overwinter in the ice. Overwintering resting eggs that hatch up to five months after being laid have been found in calanoid copepods (Grice and Gibson, 1975). Second, it has been shown that certain harpacticoids have nauplii that undergo delayed development (Coull and Dudley, 1976), which could enable some offspring to survive under limited food conditions. Delayed naupliar development might explain the sudden influx of early copepodites on 2 June unlike adults and copepodites. Nauplii of benthic harpacticoids cannot swim (Hauspie and Polk, 1973), so colonization of the ice could not be by nauplii unless they were advected to the ice from the sediments.

It is common for sex ratios to vary temporally in species of marine copepods (Moraitou-Apostolopoulou, 1972; Hicks, 1977). This was true for Harpacticus sp. and Cyclopina gracilis collected from the ice. There was a general trend in which the percentage of Harpacticus sp. females increased through the study. Since it appeared that the individuals belonged to a single season's production of offspring, males may mature earlier than females. Males reached sizes at which they could be sexed before females did, as indicated by the initial low percentage of females in the total sexable segment of the population. Earlier male maturation has been noted for Huntemania jadensis (Feller, 1980a) and Harpacticus uniremis (Jewett and Feder, 1977). It is not possible to discuss the relative development rates of C. gracilis males and females since recruitment to the population appeared to be continuous; however, Smyly (1961) reported that the males of Cyclops leukarti, a freshwater cyclopoid, mature earlier than females. Females predominated early in the study when the population density was low. This has been found in other marine copepods (Moraitou-Apostolopoulou, 1972).

No life-history strategies unique to the ice environment are evident from the data collected in this study. These two copepod species are not very different in their reproductive activity from other copepods living on the bottom. Previous studies (Coull and Vernberg, 1975; Jewett and Feder, 1977) have shown that the dominant copepod species reproduce continuously, while rare species in the same environment reproduce seasonally. This might also be true for ice copepods where the dominant species, Cyclopina gracilis, was found to reproduced continuously throughout the study, while the less abundant Harpacticus sp. showed seasonal reproduction.

It is not possible to describe the complete life-history of any species when sampling takes place only during one season. The ice scraper samples were used to extend the sampling period as much as possible, even though these samples were taken outside of the study area. The size-frequency distributions of Harpacticus sp. and Cyclopina gracilis in these samples generally fit the trends exhibited in the cores. The only exception to this agreement is with the size-frequency distribution of C. gracilis on 14 April. The population appear to be more mature in this sample than in those collected on 24 April. Small-scale spatial heterogeneity in the population size-structures of benthic organisms has previously been observed (Curtis and Peterson, 1977), and may explain the apparent discrepancy in the size-frequency distributions between 14 April and 24 April. Sampling throughout the year, in the ice when the animals are there, and on the bottom when they inhabit the sediments, is required to fully describe the life-history strategies of these organisms.

This study has shown that frequent sampling is required to observe changes in the population structure of meiofauna. Significant changes in the size-frequency distributions for the two dominant ice copepods occurred on time scales of less than one week. Size-frequency distributions have previously been employed to study copepod life-histories (Lasker et al., 1970; Jewett and Feder, 1977; Fleeger, 1979), but not with samples taken as frequently as in this study. Many copepod species can undergo complete development in the lab, from hatch to hatch, in less than 30 days (Rosenfield and Coull, 1974), so frequent samples must be taken to observe the rapid changes in the populations. Feller (1980b) observed that the lengths of some copepodite stages of Huntemania jadensis overlapped. Although this was true to some extent for both ice species studied, the utilization of size-frequency distribution provided useful information in less time than would be required to identify each copepodite to its stage.

With the objective of determining the source of the ice meiofauna at Narwhal Island, scrapings were made of macro-algae in Stefansson sound. The cyclopoid copepod Cyclopina gracilis has been reported as epiphytic (Sars, 1918), and the macro-algae at the Boulder Patch (Dunton et al., 1982) could be the source of this species for colonization of the ice undersurface. No C. gracilis were collected from the sediments at the Stefansson Sound Ice Station (Carey and Montagna, 1982). Though cyclopoid copepods were present in the algal scrapings, no specimens of C. gracilis were found (Table 3). This species was collected near the bottom (Horner and Schrader, 1981), and thus may be plankto-benthic in existence.

Table 3. Copepods and nematodes from scrapings of macro-algae fronds at the Stefansson Sound ice station (SS). Collections made in 1981.

Scrapings	Algae	Cyclopoid/Harpacticoid	Calanoid	Nematodes	Cyclopina gracilis
1	Red	243	1	+	No
2	Brown	25	14	+	No
3	Red	125	1	+	No
4	Brown	24	12	+	No
5	Red	11	5	+	No
6	Brown	32	9	+	No
7	Brown	36	3	0	No
8	Red	151	4	+	No
9	Red	58	2	+	No
10	Brown	50	8	+	No

C. Particle flux to sediments (Narwhal Island)

Various workers have conjectured that the ice biotic assemblage is an early source for the arctic ecosystem and that there should be a pulse of downward organic flux during ice melt and break-up (Alexander, 1980, 1981; Golikov and Scarlato, 1973; Horner and Schrader, 1982). Our data suggest that this community does provide an early source of food for the benthos. The fluxes of organic carbon are relatively high even at the time of the first collection toward the end of April. However, the lack of temporal trends does not support the hypothesis that there is a sudden pulse of particle flux during ice melting. It is possible, however, that field activities had to be curtailed before such an event took place. Divers' observations indicate that the ice algal layer had almost entirely disappeared at the time of the last particle trap deployment. It was also noted that turbidity in the water column was high, perhaps caused by the ice algal cells released from the ice. Therefore, downward transport of this material is slower than anticipated. Results from Pett et al. (1983) also support this conclusion; results from the Canadian Beaufort Sea did not demonstrate a pulses of organic flux during ice melt.

VIII. Conclusions

A. Benthic continental shelf fauna: cross-shelf trends

1. The macrobenthos are most abundant numerically nearshore, while their biomass peaks at the shelf edge and upper continental slope.
2. The megabenthos are most abundant on the outer shelf and upper level of the continental slope.
3. The major part of the community causing the increased densities and standing stocks are polychaete worms (*Minuspio cirrifera*) for the macrofauna and several species of Ophiuroidea for the megafauna.
4. Species richness for the polychaetous annelids and bivalve molluscs is highest on the inner continental shelf. This contrast to temperate patterns is hypothesized to be caused by low wave turbulence in the Arctic.
5. The higher benthic numerical densities and standing stocks in the SW Beaufort Sea are similar to levels found in rich temperate marine environments.

B. Ice fauna (Narwhal Island)

1. Large densities of several invertebrate taxa, most notably nematodes, copepods, and turbellarians, were present in the fast ice of the Beaufort Sea in 1980. Although the density of the ice fauna was low compared to what is typically found in sediments, it was much greater than had previously been reported from the ice.
2. The life-histories of two copepods, *Cyclopina gracilis* and *Harpacticus* sp., while inhabiting the ice are similar to the life-histories of exclusively benthic copepods. The ice species were different from each other in terms of their life-histories, so it appears that there is not a life-history strategy unique to the ice. If this is the case, it is surprising that more species do not utilize the ice environment.
3. The midwater and underice samples indicate that the harpacticoid and cyclopoid copepods leave the ice during the rapid salinity decrease in early June and are then present midwater. The hypothesis that they migrate (fall?) to the bottom is being tested.
4. Five species of gammarid amphipods form the ice macrofaunal assemblage (99.3%) on the inner shelf in the SW Beaufort Sea.
5. A normally benthic species, *Pseudalibrotus* (=*Onisimus*) *litoralis*, dominates the assemblage and feeds, grows and releases young at the ice undersurface.
6. The midwater collections of gammarid amphipods suggest a frequent interchange between the benthic and epontic populations with a diurnal maxima between 0100-0300 hrs, and a seasonal increase in activity in early April and early June.
7. The ice biotic community is hypothesized to be a feeding ground for amphipod juveniles.
8. The ice substrate and ice algae in the arctic provide an alternate environment and an early food source to a mixture of pelagic and benthic gammarid amphipod species.
9. It is hypothesized that the benthic gammarid amphipod, *P. litoralis*, migrates to the bottom layer in the season with two environmental cues: reduced salinities and the onset of dark periods during the arctic summer.

C. Particle flux

1. The particulate carbon and nitrogen flux to the sediments was relatively high during the entire study period.
2. There was no major increase in flux of particulate organic matter to the sediments during the melting season.
3. Fecal pellets from 2 crustacean species were among the few recognizable large particles; their fluxes varied during the study period.
4. Fecal pellets attributed to *P. litoralis* demonstrate that this species is feeding directly upon the underice diatom assemblage.
5. Though the fluxes to arctic shallow water sediments are low compared to rich temperate environments, the ice diatom assemblage is likely to be the earliest source of new carbon to the arctic ecosystem.

IX. Needs for further study

Though general and some specific patterns of distribution and abundance of the benthic invertebrate fauna have been determined from the inner continental shelf to the upper slope, much remains to be accomplished in three main areas of research: (1) food web, (2) ice fauna, and (3) biological rates.

A. Food web

Offshore of the barrier islands the continental shelf benthic food web is poorly defined. The food habitats of large predators such as demersal fishes, seabirds and marine mammals that feed on the benthos are not well known. Offshore populations of adult arctic cod have not been well-studied, and their food sources are not known. Data from inshore waters indicate that epibenthic animals, particularly mysids and amphipods, are pivotal food web links and that the infaunal invertebrates are not important in the oceanic food web (Griffiths and Dillinger, 1981). This hypothesis should be extensively tested to define the role of the benthos in the ecosystem. It is possible that there are few higher predators on the Beaufort Sea infauna; therefore, larger stocks of benthos may exist, e.g., at the shelf edge and upper slope.

The role of the sea ice algal blooms in the benthic (and pelagic) food web remains not well known. The carbon input to the ecosystem by this community is not known, nor are the vertical fluxes through which the ice community and the benthic community would interact. Data from other studies (RU #537 and 467) indicate that ice algal blooms are present on the undersurface of the sea ice out to at least 100 n.m. from shore, so this carbon source may be important over large areas.

B. Ice fauna

Though initial description of the invertebrate sea ice assemblage has been achieved in nearshore waters beyond the barrier islands, there is a basic lack of knowledge about the ice fauna and its relationship to the benthos and pelagic fauna beneath. Nor do we know the areal extent and patchiness of the ice fauna and its relationship to ice as a substrate--with or without a food source at the ice-water interface. The ice may act as a concentrating interface for advanced and metamorphosing larval stages of benthic invertebrate fauna because it is a solid substrate--albeit upside down. Further offshore in the polar pack where the bottom drops away in deeper water, are there macrofaunal grazers primarily from the water column associated with the ice? Are there benthic meiofauna that exist as permanent members of the ice assemblage? And what is the food web associated with the sea ice in this environment?

C. Biological rates

Much basic information is needed on biological rates--reproductive, growth, mortality, recolonization and metabolic for the purpose of determining the biological activity of the arctic fauna. What are the turnover rates of the benthos (production/biomass) beyond the barrier islands; are the secondary production rates lower than in more temperate environments? Knowledge of the recolonization rates pertain directly to the ability of the fauna, particularly the important mysid and amphipod crustaceans, to recover after a natural or pollution disturbance event. This information would be most useful in modelling food web recovery rates of a region of the inner shelf of the Beaufort Sea after a major oil spill.

X. Auxiliary Material

A. References cited

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B. Papers in preparation or in print

These papers and manuscripts listed below are totally or partially derived from OCSEAP subprojects by RU #006 covered in this Final Report.

1. In print

Kern, J. C. and A. G. Carey, Jr. 1983. The faunal assemblage inhabiting seasonal sea ice in the nearshore Arctic Ocean with emphasis on the copepods. Mar. Ecol. Progr. Ser. 10:159-167.

Carey, A. G., Jr., P. H. Scott and K. R. Walters. 1984. Distributional ecology of shallow SW Beaufort Sea (Alaska) bivalve Mollusca. Mar. Ecol. Progr. Ser. 17(2).

2. In press

Carey, A. G., Jr. Marine ice fauna: Arctic. In: R. A. Horner (Ed.), Ice Biota. CRC Press, Boca Raton.

3. In preparation

Boudrias, M. A. and A. G. Carey, Jr. Life-history strategy and feeding ecology fo Pseudalibrotus (=Onisimus) litoralis (Crustacea: Amphipoda): An underice population of the SW Beaufort Sea. Ophelia.

Carey, A. G., Jr. Cross-shelf trends in the southeastern Beaufort Sea: macrobenthos and megabenthos. Polar Biology.

Carey, A. G., Jr., R. E. Ruff and K. R. Walters. Community ecology of shallow SW Beaufort Sea Polychaeta (Annelida). Coastal and Estuarine Science.

C. Oral Presentations

1. The distribution and abundance of benthic macrofauna and megafauna across the northern Alaska shelf and upper slope of the SW Beaufort Sea. ASLO Annual Mtng. North Carolina State Univ., June 1982.

2. Shallow southwest Beaufort Sea (Alaska) ice macrofauna: Interactions with the epibenthic community. ASLO/AGU Meeting, San Francisco, CA, December 1982.

3. The structure source and ecology of underice fauna assemblages. Benthic Ecology Meetings. Melbourne, FL, March 1983.

4. Particle and faunal fluxes between the sea ice and benthic environments in the shallow SW Beaufort Sea (Alaska). Western Society of Naturalists Annual Meeting, Burnaby, B.C., December 1983.

Appendix I. Pingok Island Cross-Shelf Transect Data.

Table 4. Cross-shelf trends macrofauna station collection information (PIB = Pingok Island Benthos, R/V ALUMIAK cruise; WBS = Western Beaufort Sea WEBSEC cruise, USCGC GLACIER.

Depth	Station	Replicates	Position	Date
5 m	PIB-5	5	70°34.9'N 149°32.0'W	22 Aug 1976
10 m	PIB-10	5	70°34.8'N 149°32.3'W	22 Aug 1976
15 m	PIB-15	5	70°38.2'N 149°34.6'W	24 Aug 1976
23 m	WBS-30 CG-63	5	70°43'N 149°00'W	7 Sept 1971
47 m	WBS-23 CG-44	5	71°01'N 148°22'W	31 Aug 1971
100 m	WBS-20 CG-30	5	71°06'N 147°57'W	30 Aug 1971
200 m	WBS-41 CG-83	5	71°12.2'N 149°44.8'W	11 Sept 1971
360 m	WBS-19 CG-29	5	71°08.7'N 148°00.5'W	29 Aug 1971
700 m	WBS-27 CG-58	5	71°14.5'N 149°25.5'W	5 Sept 1971
1800 m	WBS-26 CG-57	5	71°21.3'N 149°32'W	4 Sept 1971

Table 5. Cross-shelf trends otter trawl station locations for mega-epifauna.

Station	Position	Depth	Date	Tow Duration
WBS-25 CG-56	71°12'N 148°35'W	360 m	3 Sept 1971	10 min.
WBS-31 CG-65	70°43'N 149°02'W	30 m	6 Sept 1971	15 min.
WBS-32 CG-66	70°43'N 149°06'W	31 m	7 Sept 1971	5 min.
WBS-21 CG-36	71°11.3'N 148°31.9'W	159 m	18 Aug 1972	30 min.
WBS-22 CG-37	71°05.7'N 148°41'W	55 m	19 Aug 1972	15 min.
WBS-27 CG-43	70°59.5'N 149°33.8'W	29 m	22 Aug 1972	10 min.

Table 6. Cross-shelf trends bottom stereo photograph station locations for visible benthic mega-epifauna.

Station	Position	Depth	Data	Total Area
WBS-30 CG-47	70°50'N 150°0.9'W	25 m	23 Aug 1972	22.17 m^2
WBS-32 CG-49	71°11.5'N 150°00'W	44 m	24 Aug 1972	115.4 m^2
WBS-33 CG-50	71°12.4'N 150°02.6'W	80 m	25 Aug 1972	52.30 m^2
WBS-35 CG-52	71°17'N 150°05'W	750 m	26 Aug 1972	103.05 m^2
WBS-36 CG-53	71°35.9'N 150°01.9'W	2160 m	27 Aug 1972	20.88 m^2
WBS-46 CG-75	71°12.3'N 149°43'W	195 m	9 Sept 1972	48.37 m^2

Table 7. Animal densities for station PIB-5 per 0.1 m^2, collected on 22 August 1976.

Phylum	Class	Order	Grab Number 1419	1420	1421	1423	1424	Total per m^2	% of fauna
Nematoda			1	--	2	1	4	16	1.2
Nemertinea			1	2	3	--	--	12	0.9
Annelida:	Polychaeta		71	110	104	112	176	1146	87.2
Priapulida			4	5	7	3	2	42	3.2
Arthropoda:	Crustacea:	Amphipoda	17	5	2	4	4	64	4.9
		Isopoda	--	1	1 1	2	--	8	0.6
		Cumacea	1	--	1	6	--	16	1.2
Mollusca:	Pelecypoda		2	--	1	--	2	10	0.8
TOTAL			96	123	119	127	184	1314	100.0

Table 8. Animal densities for station PIB-10 per 0.1 m^2, collected on 22 August 1976.

Phylum	Class	Order	Grab Number 1425	1426	1427	1429	1430	Total per m^2	% of fauna
Nematoda			2	8	33	30	12	170	2.3
Annelida:	Polychaeta		475	683	606	436	860	6120	82.9
Priapulida			1	1	4	7	--	26	0.4
Arthropoda:	Crustacea:	Amphipoda	--	1	1	21	3	52	0.7
		Harpacticoida	--	--	6	--	--	12	0.2
		Isopoda	2	--	1	--	4	14	0.2
		Ostracoda	--	16	17	6	--	78	1.1
		Tanaidacea	--	--	1	4	1	12	0.2
		Cumacea	1	2	2	4	3	24	0.3
Mollusca:	Pelecypoda		39	67	109	104	101	840	11.4
	Gastropoda		--	6	6	3	3	36	0.5
TOTAL			518	776	747	585	975	7384	100.0

Table 9. Animal densities for station PIB-15 per 0.1 m^2, collected on 22 August 1976.

			Grab Number					Total	% of
Phylum	Class	Order	1432	1433	1434	1435	1436	per m^2	fauna
Cnidaria:	Anthozoa		2	1	1	--	--	8	0.4
Nematoda			--	1	2	2	--	10	0.5
Nemerthinea			--	3	3	1	3	20	1.1
Annelida:	Polychaeta		53	73	86	107	83	804	42.2
Priapulida			--	--	--	--	1	2	0.1
Arthropoda:	Crustacea:	Amphipoda	4	9	17	12	14	112	5.9
		Isopoda	--	--	3	1	1	10	0.5
		Ostracoda	--	--	4	2	--	12	0.6
		Tanaidacea	--	--	7	--	--	14	0.7
		Cumacea	8	4	1	14	3	60	3.2
	Pycnogonida		--	--	--	--	1	2	0.1
Mollusca:	Pelecypoda		25	53	31	53	58	440	23.1
	Gastropoda		5	3	1	7	7	46	2.4
Echinodermata:	Holothuroidea		2	3	2	1	--	16	0.8
Hemichordata			1	--	--	--	--	2	0.1
Chordata:	Ascidacea		10	47	60	16	40	346	18.2
TOTAL			110	196	216	214	211	1904	100.0

Table 10. Relative abundance of major macrofauna taxa (>1.0 mm) on the cross-shelf transect.

	PIB-5 5 m		PIB-10 10 m		PIB-15 15 m	
Cidaria: Anthozoa	--		--		4	0.4%
Annelida: Oligochaeta	--		--		--	
Polychaeta	573	88.3%	3060	85.0%	402	42.4%
Arthropoda: Amphipoda	32	4.9%	26	0.7%	56	5.9%
Isopoda	4	0.6%	7	0.2%	5	0.5%
Cumacea	8	1.2%	12	0.3%	30	3.2%
Ostracoda	--		39	1.1%	6	0.6%
Tanaidacea	--		6	0.2%	7	0.7%
Pycnogonida	--		--		1	0.1%
Mollusca: Pelecypoda	5	0.8%	420	11.7%	220	23.2%
Gastropoda	--		18	0.5%	23	2.4%
Echinodermata: Ophiuroidea	--		--		--	
Holothuroidea	--		--	8		0.8%
Chordata: Ascidiacea	--		--		173	18.2%
Others (Priapulida, Hemichordata, Nemertinea)	27	4.2%	13	0.4%	12	1.3%
Total	649		3601		949	

Table 10. con't.

	WBS 30 CG63 23 m		WBS 23 CG44 47 m		WBS 20 GC30 100 m		WBS 41 GC83 200 m	
Cnidaria: Anthozoa	--		1	0.1%	--		17	1.1%
Annelida: Oligochaeta	--		--		--		--	
Polychaeta	318	40.8%	520	42.4%	365	30.8%	1273	85.2%
Arthropoda: Amphipoda	10	1.3%	387	28.4%	83	7.0%	47	3.1%
Isopoda	1	0.1%	14	1.1%	--		--	
Cumacea	19	2.4%	40	3.3%	14	1.2%	6	0.4%
Ostracoda	--		93	7.6%	193	16.3%	7	0.5%
Tanaidacea	5	0.6%	26	2.1%	50	4.2%	1	0.1%
Pycnogonida	--		2	0.2%	--		--	
Mollusca: Pelecypoda	274	35.2%	158	12.9%	413	34.9%	78	5.2%
Gastropoda	132	16.9%	6	0.5%	15	1.3%	6	0.4%
Echinodermata: Ophiuroidea	16	2.1%	6	0.5%	37	3.1%	46	3.1%
Holothuroidea	3	0.4%	4	0.3%	--		--	
Chordata: Ascidiacea	--		--		7	0.6%	--	
Others (Echiuroidea, Sipuncula, Aplacophora, Brachiopoda, Priapulida, Nemertinea)	1	0.1%	8	0.7%	8	0.7%	13	0.9%
Total	799		1226		1185		1494	

Table 10. con't.

	WBS 19 CG 29 360 m		WBS 27 GC 58 700 m		WBS 26 CG 57 1800 m	
Cnidaria: Anthozoa	--		--		--	
Annelida: Oligochaeta	--		154	6.8%	--	
Polychaeta	1031	87.3%	1611	70.9%	263	39.1%
Arthropoda: Amphipoda	19	1.6%	36	1.6%	15	2.2%
Isopoda	--		3	0.1%	6	0.9%
Cumacea	3	0.3%	12	0.5%	21	3.1%
Ostracoda	62	5.2%	67	2.9%	3	0.4%
Tanaidacea	8	0.7%	57	2.5%	27	4.0%
Pycnogonida	--		3	0.1%		
Mollusca: Pelecypoda	40	3.4%	295	13.0%	320	47.5%
Gastropoda	2	0.2%	14	0.6%	1	0.1%
Echinodermata: Ophiuroidea	10	0.8%	6	0.3%	4	0.6%
Holothuroidea	--		--		5	0.7%
Chordata: Ascidiacea	--		-		--	
Others (Aplacophora, Sipuncula, Scaphopoda)	6	0.5%	15	0.7%	8	1.2%
Total	1181		2273		673	

Table 11. Biomass, preserved wet weight in grams per 0.1 m^2 from station PIB-5 (OCS-5), collected on 22 August 1976.

Group	Grab Number 1419	1420	1421	1423	1424	Total weight per m^2	% of biomass
Anthozoa	-	-	-	-	-	-	-
Sipuncula	-	-	-	-	-	-	-
Annelida	.58	.60	.49	.84	1.16	7.34	83.2
Arthropoda	.03	.47	.06	.05	.02	1.26	14.3
Mollusca	.03	-	.01	-	+	.08	0.9
Echinodermata	-	-	+	-	-	-	-
Misc. Phyla	.01	.02	.02	.02	+	.14	1.6
TOTAL	.65	1.09	.58	.91	1.18	8.82	100.0

\+ = presence, not weighable
\- = absence

Table 12. Biomass, preserved wet weight in grams per 0.1 m^2 from station PIB-10 (OCS-5), collected on 22 August 1976.

Group	Grab Number 1425	1426	1427	1429	1430	Total weight per m^2	% of biomass
Anthozoa	-	-	-	-	-	-	-
Sipuncula	-	-	-	-	-	-	-
Annelida	.87	.78	.87	.77	1.20	8.98	50.7
Arthropoda	.04	.04	.03	.07	.12	.60	3.4
Mollusca	.19	-	1.90	1.12	.70	7.82	44.2
Echiondermata	+	-	-	-	-	-	-
Misc. Phyla	.07	.01	.04	.02	.01	.30	1.7
TOTAL	1.17	.87	2.84	1.98	2.03	17.70	100.0

\+ = presence, not weighable
\- = absence

Table 13. Biomass, preserved wet weight in grams per 0.1 m^2 from station PIB-15 (OCS-5), collected on 22 August 1976.

Group	Grab Number 1432	1433	1434	1435	1436	Total weight per m^2	% of biomass
Anthozoa	-	-	-	-	-	-	-
Sipuncula	-	-	-	-	-	-	-
Annelida	1.92	3.65	1.20	1.12	.61	17.00	12.8
Arthropoda	.29	.13	.07	.18	.19	1.72	1.3
Mollusca	4.71	10.24	5.10	9.21	11.44	81.40	61.6
Echinodermata	.02	.12	.04	.08	-	.52	.4
Misc. Phyla	.74	2.73	5.87	3.27	3.19	31.60	23.9
TOTAL	7.68	16.87	12.28	13.86	15.43	132.24	100.0

- = absence

Table 14. SW Beaufort Sea Cross-Shelf Transect Polychaete species distribution.

	Polychaete Species		
Depth	No/m^2	Name	Rank
5 m	524	Minuspio cirrifera	1
	310	Ampharete vega	2
	110	Marenzelleria wireni	3
	60	Chone nr. C. murmanica	4
	32	Tharyx ?acutus	5
	30	Capitella capitata	6
	26	Sphaerodoropsis minuta	7
	14	Eteone longa	8
	6	Scoloplos armiger	9.5
	6	Sphaerodoridium sp. A	9.5
	4	Orbinia sp.	
	2	Micronephthys minuta	
	2	Onuphis quadricuspis	
	2	Paramphitrite tetrabranchia	
	2	Terebellides stroemi	
10 m	4688	Minuspio cirrifera	1
	412	Chone nr. C. murmanica	2
	234	Sphaerodoropsis minuta	3
	144	Tharyx ?acutus	4
	84	Micronephthys minuta	5
	78	Cossura longocirrata	6
	46	Capitella capitata	7.5
	46	Eteone longa	7.5
	20	Sphaerodoridium sp. A	9
	18	Ampharete vega	10
	14	Aricidea (Allia) cf. A. suecica	
	14	Ophryotrocha sp.	
	14	Sternaspis scutata	
	12	Terebellides stroemi	
	10	Marenzelleria wireni	
	6	Parheteromastus sp. A	
	2	Euchone analis	
	2	Heteromastus filiformis	
	2	Mystides borealis	
	2	Nephtys ciliata	
	2	Paramphitrite tetrabranchia	
	2	Praxillella praetermissa	
	2	Scalibregma inflatum	

Table 14. con't.

Depth	No/m^2	Name	Rank
15 m	182	Praxillella praetermissa	1
	60	Tharyx ?acutus	2
	56	Pholoe minuta	3
	48	Chaetozone setosa	4
	46	Minuspio cirrifera	5
	42	Scoloplos acutus	6
	40	Clymenura polaris	7
	26	Marenzelleria wireni	8.5
	26	Micronephthys minuta	8.5
	24	Microclymene sp.	10
	20	Ampharete acutifrons	
	18	Nereimyra aphroditoides	
	14	Brada villosa	
	14	Hesionidae gen. et sp. nov.	
	12	Eteone longa	
	12	Euchone papillosa	
	10	Laonome kroeyeri	
	10	Scalibregma inflatum	
	8	Capitella capitata	
	8	Lysippe labiata	
	8	Scoloplos armiger	
	8	Sternaspis scutata	
	6	Amphicteis sundevalli	
	6	Anaitides groenlandica	
	6	Antinoella sarsi	
	6	Nephtys ciliata	
	6	Ophelina cylindricaudatus	
	6	Polydora socialis	
	6	Sabellides borealis	
	6	Schistomeringos caeca	
	4	Aricidea (Allia) cf. A. suecica	
	4	Heteromastus filiformis	
	4	Nephtys longosetosa	
	4	Levinsenia gracilis	
	4	Terebellides stroemi	
	2	Aricidea (Allia) sp. C	
	2	Apistobranchus tullbergi	
	2	Dexiospira spirillum	
	2	Diplocirrus longisetosus	
	2	Dysponetus sp. nov.	
	2	Euchone analis	
	2	Euchone elegans	
	2	Euchone sp.	
	2	Fabricinae	
	2	Lanassa venusta	
	2	Melaenis loveni	
	2	Prionospio steenstrup	
	2	Sphaerodoridium sp. A	

Table 14. con't.

Depth	No/m^2	Name	Rank
23 m	348	Capitella capitata	1
	244	Tharyx ?acutus	2
	180	Chone nr. C. murmanica	3
	148	Minuspio cirrifera	4
	114	Pholoe minuta	5
	106	Heteromastus filiformis	6
	56	Sternaspis scutata	7
	46	Paramphitrite tetrabranchia	8
	42	Cossura longocirrata	9
	40	Ophelina cylindricaudatus	10
	34	Lumbrineris minuta	
	32	Lysippe labiata	
	28	Aricidea (Allia) cf. A. suecica	
	26	Chaetozone setosa	
	24	Parheteromastus sp. A	
	18	Scoloplos acutus	
	16	Clymenura polaris	
	14	Prionospio steenstrupi	
	12	Praxillella praetermissa	
	12	Terebellides stroemi	
	10	Brada villosa	
	10	Eteone longa	
	8	Antinoella sarsi	
	8	Lumbrineris fragilis	
	8	Lumbrineris impatiens	
	8	Micronephthys minuta	
	8	Proclea graffii	
	8	Spirorbis granulatus	
	6	Ampharete acutifrons	
	6	Schistomeringos caeca	
	4	Anaitides groenlandica	
	4	Cistenides hyperborea	
	4	Eteone flava	
	4	Nephtys ciliata	
	2	Aglaophamus malmgreni	
	2	Apistobranchus tullbergi	
	2	Chone duneri	
	2	Dexiospira spirillum	
	2	Lagisca extenuata	
	2	Scalibregma inflatum	
	2	Sphaerodoropsis minuta	
	2	Trochochaeta carica	
	2	Typosyllis cornuta	

Table 14. con't.

Depth	No/m^2	Name	Rank
47 m	556	Chone nr. C. murmanica	1
	284	Tharyx ?acutus	2
	244	Chaetozone setosa	3
	194	Lumbrineris minuta	4
	168	Aricidea (Allia) cf. A. suecica	5
	116	Nereimyra aphroditoides	6
	104	Ophelina cylindricaudatus	7
	98	Prionospio steenstrupi	8
	94	Terebellides stroemi	9
	78	Pholoe minuta	10
	74	Micronephthys minuta	
	70	Heteromastus filiformis	
	60	Exogone naidina	
	60	Parheteromastus sp. A	
	54	Barantolla sp.	
	50	Nereis zonata	
	44	Ampharete acutifrons	
	40	Lysippe labiata	
	22	Laphania boecki	
	22	Maldane sarsi	
	20	Spirorbis granulatus	
	20	Typosyllis cornuta	
	18	Minuspio cirrifera	
	16	Ampharete arctica	
	16	Lumbrineris fragilis	
	16	Scoloplos acutus	
	14	Laonice cirrata	
	12	Antinoella sarsi	
	12	Paraonis sp. A	
	10	Autolytus fallax	
	10	Lagisca extenuata	
	8	Chone duneri	
	8	Clymenura polaris	
	8	Eteone longa	
	8	Polycirrus medusa	
	6	Gattyana cirrosa	
	6	Onuphis quadricuspis	
	4	Amphicteis gunneri	
	4	Cirratulus cirratus	
	4	Diplocirrus longisetosus	
	4	Melinna elisabethae	
	4	Polydora caulleryi	
	4	Levinsenia gracilis	
	2	Apistobranchus tullbergi	
	2	Artacama proboscidea	
	2	Brada nuda	
	2	Brada villosa	
	2	Chone infundibuliformis	
	2	Diplocirrus hirsutus	
	2	Lanassa venusta	

2	Myriochele heeri
2	Nephtys ciliata
2	Nephtys paradoxa
2	Ophelina acuminata
2	Paramphitrite tetrabranchia
2	Praxillella praetermissa
2	Schistomeringos caeca
2	Sphaerodoridium biserialis
2	Sphaerodoridium sp. A

Table 14. con't.

Depth	No/m^2	Name	Rank
100 m	178	Spiochaetopterus typicus	1
	136	Micronephthys minuta	2
	104	Chone nr. C. murmanica	3
	94	Tharyx ?acutus	4
	92	Lysippe labiata	5
	84	Lumbrineris minuta	6
	78	Terebellides stroemi	7
	56	Laonice cirrata	8
	44	Ophelina cylindricaudatus	9.5
	44	Levinsenia gracilis	9.5
	40	Maldane sarsi	
	32	Pholoe minuta	
	28	Cossura longocirrata	
	28	Minuspio cirrifera	
	24	Clymenura polaris	
	24	Scoloplos acutus	
	20	Aricidea (Allia) cf. A. suecica	
	18	Myriochele heeri	
	14	Parheteromastus sp. A	
	12	Barantolla sp.	
	12	Heteromastus filiformis	
	10	Sternaspis scutata	
	8	Lagisca extenuata	
	8	Laphania boecki	
	6	Apistobranchus tullbergi	
	6	Chaetozone setosa	
	6	Exogone naidina	
	6	Glyphanostomum pallescens	
	4	Ampharete arctica	
	4	Antinoella sarsi	
	4	Lumbrineris impatiens	
	4	Scalibregma inflatum	
	4	Sphaerodorum gracilis	
	4	Typosyllis cornuta	
	2	Axionice flexuosa	
	2	Eteone longa	
	2	Euchone papillosa	
	2	Gattyana cirrosa	
	2	Lanassa venusta	
	2	Lumbrineris fragilis	
	2	Melinna elisabethae	
	2	Nephtys ciliata	
	2	Onuphis quadricuspis	
	2	Paraonis sp. A	
	2	Polydora caulleryi	
	2	Schistomeringos caeca	
	2	Sphaerodoropsis biserialis	
	2	Trochochaeta carica	

Table 14. con't.

Depth	No/m^2	Name	Rank
200 m	814	Tharyx ?acutus	1
	604	Micronephthys minuta	2
	360	Scolopos acutus	3
	336	Aricidea (Allia) <u>cf</u>. A. suecica	4
	246	Levinsenia gracilis	5
	200	Cossura longocirrata	6
	196	Lumbrineris minuta	7
	172	Chaetozone setosa	8
	112	Prionospio steenstrupi	9
	50	Lysippe labiata	10
	44	Terebellides stroemi	
	36	Eteone longa	
	30	Nephtys ciliata	
	30	Proclea graffii	
	22	Barantolla sp.	
	22	Spiochaetopterus typicus	
	10	Artacama proboscidea	
	8	Antinoella sarsi	
	8	Heteromastus filiformis	
	8	Laphania boecki	
	8	Myriochele heeri	
	8	Onuphis quadricuspis	
	6	Maldane sarsi	
	4	Anaitides groenlandica	
	4	Nereimyra aphroditoides	
	4	Owenia fusiformis	
	4	Sphaerodoridium sp. A	
	4	Sternaspis scutata	
	2	Ampharete arctica	
	2	Antinoella badia	
	2	Apistobranchus tullbergi	
	2	Cistenides hyperborea	
	2	Minuspio cirrifera	
	2	Praxillella praetermissa	

Table 14. con't.

Depth	No/m^2	Name	Rank
360 m	690	Maldane sarsi	1
	302	Scoloplos acutus	2
	224	Levinsenia gracilis	3
	208	Minuspio cirrifera	4
	142	Lumbrineris minuta	5
	92	Barantolla sp.	6
	78	Laonice cirrata	7.5
	78	Micronephthys minuta	7.5
	74	Ophelina cylindricaudatus	9
	60	Tharyx ?acutus	10
	58	Chaetozone setosa	
	44	Aricidea (Allia) cf. A. suecica	
	34	Onuphis quadricuspis	
	30	Heteromastus filiformis	
	26	Eteone longa	
	26	Sternaspis scutata	
	12	Spiochaetopterus typicus	
	12	Trochochaeta carica	
	10	Nephtys ciliata	
	10	Pholoe minuta	
	8	Chone nr. C. murmanica	
	6	Antinoella badia	
	6	Prionospio steenstrupi	
	6	Sphaerodoridium sp. A	
	4	Capitella capitata	
	4	Terebellides stroemi	
	2	Aglaophamus malmgreni	
	2	Cossura longocirrata	
	2	Diplocirrus hirsutus	
	2	Melinna elisabethae	
	2	Nereimyra aphroditoides	

Table 14. con't.

Depth	No/m^2	Name	Rank
700 m	2042	Minuspio cirrifera	1
	456	Maldane sarsi	2
	90	Laonice cirrata	3
	66	Chaetozone setosa	4
	52	Levinsenia gracilis	5
	44	Lumbrineris minuta	6
	40	Barantolla sp.	7
	38	Scoloplos acutus	8
	34	Aricidea (Allia) cf. A. suecica	9
	30	Cossura longocirrata	10
	26	Chone mr. C. murmanica	
	20	Owenia fusiformis	
	18	Onuphis quadricuspis	
	18	Trochochaeta carica	
	16	Capitella capitata	
	16	Micronephthys minuta	
	14	Sphaerodoridium sp. A	
	10	Eteone longa	
	10	Ophelina cylindricaudatus	
	10	Sternaspis scutata	
	6	Lumbrineris fragilis	
	6	Sphaerodoropsis sp. B	
	6	Spiochaetopterus typicus	
	4	Antinoella badia	
	4	Prionospio steenstrupi	
	4	Sigambra tentaculata	
	2	Anaitides groenlandica	
	2	Aricidea (Acmira) quadrilobata	
	2	Heteromastus filiformis	
	2	Sphaerodoropsis sp. A	
	2	Sphaerodorum gracilis	
	2	Tharyx ?acutus	

Table 14. con't.

Depth	No/m^2	Name	Rank
1800 m	304	Minuspio cirrifera	1
	126	Sigambra tentaculata	2
	106	Lumbrineris minuta	3
	34	Owenia fusiformis	4
	28	Aricidea (Allia) cf. A. suecica	5
	20	Terebellides stroemi	6
	16	Tachytrypane abranchiata	7
	12	Capitella capitata	8
	4	Heteromastus filiformis	10
	4	Ophelina cylindridatus	10
	4	Scoloplos acutus	10
	2	Aricidea (Acmira) quadrilobata	
	2	Diplocirrus hirsutus	
	2	Diplocirrus longisetosus	
	2	Onuphis quadricuspis	
	2	Sternaspis scutata	

Table 15. Cross-shelf trends macrofauna station environmental information.

Depth	Sediments (%)				Carbon (%)		Temperature	Salinity
(m)	gravel	sand	silt	clay	organic	$CO_3^=$	(°C)	°/₀₀
5	0.0	73.2	16.9	9.9	0.09	3.15	2.08	22.08
10	0.0	53.3	38.8	7.9	0.03	11.60	2.15	22.23
15	---	---	---	---	---	---	1.88	31.45
23	0.0	7.2	40.8	52.0	0.00	6.59	-1.02	31.27
47	20.3	32.7	24.8	22.0	0.04	7.60	---	---
100	0.0	50.3	21.9	27.8	0.95	3.09	-0.95	32.58
200	0.0	11.9	44.6	43.5	---	---	-1.41	33.28
360	0.0	6.1	44.8	49.1	0.67	2.47	0.36	34.99
700	0.0	0.8	44.5	54.7	1.03	1.87	0.38	34.96
1800	0.0	0.6	38.3	61.1	1.20	1.41	---	---

Table 16. Expected species values of polychaetes at stations on the Pingok Island cross-shelf transect.

Polychaetes	# ind	# spp	$E(S_n)$
PIB-5	565	15	13.07
	4	2	----
PIB-10	2927	23	13.04
	422	11	3.31
PIB-15	393	48	45.95
	215	12	6.57
23 m	827	43	34.77
	171	12	5.82
47 m	1370	60	40.71
	75	11	8.63
100 m	632	48	39.54
	170	8	6.67
200 m	1681	34	22.82
	61	5	4.14
360 m	1127	31	24.61
	26	3	----
700 m	1546	32	22.26
	143	4	3.55
1800 m	335	17	----
	204	5	3.12

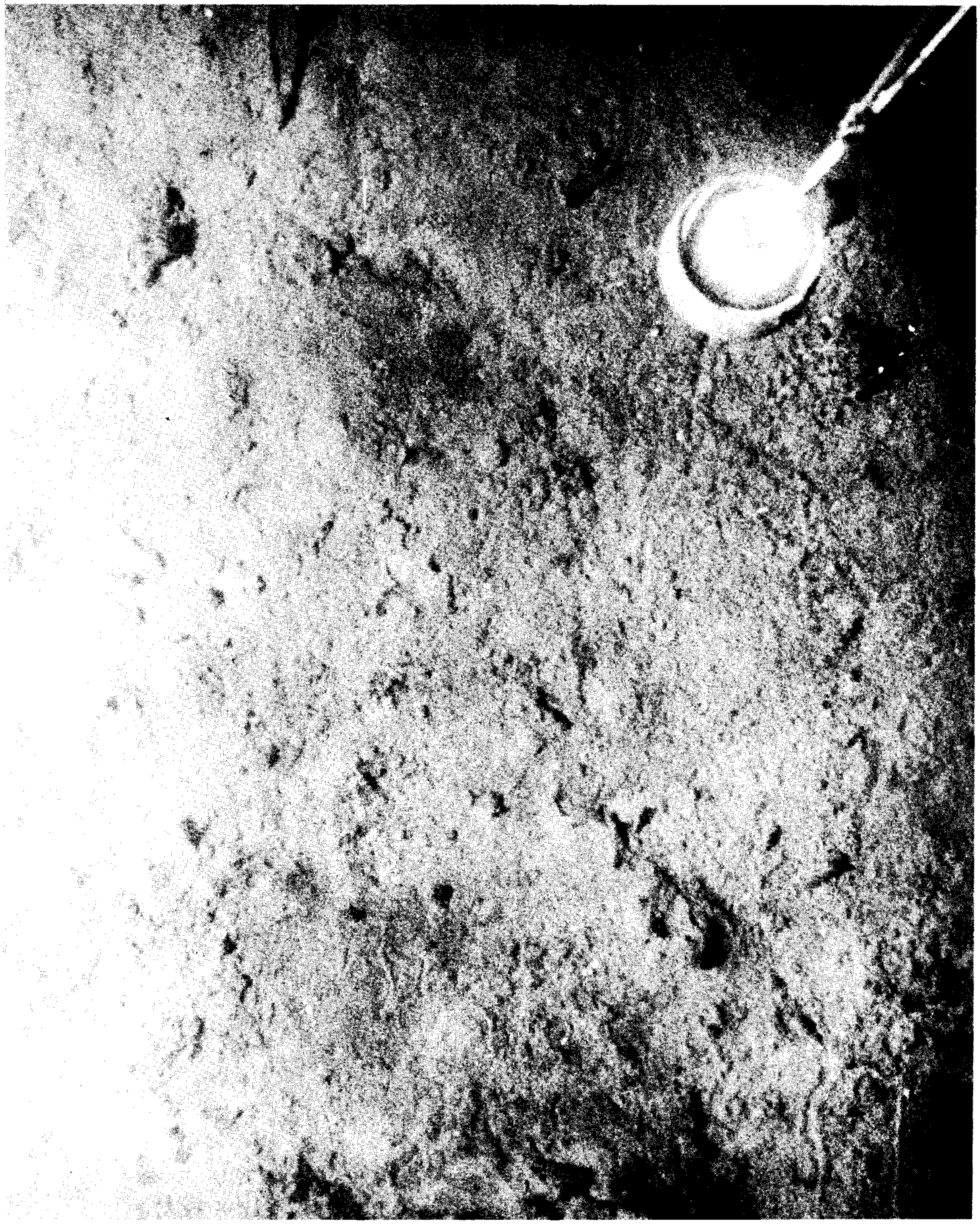

Fig. 44. Photograph of the sea floor on the cross-shelf transect at 19 m depth. A compass suspended from the camera appears in the upper right corner of the photo.

Fig. 45. Photograph of the sea floor on the cross-shelf transect at 24 m depth. The sediments are disrupted due to scour from the overlying ice pack. Ophiuroids are visible although the photo resolution is diminished due to suspended sediments in the water column.

Fig. 46. Photograph of the sea floor on the cross-shelf transect at 25 m depth. Numerous ophiuroids are visible.

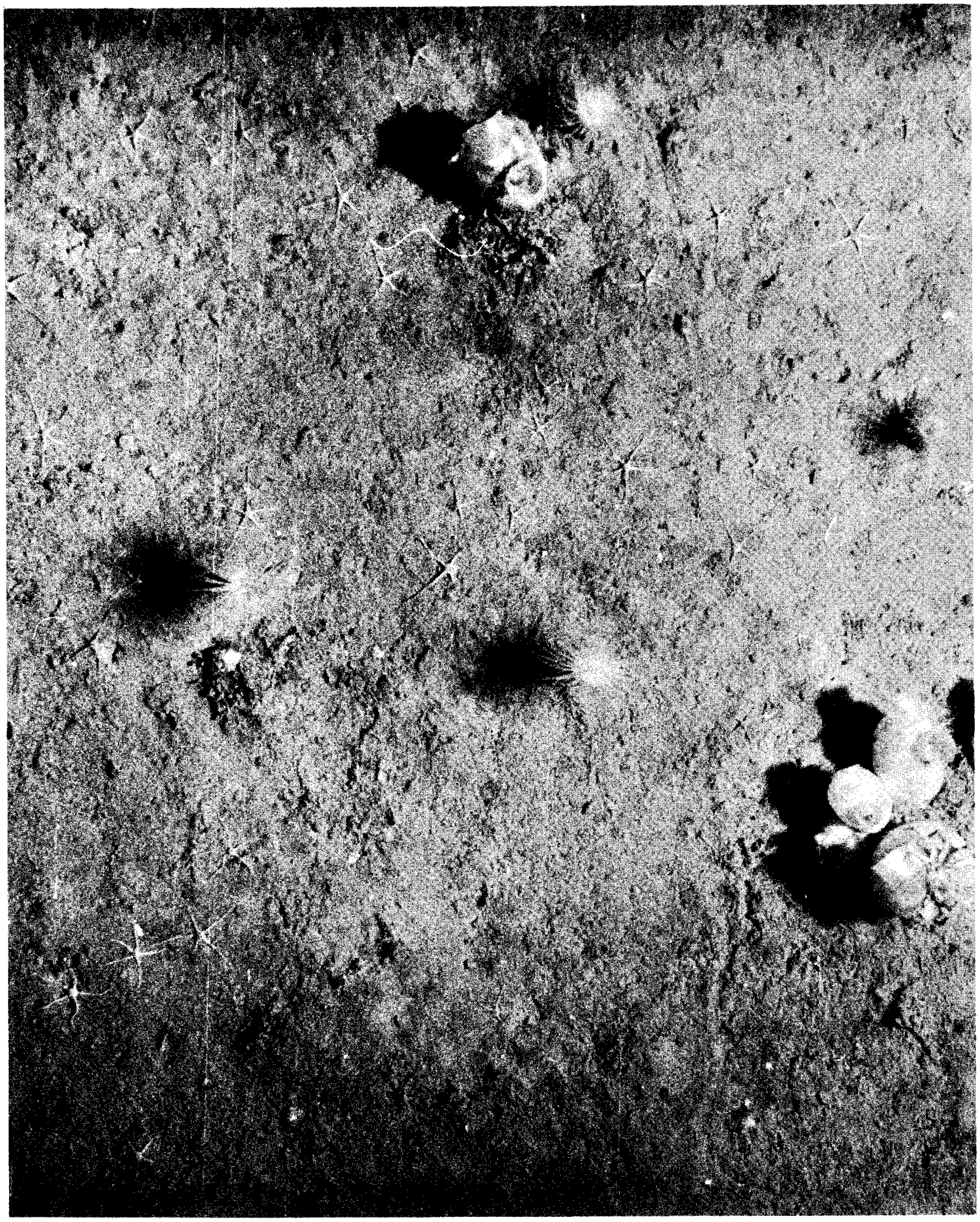

Fig. 47. Photograph of the sea floor on the cross-shelf transect at 44 m depth. Visible organisms include ophiuroids, tunicates, and burrowing sea anemones.

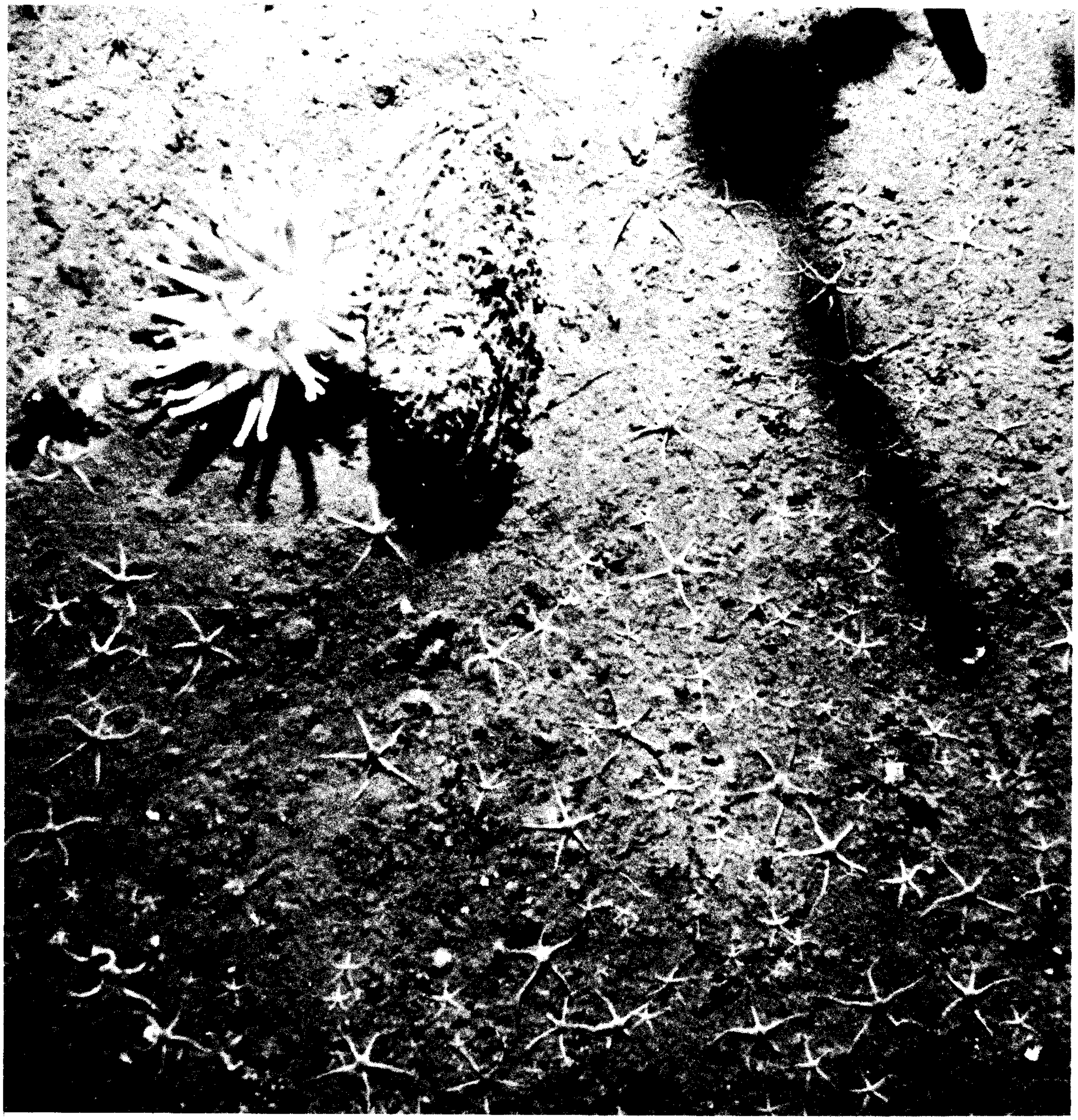

Fig. 48. Photograph of the sea floor on the cross-shelf transect at 80 m depth. Sea anemones and an abundant ophiuroid fauna are present. The shadow in the center right of the photo is cast by a compass vane suspended beneath the camera frame.

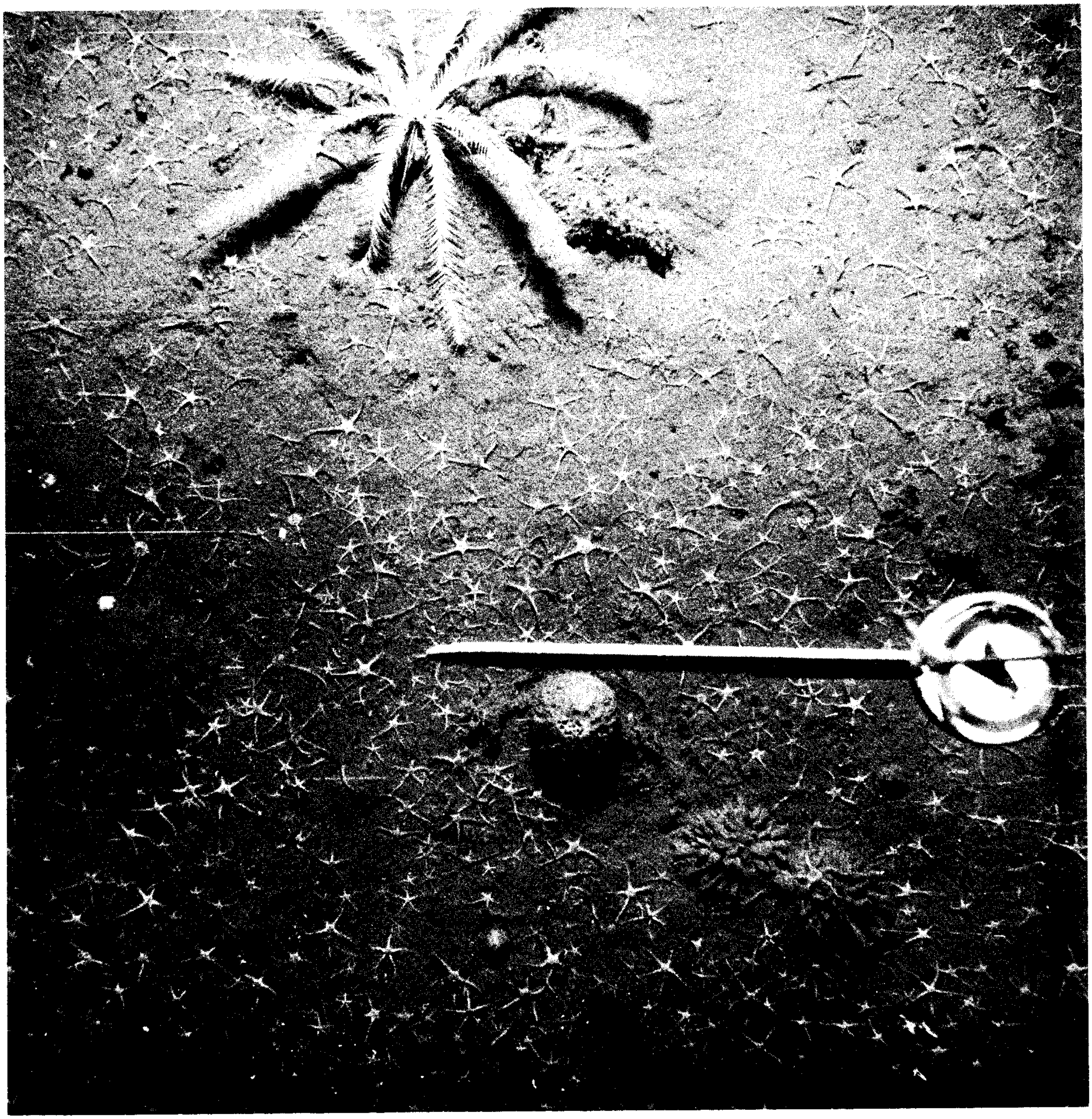

Fig. 49. Photograph of the sea floor on the cross-shelf transect at 145 m depth. Numerous ophiuroids, sponges, and a comatulid crinoid are evident.

Fig. 50. Photograph of the sea floor on the cross-shelf transect at 195 m depth. Ophiuroids, anemones, and shrimp are present, and a partially buried asteroid is visible at the top center of the photograph.

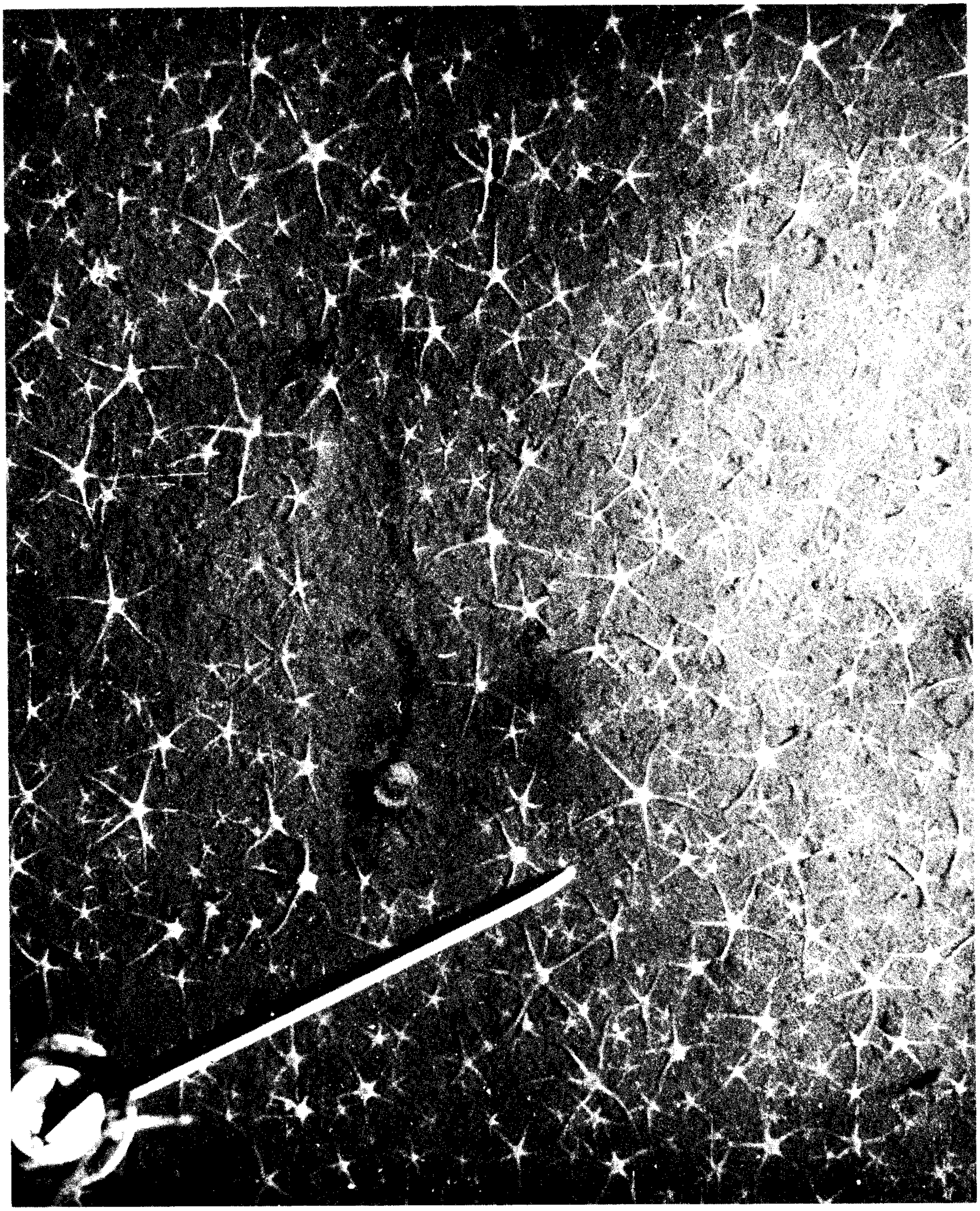

Fig. 51. Photograph of the sea floor on the cross-shelf transect at 350 m depth. An abundant ophiuroid fauna is evident.

Fig. 52. Photograph of the sea floor on the cross-shelf transect at 750 m depth. Only a few ophiuroids and a zoarcid are visible.

Fig. 53. Photograph of the sea floor on the cross-shelf transect at 1900 m depth. Numerous holothuroids dominate the sediment surface, although cumaceans and a sea pen are also visible.

Fig. 54. Photograph of the sea floor on the cross-shelf transect at 2160 m depth. A number of sea anemones are evident in the sediments. The trails visible in the bottom and center of the photo are made by a large isopod which can be seen in the upper left corner.

Appendix II. Narwhal Island Ice Station data collected during project Sea Ice-80.

Table 17. Sampling program used in 1980 sea ice meiofauna study (Kern, 1981).

	Ice Meiofauna Samples		
Date	# of quadrats sampled	# of cores per quadrat	total # of cores from uncaged ice
4/14	$	-	-
4/24	3*	3	9
5/5	3	3	9
5/11	3*	2	6
5/15	3	2	6
5/19	3	2	6
5/26	3	2	6
6/2	3	2	6
6/5	$	-	-

$ - Ice scraper samples taken within 40 m of study grid; used only for life-history studies.

* - Cores taken slightly outside study grid.

Table 18. Animal densities from ice nets (INB) from Narwhal Island ice station (NIO) collected on April 13 through June 9, 1980.

Net		Animal Group						
Number Total	Date	Amphipod	Cyclo.	Harpac.	Calan.	Cnidaria	Polychaeta	Total
INB 1	April 13	252						252
INB 2	"	195						195
INB 3	"	69						69
INB 4	"	11						11
INB 5	"	113	1					114
Total		640	1	--	--	--	--	641
INB 6	April 19	50						50
INB 7	"	70						70
INB 8	"	117			3	2	1	123
INB 9	"	45						45
INB 10	"	121						121
Total		403	--	--	3	2	1	409
INB 11	May 5	37						37
INB 12	"	38						38
INB 13	"	32						32
INB 14	"	21					1	22
INB 15	"	51						51
Total		179	--	--	--	--	1	180
INB 16	May 17	30			1	1		32
INB 17	"	172			13			185
IMB 18	"	72						72
INB 19	"	50			1			51
INB 20	"	135						135
Total		459	--	--	15	1	--	475
INB 21	May 31	36			3			39
INB 22	"	105				2		107
INB 23	"	55						55
INB 24	"	136						136
INB 25	"	98						98
Total		430	--	--	3	2	--	435
INB 26	June 9	805		2	7	1		815
INB 27	"	905		4	1			910
INB 28	"	2082		10	1			1093
INB 29	"	1144				1		1145
INB 30	"	464		2				466
INB 31	"	1564		2	1			1567
INB 32	"	1462		15				1477
INB 33	"	630		1				631
INB 34	"	512		6	1			519
INB 35	"	718		46				725
Total		10,286	--	48	11	3	--	10,348

Table 19. Numerical abundance and total wet weight of gammarid amphipod species collected from the underice surface at the Narwhal Island ice station.

Sampling date	Species	Abundance			Total wet weight(mg		
		Σ	σ_m	$\bar{x}$	Σ	σ_m	$\bar{x}$
13 April 1980	*Pseudalibrotus litoralis*	500	10.0	92.50	13504.3	2700.9	±2370.0
	Weyprechtia pinguis	4	0.8	1.30	146.7	49.2	±29.3
	Langunogammarus setosus	2	0.4	0.55	--	--	--
	Apherusa glacialis	1	0.2	0.45	9.5	1.9	±3.8
	Pseudalibrotus sp.	111	22.2	20.35	142.6	28.5	±22.5
	(*Amphipoda* spp).[1]	20	4.0	4.69	--	--	--
19 April 1980	*Pseudalibrotus litoralis*	73	14.6	20.34	1715.6	343.1	±427.9
	Halirages mixtus	8	1.4	1.34	87.8	17.6	±15.4
	Apherusa glacialis	5	1.0	1.22	20.4	4.1	±4.5
	Gammaridae sp. A	2	0.4	0.89	--	--	--
	Lagunogammarus setosus	1	0.2	0.45	3.5	0.7	±1.4
	(*Amphipoda* spp.)[1]	262	52.4	50.73	--	--	--
	Pseudalibrotus sp.	60	12.0	4.85	61.5	12.3	±6.8
	(*Gammaridae*)[2]	1	0.2	0.45	--	--	--
5 May 1980	*Pseudalibrotus litoralis*	43	8.6	7.64	1223.8	244.8	±220.1
	Halirages mixtus	2	0.4	0.55	21.8	4.4	±5.6
	Lagunogammarus setosus	2	0.4	0.55	97.6	19.5	±36.8
	(*Calliopiidae*)[3]	1	0.2	0.45	--	--	--
	Pseudalibrotus sp.	127	25.4	14.03	172.9	34.6	±15.5
17 May 1980	*Pseudalibrotus litoralis*	74	14.8	16.77	2163.2	432.6	±444.4
	Halirages mixtus	16	3.2	1.92	246.8	49.4	±32.6
	Gammaridae sp. A	2	0.4	0.55	--	--	--
	Weyprechtia pingus	1	0.2	0.45	13.9	2.8	±5.6
	(*Amphipoda* spp.)[1]	239	47.8	45.12	--	--	--
	Pseudalibrotus sp.	117	23.4	10.36	152.6	30.5	±13.9
	Weyprechtia pingus	9	1.8	2.05	--	--	--
	Lagunogammarus setosus	3	0.6	0.55	--	--	--

Table 19. (cont.)

Sampling date	Species	Abundance			Total wet weigth (mg)		
		Σ	σ_m	$\bar{x}$	Σ	σ_m	$\bar{x}$
31 May 1980	*Pseudalibrotus litoralis*	103	19.6	±14.05	3185.9	637.2	±403.5
	Lagunogammarus setosus	9	1.8	±2.49	1211.7	242.3	±297.4
	Halirgaes mixtus	2	0.4	±0.55	16.5	3.3	±4.1
	Pseudalibrotus sp.	189	37.8	±19.02	314.3	62.9	±25.2
	(*Amphipoda* sp)[1]	115	23.0	±10.32	--	--	--
	Weyprechtia pinguis	2	0.4	±0.55	--	--	--
9 June 1980	*Pseudalibtorus litoralis*	157	15.8	±18.02	5753.6	575.4	±627.0
	Lagunogammarus setosus	29	2.9	±5.55	3533.6	353.4	±878.9
	Apherusa glacialis	27	2.7	±2.75	231.3	23.1	±23.8
	Halirages mixtus	24	2.4	±2.37	317.6	31.8	±31.5
	Weyprechtia pinguis	4	0.4	±0.97	114.0	11.4	±24.7
	(*Calliopiidae*)[3]	1	0.1	±0.32	--	--	--
	Pseudalibrotus sp.	6496	349.0	±334.79	6623.8	662.4	±576.2
	(*Amphipoda* spp.)[1]	3491	649.6	±411.06	--	--	--
	Lagunogrammarus setosus	18	1.8	±1.99	--	--	--
	Weyprechtia pinguis	3	0.3	±0.95	--	--	--
	(*Gammaridae*)[2]	1	0.1	±0.32	--	--	--

[1] includes Halirages sp., Weyprechtia sp., and/or Apherusa sp.; possibly others

[2] includes *Halirages* sp., *Weyprechtia* sp., and/or *Apherusa* sp., possibly others

[3] ?*Lagunogammmarus* sp.

Table 20. Animal densities from sediment nets (SNB) collected at Narwhal Island ice station (NIO) on April 17, 1980 (OCS-11).

			Net Number					
Phylum	Class	Order	SNB1	SNB2	SNB3	SNB4	SNB5	TOTAL
Protozoa	Rhizopodea	Foraminifera		4	5		2	11
Annelida	Polychaeta				1			1
	Hirudinea				1	1		2
Arthropoda	Crustacea	Amphipoda	252	6	17	5	20	300
		Harpacticoida	1	1				2
		Ostracoda	2	2	8	1	1	14
		Cumacea	2		5			7
		Mysidacea	26	2	23	24	2	77
		TOTAL	283	15	60	31	25	414

Table 21. Animal densities from sediment nets (SNB) collected at Narwhal Island ice station (NIO) on May 2, 1980 (OCS-11).

			Net Number					
Phylum	Class	Order	SNB6	SNB7	SNB8	SNB9	SNB10	TOTAL
Arthropoda	Crustacea	Amphipoda	16	12	13	11	23	75
		Ostracoda		2		4	1	7
		Cumacea	1	3	1	2	1	8
		Mysidacea	11	4	6	10	16	47
		TOTAL	28	21	20	27	41	137

Table 22. Animal densities from sediment nets (SNB) collected at Narwhal Island ice station (NIO) on May 29, 1980 (OCS-11).

			Net Number					
Phylum	Class	Order	SNB11	SNB12	SNB13	SNB14	SNB15	TOTAL
Protozoa	Rhizopodea	Foraminifera	9	8	6	11	6	40
Annelida	Polychaeta			1				1
Arthropoda	Crustacea	Amphipoda	17	34	17	44	32	144
		Ostracoda	1	6	6	10	12	35
		Cumacea	4	12	6	9	3	34
		Mysidacea	5	2	5	5	7	24
Mollusca	Pelecypoda					1	3	4
	Gastropoda						2	2
		TOTAL	36	63	40	80	65	284

Table 23. Animal densities from sediment nets (SNB) collected at Narwhal Island ice station (NIO) on June 7, 1980 (OCS-11).

Phylum	Class	Order	SNB16	SNB17	SNB18	SNB19	SNB20	SNB21	SNB22	SNB23	SNB24	SNB25	TOTAL
Protozoa	Rhizopodea	Foraminifera	5	6	8	14	21	13	27	34	28	12	168
Nemertinea									1				1
Annelida	Polychaeta				1	3	6						10
Arthropoda	Crustacea	Amphipoda	49	69	72	71	167	70	74	48	102	135	857
		Harpacticoida						1		1			2
		Ostracoda	2	7	11	9	30	9	14	4	7	9	102
		Cumacea	32	35	36	60	91	42	128	89	107	76	696
		Mysidacea	14	17	11	11	10	7	8	5	14	14	111
Mollusca	Pelecypoda				1		2	1		2			6
	Gastropoda		1			1					1		3
		TOTAL	103	134	140	169	327	143	252	183	259	246	1956

Table 24. Environmental data measured at the Narwhal Island ice station during spring, 1980.

Date/Time		Depth(m)	Conductivity	Salinity(°/₀₀)	Temperature (°C)
17 Apr 80		0	27.41	35.82	-1.82
		1	27.24	35.93	-2.00
		2	27.08	35.64	-2.00
		3	27.08	35.09	-2.00
		4	27.07	35.28	<-2.00
		5	27.14	35.57	<-2.00
		6	27.13	35.45	<-2.00
		7	27.15	35.82	<-2.00
		8	27.24	36.02	<-2.00
19 Aor 80	1315	0	27.37	34.90	-1.40
		1	27.14	34.95	<-1.50
		2	27.10	35.50	<-2.00
		3	27.10	35.50	<-2.00
		4	27.17	35.73	<-2.00
		5	27.23	36.17	<-2.00
		6	27.34	36.30	<-2.00
	1625	0	27.16	35.50	-1.70
		6	27.33	36.03	<-2.00
24 Apr 80	1201	0	26.80	34.10	-1.70
		1	26.74	34.83	<-2.00
		2	26.75	34.96	-2.00
		3	26.78	34.94	<-2.00
		4	26.76	35.19	<-2.00
		5	26.75	35.17	<-2.00
		6	27.15	35.85	<-2.00
	1500	0	26.78	34.67	<-2.00
		6	27.82	36.78	<-2.00
28 Apr 80	1909	0	26.88	34.70	-2.00
		1	26.89	35.32	<-2.00
		2	26.86	35.28	<-2.00
		3	26.86	35.39	<-2.00
		4	26.91	35.45	<-2.00
		5	27.00	35.68	<-2.00
		6	27.24	35.76	<-2.00
30 Apr 80	0845	0	26.74	35.70	<-2.00
		1	26.80	35.84	<-2.00
		2	26.82	35.67	<-2.00
		3	26.82	35.72	<-2.00
		4	26.98	35.88	<-2.00
		5	27.06	35.92	<-2.00
		6	27.39	36.48	<-2.00
	1035	0	26.77	35.46	<-2.00
		6	27.30	36.29	<-2.00

Table 24. (cont.)

Date/Time		Depth(m)	Conductivity	Salinity(‰)	Temperature (°C)
30 Apr	1235	0	26.84	34.86	<-2.00
		1	26.82	34.37	-1.78
		2	26.85	34.70	-1.73
		3	26.85	35.01	<-2.00
		4	26.86	35.26	<-2.00
		5	26.90	35.42	<-2.00
		6	27.35	36.23	<-2.00
	1436	0	26.76	35.05	<-2.0
		6	27.14	35.69	<-2.0
	1638	0	26.79	33.74	-1.69
		1	26.75	34.70	-2.00
		3	26.78	34.88	<-2.00
		4	26.98	35.33	<-2.00
		5	27.19	35.51	<-2.00
		6	27.30	35.90	<-2.00
	1834	0	26.76	35.14	<-2.00
		6	27.29	35.91	<-2.00
	2032	0	26.92	35.05	<-2.00
		1	26.84	35.23	<-2.00
		2	26.84	35.20	<-2.00
		3	26.84	35.27	<-2.00
		4	26.94	35.51	<-2.00
		5	27.33	35.98	<-2.00
		6	27.40	35.98	<-2.00
	2230	0	26.86	35.21	<-2.00
		6	27.49	36.52	<-2.00
1 May 80	0034	0	26.81	35.08	<-2.00
		1	26.85	35.16	<-2.00
		2	26.85	35.34	<-2.00
		3	26.91	35.41	<-2.00
		4	27.12	35.80	<-2.00
		5	27.15	35.92	<-2.00
		6	27.38	36.21	<-2.00
	0240	0	26.83	35.08	<-2.00
		6	27.42	36.06	<-2.00
	0447	0	26.83	34.45	-1.65
		1	26.82	34.84	<-2.00
		2	26.82	34.95	<-2.00
		3	26.83	35.18	<-2.00
		4	26.89	35.38	<-2.00
		5	27.29	36.03	<-2.00
		6	27.37	36.14	<-2.00
	0650	0	26.77	34.93	<-2.00
		6	27.16	35.58	<-2.00

Table 24. (cont.)

Date/Time		Depth(m)	Conductivity	Salinity(°/oo)	Temperature (°C)
	0930	0	27.08	33.40	-1.30
		1	26.86	34.92	<-2.00
		2	26.87	35.05	<-2.00
		3	26.87	35.23	<-2.00
		4	27.03	35.41	<-2.00
		5	27.13	35.50	<-2.00
		6	27.55	36.39	<-2.00
	1533	0	26.91	35.23	<-2.00
		6	27.25	36.00	<-2.00
5 May 80	0920	0	27.10	33.68	-0.78
		1	26.88	33.93	-0.91
		2	26.86	34.08	-0.97
		3	26.93	34.99	<-2.00
		4	27.28	35.62	<-2.00
		5	27.45	36.31	<-2.00
		6	27.59	36.50	<-2.00
7 May 80	0935	0	27.03	34.80	-2.00
		1	26.91	35.28	<-2.00
		2	26.93	35.00	<-2.00
		3	26.93	35.21	<-2.00
		4	27.31	35.95	<-2.00
		5	27.49	36.32	<-2.00
		6	27.54	36.40	<-2.00
	1135	0	26.94	35.50	<-2.00
		6	27.55	36.79	<-2.00
	1330	0	26.71	35.56	<-2.00
		1	26.96	35.87	<-2.00
		2	27.00	35.84	<-2.00
		3	7.00	35.93	<-2.00
		4	27.25	36.27	<-2.00
		5	27.55	36.62	<-2.00
		6	27.69	36.81	<-2.00
	1535	0	26.91	35.77	<-2.00
		6	27.55	36.80	<-2.00
	1758	0	26.81	35.87	<-2.00
		1	26.93	35.89	<-2.00
		2	26.93	35.89	<-2.00
		3	26.92	35.75	<-2.00
		4	26.96	35.74	<-2.00
		5	27.18	36.21	<-2.00
		6	27.52	36.67	<-2.00
	1934	0	26.93	35.74	<-2.00
		6	26.99	36.19	<-2.00

Table 24. (cont.)

Date/Time		Depth(m)	Conductivity	Salinity(°/₀₀)	Temperature (°C)
7 May 80	2135	0	26.62	36.15	<-2.00
		1	26.92	36.52	<-2.00
		2	26.93	36.39	<-2.00
		3	26.95	36.34	<-2.00
		4	26.99	36.40	<-2.00
		5	27.42	36.98	<-2.00
		6	27.55	36.80	<-2.00
	2330	0	26.88	36.33	<-2.00
		6	27.45	37.69	<-2.00
8 May 80	0145	0	26.46	38.53	<<-2.00
		1	26.84	39.17	<<-2.00
		2	26.80	39.17	<<-2.00
		3	26.80	38.63	<<-2.00
		4	27.02	38.90	<<-2.00
		5	27.44	39.58	<<-2.00
		6	27.53	39.83	<<-2.00
	0330	0	26.57	39.31	<<-2.00
		6	26.92	40.00	<<-2.00
11 May 80	1605	0	26.90	34.70	-1.90
		1	26.79	34.92	<-2.00
		2	26.80	35.10	<-2.00
		3	26.80	35.20	<-2.00
		4	26.90	34.60	-1.99
		5	27.19	36.00	<-2.00
		6	27.39	36.30	<-2.0
15 May 80	1430	0	26.94	35.36	<-2.00
		1	26.96	35.30	<-2.00
		2	26.98	35.60	<-2.00
		3	26.90	35.42	<-2.00
		4	26.96	35.54	<-2.00
		5	27.02	35.78	<-2.00
		6	27.10	35.78	<-2.00
17 May 80	1149	0	26.88	35.30	<-2.00
		1	26.88	35.88	<-2.00
		2	26.98	35.70	<-2.00
		3	26.96	35.70	<-2.00
		4	27.06	35.72	<-2.00
		5	27.08	35.82	<-2.00
		6	27.13	36.00	<-2.00
19 May 80	0947	0	26.62	36.22	<-2.00
		1	26.72	35.44	<-2.00
		2	26.74	35.46	<-2.00
		3	26.76	35.60	<-2.00
		4	26.76	35.60	<-2.00
		5	27.06	36.20	<-2.00
		6	27.15	36.14	<-2.00

Table 24. (cont.)

Date/Time		Depth(m)	Conductivity	Salinity(°/₀₀)	Temperature (°C)
19 May 80	1145	0	26.76	35.20	<-2.00
		6	27.15	36.10	<-2.00
	1350	0	26.85	34.22	-0.80
		1	26.73	34.92	-2.00
		3	26.71	34.80	<-2.00
		4	26.74	35.12	<-2.00
		5	26.81	35.40	<-2.00
		6	26.94	35.56	<-2.00
	1742	0	26.80	32.60	0.10
		6	26.92	34.20	-1.30
	1929	0	27.08	33.14	-0.76
		1	26.84	33.30	-1.50
		2	26.84	35.00	-1.77
		3	26.88	34.92	<-2.00
		4	26.84	35.10	<-2.00
		5	26.92	35.48	<-2.00
		6	27.08	35.48	<-2.00
	2135	0	26.90	34.40	-1.30
		6	26.17	35.85	<-2.00
	2340	0	26.90	34.24	-1.70
		1	26.90	35.26	<-2.00
		2	26.90	35.20	<-2.00
		3	26.90	35.60	<-2.00
		4	26.90	35.18	<-2.00
		5	27.10	35.80	<-2.00
		6	27.26	36.12	<-2.00
20 May 80	0730	0	26.78	33.82	-1.08
		1	26.74	34.06	-1.97
		2	26.76	34.58	-1.74
		3	26.74	34.50	-2.00
		4	26.74	34.90	<-2.00
		5	26.94	34.73	<-2.00
		6	27.42	36.20	<-2.00
22 May 80	1240	0	26.18	33.59	-2.00
		1	26.28	34.27	<-2.00
		2	26.34	34.27	<-2.00
		3	26.34	34.48	<-2.00
		4	26.34	34.16	<-2.00
		5	26.50	34.30	<-2.00
		6	26.84	35.42	<-2.00
26 May 80	0930	0	26.31	34.20	<-2.00
		1	26.32	34.50	<-2.00
		2	26.31	34.43	<-2.00
		3	26.32	34.43	<-2.00
		4	26.42	34.62	<-2.00
		5	26.42	34.54	<-2.00
		6	26.54	34.96	<-2.00

Table 24. (cont.)

Date/Time		Depth(m)	Conductivity	Salinity(°/oo)	Temperature (°C)
29 May 80	0900	0	26.55	34.94	<-2.00
		1	26.55	34.98	<-2.00
		2	26.54	34.93	<-2.00
		3	26.56	34.94	<-2.00
		4	26.61	34.96	<-2.00
		5	26.65	35.06	<-2.00
		6	26.70	35.08	<-2.00
31 May 80	0945	0	26.50	35.04	<-2.00
		1	26.58	34.96	<-2.00
		2	26.58	35.12	<-2.00
		3	26.61	35.22	<-2.00
		4	26.68	35.22	<-2.00
		5	26.75	35.22	<-2.00
		6	26.85	35.22	<-2.00
2 June 80	0900	0	26.59	34.84	<-2.00
		1	26.62	34.84	<-2.00
		2	26.65	34.90	<-2.00
		3	26.69	34.98	<-2.00
		4	26.66	35.05	<-2.00
		5	26.70	35.11	<-2.00
		6	26.75	35.11	<-2.00
	1100	0	26.65	35.05	-1.75
		6	26.96	35.53	<-2.00
	1300	0	26.64	31.90	+0.57
		1	26.76	34.89	<-2.00
		2	26.76	34.99	<-2.00
		3	26.76	35.09	<-2.00
		4	26.78	34.79	<-2.00
		5	26.85	35.26	<-2.00
		6	26.82	35.23	<-2.00
	1500	0	26.76	33.04	+0.59
		6	26.69	34.59	<-2.00
	1700	0	27.04	32.49	+0.09
		1	26.81	34.61	<-2.00
		2	26.83	34.26	-1.85
		3	26.81	34.80	<-2.00
		4	26.81	34.76	<-2.00
		5	26.82	35.09	<-2.00
		6	26.85	35.18	<-2.00
	1900	0	27.01	32.88	-0.51
		6	26.90	34.95	-1.65
	2100	0	27.01	33.27	-1.03
		1	26.83	34.95	<-2.00
		2	26.83	34.94	<-2.00
		3	26.83	34.90	<-2.00
		4	26.82	34.88	<-2.00
		5	26.85	34.82	<-2.00
		6	26.85	34.94	<-2.00

Table 24. (cont.)

Date/Time		Depth(m)	Conductivity	Salinity(°/oo)	Temperature (°C)
2 June 80	2300	0	26.97	31.26	+0.64
		6	26.94	33.82	-0.70
3 June 80	0100	0	27.00	31.39	+1.14
		1	26.72	32.94	-1.32
		2	26.70	33.74	-1.45
		3	26.74	34.58	-2.00
		4	26.75	34.72	<-2.00
		5	26.79	35.06	<-2.00
		6	26.77	35.04	<-2.00
	0300	0	27.08	29.89	+0.82
		6	26.96	34.88	<-2.00
	0500	0	26.92	32.96	+0.23
		1	26.81	31.50	-0.32
		2	26.97	32.62	-0.42
		3	26.94	34.69	-1.90
		4	26.90	34.85	<-2.00
		5	26.93	35.17	<-2.00
		6	26.92	35.11	<-2.00
	0700	0	26.96	30.79	+1.22
		6	27.06	33.67	+0.06
5 June 80	0840	0	26.06	33.68	<-2.00
		1	26.75	34.47	-1.90
		2	26.84	35.03	<-2.00
		3	26.86	35.26	<-2.00
		4	26.93	35.26	<-2.00
		5	26.98	35.39	<-2.00
		6	27.01	35.54	<-2.00
7 June 80	0840	0	25.63	32.30	-1.46
		1	26.62	34.51	<-2.00
		2	26.75	34.94	<-2.00
		3	26.77	34.89	<-2.00
		4	26.89	35.23	<-2.00
		5	27.05	35.46	<-2.00
		6	27.10	35.60	<-2.00
9 June 80	0840	0	2.73	2.81	-0.44
		1	26.22	34.06	<-2.00
		2	26.30	33.86	-1.84
		3	26.54	34.71	<-2.00
		4	26.74	35.10	<-2.00
		5	26.87	35.11	<-2.00
		6	26.89	35.28	<-2.00
11 June 80	0833	0	1.56	1.56	-0.31
		1	19.58	23.48	-1.17
		2	26.06	33.82	<-2.00
		3	26.65	34.84	<-2.00
		4	26.76	35.21	<-2.00
		5	26.80	35.03	<-2.00
		6	26.90	35.38	<-2.00

Table 25. Mean abundance per 100 cm^2 for major taxa collected on each sampling date. $\bar{X}$: Mean, SD: Standard deviation. The results of one-way ANOVA's are given at right.

	4/24		5/5		5/11		5/15		5/19		5/26		6/2		Significant Change over time? (P)
Group	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	
Nematoda	3.59	1.95	9.23	10.51	34.84	33.92	6.36	17.74	175.34	129.66	186.71	145.44	250.22	76.63	Yes (<.002)
Copepoda	50.94	28.13	27.21	13.62	24.63	10.06	57.74	27.59	109.71	56.63	125.11	81.39	69.87	36.51	Yes (<.002)
Turbellaria	2.96	2.53	2.06	2.15	4.82	3.45	6.16	4.42	52.93	14.56	26.56	9.49	151.67	22.65	Yes (<.002)
Polychaeta	51.07	65.30	14.63	19.51	1.35	0.87	9.62	13.12	7.89	6.42	18.10	21.86	8.08	5.89	Yes (<.002)
Amphipoda	2.82	2.09	2.18	2.34	2.31	1.63	6.54	4.04	9.24	7.04	11.93	7.47	2.51	1.99	Yes (<.002)

Table 26. Mean abundance per 100 cm^2 for the five dominant copepod species on each sampling date. $\overline{X}$: Mean, SD: Standard deviation. The results of one-way ANOVA's are given last.

	4/24		5/5		5/11		5/15	
Group	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Cyclopina gracilis	22.97	13.26	15.27	9.43	10.20	5.99	29.65	18.00
Harpacticus sp.	10.39	7.96	6.55	4.65	5.58	3.13	11.74	6.83
Halectinosoma sp.	15.52	11.41	4.11	2.45	8.08	2.92	9.82	7.37
Oncaea sp.	0.51	0.84	0.25	0.51	0.38	0.60	2.51	2.36
Dactylopodia signata	0.77	1.15	0.13	0.38	0.0	-	0.0	-

	5/19		5/26		6/2		Significant change	
Group	$\overline{X}$	SD	X	SD	X	SD	over time?	(P)
Cyclopina gracilis	60.78	34.24	76.99	40.73	34.65	27.27	Yes	(<.002)
Harpacticus sp.	31.56	15.16	17.90	10.65	20.59	13.45	Yes	(<.002)
Halectinosoma sp.	14.05	12.38	27.52	34.51	8.08	5.01	No	
Oncaea sp.	1.35	0.87	0.38	0.95	1.73	2.71	Yes	(<.05)
Dactylopodia signata	0.77	1.19	0.35	0.95	0.0	-	No	

Table 27. Summary of life-history data for <u>Harpacticus</u> sp. and <u>Cyclopina gracilis</u>.

<u>Cyclopina gracilis</u>

Date	% Females of Adults	% Females of all Sexable	% Adults	% Gravid Females of Adult Females
4/14	94.4	96.0	18.0	0.0
4/24	79.2	68.1	4.9	11.1
5/5	58.2	67.4	56.3	0.0
5/11	32.4	39.5	64.2	9.1
5/15	34.0	41.5	65.4	5.9
5/19	36.1	46.8	46.8	1.9
5/26	43.8	48.1	47.3	4.9
6/2	45.0	47.4	55.6	0.0
6/5	55.0	57.1	60.0	0.0

<u>Harpacticus</u> sp.

Date	% Females of Adults	% Females of all Sexable	% Adults	% Gravid Females of Adult Females
4/14	-	-	0.0	-
4/24	-	25.0	0.0	-
5/5	-	40.5	0.0	-
5/11	11.1	45.0	31.0	0.0
5/15	16.7	34.4	70.0	0.0
5/19	22.8	39.1	62.6	0.0
5/26	42.7	53.8	80.6	6.8
6/2	33.9	56.0	55.1	12.8
6/5	35.3	56.5	51.0	0.0

Table 28. Amphipod species associated with the ice undersurface, water column, and sediments at the Narwhal Island ice station, spring 1980.

Gammarid Amphipod species–

		no./m^2
Underice:	Pseudalibrotus litoralis	9.1
	Haliragеs mixtus	0.5
	Lagunogammarus setosus	0.4
	Apherusa glacialis	0.3
	Weyprechtia pinguis	0.1
Mid-water:	Pseudalibrotus litoralis	
	Halirages mixtus	
	Oediceros borealis	
	Apherusa glacialis	
	Langunogammarus setosa	
	?Anonyx nugax	
	Weyprechtia pinguis	
	Monoculodes borealis	
	Acanthostepheia incarinata	
Benthos:	Monoculodes borealis	1.4
	Pseudalibrotus litoralis	0.8
	Onisimus affinis	0.6
	Onisimus plautus	0.3
	Acanthostepheia malmgreni	0.1
	Onisimus cf. derjugini	0.1
	Oediceros borealis	< 0.1
	Monoculopsis borealis	< 0.1
	Apherusa glacialis	< 0.1
	?Anonyx nugax	< 0.1
	Acanthostepheia incarinata	< 0.1
	Halirages mixtus	< 0.1
	Lagunogammarus setosus	< 0.1

Appendix III. Narwhal Island Particle Flux data collected during project Sea Ice-80.

Table 29. Sea Ice-80 Particle Data.

Sample Date	Collection Number	Material
24 April 80	Filter 11	51 - fecal pellet 'A'
		3 - fecal pellet 'small A'
		7 - fecal pellet 'B'
		8 - unconsolidated fecal pellets
	Filter 12	104 - fecal pellet 'A'
		9 - fecal pellet 'small A'
		10 - fecal pellet 'B'
		10 - unconsolidated material
		25 - crustacean exoskeletons
		1 - gammarid amphipod
		1 - calanoid copepod
		1 - ? egg
	Filter 14	41 - fecal pellet 'A'
		10 - fecal pellet 'small A'
		8 - fecal pellet 'B'
		9 - unconsolidated fecal pellets
		10 - crustacean exoskeletons
		2 - gammarid amphipods
		3 - harpacticoid copepods
3 May 80	Filter 18	40 - fecal pellet 'A'
		20 - fecal pellet 'small A'
		2 - fecal pellet 'B'
		21 - unconsolidated fecal pellets
		13 - crustacean exoskeletons
	Filter 19	17 - fecal pellet 'A'
		10 - fecal pellet 'small A'
		11 - fecal pellet 'B'
		11 - unconsolidated fecal pellets
		1 - crustacean exoskeletons
	Filter 20	34 - fecal pellet 'A'
		16 - fecal pellet 'small A'
		4 - fecal pellet 'B'
		9 - unconsolidated fecal pellets
		88 - crustacean exoskeletons
		3 - harpacticoid copepods
		1 - cumacean

Table 29. con't.

Sample Date	Collection Number	Material
11 May	Filter 26	56 - fecal pellet 'A'
		28 - fecal pellet 'small A'
		11 - fecal pellet 'B'
		20 - unconsolidated fecal pellets
		64 - crustacean exoskeletons
		2 - harpacticoid copepods
	Filter 29	70 - fecal pellet 'A'
		49 - fecal pellet 'small A'
		7 - fecal pellet 'B'
		10 - unconsolidated fecal pellets
		62 - crustacean exoskeletons
		3 - gammarid amphipods
		2 - harpacticoid copepods
	Filter 32	62 - fecal pellet 'A'
		27 - fecal pellet 'small A'
		5 - fecal pellet 'B'
		7 - unconsolidated fecal pellets
		26 - crustacean exoskeletons
22 May	Filter 34	78 - fecal pellet 'A'
		67 - fecal pellet 'small A'
		7 - fecal pellet 'B'
		10 - unconsolidated material
		9 - crustacean exoskeletons
		1 - gammarid amphipod
		2 - calanoid copepod
	Filter 35	44 - fecal pellet 'A'
		69 - fecal pellet 'small A'
		5 - fecal pellet 'B'
		15 - unconsolidated material
		1 - crustacean exoskeletons
		1 - isopod
	Filter 36	29 - fecal pellet 'A'
		50 - fecal pellet 'small A'
		11 - fecal pellet 'B'
		41 - crustacean exoskeletons
		1 - isopod
		2 - ? eggs

Table 29. con't.

Sample Date	Collection Number	Material
29 May	Filter 42	49 - fecal pellet 'A' 107 - fecal pellet 'small A' 5 - fecal pellet 'B' 4 - unconsolidated fecal pellets 15 - crustacean exoskeletons
	Filter 43	51 - fecal pellet 'A' 62 - fecal pellet 'small A' 12 - fecal pellet 'B' 3 - unconsolidated fecal pellets 4 - crustacean exoskeletons
	Filter 46	44 - fecal pellet 'A' 90 - fecal pellet 'small A' 5 - fecal pellet 'B' 2 - unconsolidated fecal pellets 4 - crustacean exoskeletons 1 - egg
5 June 80	Filter 50	2 - fecal pellet 'A' 1 - fecal pellet 'small A' 20 - unconsolidated fecal pellets 1 - gammarid amphipod
	Filter 52	1 - fecal pellet 'B' 37 - unconsolidated fecal pellets
	Filter 56	7 - fecal pellet 'A' 7 - fecal pellet 'small A' 1 - fecal pellet 'B' 34 - unconsolidated fecal pellets 6 - crustacean exoskeletons

Table 30. Total particle flux to the sediment per unit area per day.

	Total Particle Counts
Sample Date	Particle Flux/m^2/day
24 April 1980	1627 ± 768
3 May 1980	1564 ± 799
11 May 1980	2212 ± 484
22 May 1980	1648 ± 144
29 May 1980	2010 ± 325
5 June 1980	611 ± 253

Table 31. Flux Rate of Major Particle Types.

Sample Date	Collection Number	Flux/m^2/day			
		Fecal Pellet 'A'	Fecal Pellet 'small A'	Fecal Pellet 'B'	Crustacean Exoskeleton
24 Apr 80	Filter 11	806	47	111	47
	Filter 12	1643	142	158	395
	Filter 14	648	158	126	158
	Average ± s.d. =	1032 ± 534	116 ± 60	132 ± 24	200 ± 178
3 May 80	Filter 18	632	316	32	205
	Filter 19	269	158	174	16
	Filter 20	537	253	63	1390
	Average ± s.d. =	479 ± 188	242 ± 80	90 ± 75	537 ± 745
11 May 80	Filter 26	737	369	145	843
	Filter 29	922	645	92	816
	Filter 32	816	355	66	342
	Average ± s.d. =	825 ± 93	456 ± 164	101 ± 40	667 ± 282
22 May 80	Filter 34	880	756	79	102
	Filter 35	496	779	56	11
	Filter 36	327	564	124	462
	Average ± s.d. =	568 ± 283	700 ± 118	86 ± 35	192 ± 239
29 May 80	Filter 42	645	1409	66	198
	Filter 43	672	816	158	53
	Filter 46	579	1185	66	53
	Average ± s.d. =	632 ± 48	1137 ± 299	97 ± 53	101 ± 84
5 June 80	Filter 50	32	0	16	0
	Filter 52	0	0	16	0
	Filter 56	111	111	16	95
	Average ± s.d. =	42 ± 57	37 ± 64	61 ± 0	32 ± 55

Table 32. Sea-Ice 80 Particle Weight Data.

		Dry Weights (grams)				
Sample Date	Collection Number	Filter + Sample	Pre-fired Filter Wt.	Uncorrected Sample Wt.	Salt Correction (g. NaCl)	Total Sample Weight
24 Apr 80	Filter 11	1.0719	0.8232	0.2487	0.1779	0.0708
	Filter 12	1.1420	0.8206	0.3214	0.2284	0.0929
	Filter 14	1.1544	0.8226	0.3318	0.2176	0.1142
3 May 80	Filter 18	1.1004	0.8220	0.2784	0.2246	0.0538
	Filter 19	1.2598	0.8224	0.4376	0.1452	0.2922
	Filter 20	1.5045	0.8203	0.6842	0.2137	0.4705
11 May 80	Filter 26	1.4047	0.8239	0.5808	0.1414	0.4394
	Filter 29	1.1072	0.8244	0.2828	0.22329	0.0499
	Filter 32	2.0641	0.8167	1.2474	0.2809	0.9665
22 May 80	Filter 34	1.0979	0.8201	0.2778	0.2323	0.0455
	Filter 35	1.2217	0.8221	0.3996	0.1920	0.2076
	Filter 36	1.2223	0.8320	0.3903	0.1638	0.2265
29 May 80	Filter 42	1.2594	0.8243	0.4351	0.2489	0.1862
	Filter 43	1.0821	0.8232	0.2589	0.2137	0.0452
	Filter 46	1.2531	0.8262	0.4269	0.2052	0.2017
5 June 80	Filter 50	0.9115	0.8246	0.0869	0.0493	0.0376
	Filter 52	0.8900	0.8175	0.0725	0.0250	0.0475
	Filter 56	1.1081	0.8298	0.2783	0.0371	0.2412

Table 33. Total Particle Dry Weights

Sample Dates	Mean Particle Weight per collectior (grams)	Flux (grams)/m^2/day
24 April 80	0.0926 + 0.0217	1.46 ± 0.34
3 May 80	0.2722 ± 0.2091	4.30 ± 3.30
11 May 80	0.4852 ± 0.4600	6.39 ± 6.06
22 May 80	0.1599 ± 0.0995	1.80 ± 1.12
29 May 80	0.2444 ± 0.0862	1.90 ± 1.14
5 June 80	0.1088 ± 0.1148	1.72 ± 1.81

Table 34. Sea-Ice '80 Carbon/Nitrogen flux rates, Narwhal Island Ice Station.

Sample Date	Collection Number	Flux/m^2/day Carbon (mg) ± S.D.	Nitrogen (mg) ± S.D.
24 Apr	Filter 11	25.45 ± 5.08	0.33 ± 0.40
	Filter 12	59.12 ± 13.16	1.48 ± 0.88
	Filter 14	58.50 ± 17.74	1.59 ± 0.59
Average		47.69 ± 20.26	1.13 ± 0.84
3 May	Filter 18	33.93 ± 4.26	1.27 ± 0.34
	Filter 19	43.71 ± 17.09	1.05 ± 0.51
	Filter 20	43.50 ± 8.92	2.37 ± 0.94
Average		40.37 ± 11.36	1.56 ± 0.84
11 May	Filter 26	40.28 ± 14.04	1.65 ± 0.62
	Filter 29	47.03 ± 9.16	2.06 ± 0.90
Average		43.65 ± 11.84	1.86 ± 0.77
22 May	Filter 34	31.67 ± 7.21	1.39 ± 0.81
	Filter 35	29.73 ± 3.75	0.81 ± 0.43
	Filter 36	25.75 ± 2.92	1.13 ± 0.72
Average		29.05 ± 5.19	1.11 ± 0.65
29 May	Filter 42	29.12 ± 3.72	1.50 ± 0.51
	Filter 43	52.34 ± 8.56	4.92 ± 0.74
	Filter 46	57.29 ± 0.60	7.05 ± 1.10
Average		46.25 ± 13.890	4.49 ± 2.50
5 Jun	Filter 50	21.58 ± 6.95	1.02 ± 0.40
	Filter 52	20.58 ± 4.56	0.89 ± 0.50
	Filter 56	51.31 ± 10.00	2.03 ± 1.63
Average		31.16 ± 16.36	1.31 ± 1.06

Table 35. Sea Ice-80 Nitrogen Flux, Narwhal Island Ice Station.

Sample Date	Collection Number	Nitrogen Flux/Collector total (mg)	m^2 (mg)	day (mg)
24 Apr	Filter 11	0.021	1.642	0.004
	Filter 12	0.093	7.382	0.019
	Filter 14	0.101	7.965	0.020
3 May	Filter 18	0.080	6.353	0.016
	Filter 19	0.006	5.249	0.013
	Filter 20	0.150	11.863	0.030
11 May	Filter 26	0.125	9.914	0.021
	Filter 29	0.156	12.359	0.026
22 May	Filter 34	0.123	9.699	0.018
	Filter 35	0.071	5.648	0.010
	Filter 36	0.100	7.888	0.014
29 May	Filter 42	0.114	9.024	0.019
	Filter 43	0.374	29.542	0.062
	Filter 46	0.536	42.311	0.089
5 Jun	Filter 50	0.064	5.080	0.013
	Filter 52	0.057	4.466	0.011
	Filter 56	0.128	10.144	0.026

Table 36. Sea Ice-80 Carbon Flux, Narwhal Island Ice Station.

		Carbon Flux/Collector		
Sample Date	Collection Number	total (mg)	m_2 (mg)	day (mg)
24 Apr	Filter 11	1.61	127.18	0.32
	Filter 12	3.74	295.61	0.75
	Filter 14	3.70	292.52	0.74
3 May	Filter 18	2.15	169.63	0.43
	Filter 19	2.77	218.51	0.55
	Filter 20	2.75	217.48	0.55
11 May	Filter 34	3.06	241.70	0.40
	Filter 29	3.57	282.19	0.60
22 May	Filter 34	2.81	221.70	0.40
	Filter 35	2.63	208.12	0.38
	Filter 36	2.28	180.25	0.33
29 May	Filter 42	2.21	174.69	0.37
	Filter 43	3.97	314.04	0.66
	Filter 46	3.25	256.55	0.54
5 Jun	Filter 50	1.37	107.90	0.27
	Filter 52	1.30	102.92	0.26
	Filter 56	3.25	256.55	0.65

Table 37. Sea Ice-80 Carbon/Nitrogen flux rates, Narwhal Island Ice Station.

Sample Date	Collection Number	Flux/m^2/day Carbon (mg) ± S.D.	Flux/m^2/day Nitrogen (mg) ± S.D.
24 Apr	Filter 11	25.45 ± 5.08	0.33 ± 0.40
	Filter 12	59.12 ± 13.16	1.48 ± 0.88
	Filter 14	58.50 ± 17.74	1.59 ± 0.59
Average		47.69 ± 20.26	1.13 ± 0.84
3 May	Filter 18	33.93 ± 4.26	1.27 ± 0.34
	Filter 19	43.71 ± 17.09	1.05 ± 0.51
	Filter 20	43.50 ± 8.92	2.37 ± 0.94
Average		40.37 ± 11.36	1.56 ± 0.84
11 May	Filter 26	40.28 ± 14.04	1.65 ± 0.62
	Filter 29	47.03 ± 9.16	2.06 ± 0.90
Average		43.65 ± 11.84	1.86 ± 0.77
22 May	Filter 34	31.67 ± 7.21	1.39 ± 0.81
	Filter 35	29.73 ± 3.75	0.81 ± 0.43
	Filter 36	25.75 ± 2.92	1.13 ± 0.72
Average		29.05 ± 5.19	1.11 ± 0.65
29 May	Filter 42	29.12 ± 3.72	1.50 ± 0.51
	Filter 43	52.34 ± 8.56	4.92 ± 0.74
	Filter 46	57.29 ± 0.60	7.05 ± 1.10
Average		46.25 ± 13.890	4.49 ± 2.50
5 Jun	Filter 50	21.58 ± 6.95	1.02 ± 0.40
	Filter 52	20.58 ± 4.56	0.89 ± 0.50
	Filter 56	51.31 ± 10.00	2.03 ± 1.63
Average		31.16 ± 16.36	1.31 ± 1.06

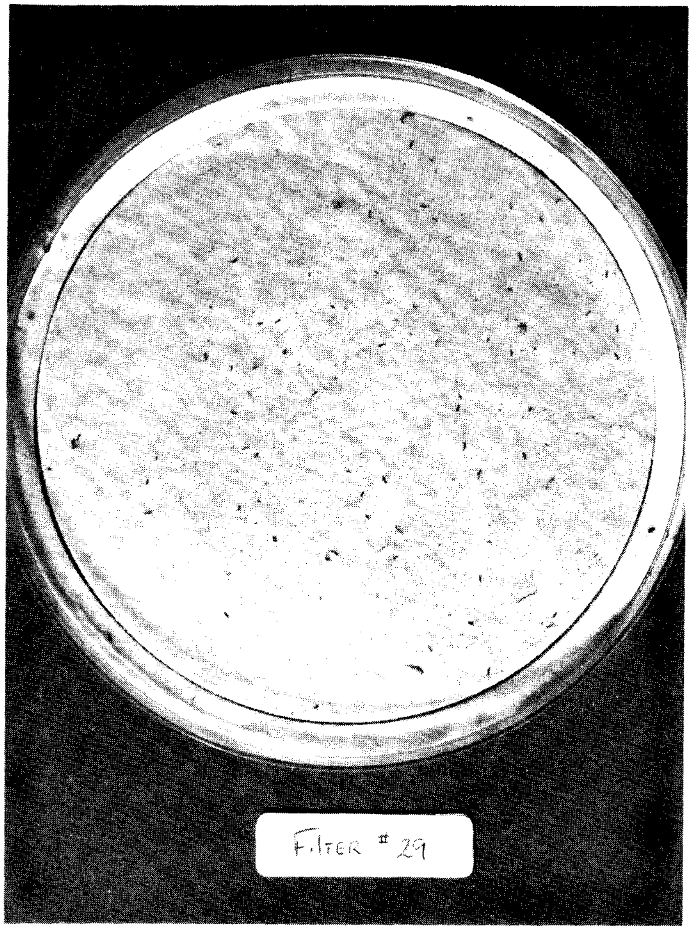

Figure 55. Total glass-fiber filter surface from a particle trap to illustrate general appearance after a six-day deployment at the Narwhal Island Ice Station, 1980. Note the exclusion of the filter edge for analysis.

Figure 56. Enlargement of "large" fecal pellet from the particle trap glass-fiber filter pads deployed at the Narwhal Island Ice Station, 1980. Formed by Mysis relicta.

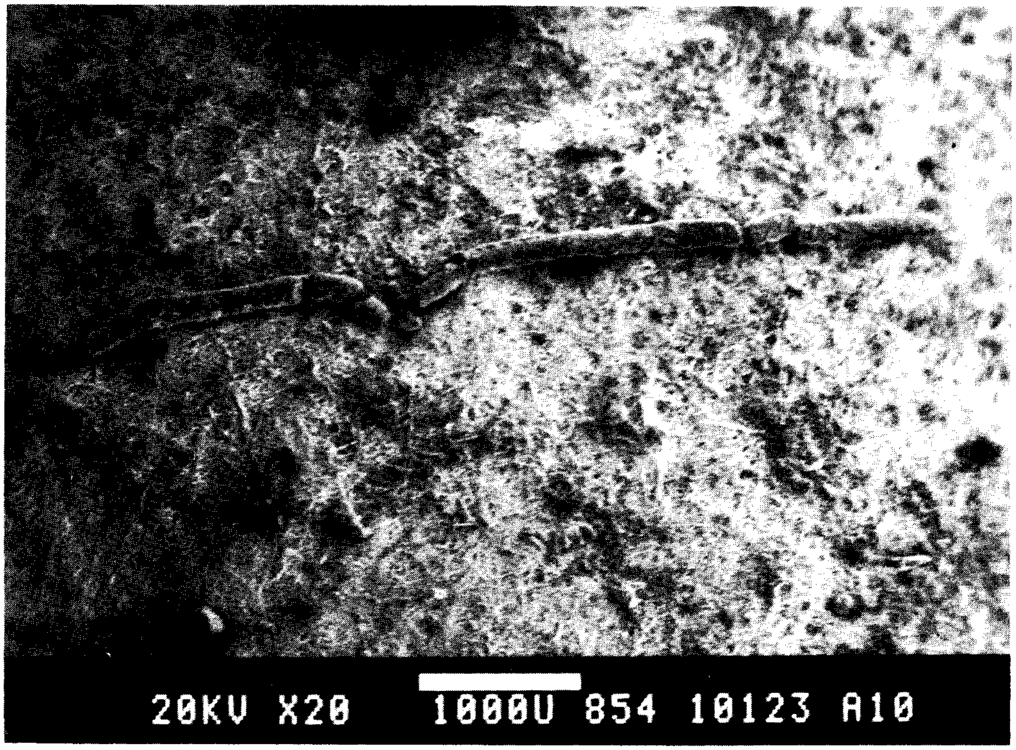

Figure 57. Scanning electron micrograph of *Mysis relicta* fecal pellet collected by particle trap, Narwhal Island Ice Station, 1980.

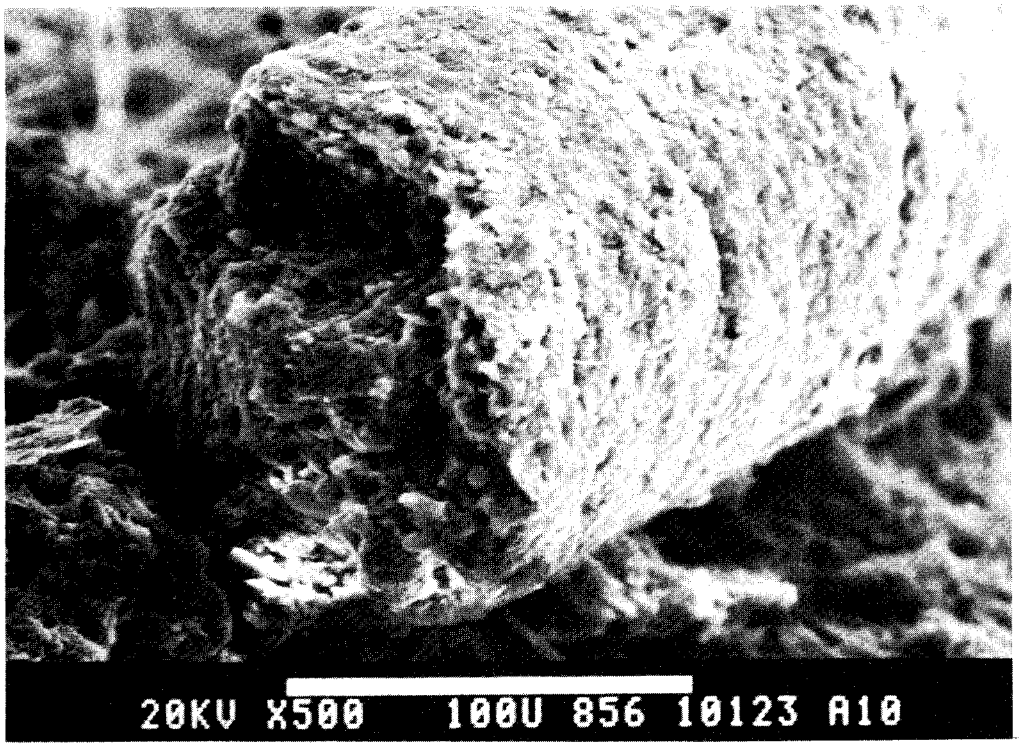

Figure 58. Detail of broken end of Mysis relicta fecal pellet collected by particle trap at the Narwhal Island Ice Station, 1980

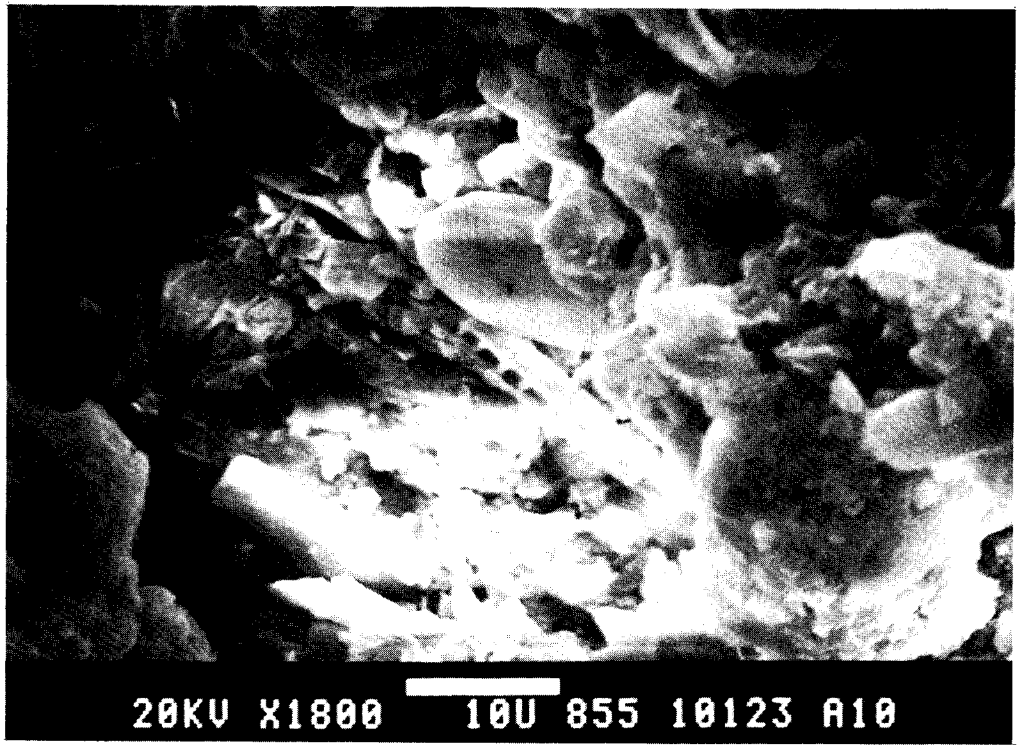

Figure 59. Further detail of broken end of *Mysis relicta* fecal pellet collected by particle trap at the Narwhal Island Ice Station, 1980. Note the heterogeneity and fragmented nature of the pellet contents.

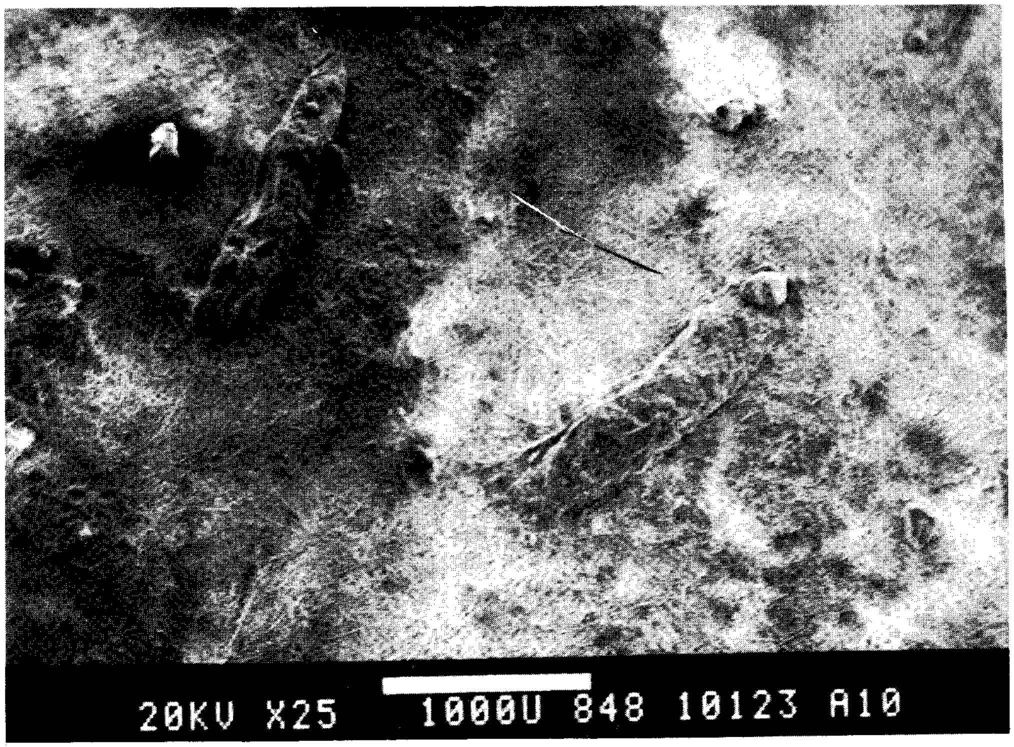

Figure 60. Scanning electron micrograph of "small" fecal pellets collected by particle trap at the Narwhal Island Ice Station, 1980. Formed by Pseudalibrotus litoralis.

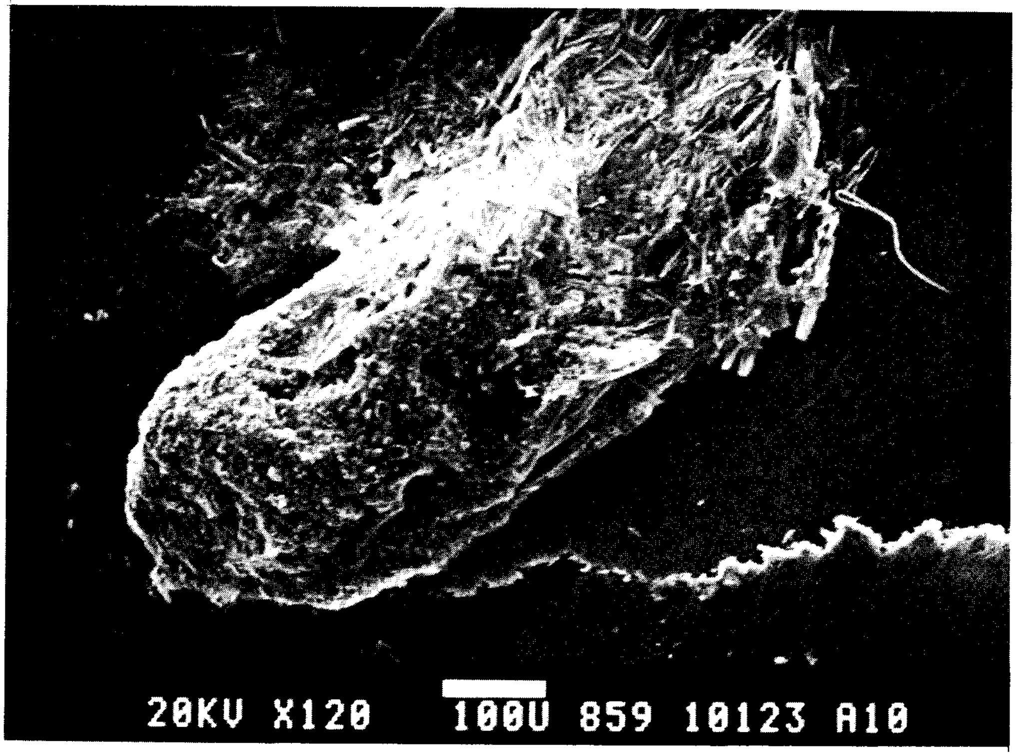

Figure 61. Scanning electron micrograph of a squashed preparation of a Pseudalibrotus litoralis fecal pellet collected by particle trap, Narwhal Island Ice Station, 1980. Note the diatom test composition.

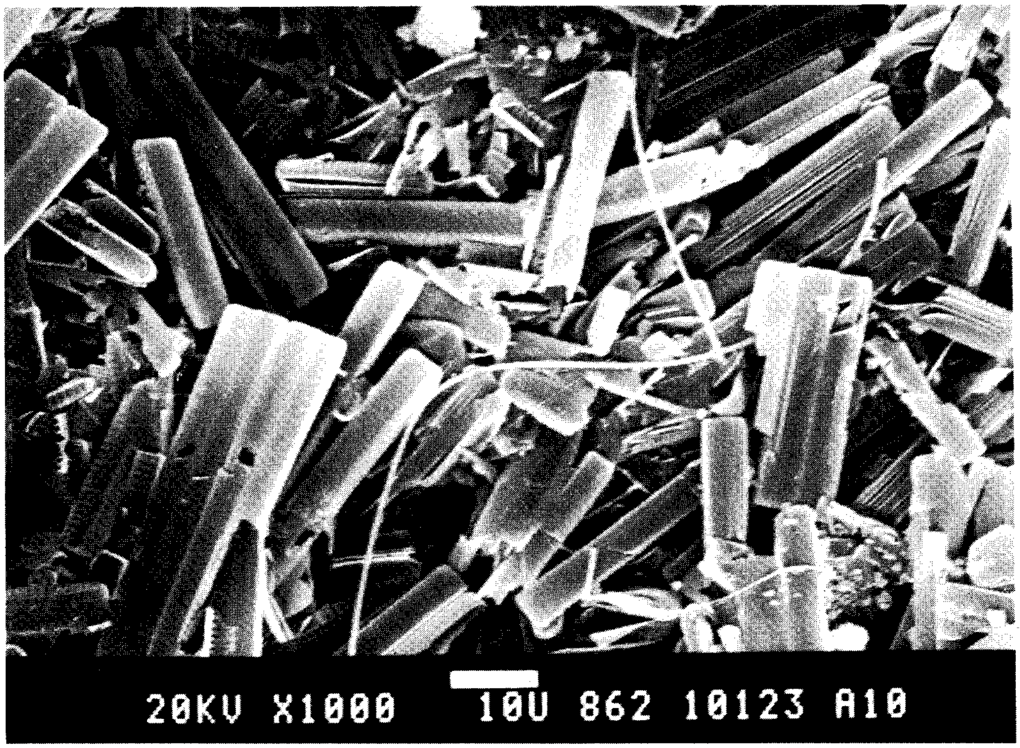

Figure 62. Detail of the diatom tests that completely fill the <u>Pseudalibrotus litoralis</u> fecal pellet in Fig. 61. Collected at the Narwhal Island Ice Station, 1980.

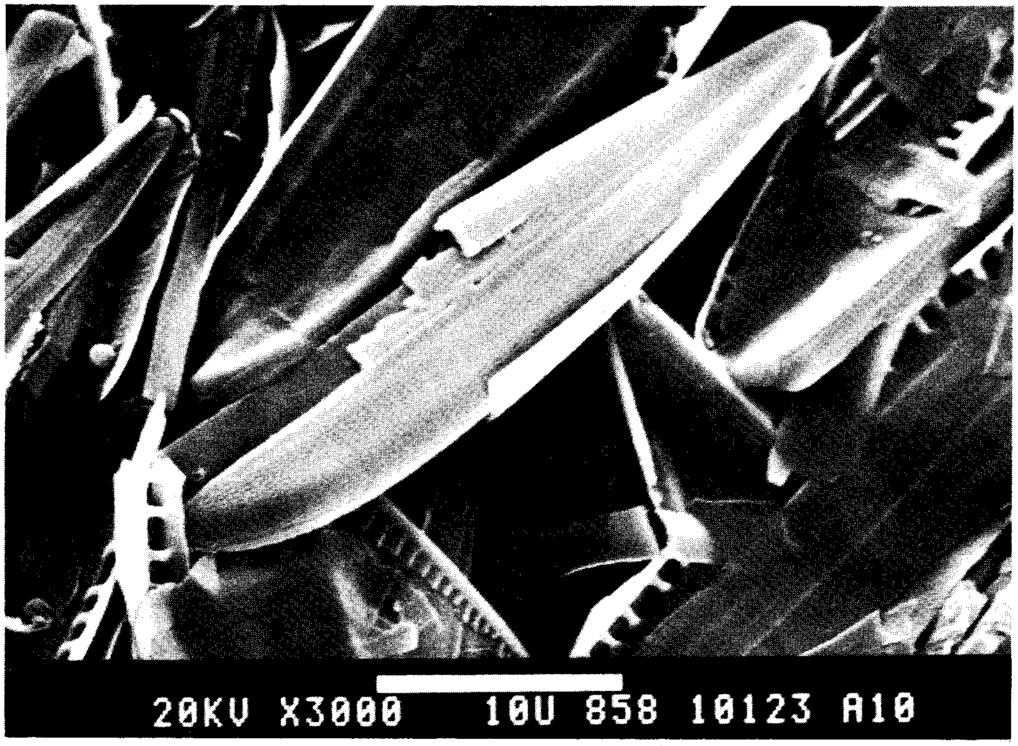

Figure 63. Additional detail of diatom test fragments that completely fill the Pseudalibrotus litoralis fecal pellet in Fig. 61. Collected at the Narwhal Island Ice Station, 1980.

Appendix IV: Voucher material submitted to the Marine Invertebrate Zoology section, California Academy of Sciences.

Table 38. List of Polychaeta: Annelida species submitted to the OSCEAP Voucher Collection, California Academy of Sciences

Aglaophamus malmgreni
Allia nr suecica
Amage auricula
Ampharete acutifrons
Ampharete arctica
Ampharete goësi
Ampharete vega
Amphicteis sundevalli
Anaitides groenlandica
Antinoella sarsi

Apistobranchus tullbergi
Arcteobia anticostiensis
Arenicola glacialis
Aricidea quadrilobata
Artacama proboscidea
Autolytus alexandri
Autolytus fallax
Axionice maculata
Barantolla sp.
Brada inhabilis

Brada villosa
Capitella capitata
Chaetozone setosa
Chone duneri
Chone infundibuliformis
Chone nr murmanica
Cistenides hyperborea
Clymenura polaris
Cossura longocirrata
Diplocirrus glaucus

Diplocirrus hirsutus
Diplocirrus longisetosus
Dorvillea sp.
Enipo canadensis
Eteone longa
Euchone analis
Euchone elegans
Euchone incolor
Euchone papillosa
Eucranta villosa

Eunoe oerstedi
Eusyllis blomstrandi
Exogone naidina
Flabelligera affinis
Gattyana cirrosa
Glycera capitata

Glycinde wireni
Glyphanostomum pallescens
Harmothoe imbricata
Heteromastus filiformis
Lagisca extenuata
Lanassa venusta
Laonice cirrata
Laonome kroyeri
Laphania boecki
Leitoscoloplos acutus

Levinsenia gracilis
Lumbrineris fragilis
Lumbrineris impatiens
Lumbrineris latreilli
Lumbrineris minuta
Lumbrineris sp. A
Lysilla loveni
Lysippe labiata
Magelona longicornis
Maldane sarsi

Marenzelleria wireni
Melaenis loveni
Melinna cristata
Microclymene sp.
Micronephthys minuta
Microspio theeli
Minuspio cirrifera
Myriochele heeri
Myriochele oculata
Mystides borealis

Nemidia torelli
Nephtys ciliata
Nephtys longosetosa
Nephtys paradoxa
Nereimyra aphroditoides
Nereis zonata
Nicolea zostericola
Nothria conchylega
Notomastus latericeus
Onuphis quadricuspis

Ophelina acuminata
Ophelina cylindricaudatus
Ophelina groenlandica
Ophryotrocha sp.
Owenia collaris
Paramphitrite tetrabranchia

Table 38. List of Polychaeta: Annelida species submitted to the OSCEAP Voucher Collection, California Academy of Sciences (cont'd)

Paranaitides wahlbergi
Parheteromastus sp. A
Petaloproctus tenuis
Pherusa plumosa
Pholoe minuta
Pionosyllis compacta
Pista cristata
Polycirrus medusa
Polydora caulleryi
Polydora quadrilobata

Polydora socialis
Polyphysia crassa
Praxillella gracilis
Praxillella praetermissa
Prionospio steenstrupi
Proclea graffii
Pygospio elegans
Rhodine gracilior
Sabellastarte sp.
Scalibregma inflatum

Schistomeringos caeca
Scoloplos armiger
Sigambra tentaculata
Sphaerodoridium sp. A
Sphaerodoropsis biserialis
Sphaerodoropsis minuta
Sphaerodoropsis sp. A
Sphaerodorum gracilis
Sphaerosyllis erinaceus
Spio filicornis

Spiochaetopterus typicus
Spiophanes bombyx
Sternaspis scutata
Syllides longocirrata
Terebellides stroemi
Tharyx ?acutus
Travisia sp.
Trichobranchus glacialis
Trochochaeta carica
Trochochaeta multisetosa

Typosyllis cornuta
Typosyllis fasciata

Table 39.

Pelecypod voucher specimens sent to California Academy of Sciences

Species	Smith/McIntyre grab number	Specimens
Nucula bellotii	1436-11	1
Nucula bellotii	1462-11	2
Nuculana minuta	1546-18	1
Nuculana pernula	1630-15	1 + 1 pair valves
Nuculana radiata	1102	1 pair valves
Portlandia arctica	1434-13	11 + valves
Portlandia frigida	1448-13	2
Portlandia lenticula	1639-15	7 + 3 valves
Yoldia hyperborea	1378-07	1 broken pair valves
Yoldia myalis	1374-08	1 broken pair valves
Bathyarca glacialis	1643-14	1
Crenella decussata	1448-13	1
Dacrydium vitreum	1646-14	7 + 2 pair _ 3 valves
Musculus corrugatus	1637-16	1
Musculus discors	1089	2
Musculus niger	1085	2 valves
Arctinula greenlandica	1456-09	5 + 2 pair valves
Axinopsida orbiculata	1454-11	6
Thyasira equalis	1624-13	6 + 2 pair valves
Thyasira gouldii	1093	4
Mysella planata	1342-14	1
Cyclocardia crebricostata	1123-19	1
Astarte crenata	1647-14	2 valves
Astarte borealis	1339-16	1
Astarte montagui	1577-15	6
Clinocardium ciliatum	1545-16	1
Serripes groenlandicus	1107-12	1 matched pair + 1 valve
Macoma calcarea	1470-15	18
Macoma loveni	1557-12	1
Macoma moesta	1334-14	2
Liocyma fluctuosa	1386-10	19 + 1 pair valves
Mya pseudoarenaria	1475-10	1 pair valves
Hiatella arctica	1437-07	1
Pandora glacialis	1468-13	6
Lyonsia arenosa	1469-12	2 matched pair + 2 valves
Periploma aleutica	1578-11	1
Thracia devexa	1647-14	1 pair valves
Cuspidaria glacialis	1641-16	1

GEOPHYSICAL AND BIOLOGICAL RECONNAISSANCE OF ROCK HABITATS IN EASTERN CAMDEN BAY, BEAUFORT SEA, ALASKA

by

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Institute of Water Resources
University of Alaska
Fairbanks, Alaska 99701

Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 630

1 January 1983

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ACKNOWLEDGMENTS

We wish to thank Paul Plesha, Dan Pope, and Cliff Moore for diving assistance, especially under poor sea and weather conditions. Paul Plesha, as usual, did an excellent job in all aspects of this study, particularly navigation; Dan Pope again took charge of dive sled operations on the R. V. Scallop; and Cliff Moore was instrumental in calibrating the Ross SL-500 receiver. We are also grateful to Alan Paulson who photographed many of our activities documenting our field work, and who assisted in the final preparation of this report. Our thanks to the good people at Ross Laboratories, particularly Bruce Simmonds, for providing us with the necessary knowledge to keep our SL-500 in good running condition throughout the field program. Finally, we are grateful to the U.S. Fish and Wildlife Service who provided the permits allowing us to work in Camden Bay.

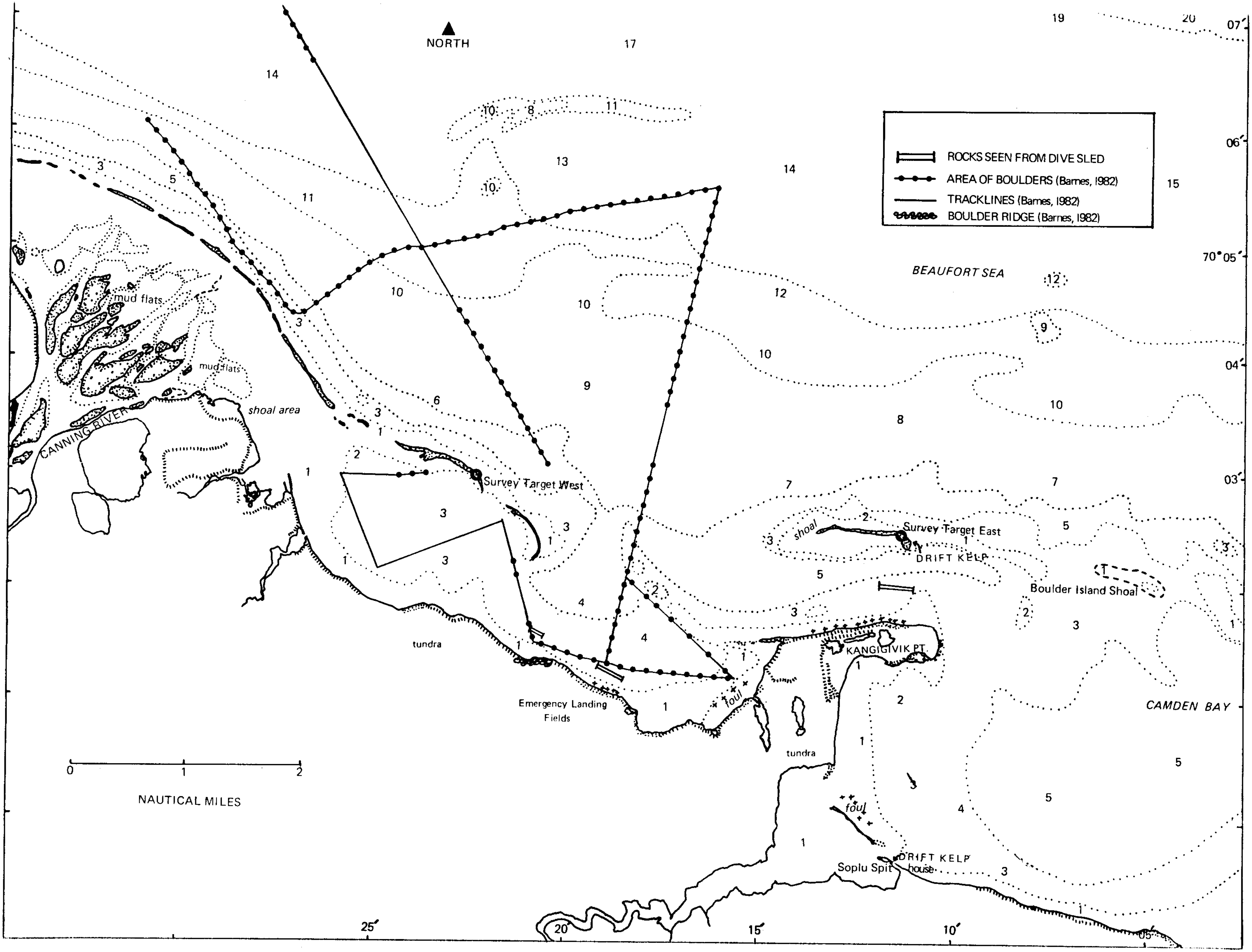
I. SUMMARY OF OBJECTIVES, CONCLUSIONS AND IMPLICATIONS WITH RESPECT TO OIL AND GAS DEVELOPMENT

This report presents the results of a 10 day geophysical and biological survey in western Camden Bay, in the Alaskan Beaufort Sea. The primary objective of this survey was to confirm the existence of boulders and cobbles on the seafloor as reported by Barnes (1981; 1982). The survey area extended from the eastern edge of the Canning River (mud flat area) to Kangigivik Point and seaward to the 14 m contour line (Fig. 1). A solid boundary of pack ice prevented any survey work seaward of the 14 m contour. We had proposed to examine the seabed to the 18 m contour.

Diving traverses, spot dives, and interpretation of fathometer records indicate the absence of boulders and cobbles in the survey area, except in shallow water (2-4 m) directly northwest of Kangigivik Point. Dredge hauls made throughout the survey area also yielded no attached macroalgae except in the immediate region of Kangigivik Point. The existence of attached macroalgae and invertebrate life in western Camden Bay therefore has been visually documented only in the nearshore region in water depths less than 4 m (Dunton and Schonberg, 1982). Our results contradict the work of Barnes (1981), who reported boulders offshore, and the reasons for this disagreement are discussed.

We did collect large amounts of drift kelp following storms on the beaches southeast of Kangigivik Point and on the eastern shore of the barrier island offshore of Kangigivik Point. It appears that the source of this drift kelp is not entirely from the shallow areas north and west of Kangigivik Point. The rocks in these shallow waters support few mature healthy plants of *Laminaria solidungula* (Dunton and Schonberg, 1982; this study). Instead a second source must be present, and based on discussions with E. Reimnitz (USGS), the source is likely a submerged shoal east of Kangigivik Point, which was formerly known as Boulder Island. In our beachcombing efforts to the west of Kangigivik Point to the Canning River delta, macroalgae were seldom seen. Thus it appears that the major source of drift kelp is to the east of Kangigivik Point.

Figure 1. The study area extended from the eastern edge of the Canning River (mud flat area) to Kangigivik Point and seaward to about the 14 m contour line (as far north as sea ice permitted). The occurrence of rocks on the seabed reported by Dunton and Schonberg (1982, from diving observations) and Barnes (1982, from geophysical data) is shown. Depths are listed in meters.


NORTH
ROCKS SEEN FROM DIVE SLED
AREA OF BOULDERS (Barnes, 1982)
TRACKLINES (Barnes, 1982)
BOULDER RIDGE (Barnes, 1982)
BEAUFORT SEA
CAMDEN BAY
CANNING RIVER
mud flats
mud flats
shoal area
Survey Target West
Survey Target East
shoal
DRIFT KELP
Boulder Island Shoal
KANGIGIVIK PT.
foul
foul
Emergency Landing Fields
tundra
tundra
DRIFT KELP
Soplu Spit
house
0
1
2
NAUTICAL MILES
07′
06′
70°05′
04′
03′
25′
20
15′
10′
05′
19
20
17
14
14
13
11
10
8
11
10
3
5
11
14
15
12
12
10
10
9
10
10
9
6
8
3
1
2
1
3
3
3
1
1
7
7
3
2
1
5
5
3
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4
4
2
3
1
1
1
1
2
3
1
1
2
1
4
5
5
3
1

It is difficult to assess the size and possible significance of any kelp bed east of Kangigivik Point, although it seems likely that it is limited to the vicinity of the Boulder Island shoal. Collection of drift kelp along Soplu Spit, south of Boulder Island (Fig. 1) indicated that 72 kg of kelp washed up on the beach, equivalent to 5,400 square meters of "boulder patch" type seabed, assuming the drift material represents 10% of the actual bed itself. Based on the importance of this area to industry for oil and gas development, it may become necessary to investigate the small area in the vicinity of the Boulder Island shoal to confirm the presence of rocks with attached kelp. The possible significance of the benthic macroalgae to the nearshore trophic system in western Camden Bay is thus difficult to predict without; (1) accurate knowledge of the size of the kelp bed, and (2) the degree by which invertebrate consumers of Camden Bay depend on carbon derived from kelp.

II. INTRODUCTION

General Nature and Scope of Study

The primary goal of the benthic survey in western Camden Bay was to provide information on the spatial distribution of cobbles and boulders and the utilization of these substrates by epilithic organisms as kelp, red algae, soft corals, sponges, etc. The survey area extended from the eastern edge of the Canning River to Kangigivik Point and seaward to the 14 m contour line, as far north as sea ice conditions permitted (Fig. 1). A Ross SL-500 recording fathometer was used in conjunction with diving observations to map the character of the seabed.

Specific Objectives

1. Confirm the existence of cobbles and boulders previously reported by Barnes and Ross (1980) in eastern Camden Bay through visual (diving) examination of rock patches.

2. Determine the overall extent of cobbles and boulder distribution in western Camden Bay in water depths greater than 6 m using an accoustical system and a diving sled.

3. Visually confirm through diving the presence (or absence) of biota associated with rock substrata, and describe both the composition and relative abundance of the biotic assemblages.

Relevance to Problems of Petroleum Development

In Stefansson Sound, the presence of an abundant and diverse flora and fauna associated with cobbles and boulders resulted in special protection for the Boulder Patch from industrial activity related to petroleum exploration. The kelp in the Boulder Patch contributes the largest fraction of carbon in this area, and this carbon source is utilized by many invertebrate consumers. The presence of a similar kelp community in western Camden Bay may thus require similar attention, depending on its size and composition.

III. CURRENT STATE OF KNOWLEDGE

Kelp as a Carbon Source

Although peat derived from terrestrial marine primary production supplies nearly all of the carbon used in arctic marine foodwebs (Schell et al., 1982). Most of this carbon is supplied by phytoplankton, but benthic microalgae and ice algae also contribute carbon on a less consistent temporal and spatial scale. The discovery of the Boulder Patch and its large population of flora and fauna by E. Reimnitz in 1971, also led to the discovery of another marine carbon source of unknown magnitude -- kelp. Subsequent long-term in situ productivity studies indicated that the carbon contribution made by kelp in the Boulder Patch doubled the amount of carbon available to consumers in that region (Dunton et al., 1982). It also appears that kelp is an alternate food source for many animals that rely on phytoplankton. Thus, the kelp communities found in association with "boulder patches" may not only be unusual but do supply a source of carbon that is utilized by organisms that are eaten by birds, fish, and marine mammals (Dunton and Schell, 1982).

Cobbles and Boulders in Western Camden Bay

The presence of cobbles and boulders in eastern Camden Bay was first reported by Barnes and Ross (1980). Subsequent investigation of the seabed using underwater television showed that the rocks supported a diverse benthic community (Barnes, 1981). This benthic community appeared similar to the Boulder Patch (Reimnitz and Ross, 1979; Dunton et al., 1982) in the types of organisms present. In August 1981, some of the nearshore boulder ridges described by Barnes (1981) were examined by divers (Dunton and Schonberg, 1982). Their short examination revealed patchy occurrences or rocks where Barnes (1981) had indicated but the benthic fauna and flora was not comparable in density or diversity to that of the Boulder Patch. However, only a few rock patches were examined, and these were in relatively shallow water (less than 3.5 m depth). Biological assemblages are more likely to possess a greater luxuriancy in deeper water which affords greater protection from the thick winter ice sheet.

From sonographs, Barnes and Ross (1980) identified several locations where boulders and cobbles exist on the seabed in deeper water (Fig. 1). None of these locations were examined visually. The existence of the rocks offshore is based entirely on two transect lines which extend nearly four nautical miles offshore. In this study, we attempted to rediscover the locations that contain rocks on the seafloor.

IV. STUDY AREA: BEAUFORT SEA (100 PERCENT)

The study area for this project is western Camden Bay, between longitude 145°30' and 145°10', in water depths ranging from 5 to 14 m (Fig. 1). Calibration of geophysical instruments was conducted at OCSEAP DS-11 in Stefansson Sound, and directly northwest of Kangigivik Point in western Camden Bay (water depth 2-4 m).

V. SOURCES, METHODS, AND RATIONALE OF DATA COLLECTION

Geophysical survey data and samples were collected from the R.V. Proteus, a 25 foot Boston Whaler leased to OCSEAP by Arctic Marine Research Associates. The vessel carried a crew of four, was fully canvassed and powered by twin 140 HP outboard engines. Navigation equipment included a Furuno 16 mile radar, flasher fathometer, compass, and RDF (radio direction finder). Mast, boom and outriggers provided a means to tow and retrieve trawl equipment from the stern, port, or starboard sides.

Geophysical Survey

Geophysical coverage along 92 km of trackline was obtained across the study area shown in Figure 1. The accoustical system used was a Ross 200 Khz recording fathometer (Model SL-500). This instrument has been used successfully in previous studies in Stefansson Sound to locate boulder patches. It uses a narrow beam 200 Khz transducer and produces a paper copy fathogram. Boulders and cobbles on the seafloor are indicated on traces by elongate return signals and by slight surface roughness. All survey tracklines were established using a compass and radar fixes from natural and artificial land targets. Radar targets were placed on two offshore barrier islands (Fig. 1). Navigation fixes are generally accurate within ±200 m.

Calibration

A comprehensive calibration of the Ross SL-500 preceded the geophysical survey. Instrumental calibration was conducted both at DS-11 in Stefansson Sound and directly northwest of Kangigivik Point in western Camden Bay. At both locations, divers' observations of the seafloor were correlated with the character of signal returns recorded on the Ross SL-500. The sensitivity of the instrument was adjusted to obtain maximum signal clarity for rocky and nonrocky bottom types.

Direct Seabed Observations

Divers conducted direct underwater observations of the seabed along some 4 km of survey trackline and on 13 dives. The diving observations were used to interpret distinct signal returns or to confirm our interpretations of traces recorded by the Ross SL-500. Observations were made by towing a diver on a specially constructed sled (Fig. 2) or by a diver swimming along the bottom at a designated site.

Biological Sampling

Biological samples were collected by divers, and by three types of sampling gear towed behind the boat. These included an epibenthic sled, a plankton net, and a Pope sled, a specially designed sled for sampling the bottom. The Pope sled was built in the field by Dan Pope, one of the divers, after he had accidentally lost the epibenthic sled on a transect made 8 km offshore. The Pope sled was constructed of 5 cm mesh vexar and was of the same size and shape of the epibenthic sled it replaced.

VI. RESULTS AND DISCUSSION

Surficial Bottom Features

Table 1 lists the five predominant bottom types encountered in western Camden Bay. Each bottom type is characterized by a distinct signal return on the Ross SL-500 trace. Figures 3 and 4 show signal returns that are characteristic of bottoms that contain rocks or are dominated by unconsolidated sediments. Rocky bottoms were characterized by irregularly elongated signals and by slight surface roughness.

Diving observations revealed that most of the topographical relief shown in the Ross SL-500 traces could be attributed to ice gouging. The most spectacular traces obtained were attributed to gouging by large deep draft ice which formed deep V-shaped furrows in the seafloor (Fig. 5). A second trace, showing a rough bottom, actually reflected a pattern of shallow (15-40 cm) furrows in a crisscross pattern on the seafloor (Fig. 5). This was also attributed to ice gouging, but of a more frequent nature that did not involve large bergs.

Figure 6 shows the trace which led to the discovery of "buttes", unusual topographical features which may be the result of crisscross ice gouging (E. Reimnitz, personal communication). The buttes in western Camden Bay are flat-topped, have vertical dimensions of 0.1 to 0.5 m and have horizontal dimensions of 0.50 to 2.0 m. They are composed of mud,

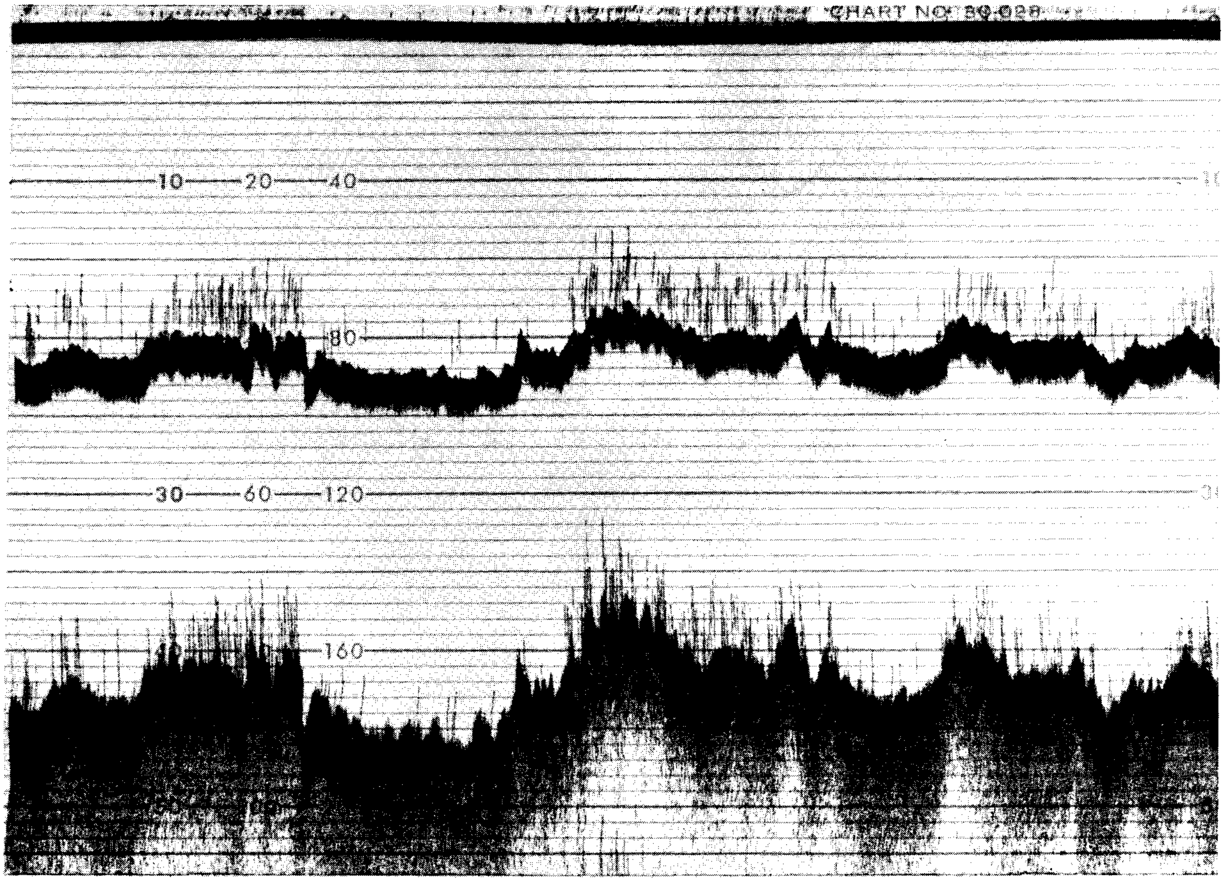
Figure 2. Dan Pope preflights the diving sled used for surveying the seafloor in this study. Photograph by Alan Paulson.

NOAA

TABLE 1. The predominant bottom types encountered in the geophysical survey of western Camden Bay. The corresponding Ross SL-500 trace for each bottom type is indexed by Figure number.

Bottom Type	Description	Location of Ross SL-500 trace
Smooth	Flat, mud or sand, with occasional ripple marks.	Figure 3, 4
Rough	Crisscross ice gouging. Haphazardly arranged furrows 15-40 cm deep in sand or mud.	Figure 5
Deep Ice Gouge	Larger scale relief in seafloor, attributed to deep draft ice.	Figure 5
Butte	Flat topped topographical features rising vertically 0.1 to 0.5 m above seafloor. Mud with occasional rocks.	Figure 6
Rock	Pebbles, cobbles, or boulders on muddy bottom. Kelp infrequent.	Figure 3, 4

Figure 3. The Ross SL-500 depth recorder trace of a boulder patch (top) near DS-11 in Stefansson Sound and a smooth seafloor surface (bottom). Rocky bottoms are characterized by irregularly elongated signals and by slight surface roughness. The reason for the occurrence of the diffuse, lighter colored marks above the bottom trace is currently unknown.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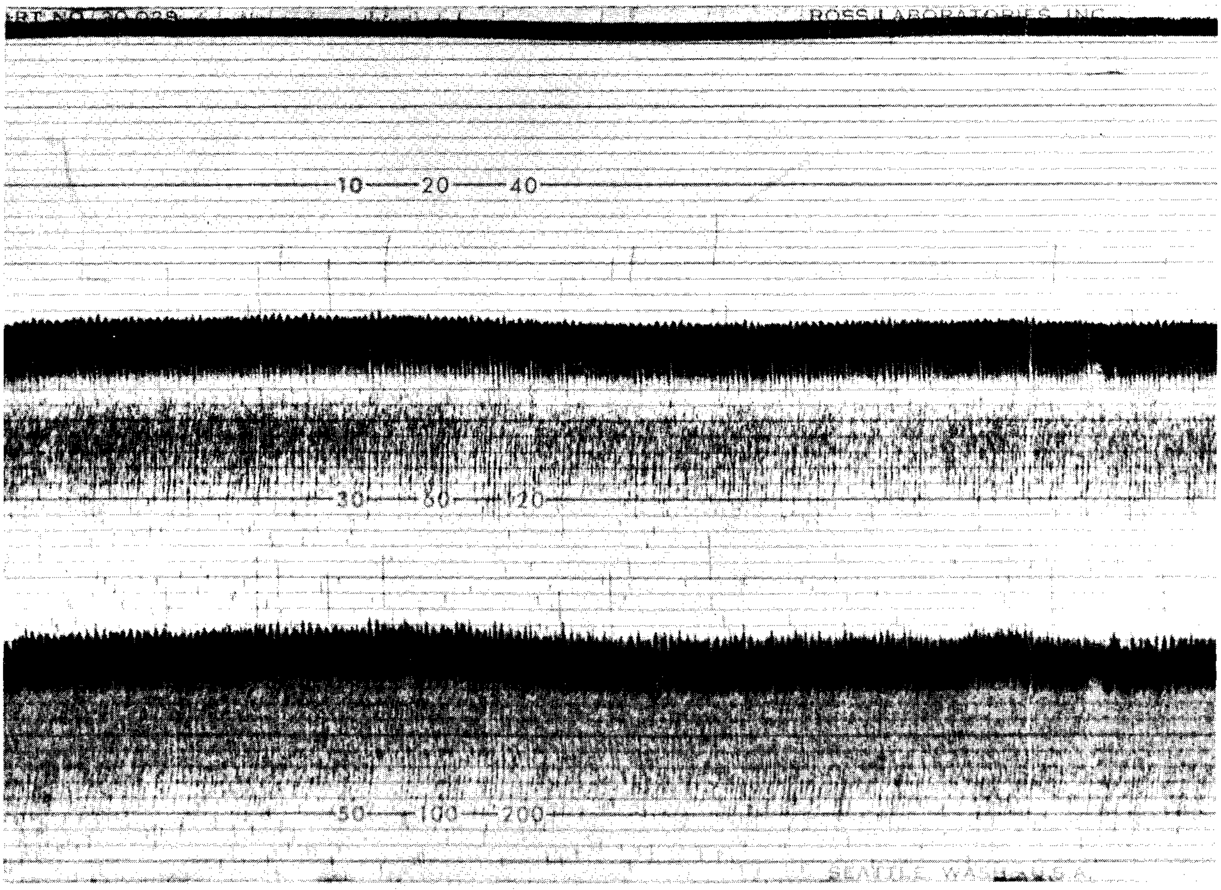
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Figure 4. Ross SL-500 trace of the seafloor along a survey line northwest of Kangigivik Point (See Fig. 8 for location of survey line).

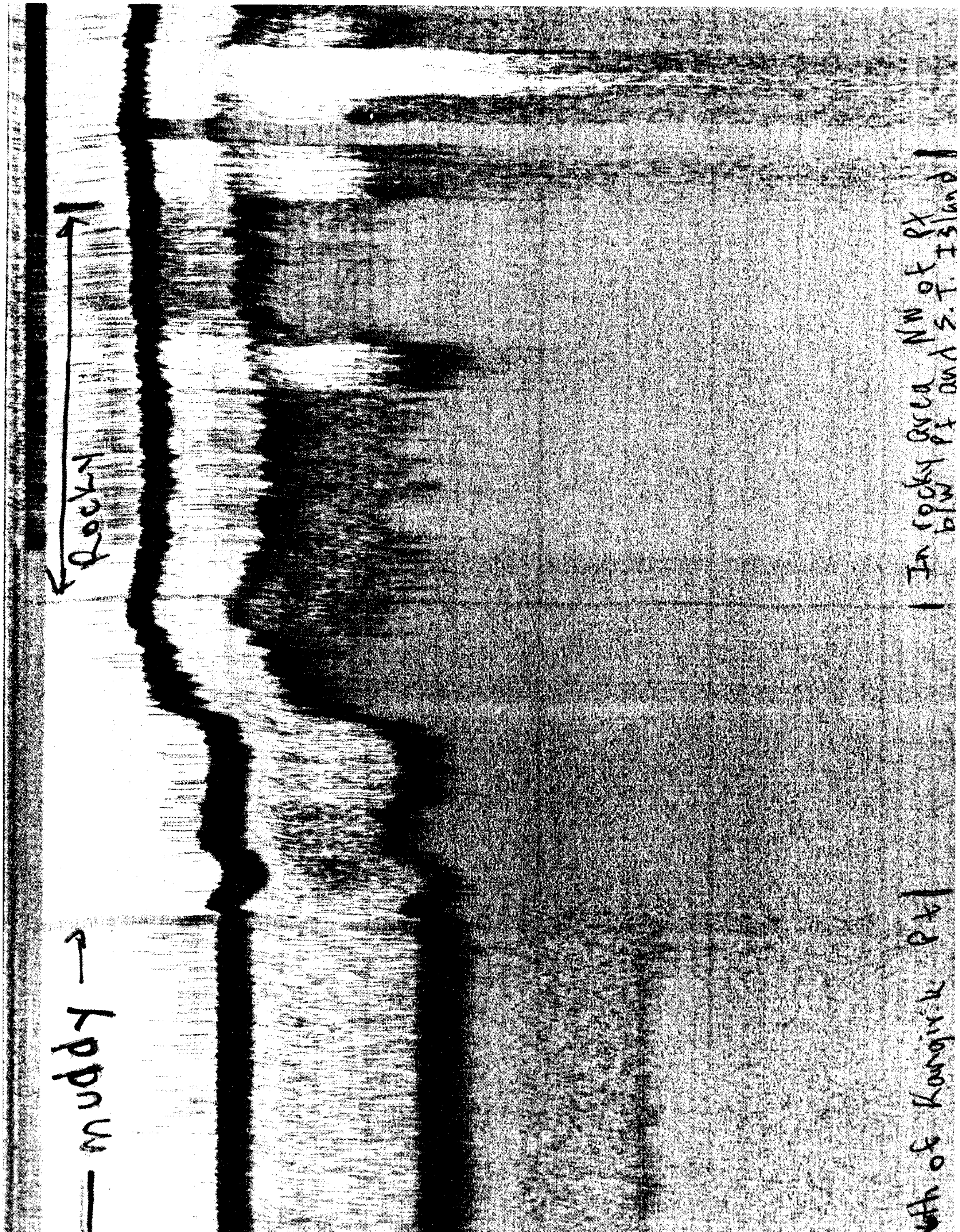
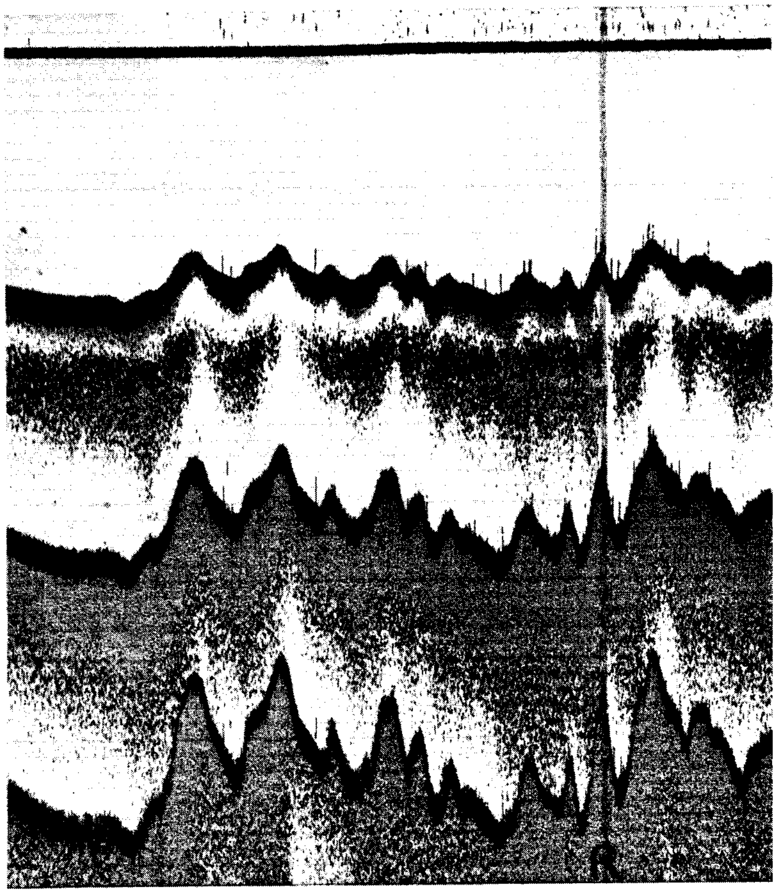

← muddy →
← Rocky →
South of Kangirik Pt
In rocky area NW of Pt
btwn Pt and S.T. Island

Figure 5. A Ross SL-500 trace of ice gouging caused by deep draft ice (top) contrasts the "rough bottom" trace (bottom) which is attributed to the crisscross pattern of furrows on the seafloor observed by divers. We believe this haphazard pattern of furrows is due to frequent shallow draft ice gouging, which we refer to as "crisscross ice gouging."



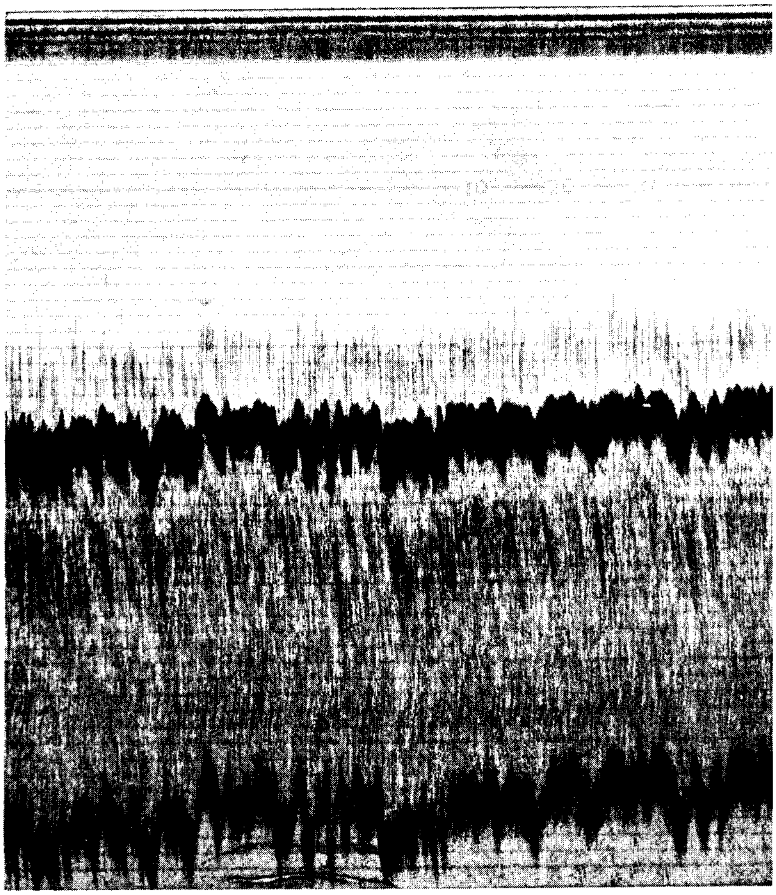
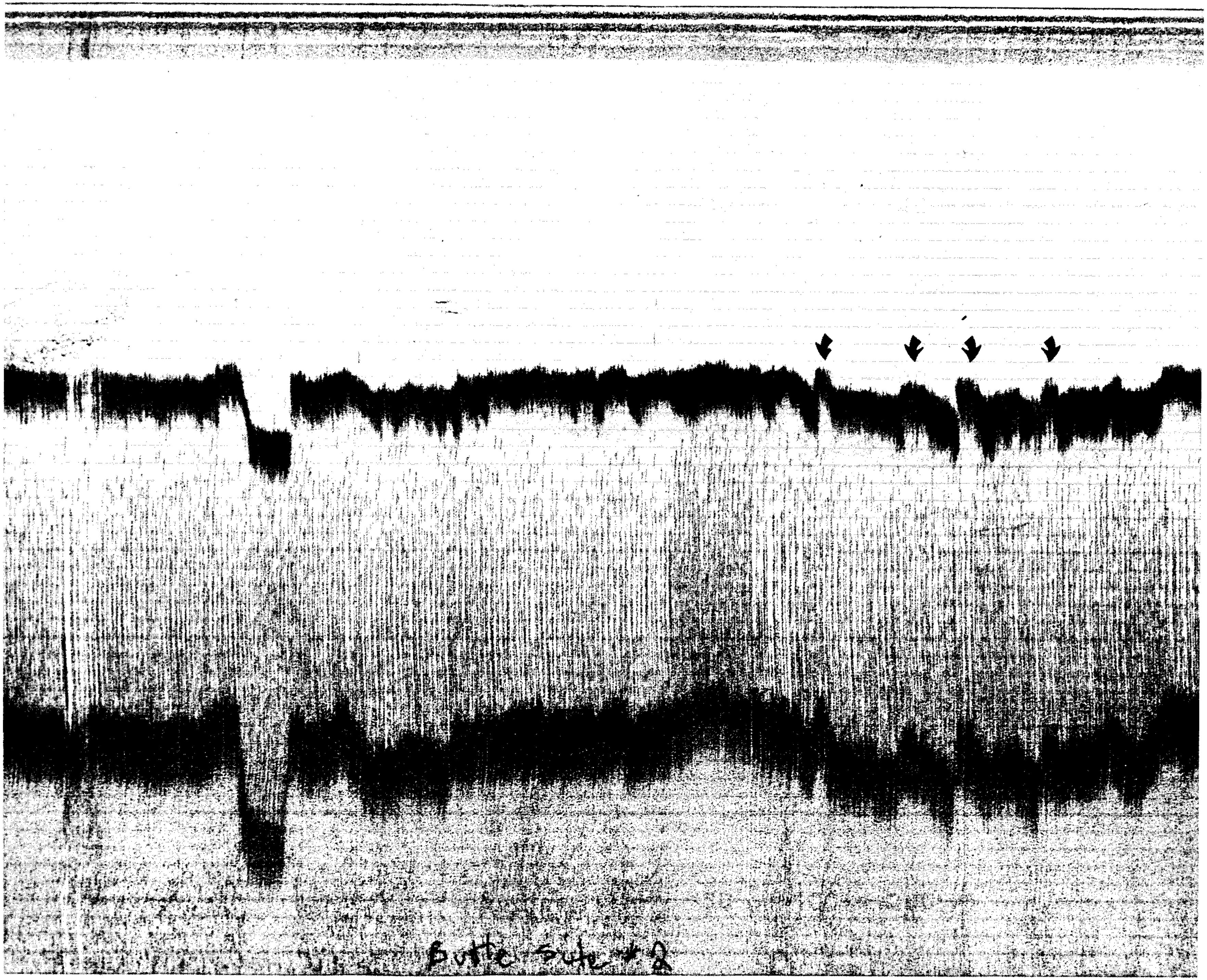


Figure 6. The Ross SL-500 trace of the buttes located by divers. Vertical dimensions of individual buttes (marked) range from 0.2 to 0.5 m and have horizontal dimensions of 1.0 to 2.0 m.


Butte Site #8

although rocks (pebbles, cobbles, or boulders) were occasionally seen amongst them. Kelp blades and other species of algae were observed in troughs surrounding some buttes.

Direct Seabed Observations

The location of dive sled transects and spot dives made during the survey are shown in Figure 7. The observations recorded from the dives on the character of the seafloor are summarized at the various sites. These observations indicate that rocks are extremely rare offshore. Drift algae was also rarely collected by the divers.

Rough sea conditions during most of the project, together with rain and snow accompanied by strong southwesterly storms, limited underwater visibility to less than 0.5 m on all dives. As a result, no attempts were made to photograph the major bottom features that characterize western Camden Bay.

Trackline Coverage

A total of 92 km of geophysical tracklines and 4 km of direct seabed observations was covered during survey operations (Fig. 8). A solid boundary of floating pack ice precluded the collection of data north of the 14 m contour line. The northernmost transect was accomplished by following the edge of the floating ice pack to a shallow 10 m shoal covered with grounded ice. The collection of data westward of this point was prevented by grounded ice along the entire shoal (Fig. 9). Dense floating ice was common along most of the survey lines.

Rock Cover and Sea Floor Topography

The topography and composition of the seafloor in western Camden Bay, based on geophysical survey data, bottom samples, and dive notes is shown in Figure 10. Rock cover in the area surveyed, based on geophysical data and diving observations, is almost nonexistent. Rocks of various sizes were occasionally observed at the butte sites, and pebbles were infrequently observed by divers at other locations.

However, when rocks were located by divers, they were bare of macroscopic attached fauna or flora.

Ice gouging appears to a frequent occurrence in the area surveyed (Fig. 10). Nearly 40% of all the geophysical data reflects ice gouging. Protection from ice scour and disruption from deep draft ice is one of the requirements for the establishment of a kelp community in the Beaufort Sea (Dunton et al., 1982). Thus, it is doubtful that such a community could exist in the surveyed area regardless of rock cover.

The results of this survey contradict the offshore (but not inshore) work of Barnes (1982), who reported boulders and cobbles offshore in depths ranging from 4 to 13 m (Fig. 1). However, Barnes based his results on his interpretation of side-scan sonar data which showed images of boulder-like objects, but no confirmation of these objects were made by divers. It is possible that the interpretation of Barnes is correct, but such boulders would have to be fairly infrequent. It is also possible that topographical features such as buttes could be confused as boulders on a side-scan image.

Fauna and Flora Collected

The fauna and flora collected by divers and various sampling equipment in this survey will be listed in our final report. Animals and benthic macroalgae commonly found on hard rock substrata were rarely collected except in the vicinity of Kangigivik Point. Since the area around Kangigivik Point has been studied previously (Dunton and Schonberg, 1982), no biological data will be included from this region.

Drift Kelp on Surrounding Beaches

Despite the absence of rocks and kelp in the area surveyed, and the general absence of kelp in the rocky area northwest of Kangigivik Point, large amounts of kelp drifted onto two nearby beaches following storms (Fig. 11). We noted drift kelp on Soplu Spit and on the eastern end of Survey Target Island East, north of Kangigivik Point (Fig. 1). We did not observe kelp as drift on any of the other beaches in the survey area.

Figure 7. The character of the seafloor at various locations in western Camden Bay based on spot dives and diving sled transects.

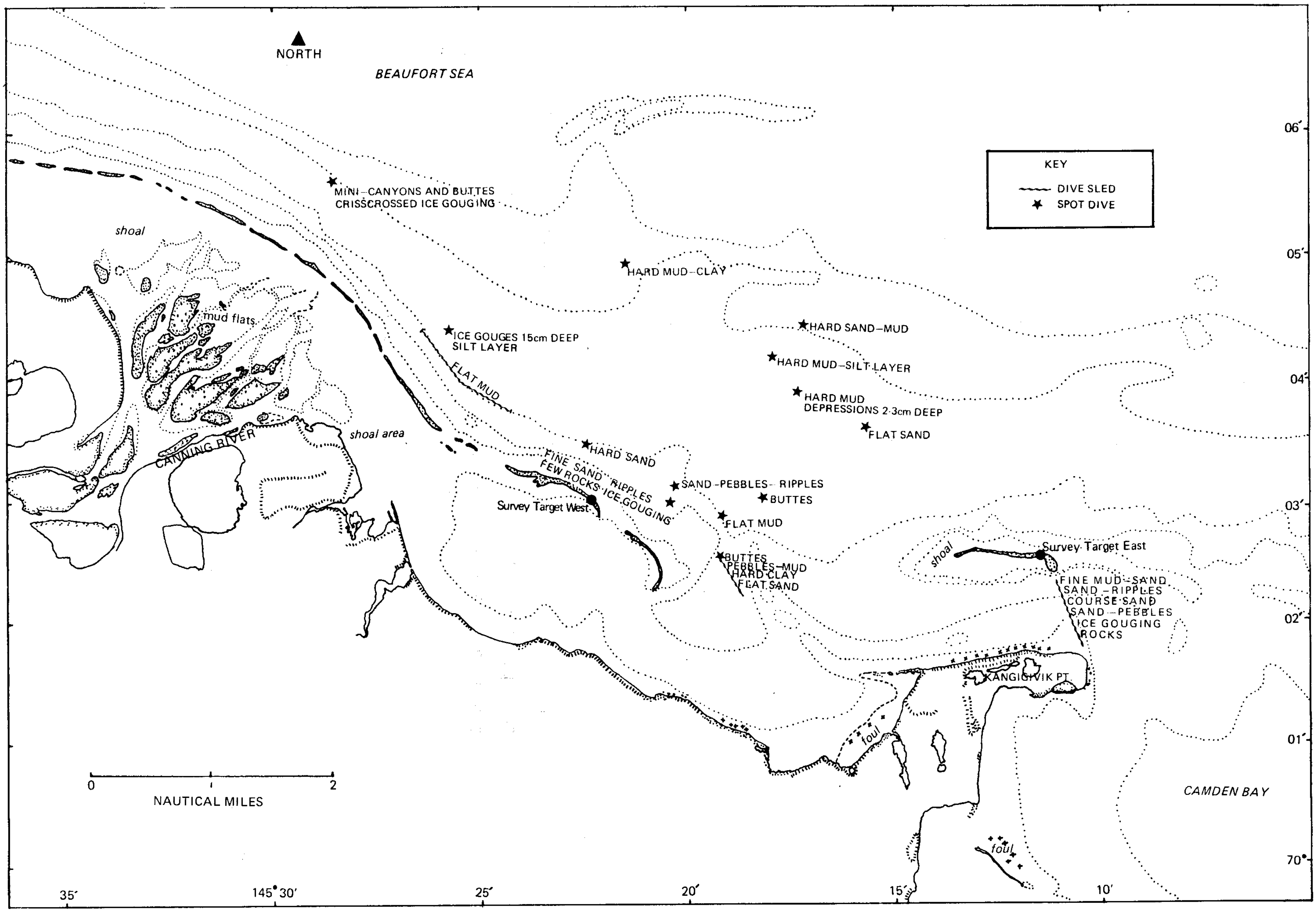

NORTH
BEAUFORT SEA
KEY
DIVE SLED
SPOT DIVE
MINI-CANYONS AND BUTTES
CRISSCROSSED ICE GOUGING
shoal
HARD MUD-CLAY
mud flats
ICE GOUGES 15cm DEEP
SILT LAYER
FLAT MUD
HARD SAND-MUD
HARD MUD-SILT LAYER
HARD MUD
DEPRESSIONS 2-3cm DEEP
FLAT SAND
shoal area
CANNING RIVER
HARD SAND
FINE SAND RIPPLES
FEW ROCKS ICE GOUGING
SAND-PEBBLES- RIPPLES
BUTTES
Survey Target West
FLAT MUD
BUTTES
PEBBLES-MUD
HARD CLAY
FLAT SAND
shoal
Survey Target East
FINE MUD-SAND
SAND-RIPPLES
COURSE SAND
SAND-PEBBLES
ICE GOUGING
ROCKS
KANGIGIVIK PT.
foul
foul
CAMDEN BAY
0
1
2
NAUTICAL MILES
06'
05'
04'
03'
02'
01'
70°
35'
145° 30'
25'
20'
15'
10'

Figure 8. The location of geophysical survey lines, showing the usage of the epibenthic sled, dive sled, Pope sled, and plankton net along various line segments.

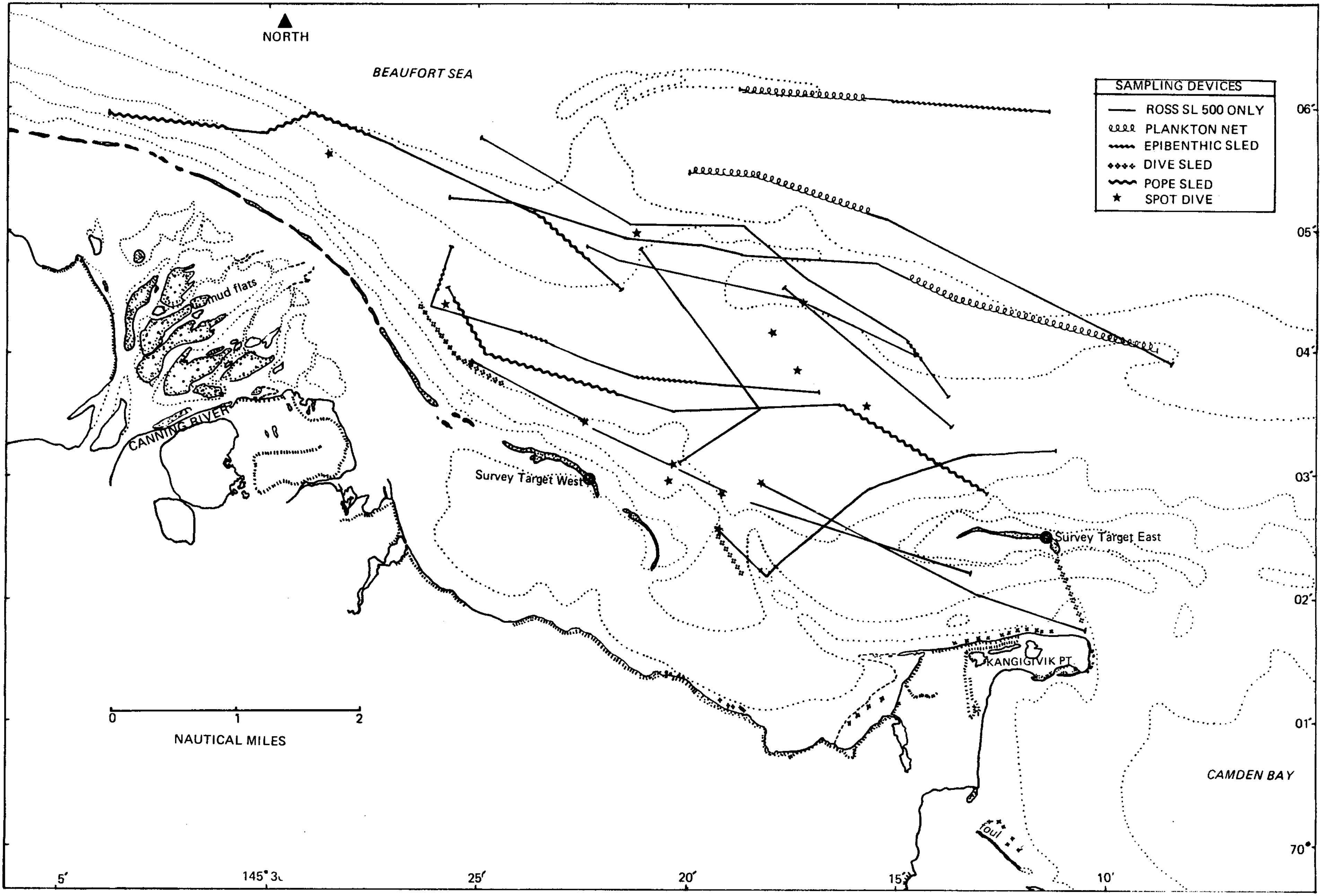

NORTH
BEAUFORT SEA
SAMPLING DEVICES
ROSS SL 500 ONLY
PLANKTON NET
EPIBENTHIC SLED
DIVE SLED
POPE SLED
SPOT DIVE
mud flats
CANNING RIVER
Survey Target West
Survey Target East
KANGIGIVIK PT.
CAMDEN BAY
foul
0
1
2
NAUTICAL MILES
06′
05′
04′
03′
02′
01′
70°
5′
145° 30′
25′
20′
15′
10′

Figure 9. Paul Plesha (holding binoculars) and Ken Dunton (with sextant) re-establish the western terminus of our most northerly transect. Grounded ice prevented further movement to the west (or to the right in this photograph). Extremely thick floating ice (on left) prevented any diving along this transect. Photograph by Alan Paulson.

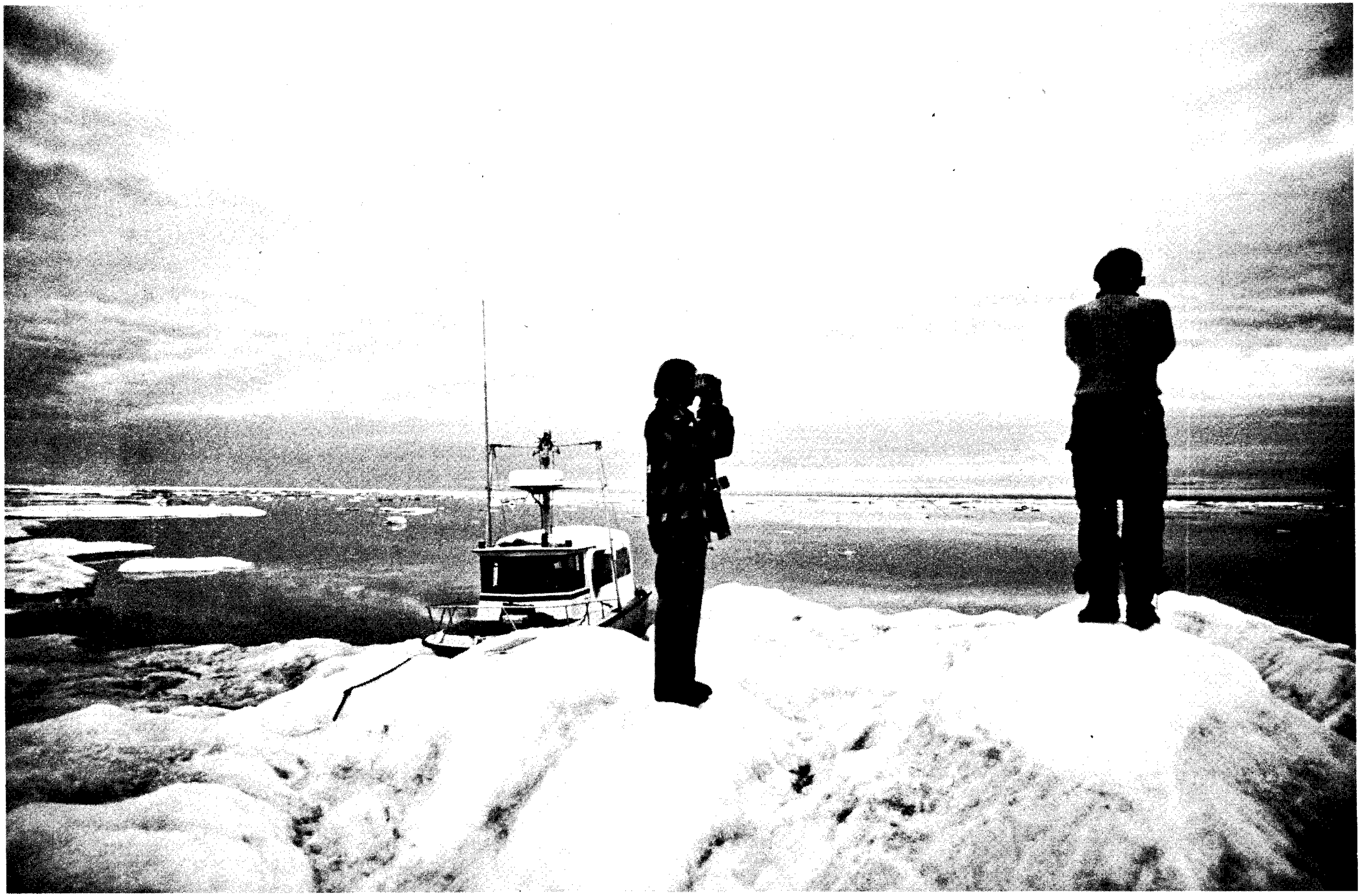


Figure 10. The topography and composition of the seafloor in western Camden Bay based on geophysical survey data, bottom samples, and dive notes. The occurrence of rocks (cobbles or boulders) on the seafloor is denoted by solid circles. Rough bottom is interpreted as crisscrossed ice-gouged furrows in the seafloor (based on diving observations, see text and Fig. 5). Depths shown in meters.

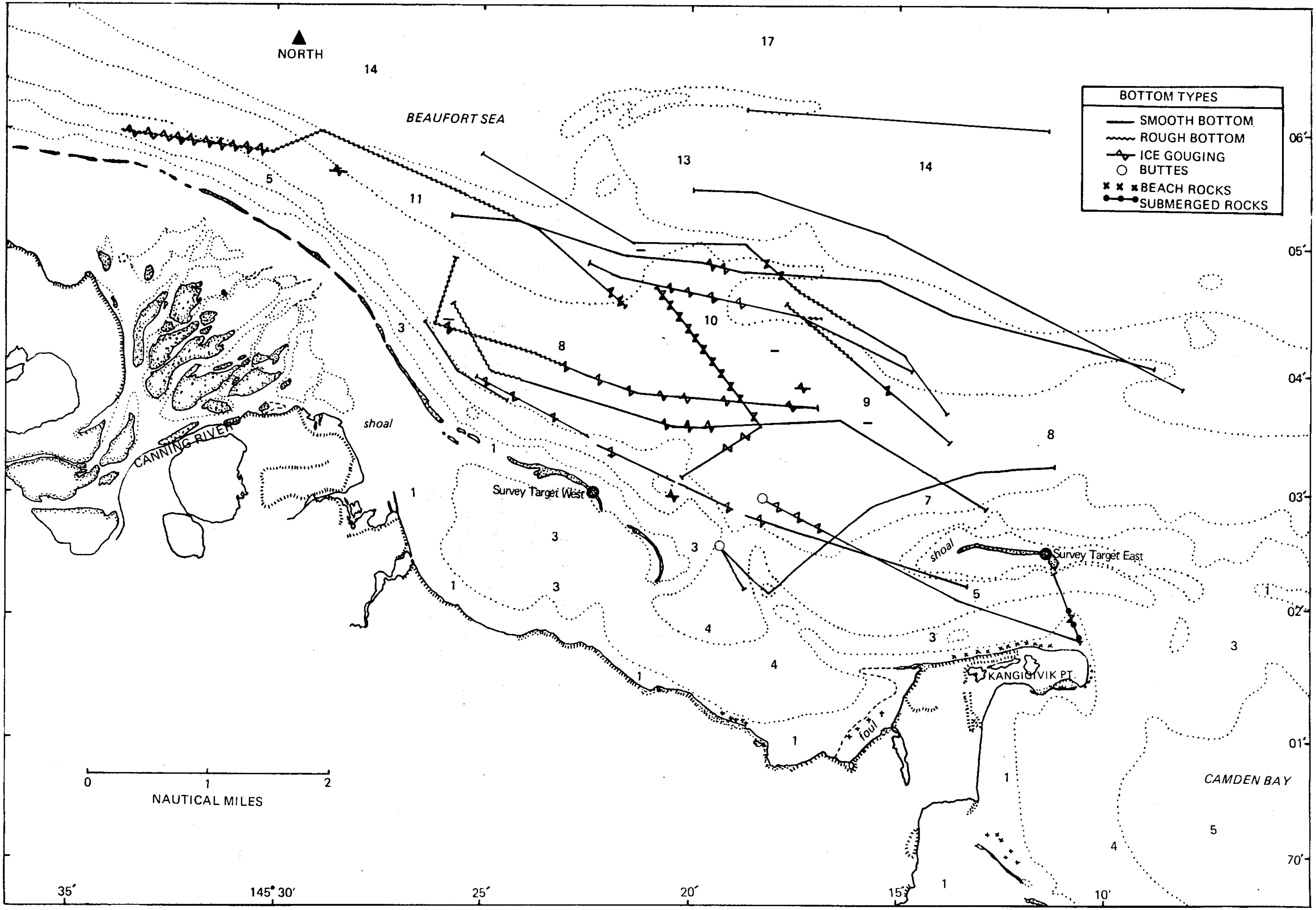

NORTH
BEAUFORT SEA
BOTTOM TYPES
SMOOTH BOTTOM
ROUGH BOTTOM
ICE GOUGING
○ BUTTES
× × × BEACH ROCKS
SUBMERGED ROCKS
17
14
13
14
5
11
10
8
3
9
8
7
1
1
3
3
3
1
4
4
3
5
1
1
1
3
1
4
5
1
shoal
shoal
CANNING RIVER
Survey Target West
Survey Target East
KANGIGIVIK PT.
foul
CAMDEN BAY
0
1
2
NAUTICAL MILES
35′
145° 30′
25′
20′
15′
10′
06′
05′
04′
03′
02′
01′
70′

Figure 11. Large amounts of kelp drifted onto the eastern end of survey target island east (north of Kangigivik Point), following a storm on August 2 and 3. Much of the drift on the beach is *Laminaria solidungula* but the large 3 m long specimen held by Paul Plesha is *Alaria esculenta*.

We were able to examine the drift plants on Survey Target Island East on August 4, before they had become desiccated, and found the specimens large and healthy. Their condition contrasts the small and ragged plants we collected in situ northwest of Kangigivik Point a few days earlier. It appeared that at least some of the plants stranded in drift lines had come from another area.

A week earlier, we noticed large amounts of kelp in a drift line on the seaward side of Soplu Spit. The kelp was slightly desiccated, so it was difficult to assess its size and health. In an attempt to quantify the amount which had been deposited on the beach, we collected all kelp within ten 1 m^2 plots along the beach (Fig. 12). The algae from each plot was bagged and later weighed in the laboratory. The mean dry weight of the kelp in the 10 plots was 22.5 g. Over 600 meters of shoreline this translated to 72 kg of kelp (wet weight). In a conservative estimate, the material cast onto the beach probably represents less than 10% of the kelp bed itself. If the mean biomass of kelp is 137 g m^{-2} in a typical boulder patch (Dunton et al., 1982), then the size of the unknown kelp bed in Camden Bay is approximately 5,400 square meters.

The most likely source for such a kelp bed is a submerged shoal east of Kangigivik Point, formerly known as Boulder Island. This shoal was brought to our attention by Erk Reimnitz (USGS) following a discussion of our observations concerning the possible source of drift kelp in this area. Reimnitz also recalls kelp in association with this island several years ago. The size of the shoal (about 25,000 square meters) and the observations of Reimnitz indicate that it may support a small kelp bed.

Figure 12. Dan Pope (left) and Paul Plesha (right) collect dried kelp recently cast up on the beach in a 1 m^2 area on Soplu Spit. Photograph by Alan Paulson.

NEEDS FOR FURTHER STUDY

The only unsolved mystery for this area is the source of large amounts of drift kelp on beaches east of the survey area. It appears that the only possible source for this kelp is in the vicinity of the Boulder Island shoal, but this is speculative at best.

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TEMPERATURE PREFERENCE OF JUVENILE ARCTIC CISCO (COREGONUS AUTUMNALIS) FROM THE ALASKAN BEAUFORT SEA, IN RELATION TO SALINITY AND TEMPERATURE ACCLIMATION

by

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Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 467

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ABSTRACT

Horizontal-thermal-gradient apparatus of previously undescribed design was used to determine the temperature preference of juvenile arctic cisco, Coregonus autumnalis, as a function of acclimation temperature and acclimation-test salinity. Mean preferred temperature ranged from 11.5 C for fish acclimated to 5 C/5 ppt to 15.4 C for the 15 C/15 ppt acclimation group. Estimated final temperature preferenda were 13.5 C at 30 ppt and 15.6 C at 15 ppt. Preferred temperatures at 5 and 30 ppt were lower ($P < 0.05$) than that at 15 ppt. Qualitative observations of fish in the acclimation tanks suggested that physiological optimal temperatures of juvenile arctic cisco also exceed 10 C over the salinity range of 5-30 ppt.

These results are consistent with the summer distribution of arctic cisco in the Alaskan Beaufort Sea: fish concentrate in a near shore band of relatively warm water of moderate salinity.

Key Words: Temperature preference, arctic cisco, Beaufort Sea, salinity, summer distribution, behavior.

ACKNOWLEDGEMENTS

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INTRODUCTION

The arctic cisco, Coregonus autumnalis, is one of the most abundant anadromous fishes in Alaskan arctic waters. From spawning areas in the Mackenzie River system (Hatfield et al. 1972, O'Neill 1981) and possibly other major river systems of the North Slope region, juveniles migrate into the nearshore waters of the Beaufort Sea where they live during the ice-free period from mid-June to early September (Craig and Haldorson 1980). Freshwater runoff along with intense solar heating make these shallow coastal habitats relatively warmer and less saline than deeper offshore waters (Truett 1980). Nearshore areas also serve as primary summer feeding grounds for arctic cisco due to shoreward and longshore transport of invertebrate-rich ocean waters (Griffiths and Dillinger 1980). Despite a relatively homogeneous distribution of forage within the warm coastal regions of the Beaufort Sea, arctic cisco tend to concentrate in a narrow (20-50 m) corridor that lies adjacent to the shore, except in the vicinity of river deltas where the band can be from 1-4 km wide (Craig and Haldorson 1980). This corridor typically attains the highest temperatures locally available.

The abundance of arctic cisco and other anadromous species in warm water areas during summer has prompted speculation as to the effects of temperature on the migration and distribution of these fishes. In response, we conducted a laboratory study of the temperature preference of juvenile arctic cisco as a function of both acclimation temperature and acclimation-test salinity. Although a multitude of temperature preference data has been published (Coutant 1977), none is available for this species or any other high-arctic coregonine. Temperature preferences were measured in a horizontal-thermal-gradient apparatus of previously undescribed design.

MATERIALS AND METHODS

Arctic cisco (83-136 mm) were taken by fyke net from the Beaufort Sea near Prudhoe Bay, Alaska, during July and August 1981. The fish were flown the day of their capture to a laboratory in Fairbanks. Water temperature and salinity during transport and during an initial 48-h holding period at the laboratory were maintained at levels similar to those recorded in the field at time and place of capture (i.e. 5-8 C and 10-25 ppt).

Groups of 20-25 fish were held in 450-liter, filtered aquaria under constant light. (At the latitude—approximately 70°N--and season of fish collection, day length was 24 h.) Dechlorinated tap water supplemented with Instant Ocean® salts was used in all phases of the experiment. Conditions of acclimation were organized in a 3x3 design--salinities of 5, 15 and 30 ppt (± 2 ppt) versus temperatures of 5, 10 and 15 C (± 0.5 C); however, owing to numerous logistical problems the 5 ppt/15 C acclimation group was never tested. Groups were brought to their specific acclimation conditions by incrementally adjusting temperature and salinity at the rates of 2 C/day and 5 ppt/day, respectively. Fish were maintained at their final acclimation levels for a minimum of ten days prior to testing. During the acclimation period they were fed to satiation 2-3 times daily on a mixture of commercial freeze-dried euphausids and brine shrimp. Once testing of a particular group began, fish were fed to satiation 20-30 minutes before the beginning of each temperature-preference trial.

Test Apparatus

Horizontal-thermal-gradients were formed in an elongate chamber made from a 5-m length of transparent polyvinyl chloride (PVC) Excelon® pipe with an internal diameter of 102 mm. Lying within this primary structure, and extending its entire length along the bottom, were three smaller tubes--a 12.7-mm diameter PVC pipe flanked by two 15.9-mm diameter titanium pipes (Fig. 1). A 50-mm wide slit in the top of the primary tube permitted the investigator free access to any portion of the chamber.

Gradients were established by pumping coolant (ethylene glycol) through one titanium pipe while simultaneously pumping hot water through the other in the opposite direction (Fig. 1). This counter-current arrangement for heat exchange was augumented by heterogeneous insulation of the titanium pipes: the upstream third of each was bare; the second third was spirally wrapped with 6.4-mm thick clear vinyl so that the proportion of bare conductive surface progressively decreased; and the downstream third was completely insulated with vinyl wrap. This system

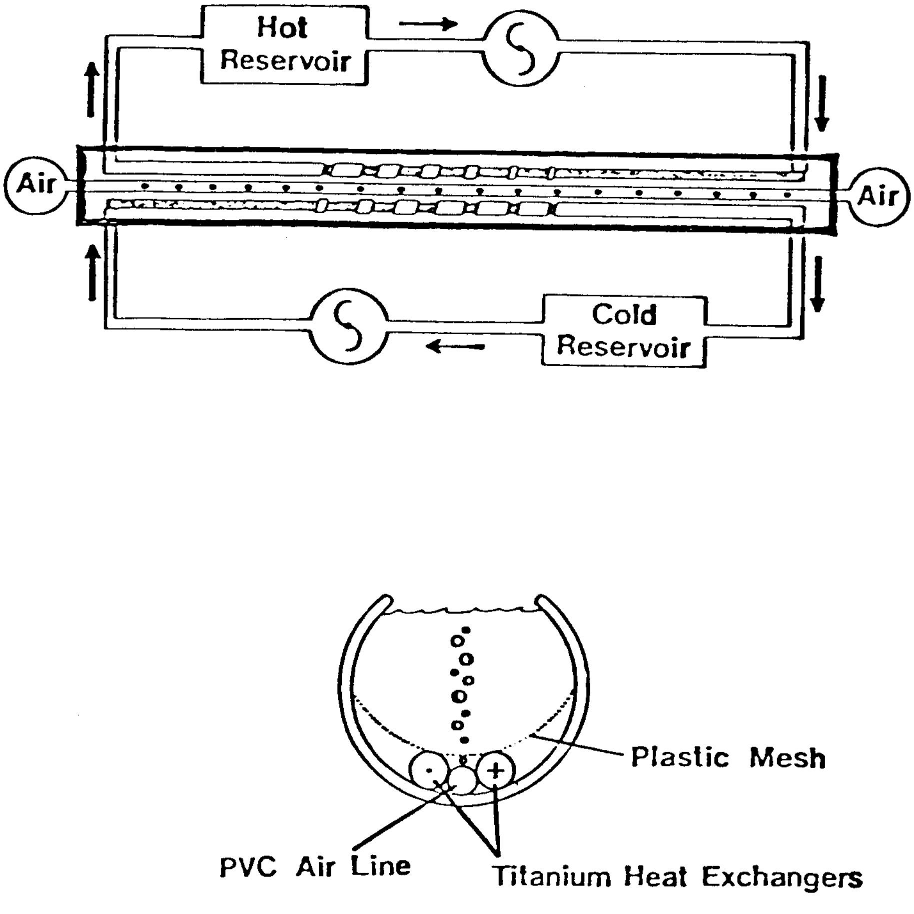

Fig. 1. Schematic representation of one of the thermal gradient systems (above) and a cross-sectional view of a gradient tank (below).

produced linear to slightly sigmoidal gradients as great at 18 C (Fig. 2), with specific gradients obtainable through adjustments in the temperature and flow rate of the liquid within each heat exchanger. Compressed air, bubbled from the central PVC line via 0.5 mm holes at 20 cm intervals, prevented cross-sectional thermal variation in addition to providing aeration. A screen of plastic mesh prevented fish from contacting the heat exchangers and aeration pipe.

Each of four such gradient tanks (mounted one above another) was marked off at intervals of 50 cm, to give 10 stations. A copper-constantan thermocouple submerged at each station was interfaced with a Baily Instruments Inc. digital thermometer (Model BAT-12; display accuracy = 0.1 C) to provide data on water temperature. Flourescent light reflected off a white background provided low-level, uniform illumination from the side of the tank opposite the observer.

Experimental Procedure

A single fish was netted at random from the desired acclimation group and placed in a pre-formed gradient at the temperature corresponding with that of acclimation. The salinity in the gradient was homogeneous and equal to the acclimation salinity (± 1 ppt). In order to accommodate initial disorientation that might have led to the fish rushing headlong into areas of stressful temperature, small blocking nets were placed in the gradient at points equivalent to the acclimation temperature (± 3.0 C). The blocking nets were removed after 30 minutes and the fish was given an additional 90 minutes to habituate to the test apparatus. The fish's position in the gradient tank was then recorded in tenths of a division between each marked station (e.g. 1.6, 3.7 etc.) every 2 minutes for 60 consecutive minutes. Gradient temperatures were recorded at the beginning of each trial and after the 10th, 20th and 30th observations. Temperature between adjacent thermocouples and between observations taken at a single thermocouple was assumed to vary linearly. Temperatures observed or calculated (if between thermocouples) for each positional observation were tabulated and the median taken as the preferred temperature for that particular trial. Frequency distributions based on temperature (1 C increments) and position (50 cm increments) were also

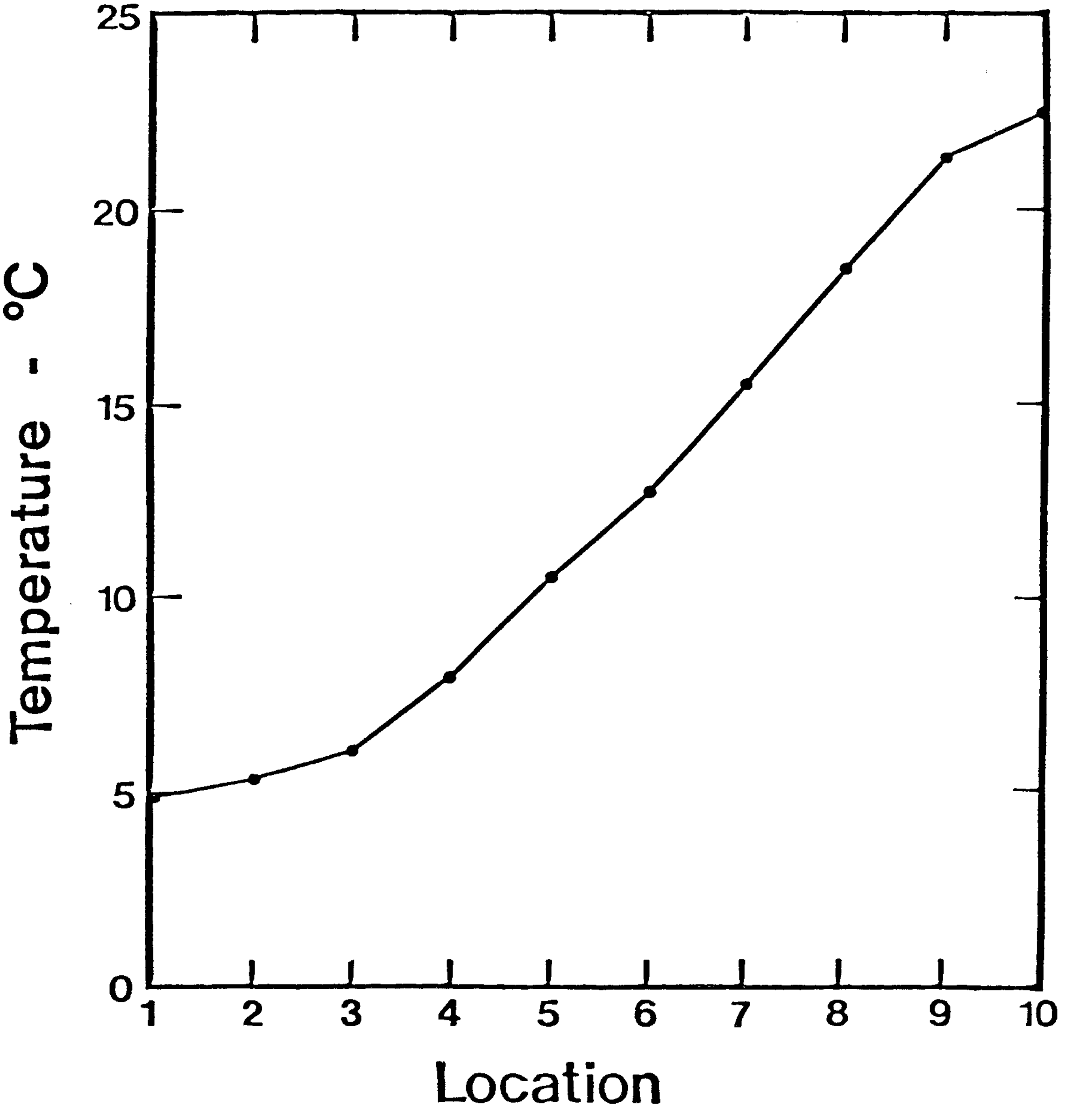

Fig. 2. Water temperature versus location (at 50 cm intervals) for a typical horizontal thermal gradient.

calculated. Fish from a particular acclimation group were tested in a minimum of two different gradient tanks which were oriented in opposite directions, and gradients within specific tanks were varied among trials in order to detect any bias, other than temperature, that may have affected spatial distribution. Analysis of variance, Student's t test and Duncan's multiple-range test (Ostle and Mensing 1975) were used to evaluate differences among acclimation groups.

RESULTS

Temperature Preference Trials

Individual cisco tended to generate monomodal frequency distributions with respect to temperature. Strongly platykurtic distributions (i.e. those with a moment coefficient of kurtosis greater than 1.0 and positionally covering more than 80% of the gradient) were removed from the data base because the median temperature in such cases more likely reflected the distribution of gradient temperatures than the fish's temperature preference. Most of the seven (of 110) trials that were rejected on this basis involved fish that appeared highly stressed and unable to adapt to the test apparatus. The results of three other fish were also discarded because their distributions were sharply truncated at either end of the gradient.

Plots of sample variance against standard fish length indicated that size had a negligible effect on temperature-frequency distribution. The possibility of temperature re-acclimation during the course of any experimental trial was discounted because examination of consecutive observations provided no indication of consistent drift in the temperature at which fish were observed. Variation in preferred temperature among gradients and test tanks proved to be non-significant ($P > 0.10$); therefore, data within acclimation groups were pooled for further analysis.

Mean temperature preferendum ranged from a high of 15.4 C for fish acclimated to 15 C/15 ppt to a low of 11.5 C for the 5 C/5 ppt acclimation group (Table 1, Fig. 3). Arctic cisco acclimated to 15 C preferred temperatures that were higher ($P < 0.05$) than those preferred by either

Table 1. Mean preferred temperature ± 1 standard error (sample size) for arctic cisco acclimated to various combinations of temperature and salinity.

Acclimation Salinity (ppt)	Acclimation Temperature (°C) 5	10	15
5	11.5 ± 0.7 (12)	12.8 ± 0.6 (15)	-
10	13.7 ± 0.5 (10)	13.8 ± 0.4 (14)	15.4 ± 0.4 (16)
30	12.8 ± 0.7 (11)	12.7 ± 0.6 (12)	14.1 ± 0.9 (10)

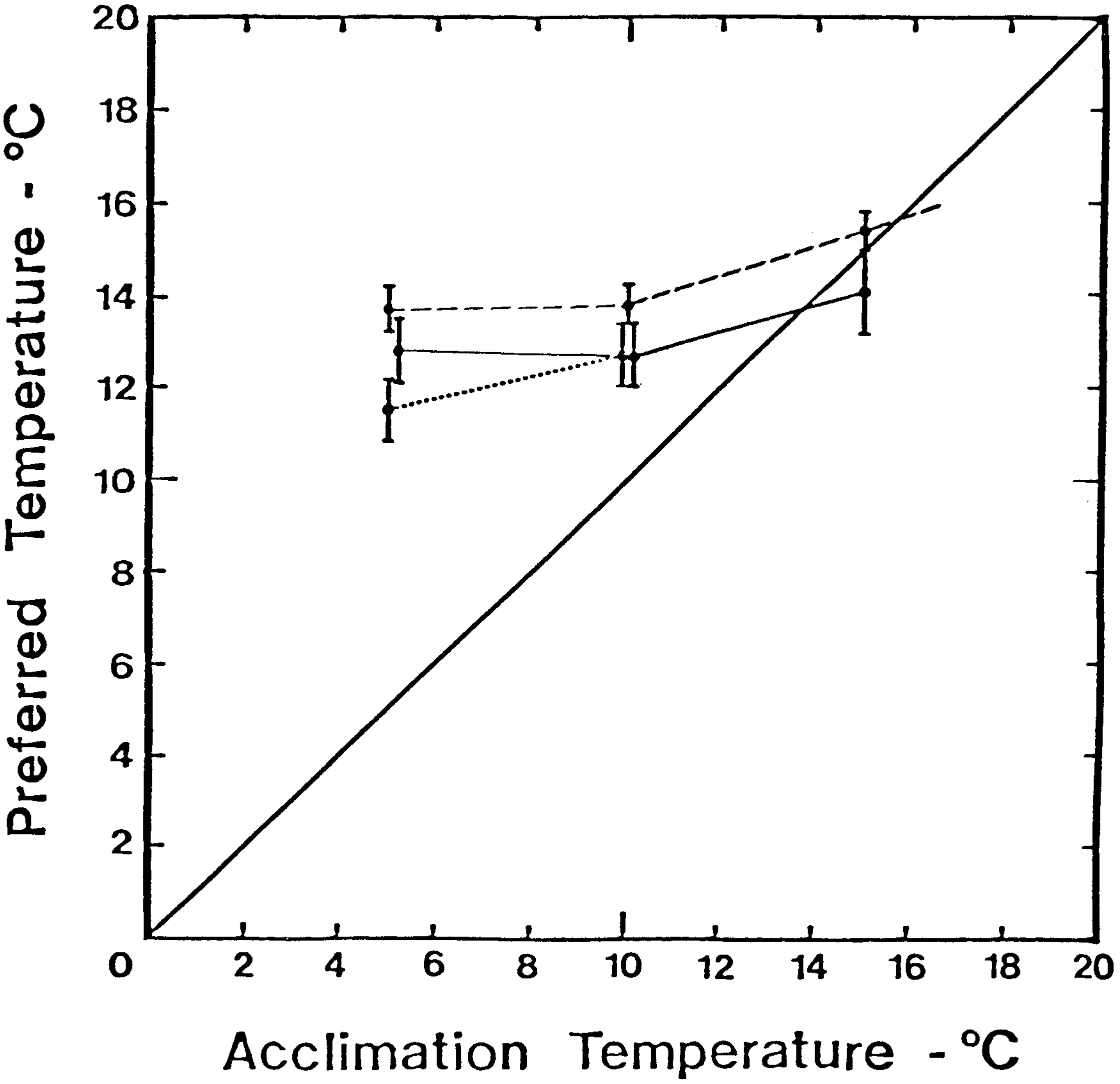

Fig. 3. Preferred temperature (+ 1 SE) versus acclimation temperature for acclimation-test salinities of 5 ppt (dotted line), 15 ppt (dashed line) and 30 ppt (solid line).

the 5 C or 10 C acclimation groups; however, there was no significant ($P > 0.05$) difference in thermal preference between fish acclimated to 5 and 10 C. The mean temperature preferendum was significantly ($P < 0.05$) higher than the temperature of acclimation in all groups with the exception of those acclimated to 15 C. The final temperature preferendum, defined as the point at which the temperature-preference trendline intersects the 45° diagonal (Fry 1947), was graphically estimated to be 15.6 C at 15 ppt and 13.5 C at 30 ppt (Fig. 3).

Preferred temperatures at salinity extremes of 5 and 30 ppt were lower ($P < 0.05$) than that at 15 ppt (Fig. 4).

Behavioral Observations

Behavior of the fish in the acclimation tanks suggested that physiologically optimal temperatures exceed 10 C. Fish acclimated to 15 C appeared alert, perceptive and proved to be extremely elusive during capture attempts. When slowly pursued about the holding tank the majority of individuals tended to form cohesive, well-organized schools. Frenzied feeding activity and a comparatively high rate of food consumption (fish fed to apparent satiation actively accepted food within two hours) were undoubtedly linked to elevated metabolic rates induced by the high temperature. Of approximately 45 fish acclimated to 15 C for a period of 10-20 days, the only fatalities involved individuals that jumped out of the holding tanks.

Conversely, arctic cisco acclimated to 5 C appeared lethargic and lacked the locomotory agility noted in their 15 C counterparts. Tenuous schools, consisting of loose aggregates of 6-8 individuals, persisted no longer than several seconds. Feeding behavior was casual, and these fish, once satiated, refused food for at least the next 6-8 hours. A mortality rate of approximately 0.5 fish/day was noted in all of the 5 C acclimation groups.

These qualitative differences were very apparent when comparisons were made between the 5 and 15 C and between the 5 and 10 C acclimation groups. Differences between the 10 and 15 C groups were subtle except with regard to schooling behavior, which was substantially more

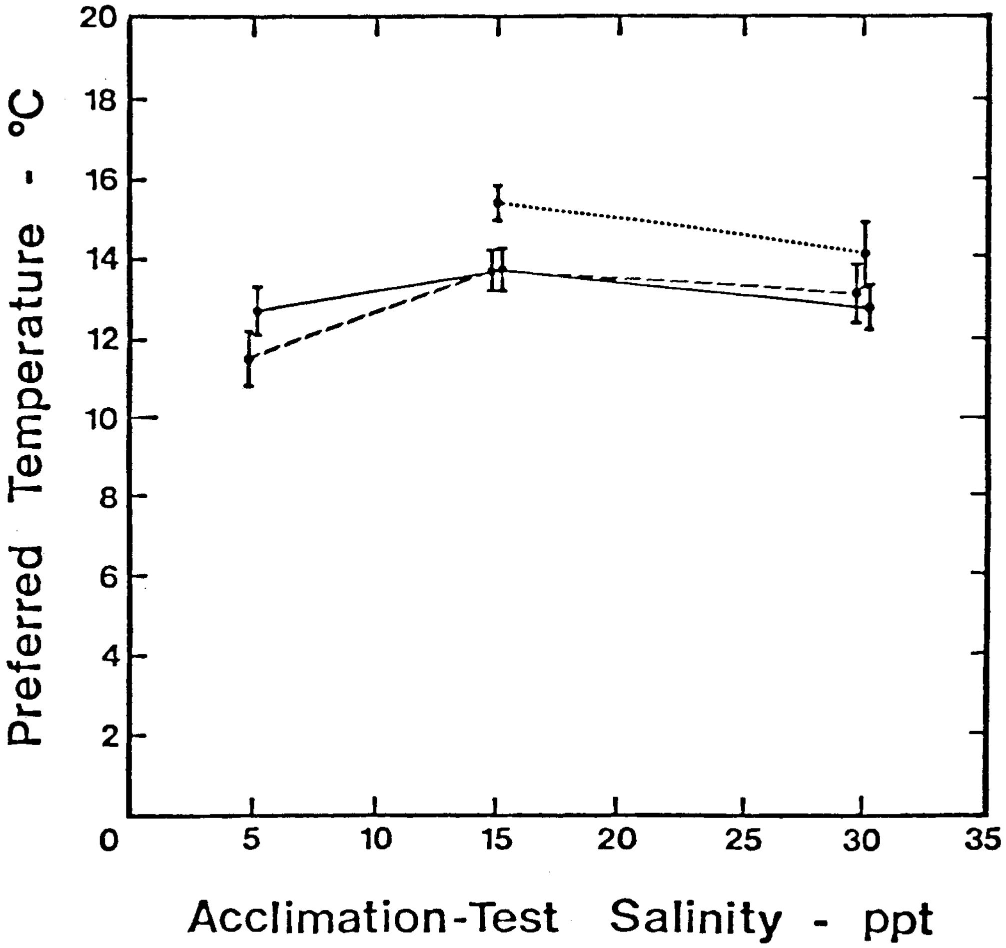

Fig. 4. Preferred temperature (± 1 SE) versus acclimation-test salinity for acclimation temperatures of 5 C (dashed line), 10 C (solid line) and 15 C (dotted line).

conspicuous in the 15 C groups. There were no mortalities in the 10 C acclimation groups.

Within temperature-acclimation groups, differenses in performance among salinity groups were not detected.

DISCUSSION

Thermal Optima

The major premise behind temperature preference studies is that fish, being mobile poikilotherms living in a heterothermal environment, will seek out temperatures that allow them to conduct their joint physiological and biochemical processes in the most optimal and efficient manner. Over the past several decades, a variety of studies concerned with the effects of temperature on the physiological mechanisms of fishes have tended to support this hypothesis. The classical bioenergetic experiments of Brett et al. (1969) demonstrated that growth, meal size and gross food conversion efficiency for sockeye salmon, Onchorhychus nerka, were all maximized at the fish's preferred temperature of 15 C. Jobling (1981), using an accumulation of published data for 49 species of fish, concluded that there is good correlation between preferred temperature and the temperature that promotes maximal growth. Although such relationships between temperature and bioenergetics are dependent on other variables, the most obvious of which is food availability, they nonetheless represent an inherent physiological capability that could prove important in the trophic ecology of the species.

Thermoregulatory behavior also exhibits a strong correlation with various aspects of activity. The maximum sustainable swimming speed of sockeye salmon (Brett 1967) and goldfish, Carassius auratus (Fry and Hart 1949); the maximum distance moved by Atlantic salmon, Salmo salar, and brook trout, Salvelinus fontinalis, as a result of electrical stimulation (Fisher and Elson 1950); and peaked levels of spontaneous activity for brook trout (Elson 1942), have all been reported to occur at respective preferred temperatures. One of the most ecologically important aspects of activity concerns its scope; i.e. that portion of available energy, exclusive of maintenance metabolism, which can be used for locomotion (attacking, escaping, migrating and all ancillary costs such as increased heart rate and breathing action). Measurements of oxygen consumption rates for sockeye salmon (Brett 1964) and largemouth bass, Micropterus salmoides (Beamish 1970a), again show a strong association between maximum scope for activity and preferred temperature.

These thermal optima reflect the combination of an underlying positive effect of temperature on biochemical reaction rates and inherent physiological limitations (e.g. increasing net cost of oxygen delivery) which come into play as temperature approaches the upper lethal limits of the organism. From this perspective, the enhanced survival, schooling, feeding and locomotory performance noted in arctic cisco acclimated to 10 and 15 C qualitatively corroborate the thermal preferenda (11.5-15.4 C) determined from the gradient experiments. Further experimentation, particularly in the areas of growth and scope for activity could ultimately confirm the existence of such thermal optima in arctic cisco.

Acclimation and Temperature Preference

In a constantly changing thermal environment the physiological character of fish undergoes continuous readjustment in an attempt to remain functionally cohesive with regard to temperature. These compensatory responses, which collectively represent the process of thermal acclimation, enable fish to perform more efficiently at new temperatures. Some adjustments such as changes in enzyme-substrate interaction and enzyme structure occur almost instantaneously (Hazel and Prosser 1974). Other processes are slower, taking several hours to several weeks to complete their full transition; examples include biosynthesis of enzyme varients (Hochachka and Somero 1973), restructuring of cell membranes (Caldwell and Vernberg 1970) and shifts in blood chemistry (Houston and Dewilde 1968).

It is important to distinguish between the terms "most efficient" and "optimally efficient". Fish which have been subjected to a particular temperature for several weeks will have most of their physiological processes shifted to operate best at that temperature; the fish are fully acclimated and are physiologically most efficient relative to that temperature. However, it's optimum state, which represents some as yet unexplained geneotypic characteristic of the species, may occur at a different temperature. The fish is thus faced with the choice of selecting from a thermal spectrum that is bounded by the temperature to which it is acclimated and the temperature to which it is genetically directed. The best response, given that all temperatures are available, would be to select a temperature close to its optimal-state yet near enough to the temperature of acclimation so as not to overstress the physiological process to which it is synchronized.

This acclimation-preferred-optimal temperature relationship can be viewed in terms of our trendline data for 15 ppt acclimated arctic cisco (Fig. 3). Fish acclimated to 10 C preferred a temperature of 13.8 C. However, physiological processes immediately begin reacclimating to this new temperature. Fish which subsequently become acclimated to 13.8 C will prefer a temperature of approximately 14.8 C (graphically estimated), again resulting in reacclimation—etc.

At some point the acclimation temperature equals the preferred temperature; this graphically corresponds to the point where the preferred temperature trendline intersects the 45^o diagonal (Fig. 3). This final temperature preferendum (T_{fp}) is indicative of the physiologically optimal temperature for the species. Beyond the T_{fp} selected temperatures will invariably be lower than the temperature of acclimation (Zahn 1967), albeit, our experiments did not cover a broad enough thermal regime to indicate such a trend. Preferred temperatures are thus higher than the temperature of acclimation below the T_{fp} and lower than the acclimation temperature above the T_{fp}. Defined by Fry (1947) as "the temperature around which all individuals will ultimately congregate regardless of their thermal experience", T_{fp} "offers a convenient and meaningful index of the influence of temperature as a directive factor"; e.g. arctic cisco (at 15 ppt) acclimated to temperatures below 15.5 C will be biased toward warmer water while fish acclimated to temperatures above 15.5 C will be directed toward colder water.

The acclimation-preferred temperature relationship observed for arctic cisco is basically similar to that of other species (Zahn 1967). Likewise, the final temperature preferendum (13.5 and 15.5 C) are comparable to those for other juvenile salmonidiforms (Coutant 1977).

Photoperiod and Age

Arctic cisco were acclimated and tested under conditions of constant light which corresponded with the 24-day length indicative of the latitude (~70°N) and season of fish capture. Given that preferred temperatures are typically highest for juveniles of a species (Coutant 1977) and under conditions that simulate summer photoperiod/seasonality (Sullivan and Fisher 1953, Zahn 1963), our results may represent maximum values of temperature preference for this species.

Feeding Regime

Food availability is another factor that can significantly affect thermoregulatory behavior in fish. The elevated metabolic rate that accompanies increased temperature is only sustainable given an adequate supply of energy. In cases where energy demand exceeds supply (i.e. low food availability and high metabolic rate), fish would be forced to either tap their body energy reserves or lower their metabolism by reducing ambient temperature. Since a net energy loss to the environment is biologically unfavorable, the latter response seems the most practical alternative. Food availability thus functions as a controlling and/or limiting factor in temperature selection. Javid and Andersen (1967) reported that brook trout, *Salvelinus fontinalis* and rainbow trout, *Salmo gairdneri*, significantly lowered their preferred temperatures within 24 hours after cessation of feeding and subsequently returned to pre-starvation levels within 24 hours after the resumption of feeding. They also noted an increase in the temperatures preferred by starved Atlantic salmon, *Salmo salar*, but attributed this behavior to a positive phototaxic response to stress.

We believe that the feeding regime employed during these experiments essentially negated the controlling and/or limiting effects of food availability; arctic cisco were fed to satiation 2-3 times daily during acclimation periods and 20-30 minutes prior to each temperature preference trial. If one further assumes that a reduction in thermal preferenda is the typical response to lowered feeding rates, then the temperatures selected by our well-fed arctic cisco may, as was the case with photoperiod and age, represent maximum values for the species.

Salinity Effects

The tendency for arctic cisco to select highest temperatures at intermediate salinities is similar to that reported for the threespine stickleback, Gasterosteus aculeatus (Garside et al. 1977). In the latter case, intermediate salinities were those isosmotic for the species, suggesting that thermoregulatory behavior may compensate for osmotic stress. The potential severity of such stress is indicated by the observations of Rao (1968): in terms of oxygen consumption, the cost of osmoregulation for rainbow trout (Salmo gairdneri) reached 20-27% of total metabolic demand as environmental salinity diverged from isosmoticity. At salinity extremes, the selection of a lower temperature would reduce standard metabolism and partially offset the elevated oxygen demand created by osmotic loading. Higher oxygen concentrations at lower temperatures might also prove beneficial in supporting increased metabolism. Our experimental temperature gradients were accompanied by relatively linear dissolved oxygen gradients ranging from approximately 9 mgO_2/liter at 20 C to 14 mgO_2/liter at 5 C.

Farmer and Beamish (1969) likewise found that oxygen consumption rates for Tilapia nilotica were lowest under isosmotic conditions. Yet, this species, when acclimated from 15 to 30 C, showed a preferred temperature trend essentially opposite that of arctic cisco and threespine stickleback: selected temperatures were lowest at intermediate salinities (Beamish 1970b). Such contrasting results lead one to consider the importance of habitat and niche diversity when assessing the species-specific effects of temperature and salinity interactions.

This preferred temperature-salinity relationship has an ecological compliment. Throughout the summer arctic cisco occupy the warm, brackish water corridor along the coastline. At intermittant intervals wind-driven incursions of arctic ocean water cause a rapid decrease in temperature while simultaneously increasing salinity (Craig and Haldorson 1980). Conditions are thus either warm and brackish (higher preferenda at intermediate salinities) or cold and saline (lower preferenda at high salinities). This occurrence further confounds the role of salinity in altering thermal preferences. Salinity may act as an osmotic stress which must be compensated for through changes in ambient temperature (preferenda), or it may act as a signaling stimulus; forewarning the fish of an ensuing change in temperature and thus acting as a thermal acclimation catalyst.

Ecological Implications

Regardless of the variation induced by salinity and acclimation temperature, the selected temperatures of juvenile arctic cisco either approach or exceed the upper limits of the thermal spectrum typically available to them during the summer season. Moderately saline (18-25 ppt), nearshore waters of the Alaskan Beaufort Sea reach annual maximum temperatures of 10-12 C during the month of August (Craig and Haldorson 1980), although temperatures as high as 15 C have been reported (D. Schmidt, pers. comm.). Given these environmental conditions and the results of our experiments it seems reasonable to assume that temperature plays a role in the distribution of this species. The thermal structure of the coastal environment would consistently result in an orientation bias in favor of a shoreward movement. Valtonen (1970) presumed a similar role of thermal preference in the tendency of juvenile <u>Coregonus nasus</u> to occupy the warm nearshore waters along the coast of the Bay of Bothia, Finland.

During summer, arctic coastal waters not only provide the highest temperatures locally available, but also generate intense trophic support for the fish species that occupy them. This simultaneous occurrence of elevated temperature and abundant forage no doubt confers an ecological advantage in terms of growth potential. Assuming that the previously noted correlation between preferred temperature and the temperature for maximum growth (Jobling 1981) holds for arctic cisco, juveniles are ecologically and physiologically positioned to make optimal use of their limited feeding season.

Several studies have inferred that thermal preferenda may be reflective of spawning optima (Banner and Hyatt 1975, Smith 1975). This is an interesting correlation in light of the migratory patterns of adult cisco. Mature fish undergo extensive upstream spawning runs in the Mackenzie River during July and August, reaching areas as far as 725 km up-river (Stein et al. 1973, Griffiths et al. 1975). Suspension of feeding during the migration lasts until spawning is completed (Hatfield et al. 1972). Runs are finished by the middle of October, with spent fish subsequently moving back downstream to overwinter in the vicinity of the estuary delta (O'Neil et al. 1981).

Measurements taken around the Mackenzie River delta show July-August temperatures ranging from 11-18 C, decreasing to 7-9 C by the end of September (P. Craig, pers. comm.). It is likely that such temperatures occur in the more southerly reaches of the river system. Assuming a slight lag in seasonal temperature decay as one moves upstream, arctic cisco might well encounter their warmest waters during this critical spawning period.

Lack of larval arctic cisco in up-river areas during the spring breakup suggests that fry are transported downstream during the spring flood and rear in the lower reaches of the Mackenzie (O'Neill et al. 1981). Stein et al. (1973) located nursery grounds at the head of the Mackenzie River delta. Nursery utilization, another critical period in a fishes life cycle, could again correspond with seasonally high temperatures of around 15 C.

Although our experiments implicate temperature as an environmental determinant in the summer distribution of arctic cisco, it is only one of many factors that can affect population movement. Variables such as abundance of forage, shallowness of nearshore waters, substrate composition or the dynamics of coastal currents may compete directly with temperature in determining specific patterns of dispersion and migration. Laboratory studies have demonstrated that behavioral thermoregulation in fishes can be modified by territoriality (Beitinger and Magnuson 1975), bacterial infection (Reynolds et al. 1976), photoperiod (Sullivan and Fisher 1954), competition and niche availability (Fleming and Laverster 1956), food availability (Javid and Anderson 1967), age (Coutant 1977) and salinity (Beamish 1970b). Yet despite such complex interactions field studies have demonstrated temperature to be an important factor in controlling environmental distributions (Fry 1937, Dendy 1948, Hancock

1954, Martin and Baldwin 1958, Horak and Tanner 1964, Neill 1971, Brandt et al. 1980).

While the exact ecological role of temperature will depend upon temporal and spatial integration of both species and environmental characteristics, the strong thermal dependency of physiological mechanisms in fishes demand its serious consideration. In the case of juvenile arctic cisco, preference for warm waters along the Beaufort Sea coast would appear to be a sensible adaptive strategy in that it would enable them to realize their physiological potential and thereby maximize the probability of successfully coping with a vigorous environment.

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AN ASSESSMENT OF THE BEAUFORT SEA STOCK OF ARCTIC CISCO (COREGONUS AUTUMNALIS) BASED UPON THE DERISO MODEL APPLIED TO THE CATCH AND EFFORT DATA FROM THE HELMERICKS' COMMERCIAL FISHERY

by

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ABSTRACT

Prompted by an apparent decline in the numbers of Arctic cisco which occurred between 1976 and 1979, we undertook the task of performing a stock assessment analyzing commercial fishery data using the Deriso (1980) model. The model estimates the various survival and recruitment parameters that result in the best fit of a predicted sequence of catch-effort data with the observed pattern. This analysis was performed to determine whether the apparent declines resulted from a normally occurring population cycle or from other factors such as overfishing and offshore oil and gas development.

The results of the analysis showed that the observed fluctuations in population levels could be explained if Arctic cisco are characterized by a strong density-dependent stock-recruitment function and if a large proportion of spawners are not vulnerable to the fishery. There is some evidence to support this hypothesis. Few running-ripe or spawned-out Arctic cisco are taken in the commercial fishery. The Mackenzie River (N.W.T.) system appears to be the main spawning area of this species for the North Slope of Alaska and Canada.

However, given the short period of record, the observed and simulated patterns of abundance could have resulted from a few "bad" ice years (years in which the ice does not move off the mainland shore for most of the summer—e.g. 1974-1975). The results of a few more years of catch and effort data from the fishery should enable us to distinguish between the two hypotheses. In the interim, additional work describing the functional responses of Arctic fishes to environmental factors as a basis for attempting population level assessments is needed.

INTRODUCTION

The Arctic cisco, Coregonus autumnalis, is both one of the most abundant and valued of the anadromous fishes occurring along the North Slope of Alaska. As a subsistence fish, it is considered to be "much fatter, larger, and more tasty" than other commonly-occurring whitefish (Flossie Hopson, Environmental Protection and Conservation Office, North Slope Borough, 1980, pers. comm.). In Alaska, Arctic cisco are at present the target of seasonal subsistence fisheries at Nuiqsut in the Colville Delta and at Griffin Point east of Barter Island, Alaska. The former is a fall/winter fishery, whereas the Griffin Point fishery operates during summer. A commercial fishery (permitted to take a maximum of 50,000 Arctic cisco) also operates in the Colville River Delta in fall and early winter. In the Mackenzie River valley in Canada the Arctic cisco also represents an important component of the domestic fishery (Hatfield et al. 1972).

The Arctic cisco ranges from northern Europe and Siberia to western Arctic North America. In the latter region, it is distributed along the Arctic coast from about Point Barrow, Alaska to Bathurst Inlet, Northwest Territories, Canada (Fig. 1, Morrow 1980). The population is apparently centered in brackish waters around the Mackenzie (Canada) and Colville (Alaska) River Deltas, habitats which are used for overwintering following summer feeding dispersals into the nearshore Beaufort Sea. In the Mackenzie River system, Arctic cisco range as much as 1600 km above the delta (Laird River) during late summer-fall spawning runs (O'Neill et al. 1981). This run is similar to those which have been reported for Arctic cisco in Siberia, where the fish migrate over 1500 km from the sea to spawning areas in the upper parts of the Yenisei River (Nikolsky and Reshetnikov 1970). Following spawning, adult Arctic cisco undertake post-spawning migrations to brackish-water delta regions where they overwinter with other segments of the population (Wynne-Edwards 1952, Nikolsky and Reshetnikov 1970, Craig and Mann 1974, O'Neil et al. 1981).

In conjunction with oil and gas development numerous fish studies have been conducted in western Arctic North America since the mid-1970's. Some of these studies (e.g. Bendock 1977, Doxey 1977, Craig and Haldorson 1981) have emphasized summer tagging programs, with the recapture effort supplemented by fall-winter tag returns and catch data obtained from the Colville River commercial fishery. Craig and Haldorson (1981) used these data as the basis for population estimates which suggested that an 86% decline in the numbers of Arctic cisco overwintering in the Colville River Delta occurred between 1976 and 1979. This observation was supported by the commercial catch data which, during 1979, dropped to only 25% of its average during previous years. The 1980 commercial catch and population estimates were also low, similar to 1979 levels.

The timing of the apparent Arctic cisco decline corresponded with not only the first major offshore oil and gas development of consequence, but also with the establishment of the village of Nuiqsut at the head of the delta (see Fig. 2) in 1973. The latter event undoubtably increased the local demand for and take of fish, including Arctic cisco. Craig and Haldorson (1981) using an estimated Nuiqsut population of 157 persons, determined the annual village requirement for fish could be as much as 68,874 pounds. The increase in the take of fish from the Colville River Delta raised the question of overfishing as a major factor contributing to the observed decline.

The offshore development in question was the construction in 1975 of the 1.3-km long, solid-fill causeway just west of Prudhoe Bay which was extended offshore by an additional 1.5 km in 1976, and further extended by 1125 m in 1981. Given that causeways might directly impede fish migrations or indirectly affect anadromous fish by altering longshore currents and local temperature and salinity regimes, there was some concern that, if the decline in abundance of Arctic cisco was real, it might in someway have been related to this structure. In any case, it was clearly evident that a great deal more information about the population dynamics and biology of Arctic cisco was needed before any interpretive judgements could be made with regards to the apparent decline.

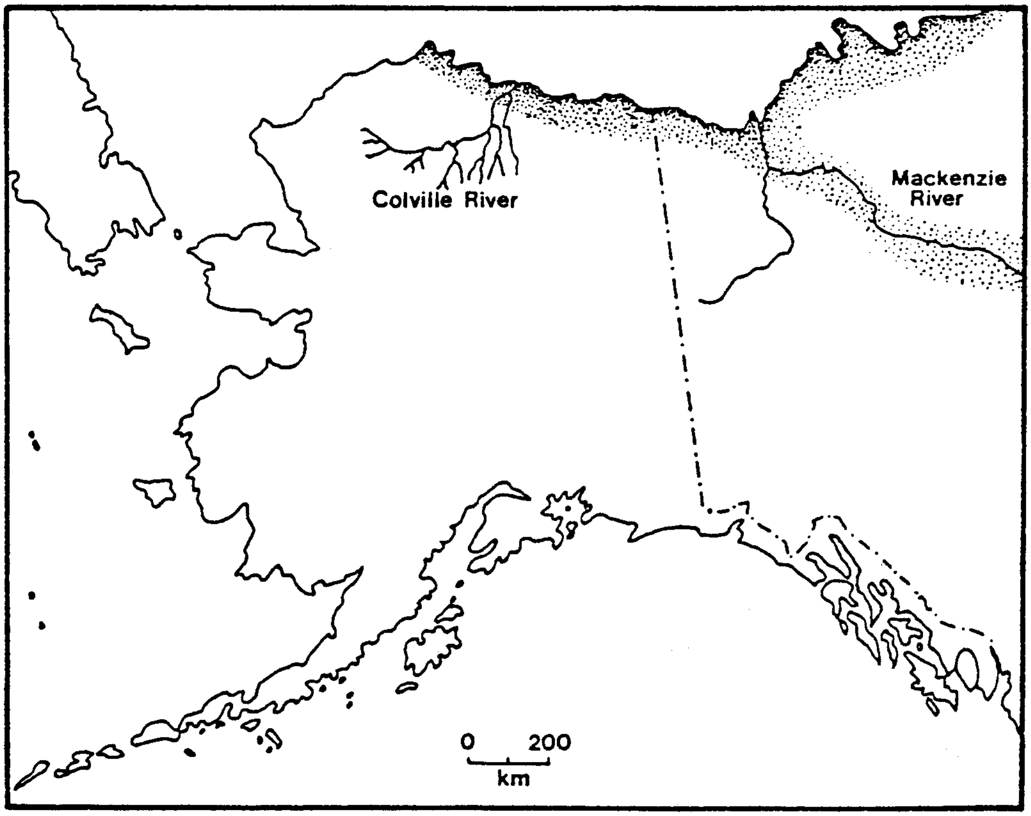

Fig. 1. The distribution (stippled area) of the Arctic cisco (*Coregonus autumnalis*) in Alaska and Canada (after Morrow 1980).

Deriso (1980) provided a major breakthrough in population dynamics methodology. His contribution was the derivation of a model incorporating features such as time lags, growth, mortality and recruitment (all of which can be related to biological processes) whose parameters could be estimated from a time series of catch/effort (CPUE) data. Prior to Deriso's efforts, such dynamic pool models could be constructed, but required a time series of accurate age composition data (which are seldom available) as opposed to simple catch-effort data. Given this tool, and the availability of a time series of catch/effort data from the Colville Delta commercial fishery dating from 1967, we undertook the task of describing the apparent population dynamics of the Arctic cisco. Whereas the main purpose was to contribute to the understanding of the biology of this species, another goal was to evaluate whether the observed decline could best be explained by population attributes, overfishing, or impacts resulting from environmental conditions.

THE DERISO MODEL

The Deriso model, simply stated, says that next years' biomass will be the survivors of the years stock, corrected for weight growth, plus new recruits. When numbers are modeled instead of biomass, the Deriso model can be simplified to:

$$C_{t+1} = \ell(1-qE_t+m)C_t+\ell^2 m(\ell-qE_{t-1})C_{t-1}+q(1-m)$$
$$+q(1-m)R\{(1-qE_{t-1-k})C_{t+1-k}/_q\}$$

where the variables are:

C_t = CPUE during year t

E_t = effort during year t

$R(.)$ = recruitment function with $R(s) = Se^{\alpha\beta s}$(Ricker curve)

and the parameters are:

ℓ = annual natural survival

q = catchability coefficient

α, β = Ricker recruitment parameters

1-m = fraction of spawners vulnerable to fishery (allows for incomplete recruitment)

k = lag time between birth and recruitment (k+1=age at recruitment)

We modeled numbers instead of biomass because number of fish caught (not biomass) was recorded by the fishery.

Parameters were estimated using Walters' (1981) Applesoft Basic computer program written for a 48k Apple II plus micro-computer with DOS and a single disc drive. In this program, the approach is to use quasi-linearization and non-linear Newton's methods to estimate the set of survival and recruitment parameters that will make a predicted sequence of catch/effort agree best with the observed sequence (see Deriso 1980 and Walters 1981).

THE FISHERY

The Helmericks' commercial fishery in the Colville Delta has been operated during fall and early winter in essentially the same fashion every year since 1967. Fishing is conducted in the Main (Kupigruak) and East channels of the river adjacent to Anachilik Island (Fig. 2). When the ice becomes thick enough to walk on, holes are drilled and gill nets are set in a continuous series along the deep bottoms of the channels. The nets are typically 2x50 m, having either 7.6 (3 in) or 10.2 (4 in) cm stretched mesh. The smaller mesh is used in both channels, but the larger mesh is used exclusively in the Main Channel where humpback whitefish (a species larger than the ciscoes) occur more commonly. Effort with the small mesh nets has comprised over 98% of the total soak time expended by the fishery over the 1967-81 period.

Fishing usually begins about the first of October and is terminated towards the end of November. The nets are typically picked every day with the exception of Sundays. The catch is recorded by date and usually by location. Effort records are maintained by date and location. The nets

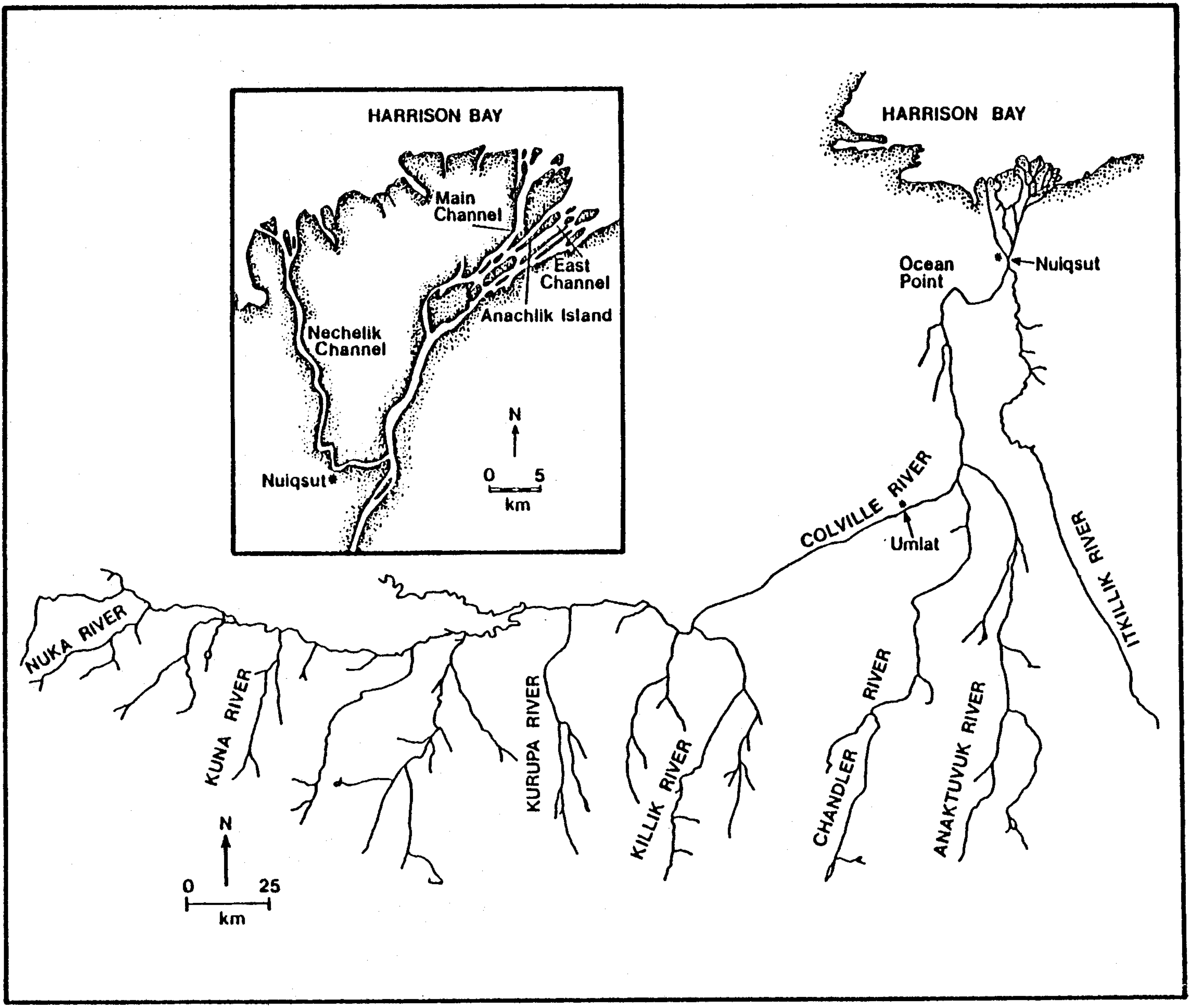

Fig. 2. The Colville River of Alaska with detail of the delta region (insert) showing major fishing sites.

are set and fished over the entire period, although they are occasionally moved. The nets are removed as the quota is approached or the catches are considered too low to continue fishing.

With the exceptions of six years, the pattern of daily effort has been reasonably regular in that maximum effort has ranged from about 10 to 25 nets fished/day, and most fishing has been conducted in October and November (Fig. 3). The years 1968, 1971 and 1976 were characterized by unusually high levels of maximum effort (31 to 41 nets fished/day), levels which were sustained for longer periods in 1968 and 1971 than in 1976. The years 1978-80 differed from all other years for the period of record in that fishing effort was extended well into December. Further, in two of these years (1978 and 1979), fishing was initiated several days later than usual, this was also the case for the years 1973 and 1981 (Fig. 3).

Because the catch data were sometimes recorded as total catch for a given day or group of days and were not always designated between each of the two fishing sites, we combined the total effort and catch data from each of the two habitats, respectively. Effort in the East Channel has historically been greater than effort in the Main Channel, and the annual patterns of effort for each habitat have been quite similar (Fig. 4b). Arctic cisco are believed by the fishermen to mainly use the shallower East Channel, whereas broad whitefish and least cisco are believed to mostly use the deeper Main Channel.

The annual catch of Arctic cisco taken in the fishery (Fig. 4a) has ranged from a high of 71,575 in 1973 to a low of 9268 in 1979. The catch levels among these years suggest a marked decline as described in the introductory section. During the same years, effort levels, although variable, suggested an increasing rather than a decreasing trend (Fig. 4b). Maximum effort for the period of record was expended in the years 1968 and 1971.

Craig and Haldorson (1981) showed that the Arctic cisco taken in the commercial fisheries are moderately large fish (range 240 to 380 mm in length). However, most of these fish fall within the 280- 340 mm length range (Fig. 5). The age composition of the catch ranges between 3 and 10 years, but fish aged five to eight dominate the catch. Male and female

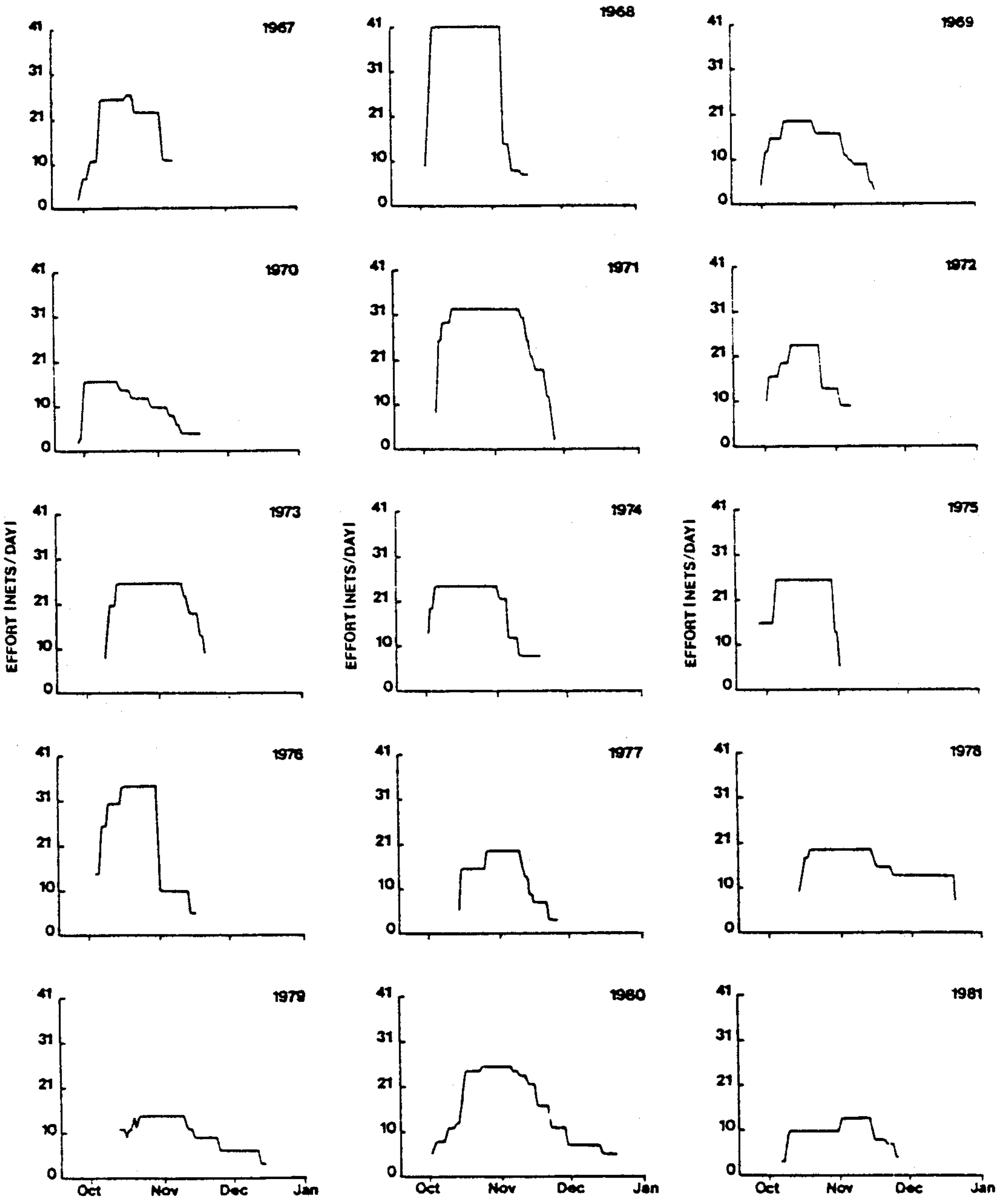

Fig. 3. Patterns of daily commercial fishing effort for the 15-year period of record for the Helmericks' Commercial Fishery.

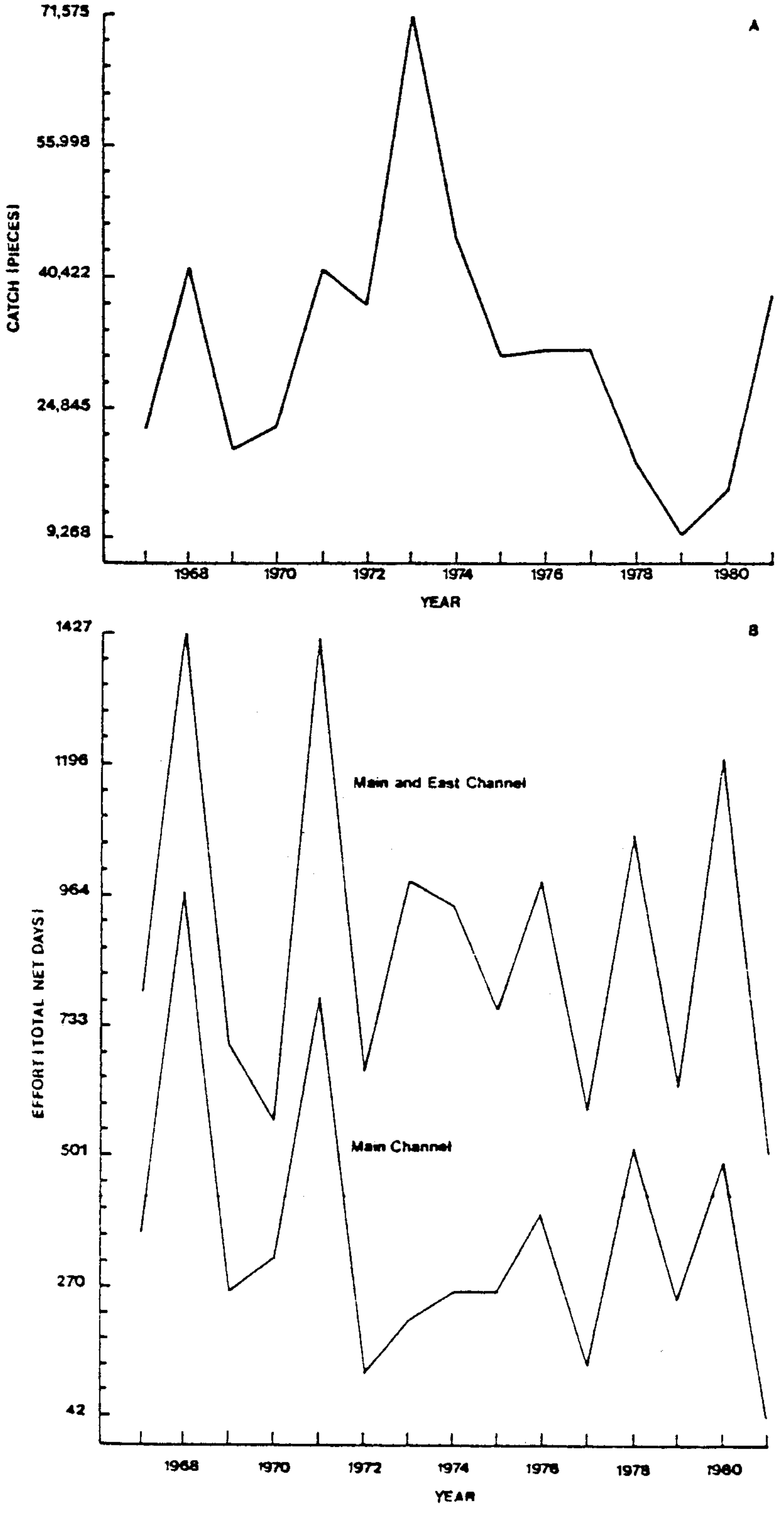

Fig. 4. Patterns of annual catch (A) and fishing effort (B) for the Helmericks' Commercial Fishery, 1967-1981.

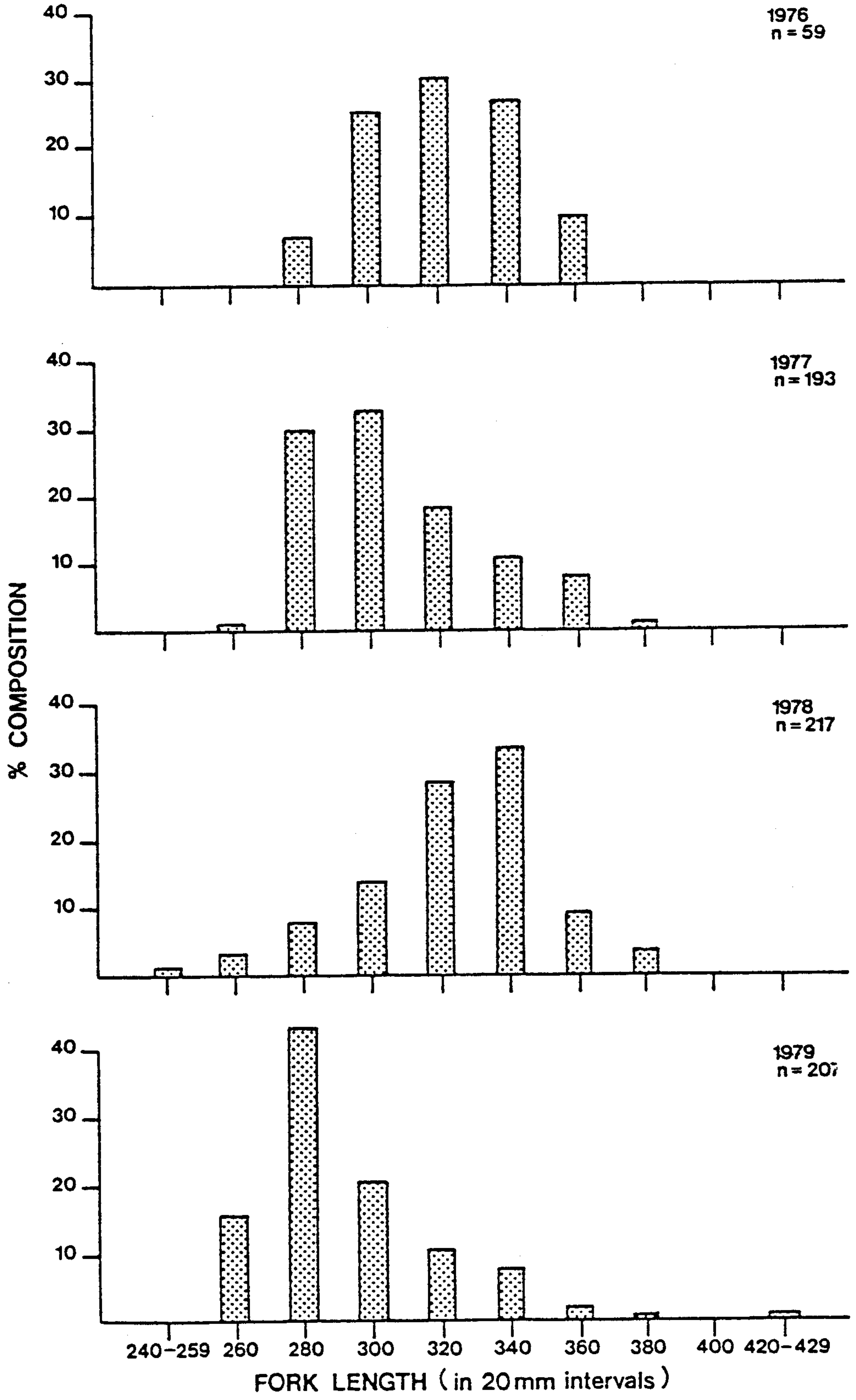

Fig. 5. Size distribution of Arctic cisco taken in the Helmericks' Commercial Fishery, 1976-1979 (after Craig and Haldorson 1981).

Arctic cisco first attain sexual maturity at ages seven and eight, respectively (Craig and Haldorson 1981). From Fig. 5, dominant age/size groups can be seen to move through the fishery in a pulsed fashion.

Based upon Craig and Haldorson's (1981) examination of about 200 specimens taken each year from the commercial catch during 1977-79, sexually mature fish comprised some 49 to 57 percent of the catch. During 1976, only 12% of the catch was estimated to have been sexually mature, but the sample consisted of only 59 fish. However, no fish in spawning condition or spawned-out fish were found in any of the samples examined by Craig and Haldorson (1981), which was surprising considering that the spawning period immediately preceeds and/or overlaps the fishing season. When requested in 1979 to supply any spawned-out fish, the fisherman provided only nine fish out of the entire catch, of which only one spawned-out male and two "possibly" spawned-out females were confirmed by Craig and Haldorson (1981). The autumn commercial fishery in the Colville Delta harvests essentially a non-spawning segment of the Arctic cisco population.

RESULTS AND DISCUSSION

Peak population levels of catchable Arctic cisco according to CPUE data occurred in 1973 and 1981, with a lessor peak occurring in 1977 (Fig. 6). The Deriso Model provided a very good fit of the historical record (Fig. 6), with the best fit obtained using the parameter estimates of $k=5$; $\ell=0.37$; $q=0.33$; $\alpha=4.8$, $\beta=5.5\times10^{-5}$; and $m=0.64$. The model did not reflect a minor peak in 1977, nor was this peak suggested by independent population estimates calculated from mark-recapture data available from other studies (Craig and Haldorson 1981, Griffiths and Gallaway 1982) covering the period 1976 through 1981 (see Fig. 6). With the exception of 1977, each of the three population estimators (CPUE, MODEL, MARK-RECAPTURE) reflected a similar trend in population levels for the years held in common.

The model was very sensitive to the five-year lag period between events, as well as to the m value of 0.64 which indicates an exceptionally high uncatchable proportion of spawners. These data suggest that the bulk of the catch should consist of fish of ages five to seven , and spawners

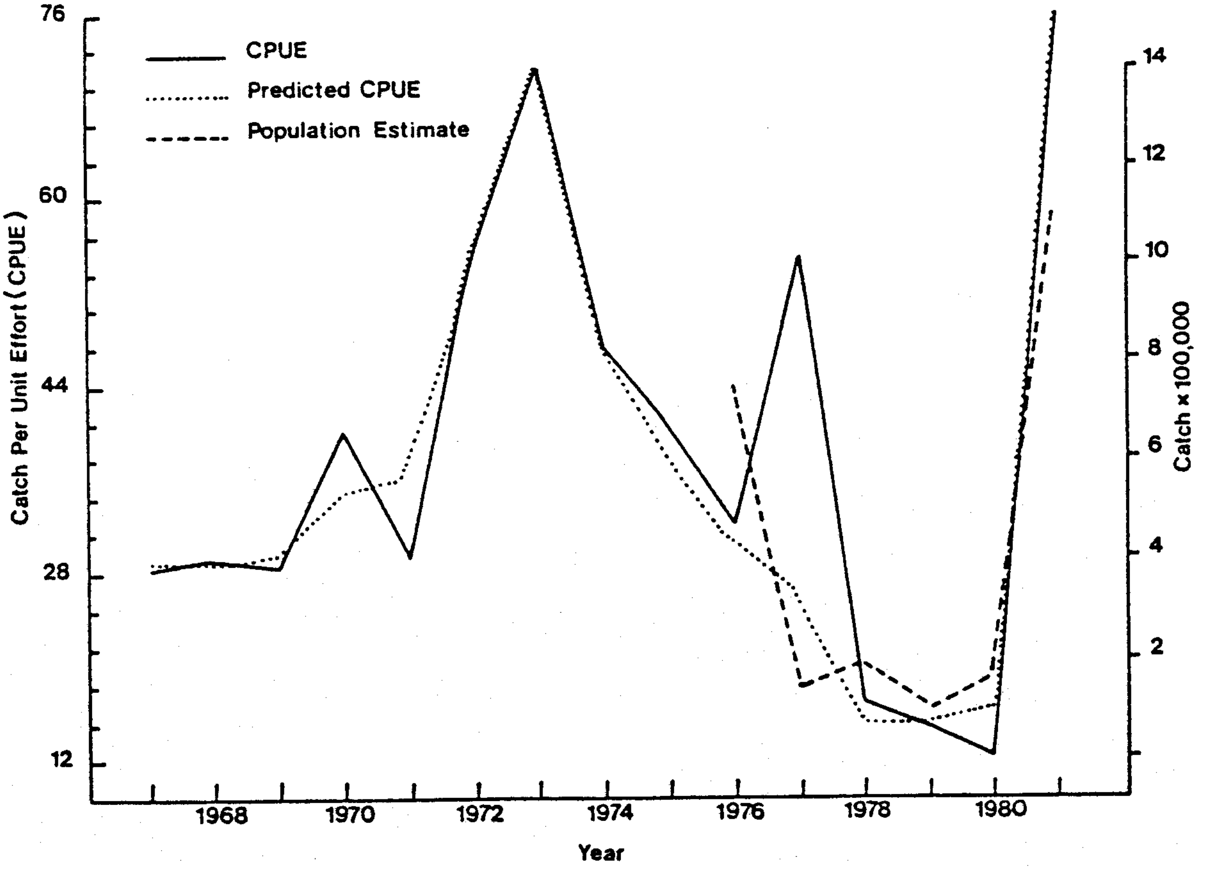

Fig. 6. Population trends of Arctic cisco (Coregonus autumnalis) based upon CPUE, model, and mark-recapture data from the Helmericks' Commercial Fishery, 1967-1981.

should comprise a small proportion of the catch as compared to mature non-spawners. Both of these implications from the biological model agree well with the observed age and maturity composition of the actual catch from the fishery, suggesting model validity. However, the question of why spawners are largely non-vulnerable to the fishery remains unanswered.

One of the explanations is that the Arctic cisco overwintering in the Colville River, for the most part, leave this system in the spring and summer period of the year following the attainment of sexual maturity. We believe that these sexually mature fish travel to the Mackenzie River to spawn; i.e. we suggest that there are not two stocks of Arctic cisco--one associated with the Mackenzie and the other with the Colville River--as has been previously postulated (e.g. Craig and Mann 1974), but rather only one which is reproductively associated with the Mackenzie system.

Spawning migrations and early life histories of Arctic cisco are reasonably well-documented for the Mackenzie River system. Spawners leave nearshore, brackish waters and enter the Mackenzie System during late June through late July, and undertake spawning migrations to some of the larger tributaries (e.g. Peel, Arctic Red, Great Bear, Mountain and Laird Rivers). The spawning runs in these tributaries occur at different times depending upon the distance up the Mackenzie the fish must move. Hatfield et al. (1972) reported sexually mature Arctic cisco in the Artic Red River (near the Mackenzie Delta) from late June to the end of August, and at the Great Bear River (approximately mid-way up the Mackenzie River) from early August to late September. O'Neal et al. (1981) reported that Arctic cisco spawners first appeared at the mouth of the Liard River (furthest upstream Arctic cisco river reported) by mid-August in 1979, peak numbers occurred in September and the run was completed by mid-October.

During the spawning run in the Mackenzie River, Arctic cisco apparently cease feeding, and eggs increase in diameter from a range of 0.6- to 1.3-mm characteristic of mature, green females in nearshore, brackish-marine habitats (Griffiths et al. 1975, Griffiths et al. 1977, Craig and Haldorson 1981) to mean sizes of 2.03 mm (SD=0.08, range 1.9 to 2.1 mm) for green females and 2.13 mm (SD=0.10, range 2.0 to 2.3 mm) for ripe females (Gary Ash, RL and L Consultants, Vancouver, British Columbia, pers. comm. 1981).

After spawning in the fall, Arctic cisco in greatly emaciated condition (Nikolsky 1961, Hatfield et al. 1972) then undertake a distinct post-spawning migration back down the Mackenzie River. Autumn surveys have shown that large numbers of spawned-out fish occur in the West Channel of the Mackenzie River Delta during early October (Wynne-Edwards 1952; Hatfield et al. 1972).

Arctic cisco eggs hatch the following spring and the young-of-the-year are carried down the Mackenzie River to the delta during spring break-up, where they are already foraging in the shallow lakes of the delta by early June (Hatfield et al. 1972, McLeod et al. 1979, O'Neal et al. 1981, Taylor et al. 1982). Taylor et al. (1982) reported that between 80-90% of all Arctic cisco found in the lakes they sampled were young-of-the-year (Age=0) and that most Arctic cisco had left the lakes by mid-September. Some young-of-the-year are undoubtably carried into nearshore, marine habitats during the spring freshet and perhaps during other times of the year.

The Craig and Mann (1974) hypothesis of two stocks of Arctic cisco, was based on a moderate amount of evidence from the Mackenzie Drainage (Wynne-Edwards 1952, Hatfield et al. 1972, Stein et al. 1973 and a small amount of evidence from the Colville River area (Alt and Kogl 1973, Kogl and Schell 1974). Overwintering Arctic cisco had been reported from both these areas (separated by over 400 km) and, although fish in spawning condition had not been documented to occur in Alaskan waters, young-of-the-year fish had been reported in the Colville Delta (Kogl and Schell 1974). Since 1974, several fisheries investigations have been conducted but have yielded little, if any, support for the hypothesis of a spawning population of Arctic cisco associated with the Colville River. The strongest evidence against the idea of two stocks is the lack of fish in spawning condition or subsequent spawned-out fish in the fishery at the Colville River Delta. Additionally, spawning runs of Arctic cisco have not been documented for the Colville River despite summer and fall surveys conducted in 1977 and 1978 by Bendock (1979) and in 1978, 1979 and 1980 by LGL Ecological Research Associates, Inc. (McElderry and Craig 1981, Craig and Griffiths 1981). In contrast, these studies have collectively indicated that Arctic cisco likely do not penetrate the Colville River beyond Umiat (about 48 km upstream), are abundant only as far upstream as the Itkillik River (about 175 km, see Fig. 2) and few, if any, of these fish are in spawning condition. Bendock (1979) did report three male Arctic cisco taken from Seabree Creek near Umiat in mid-June 1977 that he believed were in spawning condition.

The time-at-large data for tagged Arctic cisco as compared to similar data for least cisco (Coregonus sardinella) provides additional evidence that older (larger) Arctic cisco may leave the area. Least cisco have been documented to spawn in the Colville River system. Specimens in spawning condition have been collected throughout the lower reaches of the river (Kogl 1972,McElderry and Craig 1981) and spawned-out individuals are commonly taken in the fall fishery (Jim Helmericks, unpublished data). Least cisco overwinter in the Colville River Delta area and disperse into the nearshore, brackish waters of the region for feeding during summer. Through 1980, a total of 202 tagged least cisco had been recaptured, having time-at-large (years elapsed between marking and recapture) ranging from 0 to 5 years with 100, 50, 35, 10, 1 and 6 fish recaptured each year, respectively (LGL, unpublished data). During this same period, 59 Arctic cisco were recaptured, 48 of which were taken during the same year they were marked and 11 after only one year at large. In 1981, 66 tagged Arctic cisco were recaptured. Of these, 64 were marked during 1981, and two had been marked in 1980. These latter fish and two of the others were recaptured in eastern Alaska at Griffin Point near Barter Island. These data suggest that most large Arctic cisco are scarce or absent from the Colville River area within one year of being tagged. We believe that these data support the contention that most Arctic cisco leave the Colville River Delta region when they approach sexual maturity, and likely return to the Mackenzie system for spawning.

For the above spawning scenario to be reasonable requires a dispersal mechanism to account for the presence of young Arctic cisco in Alaska. The prevailing east to west longshore currents along the Beaufort Sea coast represent an adequate dispersal mechanism. These currents generally move parallel to the coast at about 3 to 4% of the speed of the wind and in the same direction as the wind. Summer winds are typically from the northeast, and average about 5 m/sec (Mungall 1978). Coastal waters move westward under these conditions at about 15 cm/sec (13 km/day). Under these conditions, a westward drift of small (mean lengths of Age 0 and 1 fish are 7 and 11 cm, respectively) fish in the nearshore would be expected. If the transport was passive, movement from the Mackenzie to the Colville region under average conditions would require about 35 days, but could be as little as seven days under a sustained period of strong wind which is not uncommon.

Arctic cisco overwintering has been associated with brackish-water habitats in deltaic, estuarine regions--habitat provided by both the Colville and Mackenzie rivers, and perhaps other large rivers on the North Slope between these two systems (e.g. Kuparuk, Sagavanirktok, Canning Rivers). Late winter surveys of overwintering habitats in the Sagavanirktok and Kuparuk River deltas (Bendock 1979, Dew 1982) have not yielded any Arctic cisco, but all have been conducted in upstream freshwater habitats as opposed to the seaward parts of these deltas. Donald Schell (University of Alaska, Fairbanks, 1981, pers. comm.) has recently examined early spring-caught Arctic cisco for carbon composition and has determined that these fish consist primarily of carbon derived from recent marine primary production (marine overwintering) in contrast to other species of anadromous fish which, in spring, show a high percentage of carbon derived from "old" terrestrial primary production (peat) characteristic of detrital-based freshwater systems (freshwater overwintering). Whereas the Mackenzie and Colville River Deltas and estuaries may represent particularly good habitat during winter, Arctic cisco likely use other areas as well.

A conceptual model of the postulated life history cycle for Arctic cisco is shown by Fig. 7. In this model, spawning occurs in the Mackenzie River in fall and young-of-the-year use the delta as nursery grounds during their first summer as well as overwinter there but in different habitat. Some young-of-the-year may be carried by the spring freshet into the nearshore region. At Age 1, the small fish move into the nearshore environment during the summer feeding dispersal along the coast. Some unknown proportion (although variable, longshore flow in the Mackenzie Delta area is generally to the east) are shown to disperse to the west, and at some point are entrained by the strong westward-flowing longshore currents off the Alaskan coast. Upon the approach of freeze-up, the Colville River and perhaps other rivers afford brackish-water

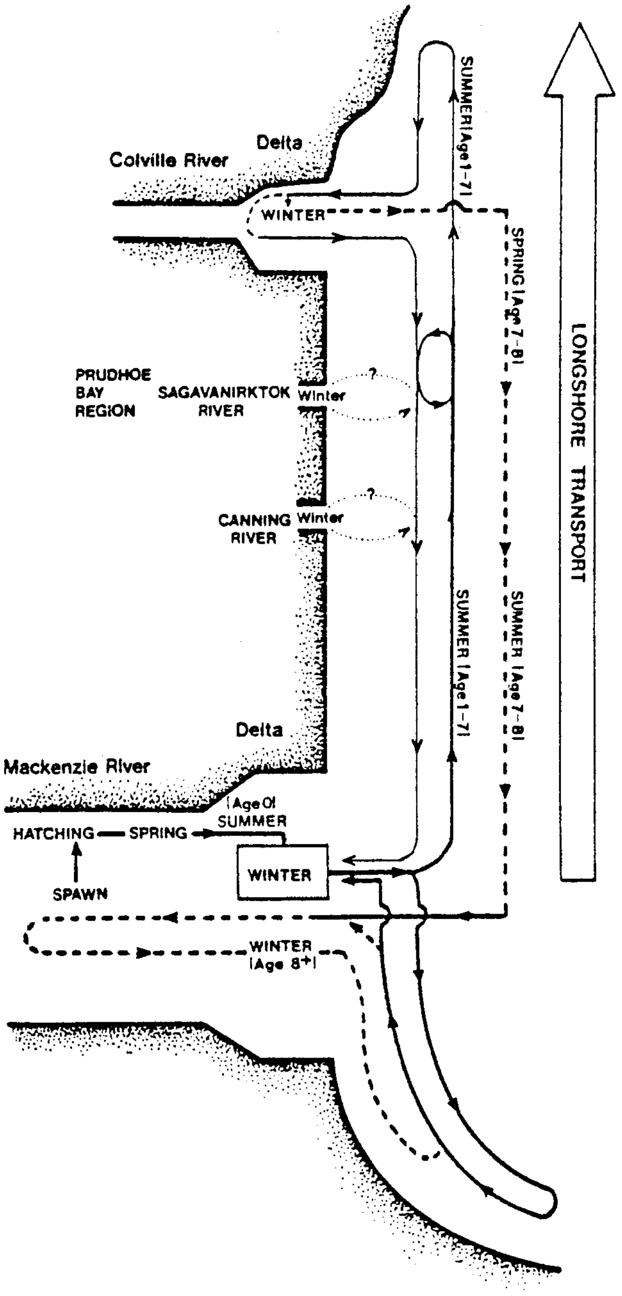

Fig. 7. Conceptual model of Arctic cisco life history cycle in Alaska and Canada.

overwintering habitat in the lower delta areas adjacent to the sea. Arctic cisco which have been transported into Alaska use at least the Colville River and adjacent environs (and perhaps others) until attaining sexual maturity (as well as a size enabling them to contend with the longshore currents) whereupon they seek their natal stream in the Mackenzie River system to spawn. Such a pattern is consistent with the observed seasonal abundance and distributional patterns of Arctic cisco and would account for a high proportion of spawners being non-vulnerable to the fishery.

The α value of 4.8 estimated by the model suggests a strongly density-dependent stock/recruitment relationship which is not unreasonable given the pattern of the catch-effort data. A strongly density-dependent relationship results in an oscillating population level of spawners because the maximum level of recruitment occurs when the spawner population is low and vice versa. Further, the lag time of five years between spawning and recruitment of fish to the fishery agrees well with the known life history of Arctic cisco. However, the value 4.8 for α is unusually high. We believe that it is more likely that the oscillations in catch are due more to regional-level environmental effects than to recruitment phenomenon. That is, whereas we have the overall dynamics represented correctly, the apparently strong density dependence of recruitment is actually only the result of a few environmentally extreme years. For example, 1974 and 1975 were particularly bad ice years (the pack ice remained along the mainland coast throughout summer) in the Beaufort Sea and were followed by a series of relatively good years (the pack ice was up to 100 km offshore during summer) until 1982. If the environmental conditions of 1974 and 1975 affected the transport or survival of Age 1 fish in the nearshore zone during these years, the effects would be seen in the fishery five years later (i.e. during 1979 and 1980). We believe that the question of the stock oscillations being attributable to stock-recruitment relationships versus environmental factors can be resolved given several additional years of data from the fishery. It should be noted that while the model fit is good, and the parameters k and m give us some confidence in the results, the data extends over only 15 years. Given a lag of five years to recruitment means we had only 10 points to fit five parameters.

Given either explanation for the stock oscillations, the fisheries of the Colville Delta probably have little impact on the population levels of catchable Arctic cisco. Mean fishing mortality ($\overline{F}$) was estimated to have been only 0.15. The commercial and subsistence catches will likely continue to fluctuate radically over the years due to either environmental conditions or density of spawners. If the latter case is true, lower densities of spawners would result in higher yields of recruits on a five- to seven-year cycle.

Finally, it is unlikely that the 3-km long causeway near Prudhoe Bay, Alaska has contributed much to the observed oscillations in population levels. Results of tagging studies (Craig and Griffiths 1981, Griffiths and Gallaway 1982) have shown no significant difference in the proportion of large Arctic cisco on the Colville River overwintering grounds between fish which were initially marked during summer on different sides of the causeway. Distributional modeling of small Arctic cisco based upon temperature preference and environmental conditions around the causeway suggest that during conditions of westward transport, small fish would also successfully move around the causeway (Neill et al. 1982). However, the level of understanding of the functional relationship of Arctic fishes to environmental factors is exceedingly low. A great deal more than what is presently known must be learned before one will be able to conclusively relate environmental perturbations resulting from development activities to impacts on fish stocks.

SUMMARY

Application of the Deriso (1980) model to the catch/effort data of the Helmericks' commercial fishery yielded a predicted sequence of CPUE data which closely mimicked the historical record. The model estimates of survival and lag time parameters appeared reasonable in light of what is known or hypothesized about the biology of Arctic cisco, but the parameter associated with recruitment showing a strong density-dependent stock-recruitment relationship appeared suspect due to its magnitude. A few more years' data should enable an assessment of the validity of this parameter estimate versus the alternative hypothesis that the observed population oscillations result from environmental effects.

The conjecture that Arctic cisco in Alaska are representatives of a Canadian stock from the Mackenzie River is proposed and the evidence supporting this concept was described. The principal argument is the lack of evidence of any appreciable spawning of Arctic cisco in Alaska waters despite considerable survey effort which has been conducted to document their spawning in this region. Further, the strategically located and timed commercial fishery does not take ripe or spawned-out fish, and there has been a low relative abundance of spawning-age fish represented in the catch. Finally, tagged fish approaching spawning size disappear after about one year at large, whereas representatives of least cisco (which have been documented to spawn in Alaska) have been taken in catches for up to five years after tagging. Longshore currents which along the Alaskan coast are predominantly from east to west were proposed as a transport mechanism accounting for the westward dispersal of small Arctic cisco into Alaska from western Canada.

The observed decline in Arctic cisco populations which occurred in Alaska during 1976-79 were part of an oscillatory cycle and the downward trend was reversed in 1981 when CPUE levels approached the maximum observed for the 15-year period of record. The oscillations may have been due to either the population dynamics of Arctic cisco or to regional-level environmental effects. Although uncertain, neither the existing 3-km long causeway which has been constructed near Prudhoe Bay, Alaska nor the local fisheries appear to have contributed in a major way to the observed oscillations in population levels.

ACKNOWLEDGEMENTS

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MODELING MOVEMENTS AND DISTRIBUTION OF ARCTIC CISCO (*COREGONUS AUTUMNALIS*) RELATIVE TO TEMPERATURE/SALINITY REGIMES OF THE BEAUFORT SEA NEAR THE WATERFLOOD CAUSEWAY, PRUDHOE BAY, ALASKA

by

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ABSTRACT

A mechanistic model was developed to evaluate the movement patterns of small arctic cisco around the Waterflood Causeway. In the model, fish movement and resultant changes in density were treated as a donor-controlled drift process biased by experimentally determined temperature preference. Based upon comparisons of model projections to independent catch data, the model performed well.

Under the assumption of model validity, small fish make heavy use of the breach as a passageway. Under the prevailing wind regime, the causeway-induced changes in water quality directed movement in a manner that should reduce entrainment and impingement potential, albeit these same water quality differences resulted in an estimated 7% reduction in density that would have been present in the area in the absence of any environmentally directed bias. Overall, we believe the breach will prove to be an effective mitigative measure.

INTRODUCTION

The Waterflood Causeway is a 30-50-m-wide quay of gravel that presently extends about 3.5 km into the Beaufort Sea from a point a few kilometers west of Prudhoe Bay, Alaska. During the arctic summer, the causeway deflects longshore currents and their entrained plumes of relatively warm, low-salinity water discharged from several rivers of Alaska's North Slope. As a result, the shallow (< 5 m deep) waters in the area of the causeway frequently are very heterogeneous with respect to temperature and salinity; differences of 10 C and 30 ppt across the causeway were recorded in July, 1981.

Anadromous fishes of the North Slope spend their summers in nearshore waters like those around the causeway. Fyke net and gillnet sampling near the causeway during summer 1981 suggested that the distributions of ciscoes (Coregonus spp.) and other anadromous fishes were influenced by the presence of the causeway and the environmental heterogeneity resulting from its presence. However, these fishes appeared in the sampling area in rather discrete pulses, making interpretation of the catch data difficult.

Concurrent with the fish sampling near the causeway as part of the Waterflood Monitoring Program, a relevant experimental study was underway at the LGL laboratory in Fairbanks under the auspices of NOAA/OCSEAP. This study measured temperature preference as a function of temperature and salinity acclimation in one of the North Slope's most abundant and important anadromous fishes, the arctic cisco (Coregonus autumnalis). Specimens used in the experiments were taken from fyke nets in the causeway area. Results indicated that young arctic cisco prefer temperatures between 11.5 and 15.6 C, depending on temperature (5-15 C) and salinity (5-30 ppt) acclimation (Fechhelm et al. ms).

This paper describes a preliminary effort to integrate the experimental and field results by means of a computer model simulating movement and distribution of young arctic cisco relative to the Waterflood Causeway.

THEORY AND STRUCTURE OF THE MODEL

We sought a conceptually adequate model that would reasonably represent shifts in the distribution of young arctic cisco near the causeway (as reflected in fyke net catch per unit effort) that might result both from density-dependent dispersive processes and from the fish's responses to time-varying temperature/salinity distributions. The requisite model not only had to be consistent with the preference behavior of young arctic cisco in experimental temperature gradients (Fechhelm et al. ms), but also had to accommodate the local geography of the causeway area, the apparent "pulsing" of the fish through the area, and a relative dearth of information on the area's fine-scale environmental structure over long spans of time and space.

The approach that seemed most appropriate was to treat fish movement and resultant changes in fish density as a donor-controlled drift process biased by experimentally determined temperature preferences (Fig. 1). Development of a more mechanistic model that would stochastically simulate fish movement as a biased random walk (e.g. Saila and Shappy 1963, DeAngelis 1978, Neill 1979) was considered but rejected because such models are extremely costly in computer-time and demand much higher resolution of environmental structure than was available for the causeway area. Our deterministic model was built "from scratch"—although it is generally consistent with the mathematical model described by Balchen (1979).

For a two-dimensional space partitioned into n sectors, the time-rate of change in fish density in the i^{th} sector attributable to movement of fish from the i^{th} sector to a contiguous j^{th} sector ($dC_{i \to j}/dt$) was taken as

$$\frac{dC_{i \to j}}{dt} = - \frac{p_j}{p_i + p_j} : \frac{s}{X_{ij}} \cdot C_i \, , \qquad (1)$$

where

p_i and p_j are the relative preference values of temperature at the centers of the i^{th} and j^{th} sectors;

X_{ij} is the distance between centers of the i^{th} and j^{th} sectors, measured through the mid-point of the common boundary;

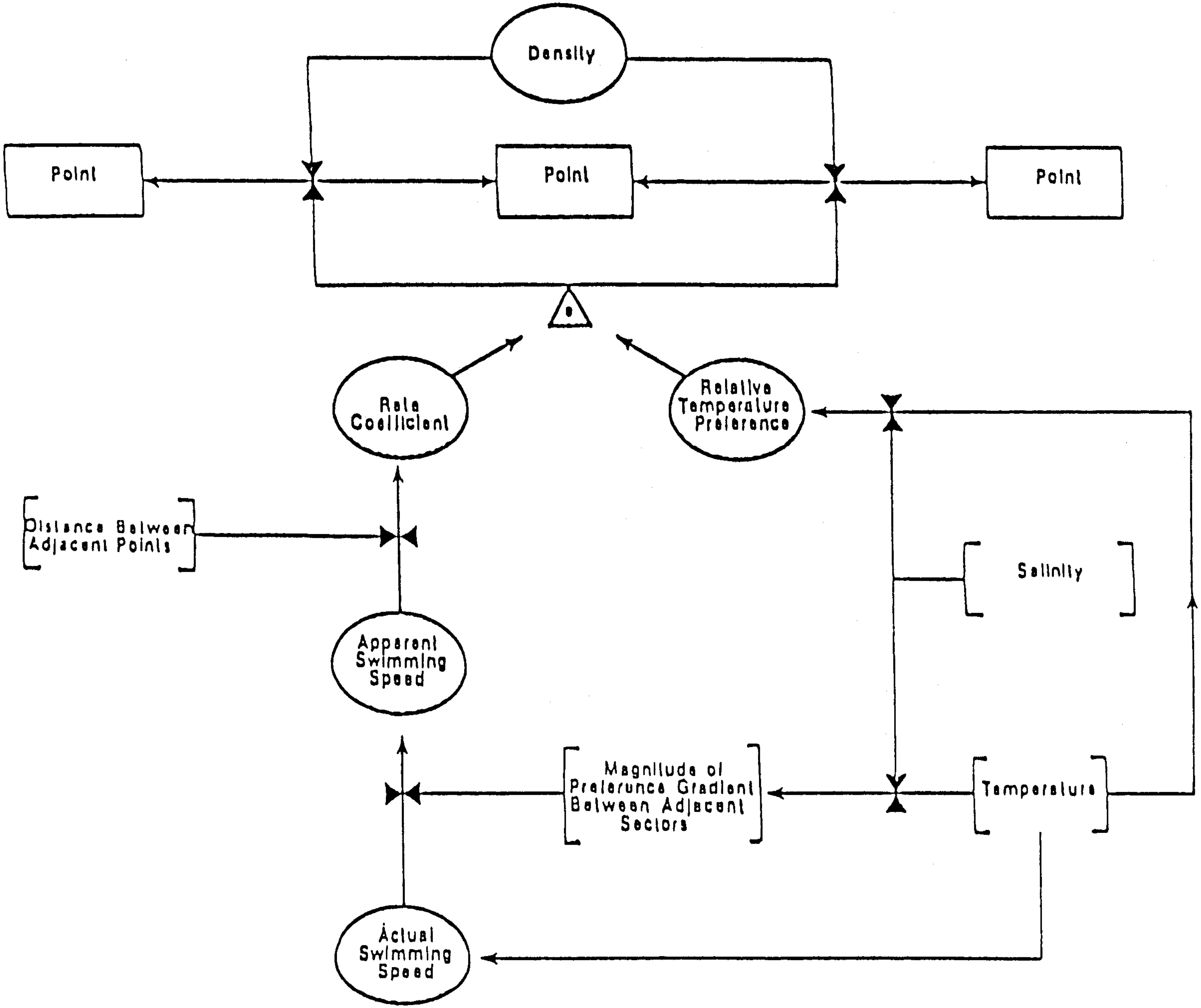

Fig. 1. Conceptual model of fish movement between adjacent points and the relationship with environmental (bracketed) and species (ovals) variables.

s is the dispersion rate coefficient, based on the swimming speeds of young arctic cisco estimated in the laboratory temperature-gradient experiments, together with assumed directedness (see below) of the swimming path; and,

C_i is the density of fish in the ith sector.

Similarly, the rate of change in fish density in the ith sector attributable to movement from the jth to the ith sector ($dC_{i\leftarrow j}/dt$) was

$$\frac{dC_{i\leftarrow j}}{dt} = \frac{p_i}{p_i+p_j} \cdot \frac{s}{X_{ij}} \cdot C_j \quad . \tag{2}$$

The rate of net transfer of fish density between the two cells ($dC_{i.j}/dt$) was then

$$\frac{dC_{i.j}}{dt} = \frac{s}{x_{ij}} \cdot \left[\frac{p_i C_j - p_j C_i}{p_i+p_j}\right] . \tag{3}$$

Now, the bracketed quantity in (3) is the instantaneous potential for net transfer of fish density between the ith and jth sectors. Addition and subtraction of $p_i C_i$ to the quantity gives

$$\frac{p_i C_i + p_i C_j - p_i C_i - p_j C_i}{p_i+p_j}$$

which, upon rearrangement, yields

$$\frac{p_i \ (C_i+C_j)}{p_i+p_j} - C_i \quad .$$

The two terms of the above expression are, first, the steady-state density of fish in the ith sector (considering only transfer between the ith and jth sectors) and, second, the existing density of fish in the ith sector. Substitution of the expression for the bracketed quantity in (3) yields

$$\frac{dC_{i.j}}{dt} = \frac{s}{X_{ij}} \cdot \left[\frac{p_i\cdot(C_i+C_j)}{p_i+p_j} - C_i\right] \cdot \tag{4}$$

Considering only transfer between i^th and j^th sectors, C_i+C_j must be a constant and $dC_{i.j}$ must be dC_i. Thus, equation (4) may be rewritten

$$\frac{dC_i}{dt} = \frac{s}{X_{ij}} \cdot (C_i(t\to\infty)-C_i) \ , \tag{5}$$

which, upon integration, gives the negative exponential equation

$$C_i(t) = C_i(\infty)-(C_i(\infty)-C_i(o)).\exp\ (-\frac{s}{X_{ij}}\cdot t) \tag{6}$$

$$= C_i(o)+(C_i(\infty)-C_i(o))\cdot(1-\exp(-\frac{s}{X_{ij}}\cdot t)) \ . \tag{7}$$

Taking advantage of the recursive property of the negative exponential relation, we may rewrite equation (7)

$$C_i(t) = C_i(t-\Delta t)+(C_i(\infty)-C_i(t-\Delta t))\cdot(1-\exp(-\frac{s}{X_{ij}}\cdot\Delta t)) \ , \tag{8}$$

or

$$C_i(t) = C_i(t-\Delta t) + \left[\frac{p_i\cdot(C_i+C_j)}{p_i+p_j} - C_i(t-\Delta t)\right] \cdot (1-\exp(-\frac{s}{X_{ij}}\cdot\Delta t)) \ . \tag{9}$$

Equation (9) states that fish density in the i^th sector at time t is the density at time t-Δt, plus the net transfer between the i^th and j^th sectors (a positive quantity if the transfer is from j to i, negative if from i to j) during the time interval Δt.

Computer implementation of the model made direct use of equation (9), except that computation for a sector exchanging fish density with more than one other sector required summation of net transfers between itself and each of the other sectors:

$$C_i(t) = C_i(t-\Delta t)+\sum_j\left[\left[\frac{p_i\cdot(C_i+C_j)}{p_i+p_j} - C_i(t-\Delta t)\right]\cdot(1-\exp(-\frac{s}{X_{ij}}\cdot\Delta t))\right]. \qquad (10)$$

Evaluation of net transfer rates was facilitated in that

$$\Delta C_{j\cdot i} = -\Delta C_{i\cdot j} \qquad (11)$$

(where $\Delta C_{i\cdot j}$ is one of the elements in the summation indicated in equation 10) and also in that $\Delta C_{i\cdot j}$ could be set equal to zero, without the necessity of calculation, for all pairs of sectors not sharing a boundary of finite length and for the trivial pairs in which $i=j$.

As indicated above, some driving variables were estimated from the laboratory experiments; these were p_i, p_j, and s. Fish moving between the i^{th} and j^{th} sectors were represented as being fully acclimated to temperature and salinity levels equivalent to the average ($\overline{T}_{ij},\overline{S}_{ij}$) of those at the centers of the two sectors ($T_i,T_j;S_i,S_j$). The values of p_i and p_j then were set equal to the frequency-densities of fish at T_i and T_j, respectively, measured in temperature-preference experiments (Fechhelm et al. ms) involving subjects acclimated to the temperature (5, 10, or 15 C) and salinity (5, 15, or 30 ppt) combination algebraically nearest $\overline{T}_{ij}$ and $\overline{S}_{ij}$. Because the temperature-preference curves were bell-shaped, the value of p_i exceeded p_j for any T_i that was nearer the preferred temperature than was T_j.

Computation of the dispersion rate coefficient s first required the calculation of voluntary swimming speed in fish-lengths per second, BLS. For young arctic cisco acclimated and tested in the laboratory, BLS was related to temperature (T) by the function

$$BLS = 0.06\cdot\exp(0.145\cdot T) \quad . \qquad (12)$$

For simulation, BLS was computed by replacing T in the above equation with $\overline{T}_{ij}$. Multiplication by standard length of fish (SL, set to 10 cm in all simulations) and by appropriate constants converted BLS to speed, S, in $km \cdot h^{-1}$:

$$S = (BLS \cdot length \cdot sec^{-1}) \cdot (SL \cdot cm \cdot length^{-1}) \cdot (3600 \cdot sec \cdot h^{-1}) \cdot (1 \cdot km \cdot (100{,}000\ cm)^{-1}) = 0.036 \cdot BLS \cdot SL \cdot km \cdot h^{-1} \ . \qquad (13)$$

Consideration that the dispersion rate ought to depend not only on the the swimming speed of fish but also on the directedness of their movement led to the inclusion of a second component in the dispersion coefficient. We reasoned that directedness of fish movement should be a function of the environmental preference gradient (g), which we defined as

$$g = \frac{\left|\frac{p_i - p_j}{p_i + p_j}\right|}{X_{ij}} \qquad (14)$$

In the absence of empirical information, we arbitrarily defined the relation between path directedness (e) and magnitude of the preference gradient (g) as follows:

$$e = 1.0 \text{ if } g >= 0.1; \qquad (15)$$

$$e = 0.2 \text{ if } g < 0.1. \qquad (16)$$

The dispersion rate coefficient s then, was defined as

$$s = e \cdot S \ . \qquad (17)$$

Thus, fish density was assumed to shift between sectors at a rate equivalent to observed swimming speed if the preference gradient was sufficiently steep; otherwise, the shift in fish density occurred at a rate only one-fifth as great. In the latter case, directed dispersion was reduced to diffusion along the fish-density gradient.

IMPLEMENTATION OF THE MODEL

The simulation model, in general form, was written in BASIC and developed on an Apple II (48 K) micro-computer. The model then was adapted for application in the causeway situation, translated into the Hewlett-Packard (HP) version of BASIC, and executed on a HP 9845 micro-computer.

Implementation of the model mainly involved appropriate sectoring of the causeway area and deciding the more difficult issue of how the model should handle peripheral sectors. Waters near the causeway were partitioned into 17 sectors (Fig. 2). Sectors were made to conform with stations at which fish and/or environment were sampled by LGL and/or Woodward-Clyde teams during summer 1981 as part of the Waterflood Project Monitoring Program. Of particular importance were sectors 1, 2, 17 and 14; in these sectors were located LGL fyke net stations 6, 5, 4 and 3 (respectively), which were the sole source of data on the actual densities of young arctic cisco (Griffiths and Gallaway 1982). Catch per 24 h at fyke net stations 3 and 6 (sectors 14 and 1) during the period 30 July-28 August 1981 was used to drive the model. At noon on each simulated day, densities of fish in sectors 1 and 14 were updated to the values of catch per net per 24 h recorded at stations 6 and 3 on the succeeding day. Because nets generally were fished for 24 h at a time, we assumed that catch reflected the density of fish in the sector averaged over a 24 h period. Density in sector 1 was propagated to east-side peripheral sectors 3, 5, 8 and 6. For the succeeding 24 h of simulation, fish density in sectors 1, 3, 5, 8, 6 and 14 was held constant. Thus, the model was made to treat these sectors as infinite fish sources/sinks; whereas, fish could transit the boundaries between peripheral and adjacent sectors, fish densities in the peripheral sectors were unaffected. Net exhange of fish density was permitted neither across the northern boundaries of sectors 6 and 11, nor across the northwestern boundaries of sectors 12 and 13. This constraint was equivalent to assuming that young arctic cisco either do not venture north and northwest of the heavy line bounding these sectors (Fig. 2) or, if they do, fish densities and environmental conditions on either side of the boundary are equivalent. Neither of these assumptions is particularly attractive, but the lack of

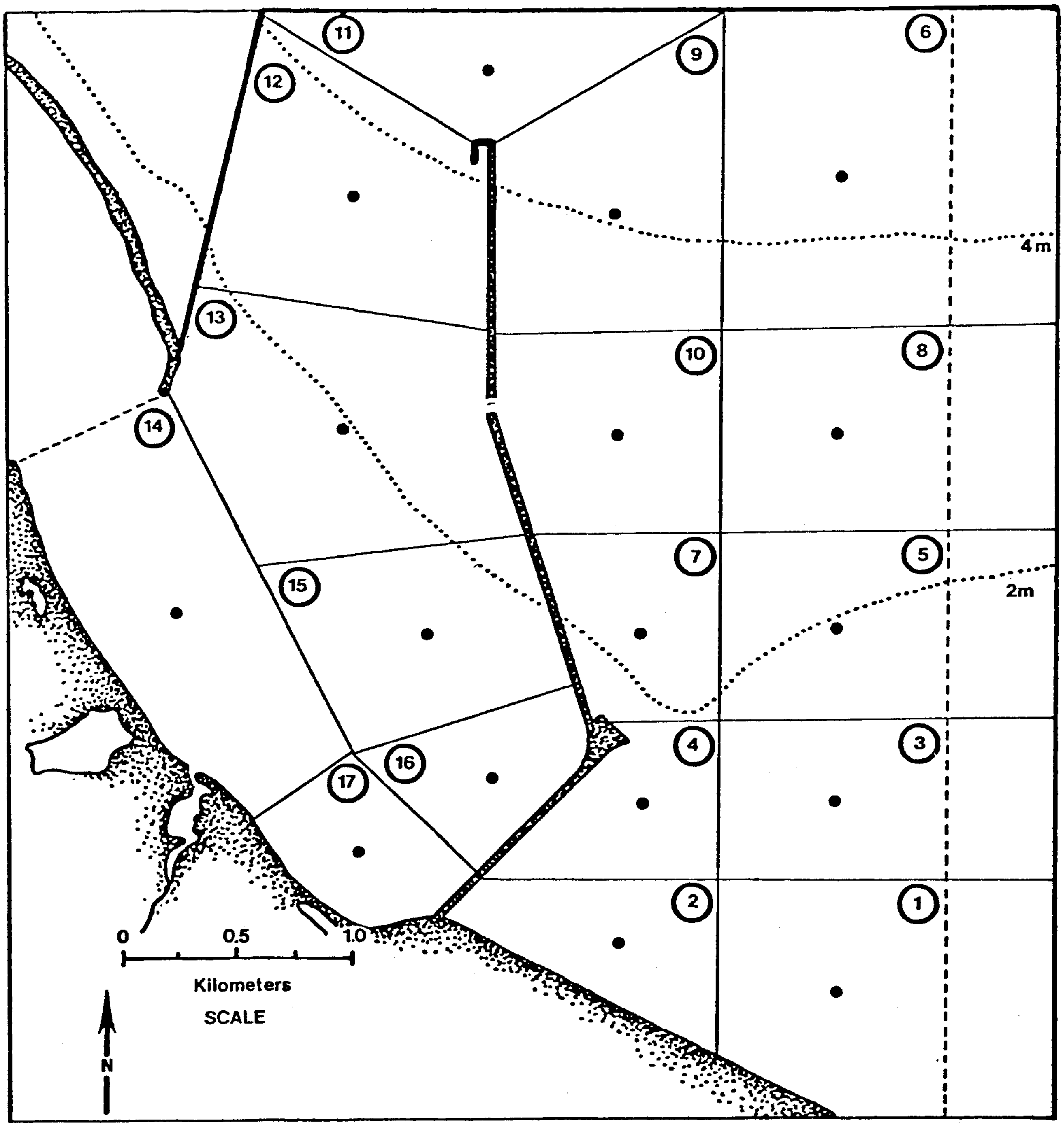

Fig. 2. Map of the causeway area, showing the boundaries and centers of the 17 sectors used in simulation.

data from the area beyond this boundary permitted no more realistic alternative. Transit across the causeway was not permitted, of course, except for that via the 30-m-wide breach that exists between sectors 10 and 13. All 22 other possible transits between the 17 sectors were permitted, giving a total of 23.

Environmental data were the limiting factor in defining the simulation milieu. A reasonably adequate description of the surface temperature/salinity regime over the simulation area was provided by Woodward-Clyde surveys (Mangarella et al. 1982) for only 12 dates during summer 1981--30 July and 3, 5, 7, 10, 12, 14, 19, 22, 23, 26 and 28 August. Even for these dates, we had to interpolate and extrapolate the existing data to provide estimates for some sectors, particularly 3, 5, 8 and 6. The simulation program linearly interpolated surface temperature and salinity between consecutive sampling dates to generate an hourly series of values for each of the 17 sectors.

Execution of the simulation program provided hourly predictions of fish density (in units of catch per fyke net per 24 h) for each sector from 1300 on 30 July through 1200 on 28 August. Apparently, few young arctic cisco were in the causeway area at the beginning of the simulation period, for only three individuals were taken in the fyke net at station 3 (sector 14) and none at station 6 (sector 1) during the 24 h ending on 31 July. Therefore, initial density values were set at 3.0 in all the western sectors (12-17) and 0.0 in all the eastern sectors (1-10); starting density in sector 11 (at the end of the causeway) was set at 2.0.

The program computed averages of predicted fish density at noon on each day for the preceding 24 h period. Also, the net density change across each sector boundary was tallied for each 24 h period.

In an effort to separate the modeled effects of environmentally-directed movements from those of simple dispersion from areas of high to low fish density, we ran the simulation both with and without incorporating the supposed directional bias associated with temperature/salinity heterogeneity. The environmentally-directed version of the model was reduced to the environmentally undirected version by setting

$$P_i = P_j$$

for transit between all pairs of sectors; i.e., movement between sectors was a simple function of density differences. However, because of dependence upon ambient temperature, swimming speed still varied between sectors and from hour to hour in the same way as before. In contrast, path directedness e, owing to the lack of directional bias, was held constant at its minimum value, 0.2. Consequently the dispersion rate coefficient s, being the product of swimming speed and e (equation 17), had a value under the undirected scenario only one-fifth that under the directed scenario.

Because we felt the constraint on s may have unfairly weakened the environmentally undirected model's performance, we also ran a version with the values of P_i and P_j reversed. This had the effect of requiring fish to move down their preference gradient, or opposite the expected direction based upon quantitative laboratory investigations.

SIMULATION RESULTS AND DISCUSSION

Under the environmentally-directed scenario, the model produced quite reasonable simulations of fyke-net catch in each of the two reference sectors. Predicted catch rates in sectors 2 and 17, when ranked among dates, generally mimicked the rankings of observed catch rates in those sectors (upper panel, Figs. 3 and 4). Both test variants of the model performed well also in sector 17, but neither did nearly as well as the environmentally-directed scenario in sector 2 (cf. three panels, Figs. 3 and 4). Relative performances of the three models in each reference sector are made more evident quantitatively by comparing the magnitudes of Kendall's rank-correlation coefficient tau and its associated probability (P) under the null hypothesis of no correlation between predicted and observed series of ranks (Siegel 1956):

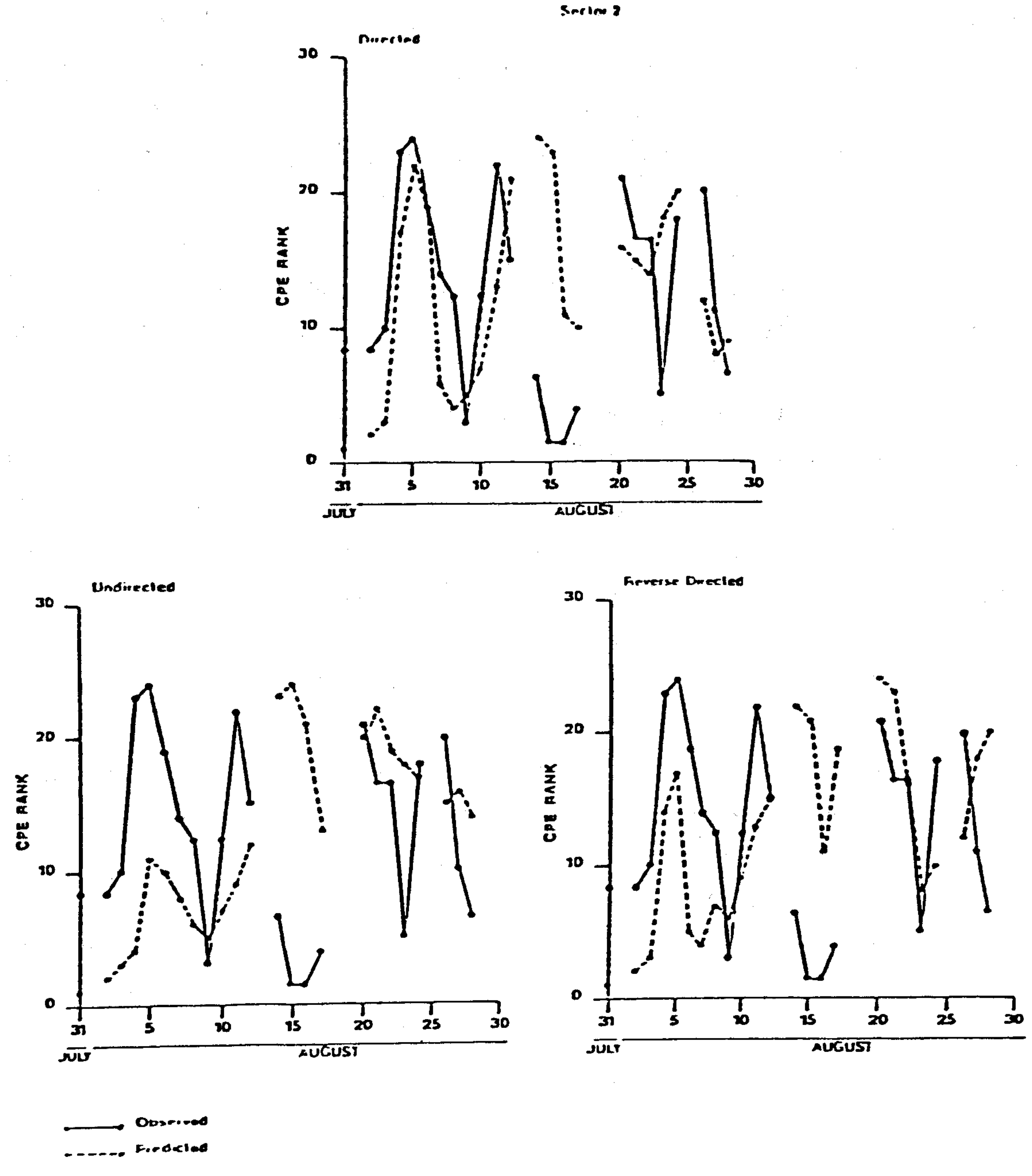

Fig. 3. Ranks of fish density (CPE) observed versus that predicted under three models in sector 2 on each date during the period 31 July-28 August for which observed values were available.

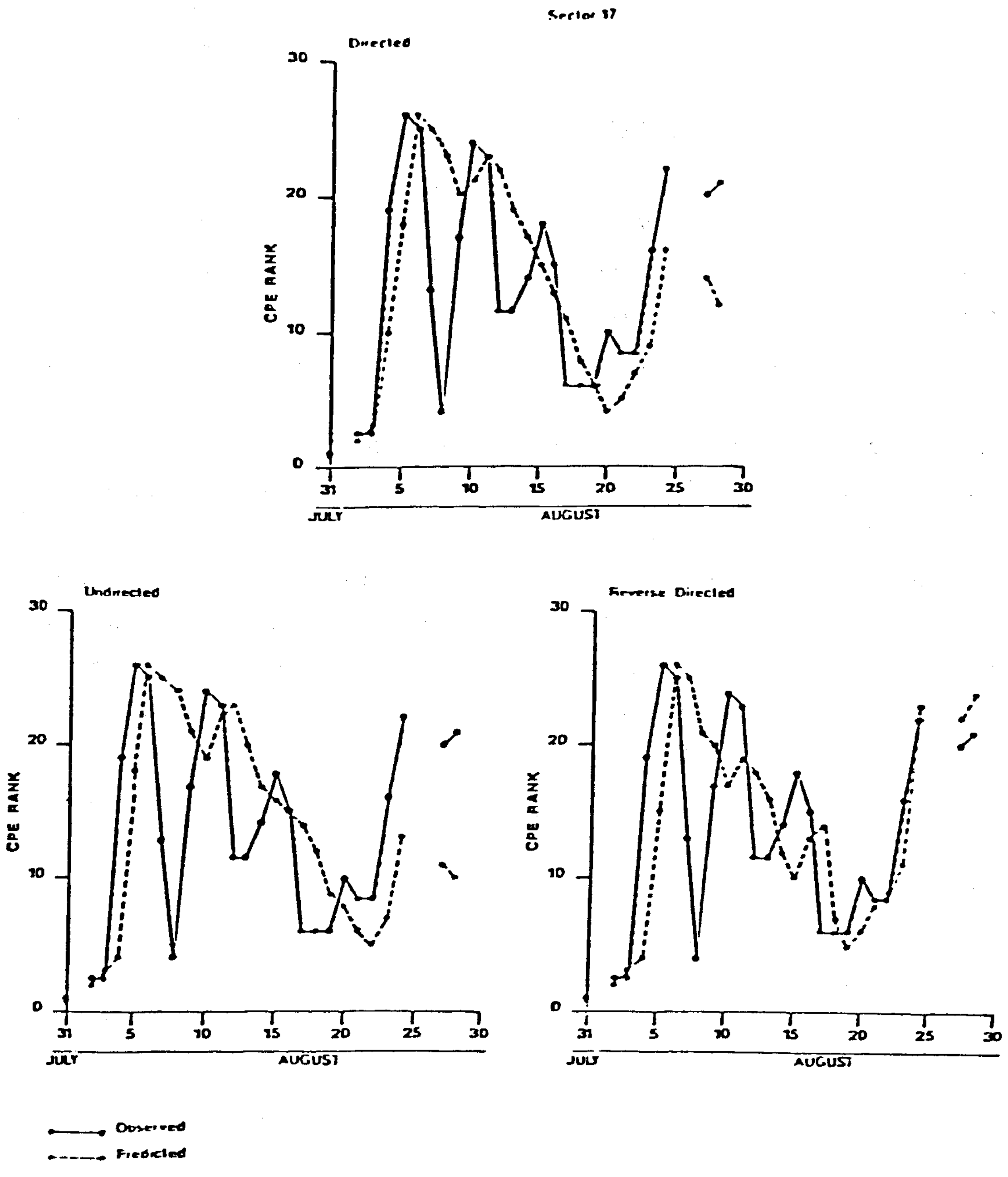

Fig. 4. Ranks of fish density (CPE) versus that predicted under three models in sector 17 on each date during the period 31 July-28 August for which observed values were available.

Model Scenario	Sector 2		Sector 17	
	Kendall's tau	P	Kendall's tau	P
Directed	0.21	0.08	0.44	0.001
Undirected	-0.05	0.35	0.33	0.01
Reverse-directed	0.11	0.23	0.46	<0.001

Why did the environmentally-directed model perform so much better in sector 17 than in sector 2? And how were the other two versions of the model able to do so well in sector 17? The answers to these questions are interrelated. First, the environmentally-directed model's lack-of-fit in sector 2 came primarily from failure to mimic behavior of the system during a single brief period (14-17 August) when observed catches in sector 2 declined precipitously to near-zero levels. It is possible that the low catches observed during this period were spurious, being not the result of reduced density of fish, but rather of reduced catchability associated with an abrupt movement of relatively cold, saline water into the causeway area. Temperatures dropped from values near 7 C on 10 August to a mean of 1.5 C in sectors west of the causeway on 12 August; by 14 August, the cold water had spread throughout the causeway area. Whether or not observed catches in sector 2 during 14-17 August were spurious, elimination of this subset from the data series greatly improved correlation between ranked catches observed and predicted under the environmentally-directed model (Fig. 5), not only in sector 2 (tau increased from 0.21 to 0.45; P decreased from 0.08 to 0.003) but also in sector 17 (tau increased from 0.46 to 0.54; P decreased from 0.001 to < 0.00003).

A second facet of the answer seems to be that fluctuations in catch rate at sector 17, compared with those at sector 2, were driven more by fish density differentials than by gradients of environmental preference, especially during the early part of the simulation period. The average absolute difference between drive and reference sector temperatures during the first six days was 0.51 C for sectors 2 versus 1, but only 0.25 C for

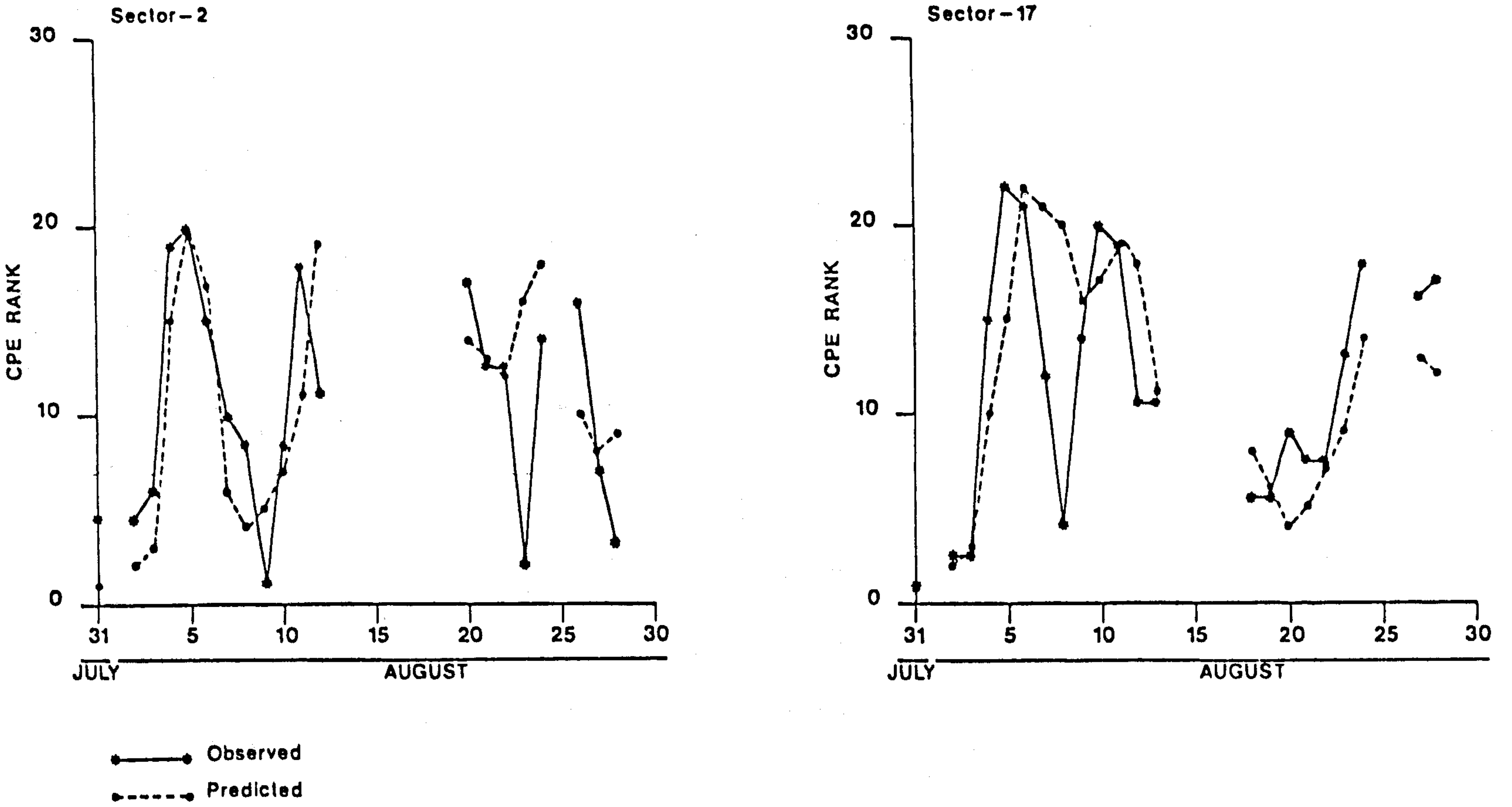

Fig. 5. Ranks of fish density (CPE) observed versus that predicted under the environmentally-directed model in sectors 2 and 17 after the removal of catch data for 14-17 August.

sectors 17 versus 14. Consequently, hypothetical fish that behaved according to the environmentally-directed model had less directive information on the west (sector 17) side of the causeway than on the east (sector 2) side . For the same reason, even the degraded variants of the model were able to perform creditably in sector 17, but not in sector 2.

Finally, the better performance of all three versions of the model in sector 17 than in sector 2 may have resulted partly from more realistic boundary definition on the west side of the causeway. Every east-side sector was contiguous with a drive sector in which supposed fish density was constant over each day at the level measured only in sector 1. In contrast, simulated fish moved into and out of west-side sectors through only one drive sector, sector 14. As a test of the influence of our conservative boundary conditions, we restricted the drive sectors for the east side of the causeway to sector 1 alone, removing any fish-density flows to and from the offshore sectors 3, 5, 8 and 6. Results for the directed model under this scenario were identical to the original outputs in sector 17 (Kendall's tau = 0.44; P = 0.001), but correlation improved for sector 2 (Kendall's tau and P were 0.25 and 0.042, respectively, as compared to the original respective values of tau 0.21 and P = 0.08). These results support the concept of shoreline affinity, at least for young arctic cisco.

The better overall performance of the environmentally-directed model can only be attributed to its provision for appropriate responses by the fish to temperature/salinity heterogeneity--responses not permitted under the environmentally undirected scenario and intentionally subverted under the environmentally misdirected scenario. The modeling exercise suggests that fluctuating densities of young arctic cisco in the causeway area reflect significant enviroregulatory responses to temperature/salinity structure, despite the overwhelming impact of time-varying immigration and emigration, and that comparison of model predictions under the directed and undirected scenarios provides a method for rational separation of the two sources of variation.

Encouraged by the environmentally-directed model's performance in the two sectors from which independent data were available for comparison, we proceeded with examination of the predictions for the entire causeway area (excluding, of course, the drive sectors--1, 3, 5, 6, 8 and 14). So that the problem of dependence among sample observations would be minimized, the analysis was restricted to only 10 of the dates; these were selected to coincide with those on which environmental surveys were conducted—3, 5, 7, 10, 12, 14, 19, 23, 26 and 28 August. Predicted densities (24 h average) under the directed and undirected scenarios were compared, as ratios, for each of the 11 sectors contiguous with the causeway on each of the 10 dates (Table 1). The geometric mean ratio of directed density to undirected density over all 11 sectors x 10 dates was 0.93--implying, under the assumption of model validity, that temperature/salinity heterogeneity associated with the causeway during August 1981 caused young arctic cisco to be about 7% less abundant in the area than they would have been had temperature and salinity provided no directional bias. Over all sectors, temperature/salinity heterogeneity resulted in elevated abundance of young arctic cisco before 12 August and markedly reduced abundance thereafter. Over all dates, temperature/salinity heterogenity caused relative concentration of young arctic cisco only in sectors 9 and 10, and reduced abundance in all other sectors, especially those on the west side of the causeway.

The above summary of results is made more emphatic and environmentally interpretable by plots of the geometric mean of predicted catch ratio and average temperature against time (Fig. 6). Under the model, the decline in causeway area temperature between 10 and 14 August occurred in such a way as to direct young arctic cisco out of the entire area, particularly out of the sectors on the west side. Fish operating under the environmentally undirected model were essentially trapped by low dispersive rates associated with the reduction in temperature.

The temporal sequence of differences between ratios of predicted catch on east and west sides of the causeway suggested that substantial shifts of fish density should have occurred around the causeway's end and through its breach. Therefore, 24-h net transit rates between sectors 9 and 11 and between sectors 10 and 13 were examined (for the environmentally-directed model) as measures of movement around the causeway's end and through the breach, respectively (Fig. 7). With the general exception of 4-7 August, 17-18 August and 22-23 August, the net east-west transit of fish around the tip of the causeway was in the same direction, although not necessarily of the same magnitude, as that through

Table 1. The ratio of simulated fish density under the environmentally directed scenario to that under the environmentally undirected scenario, by date and sector. $\bar{X}_g$ is the geometric mean for each date or sector; $\bar{\bar{X}}_g$ is the grand geometric mean over all dates and sectors.

	Sector											
Date	2	4	7	10	9	11	12	13	15	16	17	$\bar{X}_g$
3 Aug	2.68	1.64	0.96	1.13	1.36	0.83	0.71	1.45	1.24	1.05	1.10	1.21
5	1.36	1.32	0.99	1.21	1.01	1.07	1.84	2.09	1.96	2.22	1.05	1.40
7	0.66	1.07	0.97	1.26	1.10	1.24	1.50	1.38	1.43	1.49	1.47	1.20
10	0.85	0.80	1.02	1.21	1.40	1.14	1.22	1.20	0.82	1.01	1.40	1.08
12	0.95	1.02	1.07	1.57	1.48	0.64	1.09	0.63	0.83	1.07	1.40	1.03
14	1.47	0.92	0.74	1.07	1.45	0.93	0.46	0.42	0.38	0.83	0.90	0.79
19	0.61	0.47	0.43	0.58	0.95	1.29	0.49	0.37	0.23	0.40	0.26	0.49
23	0.82	0.71	0.82	0.90	0.93	0.93	0.73	0.92	0.75	0.40	0.40	0.73
26	0.67	1.19	0.92	0.94	0.93	0.90	0.81	0.93	0.90	0.69	0.77	0.87
28	0.57	1.01	1.20	1.00	0.87	0.93	0.85	1.10	1.02	0.91	0.62	0.90
$\bar{X}_g$	0.94	0.96	0.88	1.06	1.12	0.97	0.89	0.93	0.82	0.89	0.83	$\bar{\bar{X}}_g$=0.93

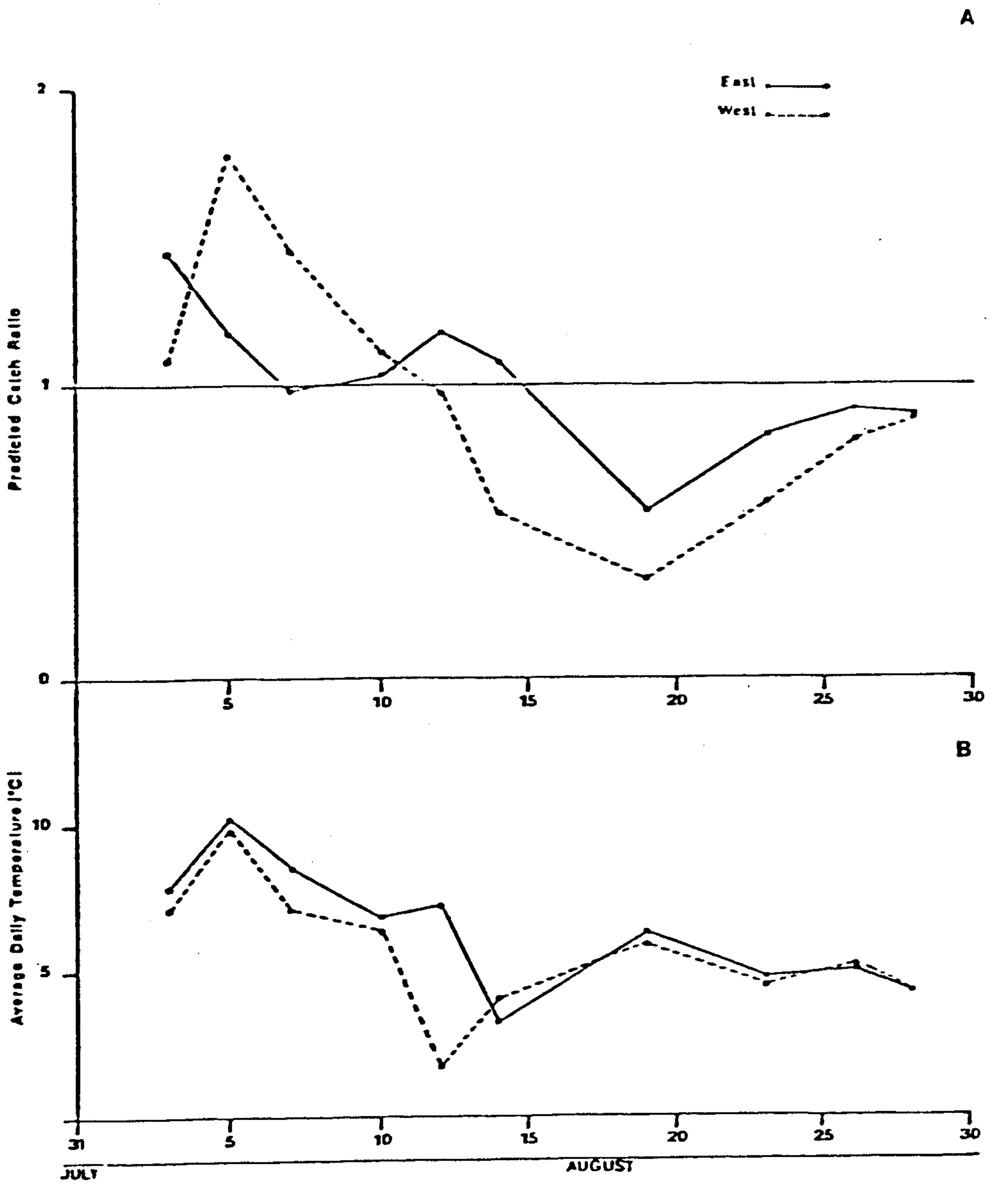

Fig. 6. A) Geometric mean ratio of catch predicted under the directed model to that predicted under the undirected model by date for east (sectors 2, 4, 7, 9, 10) and west (sectors 12, 13, 15, 16, 17) sides of the causeway. B) Average daily temperature for east and west sides of the causeway.

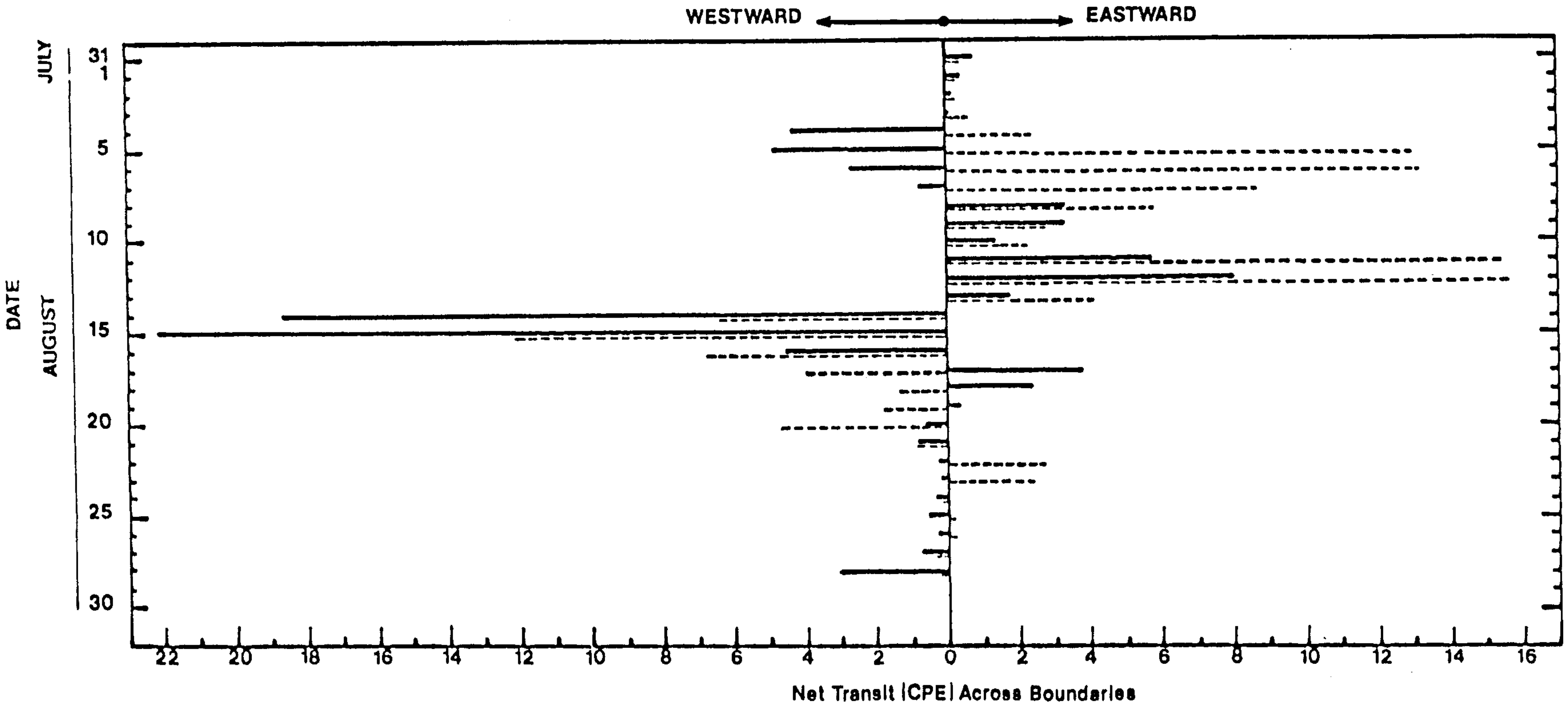

Fig. 7. Net shifts in fish density across the boundaries between sectors 9 and 11 (solid line) and between sectors 10 and 13 (dashed line) during 31 July-28 August under the directed model.

the causeway breach. During the 4-7, 17-18 and 22-23 August periods, the combined flows of fish tended to form a gyre, giving either an eastward density shift around the end of the causeway corresponding with a westward shift through the breach or vice versa. Such situations existed because of the specific heterogeneous thermal structure of the waters surrounding the causeway during those brief periods.

Overall net movement was predominantly eastward during 31 July-13 August, on 18 August and during 23-24 August (Fig. 8). Over the entire simulation period on a per day basis, 104.5 net units of fish density moved eastward and 85.4 net units moved westward, yielding a net eastward shift of only 19.1 units of fish density for the 29-day period. The trend in net movement can be partly attributed to the thermal structure of the causeway area. During the 31 July-13 August period, when net transit was in the easterly direction, the average temperature (the average of sectors 1 through 9 during 3, 5, 7, 10 and 12 August) on that side of the causeway was 8.1 C as compared with 6.4 C (average of sectors 11 through 17 during the same dates) on the west side. After 13 August, average temperatures on east and west sides of the causeway were nearly identical--4.73 C on the west side versus 4.68 C on the east side. The predominantly westward movement that occurred after 13 August superficially appears unassociated with thermal heterogeneity; however, these results are strongly weighted by <u>net</u> density shifts during 14-15 August. Net transit during these two days accounted for 70% of the total westward shift that occurred from 14 to 28 August. It also was a two-day period of highly aberrant thermal structure and as such may have disproportionately affected east-west movement across the causeway. Excluding 14-15 August, the net westerly movement of fish under homogeneous thermal conditions was 20% of that which occurred during the period of predominantly eastward movement, 31 July-13 August.

These results suggest that the area's temperature structure could force migrations of young arctic cisco from one side of the causeway to the other, and likely in a pulsed fashion, at least on a theoretical basis. Gallaway and Griffiths (1982) noted that abundance of small arctic cisco often differed greatly between sides of the causeway, especially when water quality differences were pronounced.

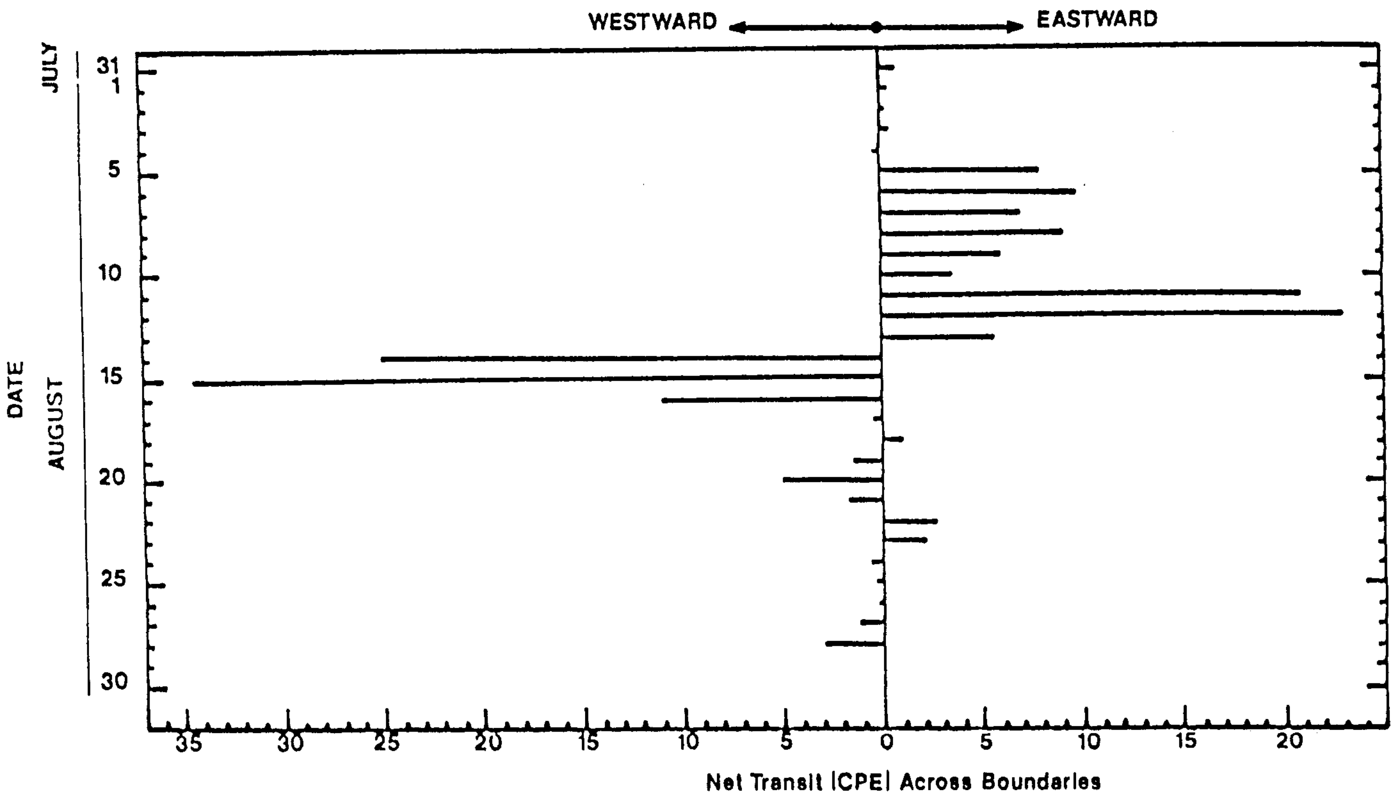

Fig. 8. Combined net shifts in fish density across the boundaries between sectors 9 and 11 and between sectors 10 and 13 during 31 July-28 August under the directed model.

As our thinking about the modeling problem matured, it became apparent that our mechanistic model was not equipped to account for many of the high-frequency shifts in fish-catch rate that were observed in sectors 2 and 17. Small arctic cisco simply could not have swum rapidly enough over the distances involved to adjust their densities at the required rates. Either they were moved by currents, or the high-frequency fluctuations in catch rate reflected high-frequency changes in catchability superimposed on more gradual changes in the density of fish available for capture. Without doubt, strong currents existed in the causeway area during the simulation period (Mangarella et al. 1982). However, the current data were inadequate to characterize the causeway area in a way sufficient to permit incorporating into the model the effects of passive drift of fish with currents. Therefore, we turned our attention to the other possibility: The high-frequency part of catch variation resulted from fish catchability, not density, variation. If the hypothesis were true, then each predicted catch series should be more highly correlated with an appropriately filtered version of the observed series than with the observed series itself. To test this hypothesis, we exponentially filtered the observed series for sectors 2 and 17, trying rate constants ranging from 0.1 to 10 days^{-1}. Each filtered series was computed by recursive application of the equation

$$C'_i = C_i - (C_i - C'_{i-1}).\exp^{-k.\Delta t} \qquad (18)$$

where

C'_i = filtered catch on i^{th} day,
C_i = actual catch on i^{th} day,
C'_{i-1} = filtered catch on $(i-1)^{th}$ day,
k = the rate coefficient, and
Δt = 1 day = the time interval between data values.

We assumed that observed catch was at steady-state on the first day; i.e.,

$$C'_1 = C_1 \; . \qquad (19)$$

For both sectors 2 and 17, the optimum filter had a rate coefficient near 0.4 days^{-1}; that is, filtering the observed series with the rate coefficient set equal to 0.4 days^{-1} produced maximum correlation between predicted and observed catches in each sector (Fig. 9). Improvement of correlation over that for the unfiltered series was modest for sector 2 (tau increased from 0.21 to 0.30; P decreased from 0.08 to 0.02), but was dramatic for sector 17 (tau increased from 0.44 to 0.85; P decreased from 0.001 to ~ 0.00001; Fig. 9). We infer from the exercise that a substantial part of the variation in daily catch rate of the fyke nets, particularly that in sector 17, was associated with factors other than fluctuations in fish density. We assume that environmentally-related changes in catchability were principally responsible. The dominant period of the "noise" was about 2.5 days (= 1/k). This value is consistent with the typical periods of barometric pressure, wind direction, and current direction in the causeway area (Mangarella et al. 1982).

ASSESSMENT IMPLICATIONS

The principal assessment implication of the above findings is that under normal conditions—when pronounced thermal differences exist between water masses on either side of the causeway--fish from the colder side will "stream" through the breach towards the warmer side. Under the conditions observed during early 1981, modeled fish on the west side would have been "held" on the warmer west side of the causeway until the reversal in prevailing winds changed the temperature/salinity structure, whereupon they would have pulsed (mainly through the breach) and dispersed to the warmer east side. The observed fyke-net catches during this period (Griffiths and Gallaway 1982) are in good agreement with the model predictions.

For the balance of the 1981 sampling season, conditions were generally warmer on the east than on the west side of the causeway. Density of arctic cisco (and anadromous fish in general) was usually higher on the warmer side, also suggesting that fish may have been held in this area by the favorable conditions.

The catch data, in conjunction with the model predictions, suggest that during the later part of the season, small cisco on the west side of

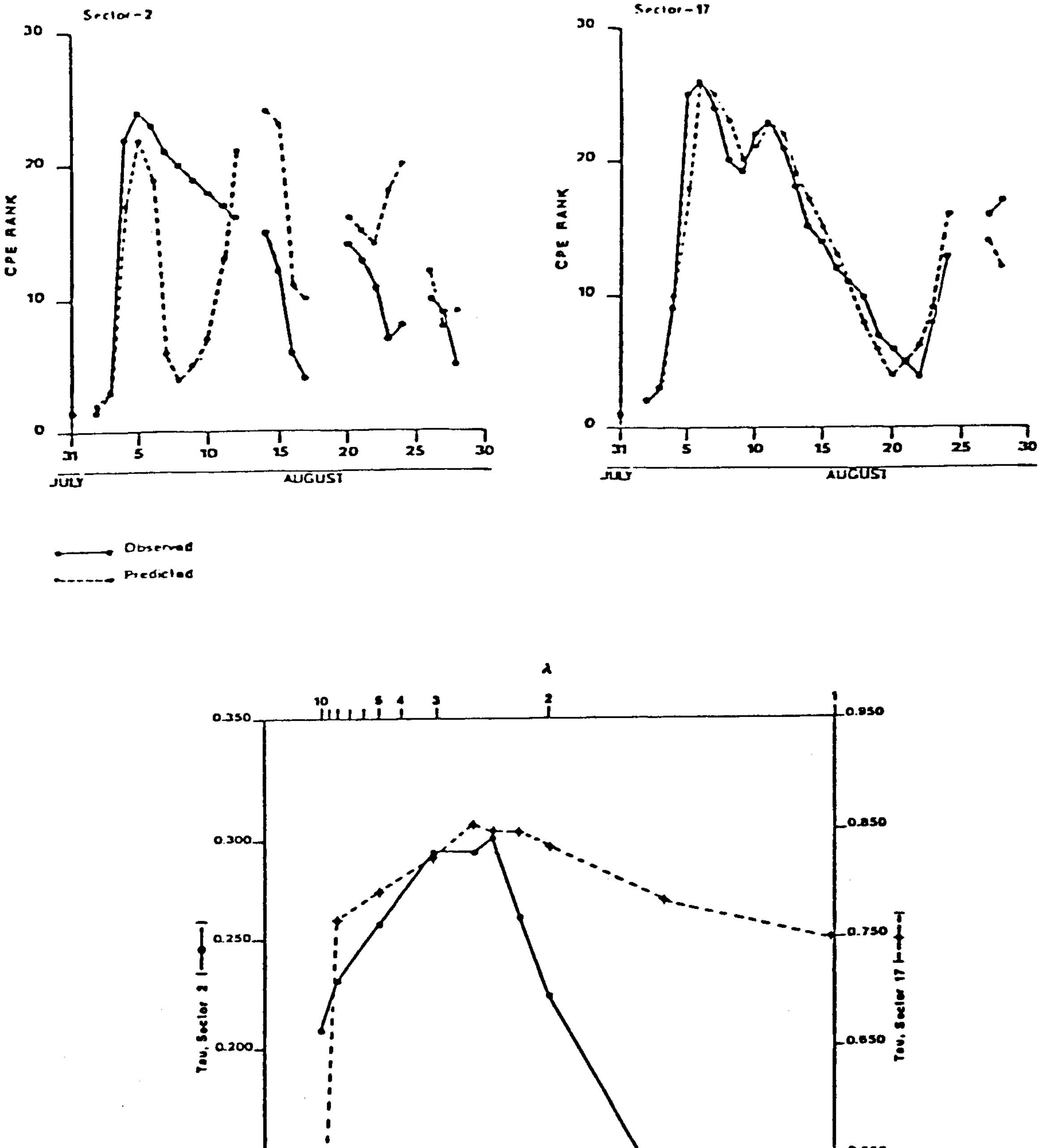

Fig. 9. Ranks of observed versus predicted catch rates after smoothing the observed series with an exponential filter employing a rate constant k of 0.4 days^{-1} (upper panels), the optimum value as measured by magnitude of Kendall's rank correlation coefficient tau (lower panel).

the causeway would have been directed to the east side, away from the Colville River overwintering habitat. However, once on the east side these fish would have strenghtened the fish-density gradient, driving dispersal towards the Colville River in the "warm" water plume flowing around the tip of the causeway to the west.

Under the rapidly deteriorating thermal conditions characteristic of this season, it is not unreasonable to believe that some of the late-season migrants do not reach the Colville overwintering grounds until late in the winter, if at all. Results of stock assessments based upon 15 years of commercial fishery catch-effort data (Gallaway et al. in prep.) suggest that the observed fluctuations in population levels of arctic cisco at the Colville River overwintering site can be accounted for only by either (1) an extremely peaked stock-recruit relationship or (2) environmental factors. Comparisons of the fluctuations to "bad" ice years, considering the lag-time between age 1 migrants and catchable-size fish, indicate that environmental factors are a more likely explanation of the observed fluctuations than is an unusual stock-recruit relationship. Of the possible environmental factors, late-season temperature declines appear to be a distinct candidate affecting the success of young fish in reaching favorable overwintering habitat.

In summary, given the prevailing wind regimes characteristic of the late-summer period and assuming that young cisco during this period are travelling, on a regional basis, from east to west, fish encountering the causeway from the east would be directed around the tip of the causeway, and on to the west along the outer shoreline of Stump Island. Such a transport feature was reflected by the model's projection, considering the period as a whole, of a net westward density flow around the tip of the causeway of about 32.3 units. For fish encountering the causeway on the west side, the prevailing temperature differential across the causeway combined with access to the "warm" side through the breach would serve to enhance movement into the relatively warm water on the east, whereupon the fish would disperse westward as described above. The model results for the period considered as a whole projected a net eastward density flow through the breach of about 51.4 units. Even though small, the breach provides an effective fish passageway, given the pronounced temperature differential between the respective sides of the causeway which is set-up and maintained by the regional winds.

Under the prevailing easterly winds, anadromous fish on the west side of the causeway will likely be effectively diverted away from the planned intake structure, instead moving through the breach and remaining in the more favorable temperature regimes occurring on the east side of the causeway. Under the less prevalent (but common) westerly wind regime, the opposite pattern should emerge; i.e., anadromous fish (or at least arctic cisco) would likely be directed towards the intake side of the causeway. Further, given the northerly currents along the causeway under these conditions, they would likely be directed towards the intake structure. These represent periods when entrapment and entrainment would be expected to be highest--fortunately such periods are not predominant.

CONCLUSIONS

The mechanistic model that was developed to evaluate the movement patterns of small arctic cisco in the vicinity of the Waterflood Causeway produced realistic density estimates. Density projections were significantly correlated with actual catches, particularly when the observed data were filtered to remove the effects of presumed high-frequency changes in fish catchability along the shoreline. The model projections were also improved by incorporating the assumption that the fish had an affinity for the shoreline. Treating spatial and temporal shifts in fish density as a donor-controlled drift process biased by the fish's preference for temperature, accounted very well for observed distributional patterns in the vicinity of the causeway over both time and space.

Assuming model validity, fish should use the breach as a major passageway to the side of the causeway with more favorable water quality. Under the prevailing easterly wind regimes, fish usage of the breach in the patterns indicated by the model would serve to greatly reduce the potential for entrainment and impingement on the intake structure. The opposite pattern would be the case for periods of westerly winds.

While temperature heterogeneity associated with the causeway during August 1981 maximized breach usage, thus serving to reduce entrainment potential, it also caused young arctic cisco to have been about 7% less abundant in the area than they would have been had temperature and salinity provided no directional bias. Overall, we believe that the breach constitutes an effective mitigative measure for the Waterflood Causeway.

The model that was developed represents a new and particularly important tool enabling one to evaluate the effects of nearshore structures in Arctic coastal waters on movement patterns of anadromous fishes based upon more than intuition or opinion of experts. A bonus of the model is that, being based upon mechanism, it is generic. By this we mean that the model can be applied equally well at different localities. Further, the model's boundaries can be appropriately adjusted, enabling one to address a broad spectrum of migration-related questions.

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SHOREBIRD LITTORAL ZONE ECOLOGY OF THE ALASKAN BEAUFORT COAST

by

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Final Report
Outer Continental Shelf Environmental Assessment Program
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I. SUMMARY

We have studied shorebird distribution, habitat relationships, trophic dependencies and behavior at several Beaufort coast sites since 1975. Our objective is to assess the degree and nature of dependence of shorebird species on arctic habitats which are potentially susceptible to perturbation from offshore oil development activities. With other researchers we have identified several sensitive sites along the Beaufort coast where shorebird use of coastal habitats is very high. We have ranked types of coastal habitats on the basis of bird use and possible effects of oil development. We have categorized the common shorebird species in terms of relative sensitivity to habitat disturbances associated with oil development and have defined seasonal habitat use patterns of all species to determine sensitive periods within the year.

During June and early July shorebird activity is centered on the tundra where shorebirds nest. In July and August a major shift in habitat use occurs, beginning with post-breeding adults and augmented increasingly by fledged juveniles moving to shorelines to forage in littoral habitats prior to southward migration. Species vary in timing and magnitude of this habitat shift, but the phenomenon is widespread across species, with many species reaching littoral zone densities far in excess of those on tundra during early summer. Within the littoral zone, species differ also in their relative use of different types of littoral habitat. On a finer scale, species exhibit microhabitat foraging preferences within littoral habitats. All these differences affect the likelihood that oil development activities or oil spill accidents will affect species populations. Specific results are detailed below.

Littoral zone movements of most shorebird species at Barrow represent more than just local breeding birds. Annual variation in post-breeding densities of most species is correlated with annual variation in temperatures during the post-breeding period but not with variation in temperatures during the nesting period. Birds which share post-breeding habitats fluctuate similarly in post-breeding densities. Annual variation in post-breeding littoral zone densities is probably determined by conditions within the littoral zone; development perturbations will affect groups of species similarly.

Measured densities of migrating birds are very sensitive to variation in turnover rates of individuals at a census site. Turnover rates of Red Phalaropes at Barrow in 1976 were rapid, suggesting that large populations of birds might be affected by a local oil spill.

The common Barrow shorebirds can be classed in four groups on the basis of seasonal patterns of tundra vs. littoral zone habitat use. Species such as Red Phalarope and Ruddy Turnstone are heavily dependent on the littoral zone while Golden Plovers are almost restricted to tundra habitats; other species show intermediate patterns.

Based on six measured habitat variables our littoral transects can be separated in principal component habitat space into groups corresponding to gravel beaches, littoral flats and slough edges. Birds respond to these differences in habitat type, with groups of species occurring in the same transect groups in each year. Species density distributions in habitat space are often quite distinctive, but different species sometimes show similar shifts in habitat use between years, probably in response to changes in environmental conditions. Groups of species emerge with similar habitat preferences within the littoral zone and with similar microhabitat preferences within habitats. These groups of species may be affected similarly by particular environmental disturbances.

Types of available littoral habitats were comparable at Barrow and Prudhoe Bay but Barrow has larger areas of gravel spit shorelines, which attract high densities of phalaropes. At Fish Creek Delta in Harrison Bay this habitat is absent, but mudflat and saltmarsh habitats, heavily used by other species, are more extensive than at Barrow and Prudhoe Bay. Red Phalaropes are much more common than Northern Phalaropes in migration at Barrow, but they are less common in Harrison Bay probably as a result of a longitudinal gradient in relative abundance as well as a gradient in habitat preference of the two species.

Shorebird concentration areas occur in areas of gravel spits and barrier islands (Icy Cape, Peard Bay, Point Barrow, Plover Islands, Jones Islands) and in areas with extensive littoral flats, saltmarshes and slough edges (Icy Cape, Barrow, Fish Creek Delta, Coleville Delta, Cape Halkett).

Species differ also in fat accumulation schedules prior to southward migration. Fat levels of Red Phalaropes and Dunlin both increase during August. Fat levels of Ruddy Turnstones and Sanderlings prior to departure are even higher than in the latter species. Semipalmated Sandpiper juveniles depart much earlier, with less fat.

Littoral zone diets of most shorebird species correspond to the habitats in which they forage rather than to strong species differences in diet preference; diets of many species overlap broadly while foraging in the same habitat type. On littoral flats, in saltmarshes and along the edges of sloughs and lagoons, shorebirds prey mainly on chironomid fly larvae, with adult chironomid flies and oligochaetes taken during some periods. Along marine shores the prey base for many species is the mix of marine zooplankton and under-ice amphipods which is highly variable in density and species composition between years and within one season. Diets of shorebirds have a strong seasonal component as species shift from tundra to littoral habitats and as prey availability within habitats changes.

Juvenile Red Phalaropes foraging along the shores of Barrow Spit altered their diets and their foraging behavior in relation to onshore wind direction, apparently in response to changes in relative abundance of marine zooplankton and under-ice amphipods. This response suggests that spits and islands may be favored foraging areas because they present more options with respect to onshore - offshore winds when compared with mainland shores.

At Prudhoe Bay, the dust shadow produced on tundra beside gravel roads reduced densities of nesting shorebirds and passerines. A tundra area where natural drainage has been altered by construction showed a reduction in shorebird breeding densities but an increase in densities of late summer migrants. An artificial gravel pier at Prudhoe Bay was used less than adjacent mainland shores by passerines and several species of shorebirds, but densities of Northern Phalaropes were extremely high. Artificial piers and islands will probably attract zooplankton foragers to areas where oil spills may be more likely.

In choice experiments, juvenile Red Phalaropes made no initial distinction between foraging on clear water or on water containing an oil film. However, on subsequent choices they avoided foraging on oiled surfaces; they also foraged longer on clear surfaces. In a related aquarium experiment, phalaropes increased time spent in escape behavior in response to thin oil films on water. If their fate is not sealed by initial contact with oil on water, phalaropes may learn to avoid it quickly enough to reduce mortality rates.

II. INTRODUCTION

Along the Beaufort and Chukchi coasts of arctic Alaska tundra habitats merge with saltmarsh, sloughs and arctic beaches. In these habitats shorebirds (Charadriiformes: Charadrii; sandpipers, plovers and their close relatives) of many species are present throughout summer months. In contrast to areas farther south, shorebirds comprise a major segment of the avifauna of the coast of arctic Alaska (Bailey, 1948; Gabrielson and Lincoln, 1959; Pitelka, 1974). The twenty-seven species listed in Table 1 occur regularly in the arctic during summer months, migrating to spend their winters in temperate and tropical regions of both northern and southern hemispheres. As a group they are an international resource, with individual species dependent in varying degrees on summer conditions along the Alaskan arctic coast.

Prior to 1975 most of the detailed studies of shorebird ecology in arctic Alaska had been done near Barrow where researchers concentrated on conditions and activities on the tundra primarily during the short arctic breeding season (Holmes, 1966a, 1966b, 1970, 1971; Holmes and Pitelka, 1968; MacLean, 1969, 1974; Norton, 1972, 1973; Pitelka 1959, 1974; Pitelka *et al.*, 1974). It had been noted at Barrow and elsewhere in the arctic that densities of several species of shorebirds increased near the shoreline as summer progressed resulting in a net increase in use of littoral habitats (Holmes, 1966a; Bengtson, 1970). This movement begins with non-breeders and is augmented progressively by a shoreward movement of local and also inland birds, especially after the young have fledged. However, the importance of this habitat shift in the breeding cycle of arctic shorebirds had not been adequately evaluated.

Since 1975 we have attempted to provide detailed and quantitative information necessary to assess the dependence of shorebirds and other species on littoral habitats along the Alaskan arctic coast. Development of petroleum resources along the outer continental shelf will produce some unknown degree of disturbance to these habitats. To the extent that shorebirds and other birds depend upon shoreline and nearshore habitats any disturbances may affect their populations. Our approach to evaluating the significance of the littoral zone to shorebirds has been to gather and analyze basic ecological data dealing with seasonal occurrence of shorebirds in different habitats; trophic relationships of shorebirds feeding in littoral habitats; and variability in these aspects both over time and over space. These efforts have been supplemented with behavioral data, experimental work and observations of bird use in habitats already subjected to development alterations. Our objectives are to define the seasonal relationships between each common species and the habitats available; to identify the species and habitats most sensitive to disturbance as well as the regions along the Beaufort coast that should be considered most important to shorebird populations; to predict the probable impact of

Table 1. Shorebird species occurring regularly along the Beaufort and Chukchi coasts of Alaska (from Connors *et al*., 1979).

Regular Breeders

Semipalmated Plover, *Charadrius semipalmatus*
American Golden Plover, *Pluvialis dominica*
Black-bellied Plover, *Pluvialis squatarola*
Ruddy Turnstone, *Arenaria interpres*
Black Turnstone, *Arenaria malanocephala*
Common Snipe, *Capella gallinago*
Whimbrel, *Numenius phaeopus*
Red Knot, *Calidris canutus*
Pectoral Sandpiper, *Calidris melanotos*
White-rumped Sandpiper, *Calidris fuscicollis*
Baird's Sandpiper, *Calidris bairdii*
Dunlin, *Calidris alpina*
Semipalmated Sandpiper, *Calidris pusilla*
Western Sandpiper, *Calidris mauri*
Stilt Sandpiper, *Micropalama himantopus*
Buff-breasted Sandpiper, *Tryngites subruficollis*
Long-billed Dowitcher, *Limnodromus scolopaceus*
Bar-tailed Godwit, *Limosa lapponica*
Red Phalarope, *Phalaropus fulicarius*
Northern Phalarope, *Lobipes lobatus*

Additional Migrants

Killdeer, *Charadrius vociferus*
Sharp-tailed Sandpiper, *Calidris acuminata*
Least Sandpiper, *Calidris minutilla*
Rufous-necked Sandpiper, *Calidris ruficollis*
Curlew Sandpiper, *Calidris ferruginea*
Sanderling, *Calidris alba*
Hudsonian Godwit, *Limosa haemastica*

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potential disturbances and to suggest alternatives or guidelines that will be useful in managing the development of the Beaufort coast.

Annual reports presenting results of these studies have been published by OCSEAP each year (Connors and Risebrough, 1976; 1977; 1978; 1979; 1980). In this final report dealing with the Beaufort coast we will attempt to summarize and synthesize results presented in those reports and to present the results of further analyses performed on the multi-year data set. In the interest of brevity and clarity, we will not present all details of subjects discussed previously but will repeat any information necessary to understanding topics discussed in this report.

III. METHODS

Study Areas

Our principle approach to the study of shorebird habitat use in the littoral zone required initially a definition of the littoral zone appropriate for the Beaufort Coast. Definitions for shorelines in more southerly regions have been established (see Ricketts et al., 1968) but the Alaskan Beaufort Coast presents some special problems. The mean tidal range at Barrow is only 29 centimeters; however, during periods of open water, storms may produce tides of 1 meter or more above normal, inundating large areas of low lying coastal habitats. Vegetation, patterns of bird use and susceptibility to petroleum pollution carried by storm waters differ markedly within this zone compared to tundra just beyond it. For these reasons, we considered the arctic littoral zone as extending from the lowest tide level up to the limits of the area likely to be flooded by storms at least once every few years. The imprecision of this operational definition results from our inability to establish the area frequency contours necessary for a more precise definition. In practice this littoral zone can readily be recognized by the brackish water in flood pools, by the presence of salt tolerant vegetation, and by the distribution of storm drift material.

We established permanent marked transects at our three principal study sites: Barrow (71° 17'N, 156° 46'W) where we censused transects for four consecutive summers from 1975 through 1978; Prudhoe Bay, (70° 15'N, 148° 20'W) where we censused transects during the summer of 1978; and Fish Creek Delta (70° 25'N, 151° 22'W) in Harrison Bay where we worked during 1980 (Figure 1). At Barrow, our main study site, we established transects in a wide variety of littoral and near littoral habitats (Table 2 and Figure 2). These included gravel spit beaches varying in wave exposure, gravel mainland beach, tundra-backed beach, ocean estuary, open lagoon estuary, closed brackish lagoon and a variety of mudflat and salt marsh habitats varying in amount of water cover, salinity of pools, type and density of vegetation, substrate grain size and proximity to ocean, lagoon or sloughs. On the basis of habitat measurements and bird use we have grouped transects into three main categories, designated as gravel beaches (G), lagoon and slough edges (E), and littoral flats (F). We established a similar systems of transects at Prudhoe Bay designed primarily to test the effects of habitat disturbances by sampling disturbed and undisturbed habitats, and in Fish Creek Delta to measure shorebird densities on the extensive littoral flats and slough edges of that area.

We supplemented our regular transect census information with observations and density measurements made in brief visits to several other sites: Icy Cape, Wainwright, and Peard Bay west of Barrow; Lonely, near Pitt Point, Oliktok, east of the Colville River, and a site west of Harrison Bay near Cape Halkett, all along the Beaufort Coast (Figure 1).

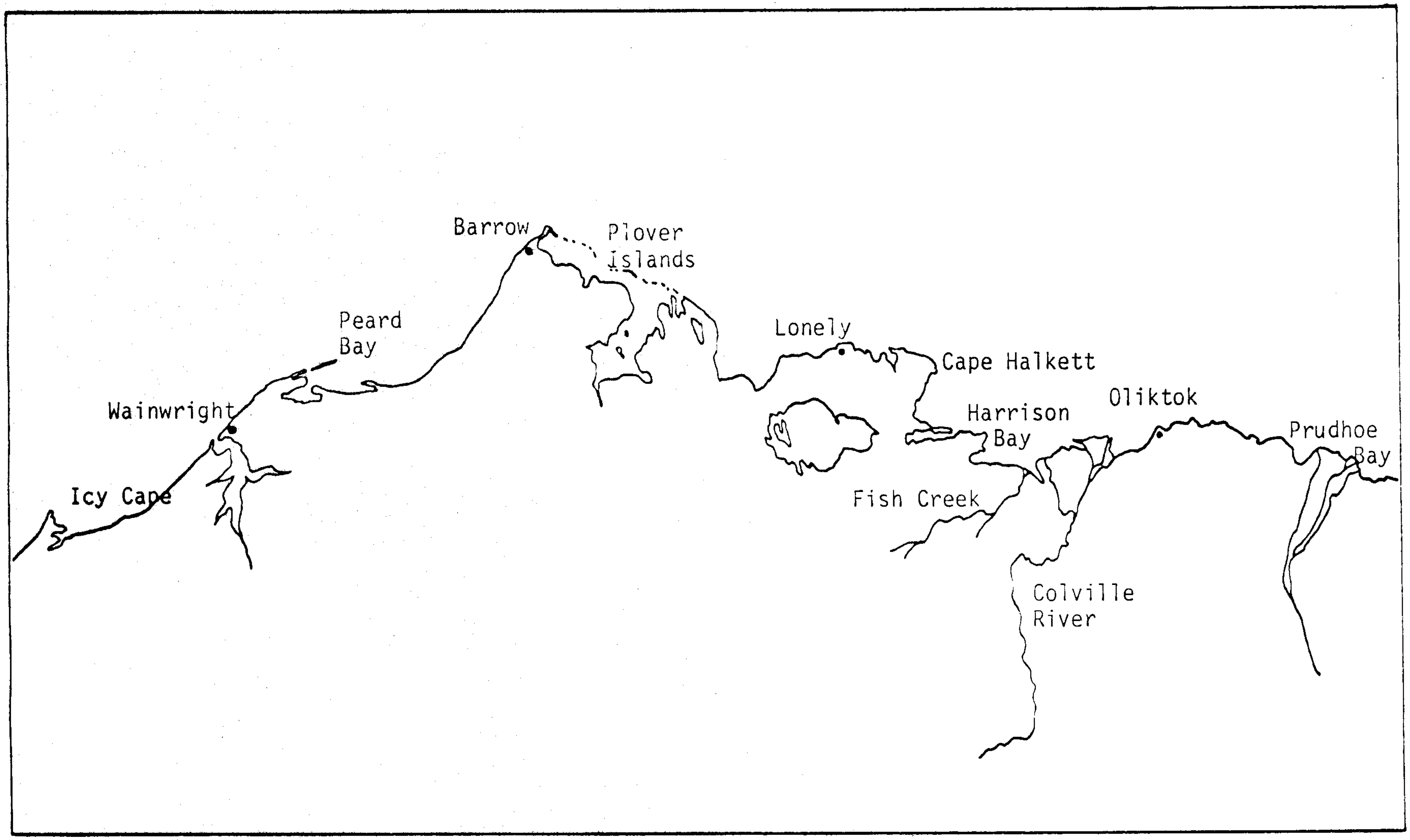

Figure 1. **Beaufort and Chukchi coast study area.**

Table 2. Littoral zone transects studied at Barrow 1975-1978.

Transect Code	Years Censused	Length (m)	Width (m)	Habitat
BAP	3	1000	50	G
BBD	3	2900	50	G
BBS	4	1000	50	G
BBV	1	1000	50	G
BCB	3	1000	50	G
BCN	3	1000	50	G
BCS	4	1000	50	G
BDM	3	1000	50	G
BDC	1	1000	50	G
BPP	3	1000	50	G
BPS	3	1000	50	G
BRW	3	1000	50	G
BTW	3	1000	50	G
BWS	4	1000	50	G
BBP	4	300	100	F
BGF	4	500	100	F
BNL	4	500	100	F
BNT	3	500	100	F
BVL1	2	500	50	F
BVL2	2	500	100	F
BCM	2	1000	50	E
BME	3	500	50	E
BMW	3	500	50	E
BNB	4	1000	50	E
BNE	4	500	50	E
BVE	2	500	50	E

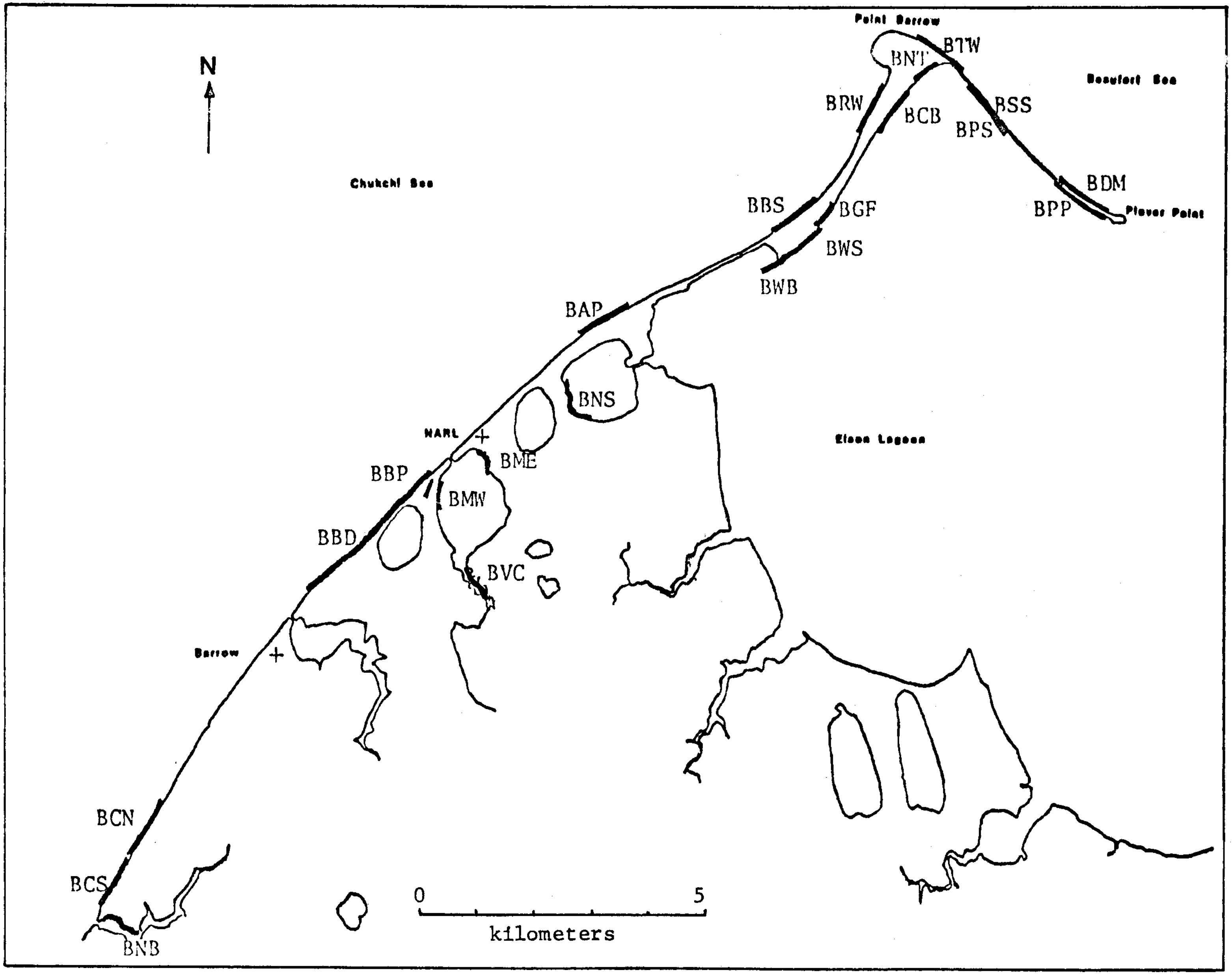

Figure 2. Location of transects at Barrow.

Airplane flights between these sites and our principal study sites gave us more extensive but less detailed information on the distribution and availability of habitats and on concentration areas of shorebirds along the coast.

Transect censusing

Permanent transects were marked with stakes at 50 meter intervals. In relatively uniform habitats such as mudflat, saltmarsh or tundra, transects were straight and 100 meters in width with 50 meter stakes running along the center line of a double row of 50 x 50 meter square plots. At Barrow transect distances varied from 300 meters to 1000 meters (Table 2). Shoreline transects, such as along lagoon edges or ocean beaches, consisted of a single row of 50 meter x 50 meter square plots following the shoreline. These transects varied from 500 meters to 2900 meters.

We censused transects once every five days and have averaged data from all years pertaining to five day periods throughout the summer. Barrow study seasons differed in different years: 16 June - 3 September 1975, 6 June - 18 September 1976, 16 July - 18 September 1977, and 11 July - 29 August 1978. We censused in all four years during the nine periods of heaviest littoral zone activity for most shorebird species, 19 July through 29 August. In discussions of inter-year variability, only these 9 periods are considered, but for full season data, average densities are computed based on the appropriate number of density estimates. The number of transects censused in different years also varied, primarily as a result of logistic considerations. Number of years each transect was censused is given in Table 2. Our census objective was to determine an instantaneous density on each 50 meter by 50 meter plot by locating, identifying and counting each individual. Some factors affecting censusing are discussed in Results.

At Prudhoe Bay we censused transects continuously in 5 day intervals from 1 June to 10 September, 1978. Transect locations and sizes are shown in Figure 3 and Table 3. At Fish Creek Delta in Harrison Bay our censuses ran from 26 July to 29 August, 1980. All transects at that site were 1000 m long by 100 m wide (Figure 4).

Table 3. Transects studied at Prudhoe Bay in 1978.

Transect Code	Length(m)	Width(m)	Transect Code	Length(m)	Width(m)
PAB	1000	50	PPI	250	50
PBB	500	100	PP2	250	50
PBS	500	100	PP3	250	50
PDW	1000	50	PP4	250	50
PEB	1000	100	PPB	500	100
PED	400	50	PPM	1000	50
PF1	700	100	PPU	350	50
PF2	800	100	PS1	500	50
PG1	500	100	PS2	500	50
PG2	500	100	PRB	400	100
PG3	500	100	PSB	1000	100
PG4	500	100	PSR	500	100
PGI	1000	50	PSS	1000	100
PIS	500	100	PW1	1000	50
PMF	300	100	PW2	1000	50
PNO	150	100	PW3	1000	50
POS	150	100	PW4	1000	50

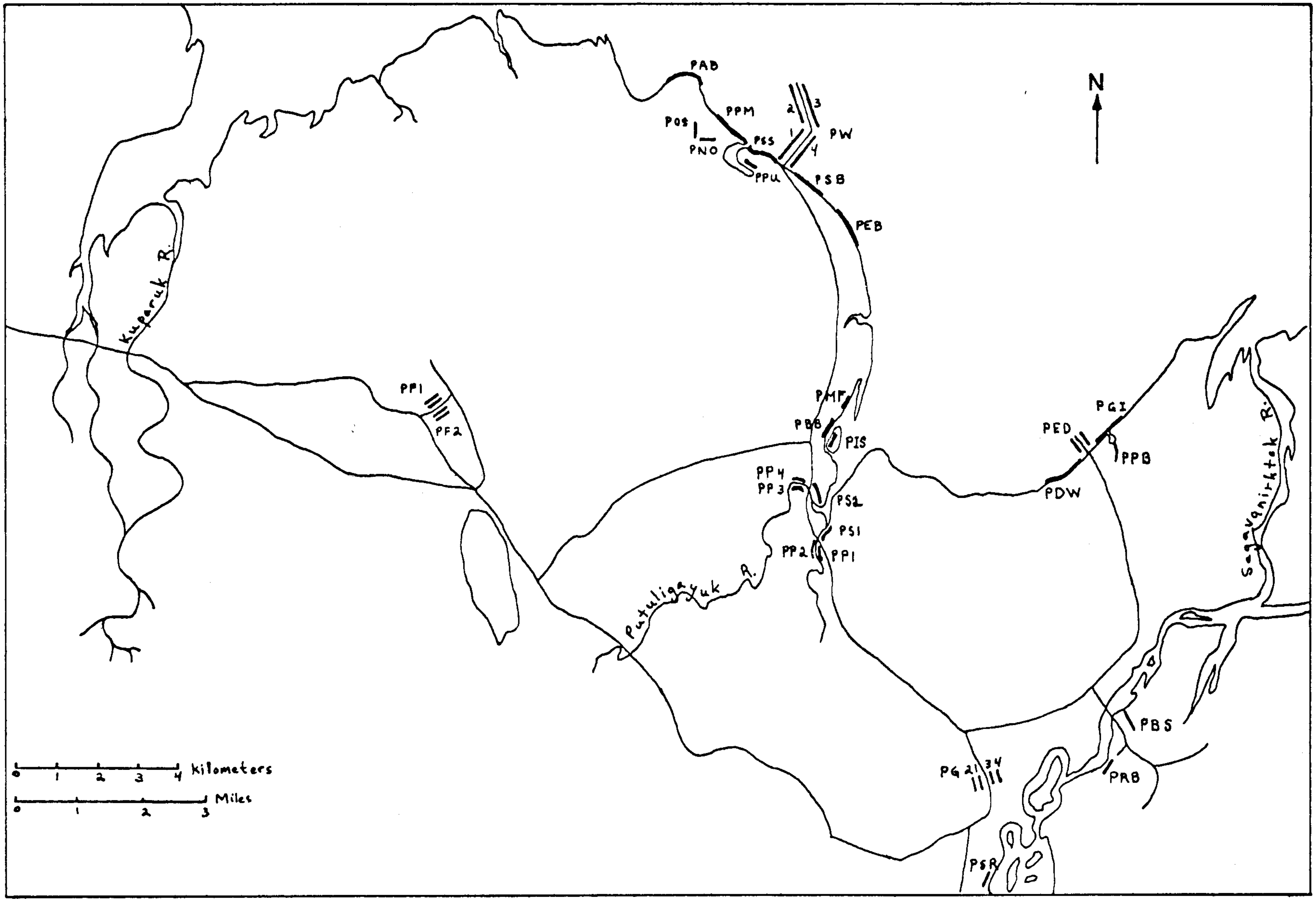

Figure 3. Locations of transects at Prudhoe Bay.

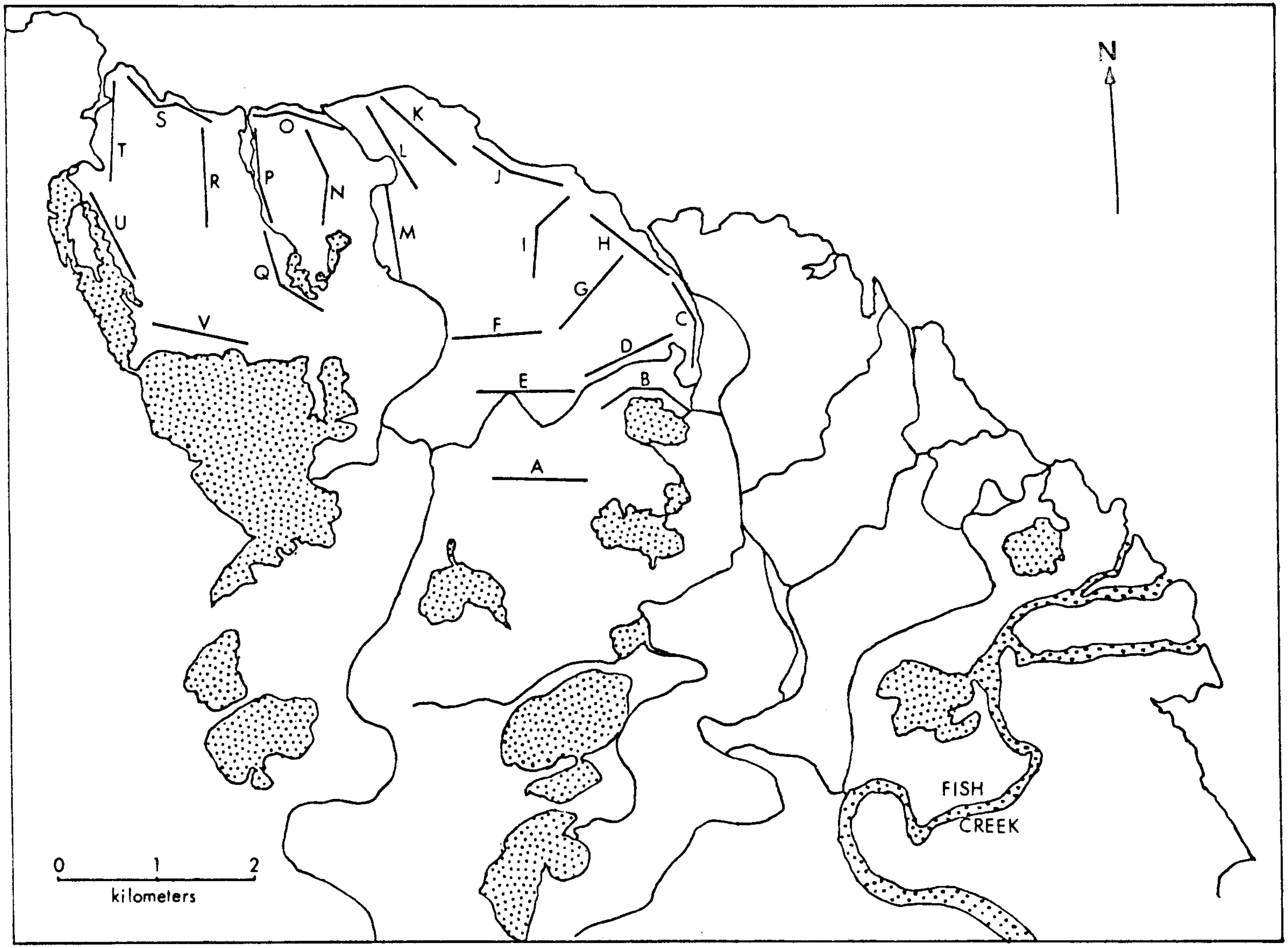

Figure 4. Locations of transects at Fish Creek Delta.

Habitat characterization

We present general descriptions of the shorebird habitats studied in Results below. To characterize our transect habitats quantitatively for further analysis we described the littoral zone transects by measuring six variables for each 50 meter plot:

1. Distance from shore (DSHORE): distance from center of 50 meter plot to nearest major shoreline (e.g. ocean, lagoon, river).
2. Width of normal flood zone (NORFLZ): distance from mean water level to highest level inundated during most years. Determined by recent drift material and by vegetation.
3. Width of maximum flood zone (MAXFLZ): distance from mean water level to highest water level as indicated by farthest inland driftwood line.
4. Water cover (WATCOV): percent of plot covered by water.
5. Substrate (SUBSTR): particle size gradient classified as mud (1), fine sand (2), coarse sand (3), fine gravel (4), coarse gravel (5).
6. Vegetation cover (VEGCOV): percent of exposed area covered by plants.

These six components were used in principal component analyses (Morrison, 1976) and as our results will show they were sufficient to identify the principal distinctions between groups of littoral habitats. We also recorded three additional categorical variables for each plot: major land form, habitat form and major plant taxa on the plot (Connors and Risebrough, 1978). We evaluated these in our subjective classifications of littoral habitats into three basic types; the results agreed with the quantitative analyses based on the first six variables (see Results). These categorical variables also contribute to a useful description of habitats, conveying a more easily communicated picture of the habitats than is possible with the quantitative analysis.

Habitat descriptions were performed during August to represent the conditions experienced by shorebirds during the period of heaviest use each year. Only one variable, percent water cover, is sensitive to the date of measurement; all other variables remain fairly constant throughout the summer.

Foraging microhabitat measurements

During late summer of 1976 at Barrow, we recorded six variables describing microhabitat in the immediate vicinity of points where shorebirds foraged in the littoral zone. The variables were: distance from foraging point to water line, depth of water at foraging point, grain size at foraging point, distance to nearest algae from foraging point, distance to nearest vascular plant from foraging point and depth of penetration of the bird's bill into the substrate. We measured a total of 1210 foraging points on 9 common shorebird species (Connors and Risebrough, 1977). We used factor analysis (Wallace and Bader, 1967) to extract coordinates which combined the measured variables to represent the major environmental gradients which describe the differencess in species foraging microhabitats. The space defined by these new coordinates can be thought of as microhabitat space with different areas representing different types of microhabitat. The locations of each species' foraging points within this microhabitat space then define the differences in foraging preferences among the species.

Trophic studies

We collected 136 individuals of 13 species over the years 1975 - 1978 at Barrow and a few nearby sites (Table 13). All were collected by shotgun with immediate injection of a formalin solution into the stomach and esophagus to preserve ingested prey items. These organs were subsequently removed in the laboratory where prey items were identified and counted. We also recorded the fat condition of each bird using a scale which combines the OCSEAP seabird fat code with a traditional museum fat description as follows: Code 1, no fat; Code 2, little fat; Code 3, moderate fat; Code 4, heavy fat; Code 5, excessive fat. Prey identified in bird stomachs were compared with densities and distributions of prey sampled in the foraging substrate (with cores and sieves) or in shallow water using a floating plankton net. The rectangular net (30 cm wide by 14 cm high at opening) was towed parallel to shore along beaches to sample zooplankton available to foraging phalaropes (Connors and Risebrough, 1977).

Phalarope oil film experiments

To test the responses of phalaropes to thin oil films on water, we first constructed a cylindrical pen of hardware cloth (1.9 cm mesh), 1.5 m diameter, 1.4 m height, wrapped with black plastic to a height of .6 m to isolate birds from visual distractions. Within this pen, we placed a continuous ring of 8 identical shallow galvinized metal pans, each 40 cm inner diameter, 9 cm depth. A central plywood disc or table (80 cm in diameter) rested on all 8 pans, but left most of each pan uncovered. A bird standing on the center table had a choice of entering any of the pans which formed a symmetrical ring around the circumference of the table. During the experiments, all pans contained seawater to a depth of 7 cm, and equal densities of live brine shrimp, *Artemia franciscana*, (1.3 ml drained brine shrimp per pan, equal to approximately 150 prey items).

Juvenile Red Phalaropes were acclimated to the experimental setup for 2 to 3 hours with water containing prey, but no oil. This acclimation period was necessary because the initial response of wild birds introduced to the cage often entailed fluttering escape attempts which resulted in the birds falling into pans. We wished to observe choices by the birds, not accidents.

For choice experiments, we placed a thin film of oil on 4 pans alternating with 4 clear pans around the circumference of the table. All pans contained equal amounts of water and prey. Oiled pans contained 10 ml of a 1:1 mixture of Prudhoe crude oil and diesel fuel (JPR-5). This formed an irregular surface film of small patches and spots of a medium brown semitransparent film, covering approximately 60% of the surface. To our eyes, the oiled and clear pans appeared distinctly different. Moving prey could be readily seen in both clear and oiled pans, but they were more visible in clear pans.

To initiate an experiment, the bird was placed under a small box in the center of the table. The box was hoisted smoothly to the top of the cage by remote control, releasing the bird in the center of the table to choose a foraging pan. Two observers sat inside a nearby laboratory above the cage, recording movements, behavior, and sequence and duration of choices for a trial period of 15 minutes per bird. The behavior of most birds, entailing a period of inspection of several pans from the table edge before entering any pan, leads us to conclude that the birds were in some way choosing foraging pans based on the results of that initial inspection. The inspection period often lasted several minutes and included visual inspection of many or all pans. Choices were scored when a bird entered a pan directly from the table, and duration of foraging periods was timed until the bird left the pan. Until the end of the 15 minute trial period, subsequent entries were scored as sequential choices.

In a second experiment, phalaropes previously acclimated to swimming and foraging in a 15 gallon glass aquarium (rectangular, 30 cm x 60 cm x 8 cm depth of seawater) were placed singly in the aquarium containing .9 ml of drained brine shrimp (approximately 100 prey). Behavior of each bird was timed for 60 seconds in the absence of oil and in the presence of very thin films (1.1 m and 2.8 m) of the 1:1 mixture of crude oil and diesel fuel.

IV. RESULTS AND DISCUSSION

The census data and habitat descriptions can be combined and analyzed to focus on several separate questions relevant to shorebird littoral zone ecology. In this section we address these topics sequentially, presenting initial results and analyses and discussing our interpretations and conclusions regarding each topic. We begin with some cautionary and explanatory remarks regarding our methodology, followed by brief descriptions of the principal types of habitats of interest along the Beaufort coast. We present an overview of the seasonality of habitat use by arctic shorebirds, and then discuss annual variation in shorebird numbers, habitat differences and shorebird habitat use patterns, geographic variation, shorebird diets, fat accumulation schedules, effects of habitat disturbances on shorebird densities, and responses of phalaropes to spilled oil. From these results we identify sensitive areas, habitats, species and times with respect to petroleum development. Finally, we present accounts of species distribution and littoral zone ecology in Appendix.

FACTORS AFFECTING CENSUS RESULTS

Habitat density averaging

In dealing with large numbers of transects in a variety of habitats, a decision must be made concerning the hierarchy of averaging steps in combining habitats to determine a final overall density. In our calculations the basic data were densities in birds per hectare for each species on each transect treated separately. On the basis of our habitat analysis we classified all littoral transects into three habitat groups, discussed below. At step two we calculated the average density for each habitat type as the mean of the densities for each transect within that habitat group. We then calculated an overall average density as the mean of the three habitat type densities. Finally we averaged these densities for all years censused (usually four years) to achieve our final mean density for each census period.

We considered two alternative methods of averaging. The simplest procedure would be to calculate directly the overall density by dividing the total number of birds of a species found on all transects by the total area of all transects censused. This value would be weighted by the amounts of different habitat types studied. It might be the method of choice if a study is of primarily local significance and if transects can be placed in proportion to the amounts of habitat types available locally.

The second alternative, computing the habitat densities separately by dividing total birds on transects of one habitat type by total area of transects of that habitat type, is more general for a study focusing on habitat densities but it is sensitive to variation in the sizes of individual transects. If all transects are of identical size, both this method and the method we chose achieve identical results. However, compared to the first alternative, these two procedures are sensitive to the choice of habitat divisions. For example, we might have considered only two habitat types rather than three, combining transects on littoral flats and lagoon edges. The effect on the final calculated average density for species with strong habitat preferences could be significant. For species which forage only on gravel transects, the final average density would be increased 50% relative to the density calculated with three habitat types. For species which forage only in littoral flat or lagoon edge habitats, or in equal densities in both, the final calculated average density would be reduced 25% from those calculated with three habitat types. At the other extreme, species with equal densities in all three habitat types would have final average densities identical by both methods. As shown below, the actual habitat use patterns of most species occur between these extremes; Figures 21 and 22 allow an estimate of the effect just described. We chose our habitat density averaging method to give us results which relate closely to habitat differences in the littoral zone but which consider all transects as equal estimates of the density at a particular site irrespective of transect size.

Turnover rate

The densities of transient populations calculated from censuses at any site are determined by two factors, the total numbers of birds passing through the site and the amount of time each individual bird stays at the site. This second factor is relatively unimportant when censusing stable populations, for example territorial breeding birds of many species, because individuals remain at the site for a long time; the number censused at one time is a good estimate of the total number of individuals present throughout the breeding season. When migrational movements are studied, however, turnover rate becomes an important factor in interpreting measured densities. At a site where birds are continually passing through, changes in turnover rate can greatly affect measured densities even though the number of individuals passing the area remains the same. To illustrate this affect, let us assume a total of 100 birds of a species are moving through our census area. We will census every day from long before to long after the birds pass through. Assume further that the arrival of the 100 birds is regular, with 10 new birds arriving on each day for 10 subsequent days. Table 4 shows the effect on peak number or density and cumulative number or density to be produced by varying the length of time each individual stays. A ten-fold increase in length of stay will produce a ten-fold increase in peak densities and in cumulative densities with no change in the number of birds passing through. Clearly, in the absence of information on turnover rates, density measurements of migrating birds cannot give reliable population estimates. This problem is central to the question of estimating popu-

Table 4. Effects of turnover rate on peak numbers and cumulative numbers recorded. Assume daily censusing at study site where 10 migrant birds arrive each day for 10 consecutive days:

Length of stay, each individual	Peak numbers censused	Cumulative number censused
1 day	10	100
2 days	20	200
10 days	100	1000
20 days	100	2000

lation effects of environmental disturbances. For example, our measured densities of migrating Red Phalaropes at Barrow permit us to estimate minimum numbers of birds potentially affected by an oil spill, but without some estimate of turnover rate they do not provide estimates of actual populations affected.

The simple example above is artifical, chosen for demonstrative purposes. For most species in migration, arrival, departure and interval dates are probably modally distributed rather than regularly distributed but environmental factors such as storms or changes in food supplies may increase the degree of synchrony, especially in southward departure date. As a result, turnover rates for different individuals may differ depending on date of arrival. Variation of turnover rate was in fact suggested in an experiment we performed on Red Phalaropes in 1976 (Connors and Risebrough, 1977). Forty-seven juvenile phalaropes were trapped and released in six groups on different dates from 8 to 23 August 1976. Each group was marked with paint in a different color pattern for easy recognition in the field. Subsequently we searched for marked individuals throughout the entire Barrow spit area on 11 different times between 11 and 25 August. We resighted eight individuals, all in the early part of the experiment. The pattern of resightings in relation to the proportion of total birds marked suggested that from 11 August through at least 15 August most birds remained in the area for at least four days. After 15 August, however, we had no resightings, implying a much quicker turnover rate in phalaropes in the Barrow spit area. A much more extensive resighting effort would have been necessary to closely determine turnover rates during these different periods. However, our tentative interpretation of these results is consistent with the overall census results which show a steadily increasing population of Red Phalaropes from August 5th through August 15th and a fluctuating population after August 15th, apparently as groups of birds left and new birds continued to arrive. The importance of this high turnover rate in most of August and early September to assessment of oil-related impacts is clear. A local habitat disturbance such as an oil spill, which might remain in a local area for 1 month or more, has the potential to affect several times as many phalaropes as are present at any one time on the area. Wave after wave of migrating Red Phalaropes from undisturbed areas might be affected as they pass through the disturbed area.

Species differences in response to observers

Although we censused all birds that occurred on our transects, we report here the results primarily for shorebirds and passerines and secondarily for gulls and terns. Our reason for omitting many other species, in particular the loons and waterfowl, relates to our choice of transect and census method. The size and type of transect was chosen specifically to allow identification of all shorebirds on each plot. This required censusing at a scale and distance which is inappropriate for many larger species which react to an observer at greater distances. Thus our data on densities of waterfowl censused in this manner would be misleading. Similarly a method of choice for measuring densities of Yellow-billed Loons, for example, might require aerial surveys which would be of little or no use for measuring shorebird densities.

HABITAT DESCRIPTIONS

Our habitat analyses based on six measured variables present objective reasons for grouping our transects in several habitat types. A general description of each of these habitats follows.

Gravel beach

Most shorelines of arctic spits and barrier islands consist of gravel beaches. These are ice-scoured and subject to gravel movement during open water storms. There are no benthic infauna of any major importance to shorebirds. Upper levels of these beaches are sparsely vegetated with salt tolerant plants such as *Honckenya peploides* and *Elymus arenarius*. Gravel beaches may be backed by high ridges of deposited beach gravel or by tundra shores, especially where gravel beaches occur along the mainland.

Littoral flats and saltmarsh

These habitats are grouped together because in most cases they vary only in the degree of vegetative cover. They are usually very flat, slightly above mean sea level and protected from wave action. They are maintained by periodic flooding with salt water during high storm tides. Substrates sometimes consist of gravel but usually this is mixed with or replaced by finer grain sizes. These habitats are stable and harbor populations of benthic invertebrates. Common and characteristic plants in these habitats include: *Puccinellia phryganodes*, *Carex subspathacea*, *Carex ursina*, and in less frequently flooded areas, *Stellaria humifusa*, *Cochlearia officinalis* and *Dupontia fischeri*.

Slough and small lagoon edges

This category includes the borders and fringes of all brackish and estuarine areas but excludes the large open water lagoons such as Elson Lagoon. Sloughs may vary from small streams entering the ocean to lagoons of one kilometer or more in diameter with openings to salt water at least during storm conditions. Borders of sloughs and lagoons vary widely, from gravel shores, especially near the mouths of lagoons, to tundra banks, sometimes with a narrow mud margin, and to broad areas of mudflat and even saltmarsh. Thus this category and the previous one merge in many instances and bird use in these cases is similar.

Mainland shores

Beaches along the mainland may be exposed or partially protected by barrier islands. Beach types vary from gravel to fine sand and may be broad and flat or narrow backed by a tundra cliff. Narrow tundra backed beaches have lower densities of bird use than any of the other littoral habitats described. At Barrow we had only one transect in this habitat which was abandoned after two years for logistics reasons. Our observations of habitats of this kind at other sites in the Beaufort and northern Chukchi corroborate our conclusion that it is the least used of all littoral zone habitats by arctic shorebirds. Mainland beaches do support moderate densities of shorebirds in some areas however, especially if they are near sloughs, lagoons or gravel spits.

Tundra

The final general category considered in our studies consists of all non-littoral habitats, classed as tundra. This varies from well-drained uplands to very wet lowlands. We distinguish lowland coastal tundra from littoral habitats such as saltmarshes on the basis of saltwater influence. Littoral habitats are at least occasionally inundated by saltwater and always differ from tundra habitats in the absence of tundra vegetation or the presence of salt tolerant plants.

SEASONALITY OF HABITAT USE: AN OVERVIEW

The transect census data yield a phenology of habitat use. Figure 6 shows the general pattern of shorebird seasonality at Barrow, contrasting densities measured on tundra and littoral transects. Tundra data in this and subsequent sections are drawn from Myers and Pitelka (1980) and Connors et al. (1979). During the nesting period in June and July, activity centers on the tundra. When birds initially arrive in late May and early June, most shoreline areas are frozen and inaccessible. As snow melt progresses during this period, birds establish territories on newly exposed tundra. Eggs are incubated during June and early July with hatching in late June through mid-July. The main prey base for shorebirds during this interval consists of freshwater zooplankton and insect larvae and adults (Holmes and Pitelka, 1968). For several species (Red Phalarope, Pectoral Sandpiper) the nesting participation by one sex ends

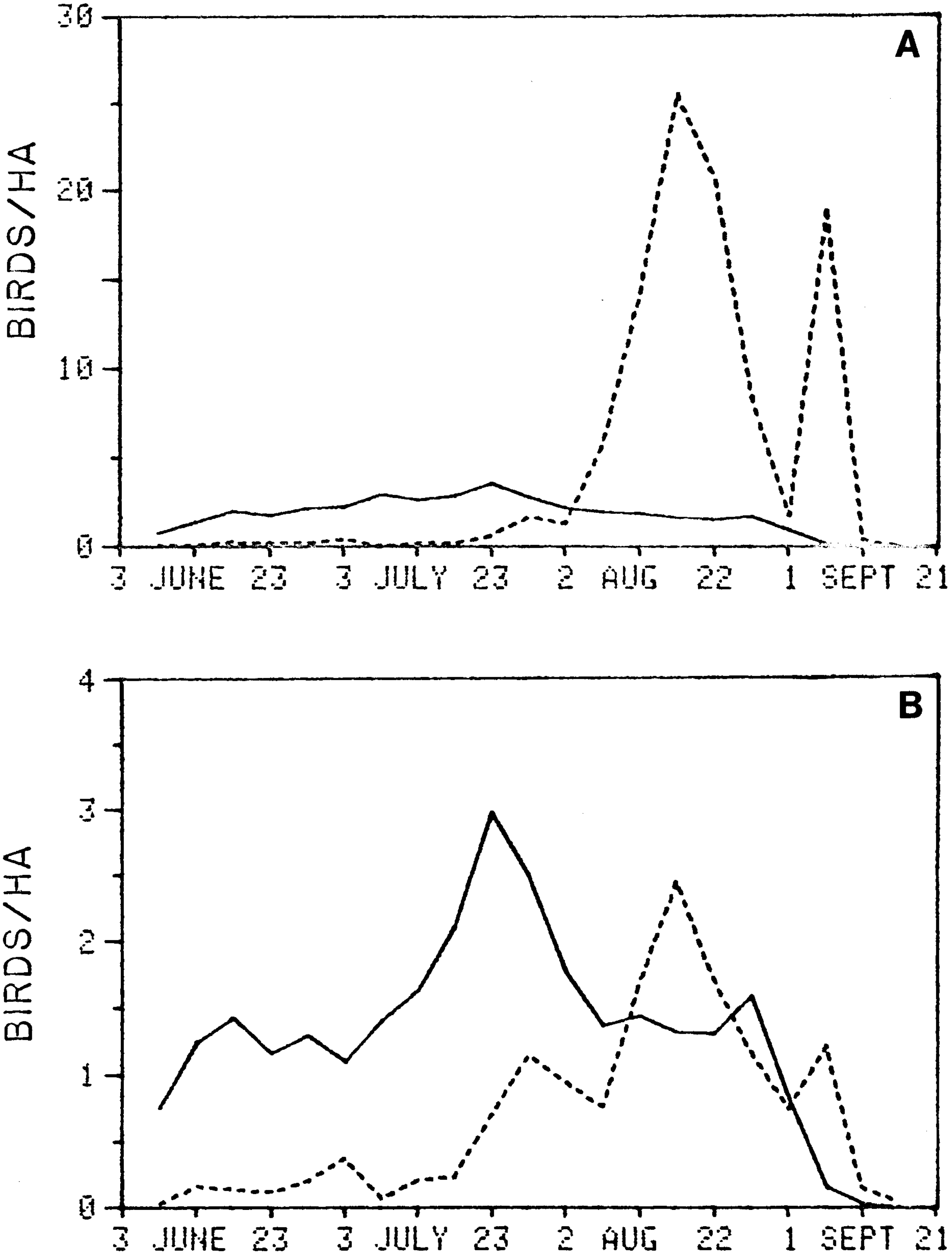

Figure 6. Seasonal habitat use, tundra (solid line) vs. littoral (dashed line). (A) all shorebirds combined (B) all shorebirds except Red Phalaropes.

before young are fledged. These released adults, together with other non-breeding or failed-breeding adults, occur increasingly on mudflats, lagoon edges and ocean shorelines as meltoff in these areas proceeds. As juveniles fledge in late July and August, large numbers of remaining adults and young occur along shorelines, shifting to a diet of oligochaetes and insect larvae on mudflats, and a wide variety of marine zooplankton along the shore. By mid-August the littoral zone has become a major foraging area for many species. Birds of different species and different age or sex classes depart Barrow to begin their southward migration at different times throughout the summer but by mid-September few birds remain.

The marked shift in habitat use from tundra to littoral use as the season progresses, displayed in Figure 6, is a composite of many individual species patterns. Species differ in the timing of population movements as well as the relative magnitude of use of different habitats. As Figure 6B indicates, the shift to littoral habitats in late summer is most pronounced for Red Phalaropes but is also a feature of the habitat use patterns of most other species. In the Appendix we discuss the seasonal habitat use patterns and the overall seasonality of littoral zone use for each of the common species individually.

ANNUAL VARIATION IN SHOREBIRD DENSITIES

Arctic ecosystems are commonly characterized as subject to extremely high variation in environmental and biological components but the data to examine annual variation are scarce. In this study we have maintained a schedule of frequent and regular censuses on fixed littoral zone transects at Barrow for at least the post-breeding season in four consecutive years, 1975-1978. Shorebird densities recorded by the same methodology on similar tundra transects are available from Myers and Pitelka (1980) for five years (1975-1979) at Barrow, and three years (1977-1979) inland at Atkasook (100 km south of Barrow). These data, together with daily meteorological records from Barrow, provide a unique opportunity to examine patterns of annual variation in numbers of shorebirds using the littoral zone at one site on the arctic coast. This combined data set consists of approximately three thousand separate transect censuses over the five year period.

To concentrate on annual variation we will consider littoral zone densities only during the late summer period of heavy use, censused consistently in all four years of the study. Our approach involves the use of Pearson correlation analysis to look for relationships among groups of species in different periods at different locations and with environmental variables. We wish to consider the question of whether the late summer shoreline movement among shorebirds represents just the local birds shifting habitats or is instead a widespread phenomenon drawing birds from farther away.

Comparisons among study sites

Table 5 gives mean densities and coefficients of variation of breeding pairs on tundra and of post-breeding migrants in the littoral zone for eight common shorebirds at Barrow. Both data sets are for the same four years 1975-1978. The amount of annual variability by species is weakly correlated between these two habitat periods. Species which vary widely in breeding densities tend to vary widely in post-breeding shoreline densities also. Furthermore the magnitude of variation is comparable in both habitat perids. Three species showed wider variation in breeding densities and five species showed wider variation in post-breeding densities. This does not necessarily imply a close relationship between shoreline densities and local breeding densities but may rather indicate consistent species differences in population dynamics over wider geographic areas.

Another indication of species differences in population dynamics is given by our correlation analyses of the relative abundances of different species between years at each of our sites. We find that breeding densities are correlated between years at Atkasook and at Barrow and post-breeding littoral densities are correlated between years at Barrow. The median dates of post-breeding movements in the littoral zone are also correlated between years. These correlations are not surprising however since they indicate nothing more than that some species are consistently more common than other species.

The degree of annual variation within a single species is shown in Figures 7 and 8A for Semipalmated Sandpiper densities on early summer tundra transects and on late summer littoral transects. In three out of four years the peak density recorded on the tundra occurred in early July as an early movement of post-breeding adults. On littoral transects the peak densities occurred in each year near the end of July as large numbers of premigratory juveniles foraged on mudflats, in saltmarshes and on the edges of lagoons.

To investigate the causes of this annual variation we looked for patterns in correlations between density measurements at different sites. Annual variation in post-breeding densities in the littoral zone was not correlated with variation in breeding densities at either the local Barrow tundra site or at Atkasook. This correlation might not be expected even if the post-breeding movement consisted primarily of local birds because breeding densities do not tell us all we need to know about productivity in each year; since the post-breeding littoral zone movement is composed primarily of juveniles of most species, annual variation in productivity might override annual variation in breeding density among local birds. However, coupled with our observations of shoreline movements of species which are particularly common at Barrow or at other sites along the coast, we conclude that annual variation in post-breeding

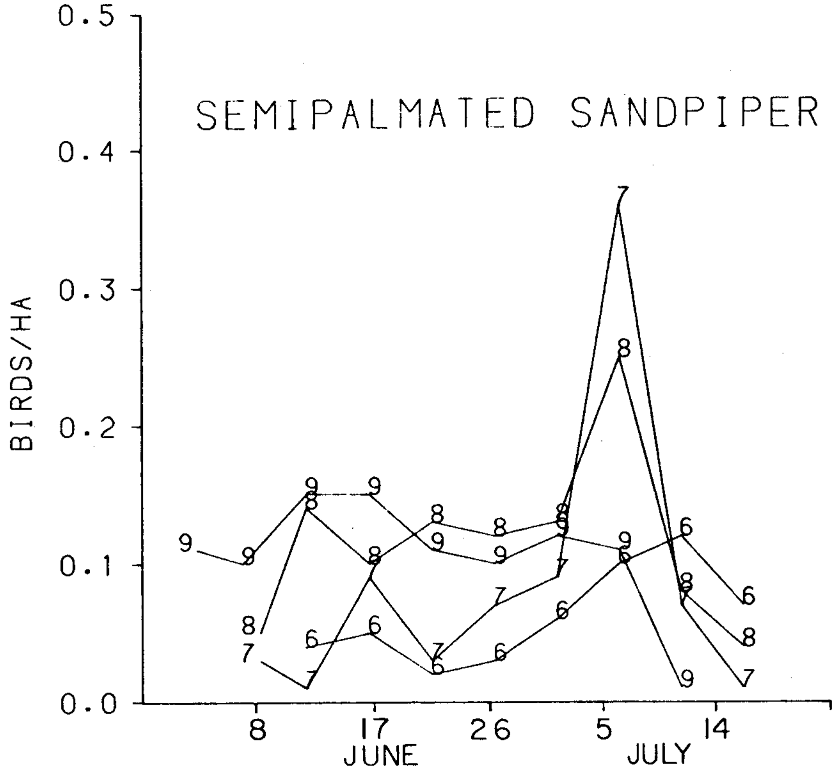

Figure 7. Annual variation in Semipalmated Sandpiper breeding season densities on tundra transects, 1976-1979.

migrant densities at Barrow reflects more than just local breeding density fluctuations. Birds foraging in the littoral zone at one site may be drawn from breeding areas distant from that site.

Correlations with temperature variation

We looked for relationships between shorebird densities and temperature in the following manner: we calculated the cumulative temperature deviation - the cumulative amount the temperature differs above or below the mean temperature for each date - for several periods of ornithological significance. This calculation separates years of warmer than average temperature from years of colder than average temperature for each period. Testing a large number of species against several temperature periods is likely to produce at least a few apparently significant correlations. In evaluating this matrix of correlations we looked for patterns of correlations exhibited by many species with temperature during a particular calendar period. Our objective criteria for this test required first a significant sign test over all species in one temperature period (almost all species with correlation coefficients of the same sign) and agreement in similar but overlapping calendar periods, that is, an insensitivity to the exact cutoff date chosen for

Table 5. Mean densities of common Barrow shorebirds.

	Tundra Breeding density		Littoral Post-breeding	
	Density[1]	C.V.[2]	Density[3]	C.V.
Golden Plover	.11	36	.02	74
Ruddy Turnstone	.05	42	.20	41
Semipalmated Sandpiper	.33	38	1.01	88
Pectoral Sandpiper	.33	106	.19	93
Baird's Sandpiper	.09	31	.13	29
Dunlin	.38	17	.89	53
Long-billed Dowitcher	.02	82	.27	97
Red Phalarope	.21	61	5.48	77

[1] Four-year mean of breeding adults (Myers and Pitelka, 1980).

[2] C.V. = coefficient of variation over four years.

[3] Four-year mean of mean densities on littoral transects during period 16 July - 29 August.

Table 6. Shorebird densities and temperature trends at Barrow: patterns across species.

Higher Temperatures During	Tundra Breeding Densities	Littoral Post-Breeding Densities	Post-Breeding Movement Median Date
Pre-breeding	--	--	--
Breeding	--	--	--
Post-breeding	--	Higher	Earlier

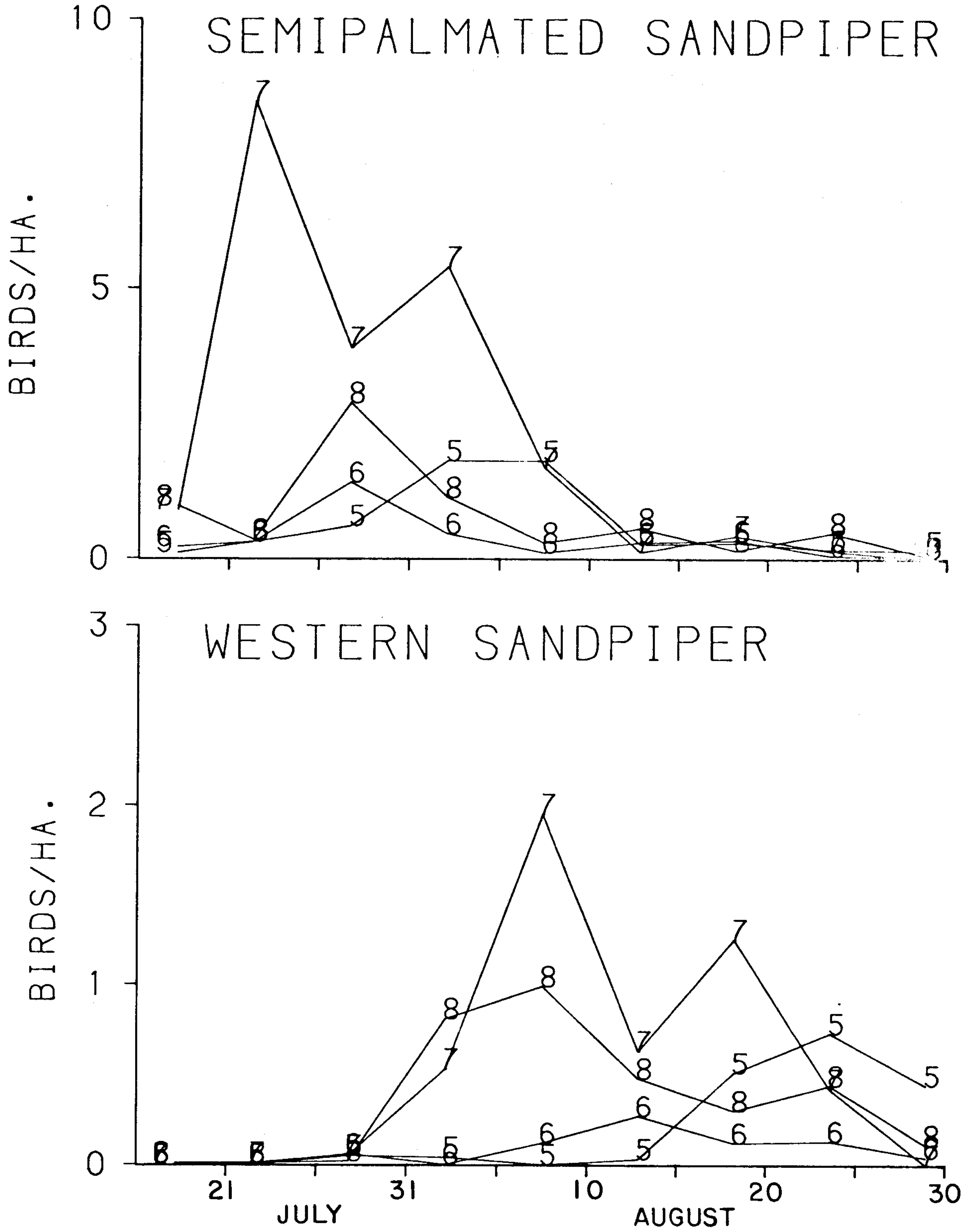

Figure 8. Annual variation in sandpiper post-breeding densities on littoral transects, 1975-1978.

our periods; and second, some individual species correlations which are significant at $p<.05$, with agreement in similar periods. Table 6 shows the only observed patterns of correlations between densities and temperature. We found no general correlation between early summer temperatures, which may determine the pattern of snow melt, and shorebird densities during any period. However, the magnitude and timing of post-breeding shoreline movements are correlated with post-breeding temperatures; in years of warmer than average late summer temperatures littoral zone densities are higher and migration peaks are earlier. It is surprising that post-breeding migrant densities are influenced more by late summer temperatures than by local breeding season temperatures, and this suggests that birds respond to conditions within the littoral zone during late summer. The numbers of birds available to use the littoral zone must already be determined before this period (by breeding densities and productivity), but the numbers which actually move to the littoral zone, the geographic distribution of birds along the coast within the littoral zone, or the turnover rates of individuals migrating within the littoral zone might be involved in this effect. The significance of changes in turnover rate on population estimates was discussed earlier.

Species comparisons

Comparisons of annual variation among species also suggest that conditions in the late summer littoral zone affect the densities of migrant birds. Figure 8 shows annual variation in littoral post-breeding densities for two ecologically similar species, Semipalmated and Western Sandpipers. The correspondence of these two sets of data is remarkable in magnitude, shape and timing in spite of huge annual fluctuations. It also suggests that these fluctuations are not random; there must be some environmental variation affecting both species similarly. We can compare variation in the two species graphically by expressing each year's cumulative density as a percent of the four year total, Figure 9. Similarly, Figure 10 displays a high correspondence of variation in densities of Pectoral Sandpiper and Dunlin with Semipalmated Sandpiper. These three species, with Western Sandpiper, form a group of species whose numbers fluctuate similarly from year to year. Red Phalaropes and Ruddy Turnstones comprise another group with numbers displaying a different pattern of annual variation. We conclude that these groups of species respond similarly to annual variation in some undetermined environmental factors.

We wish to test whether these species which fluctuate similarly year to year are associated through some aspect of their ecology during the breeding or post-breeding seasons, since this might provide a clue to the environmental mechanism which relates to these fluctuations. We classify all common Barrow shorebirds by breeding habitat on the basis

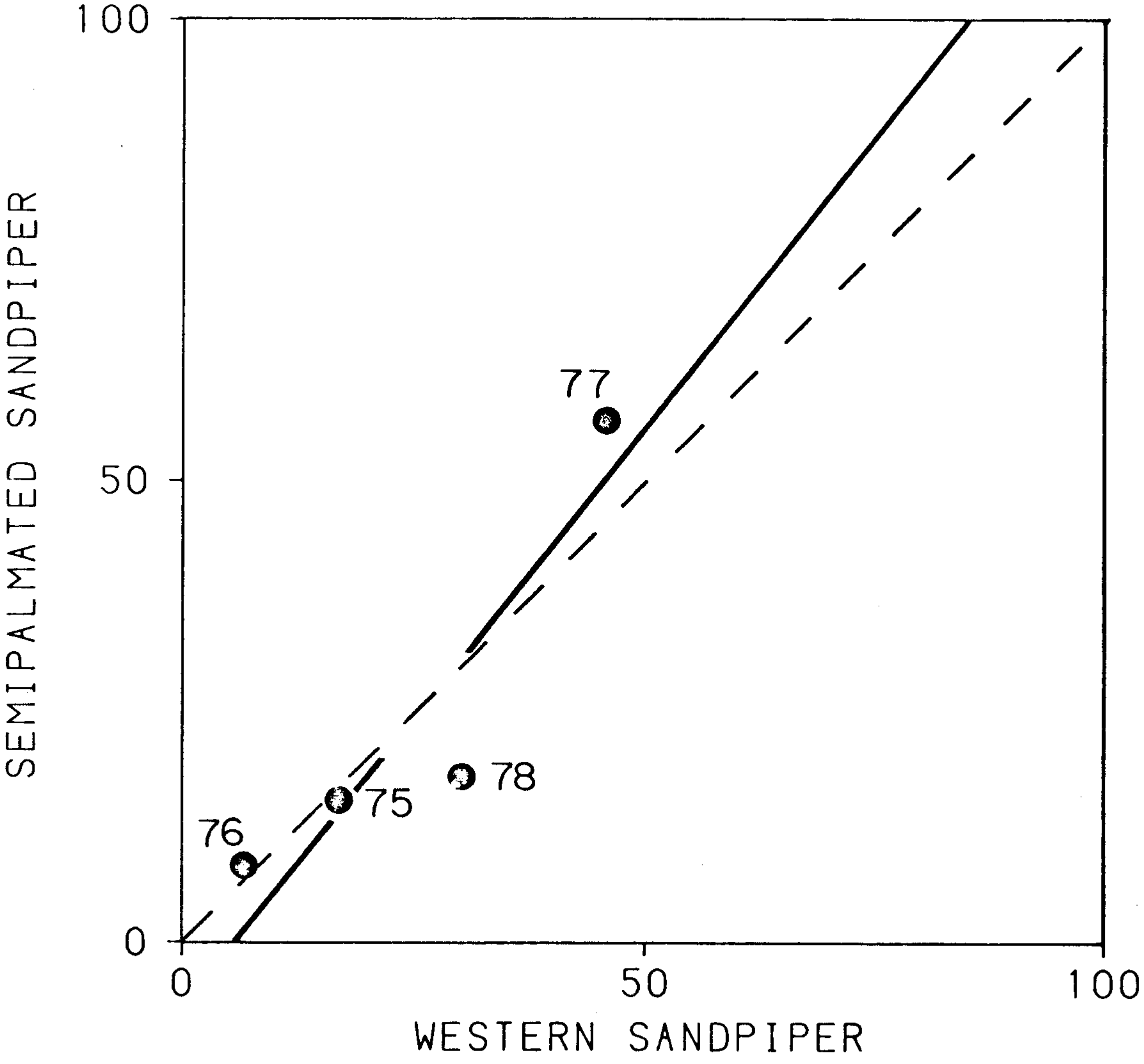

Figure 9. Per cent of 4-year cumulative density during post-breeding period on littoral zone transects, 1975-1978.

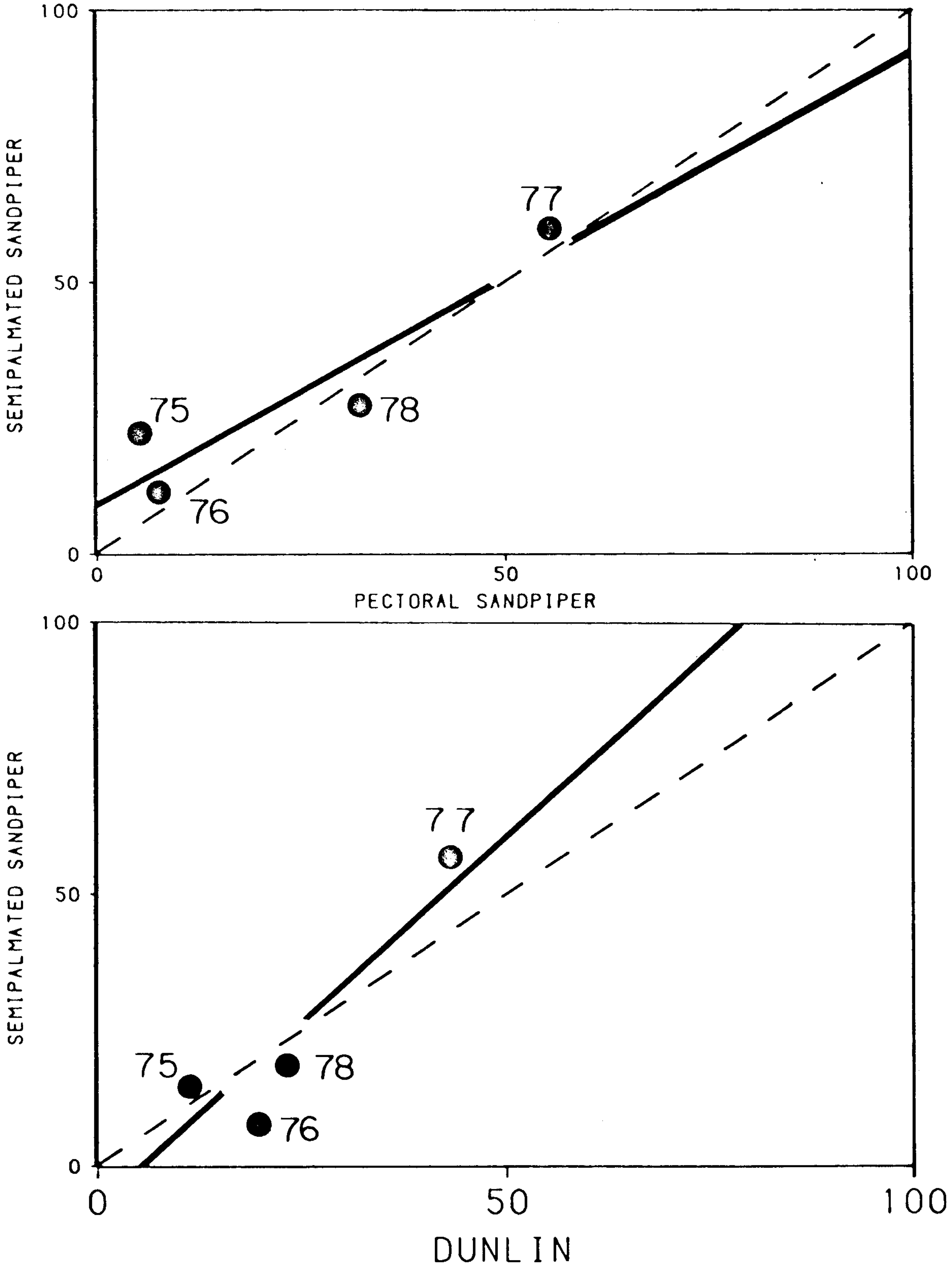

Figure 10. Per cent of 4-year cumulative density during post-breeding period on littoral transects, 1975-1978.

of habitat studies by Myers and Pitelka (1980) and again by post-breeding habitat on the basis of our results discussed below (Table 7). If we consider all pairs of species which show correlations in annual variation in post-breeding numbers (Table 8), we find that species which fluctuate similarly in the littoral zone do not in general share the same breeding habitats (p=.14). They do however occur together in the same post-breeding habitats (p<.005). This implies a connection of some sort through conditions in the littoral zone during the post-breeding period. We have also shown a relationship between post-breeding density and temperature during the post-breeding period which bolsters this conclusion.

What sort of affect can this be? Since it occurs after the birds have left the tundra, it is unlikely to be mediated through changes in breeding productivity, but post-fledging survival once birds reach the littoral zone may be involved. Differences in weather stress or in foraging profitability, through variable prey conditions, storm water levels or other habitat changes during or before this period may be responsible. These might affect the survival of individuals, the geographic movements of birds over local or large areas, or the length of time individuals remain in one area during migration. Environmental perturbations in these littoral habitats, such as might accompany oil development, will be expected to produce density fluctuations in species groups of migrant shorebirds, not just individual species.

Table 7. Seasonal habitat groups of common Barrow shorebirds.

Breeding Habitat Groups

Lowland Tundra	Upland Tundra
Pectoral Sandpiper	Golden Plover
Red Phalarope	Ruddy Turnstone
Northern Phalarope	Semipalmated Sandpiper
	Western Sandpiper
	Baird's Sandpiper
	Dunlin

Post-Breeding Habitat Groups

Gravel Beaches	Littoral Flats, Lagoon Edges
Ruddy Turnstone	Golden Plover
Sanderling	Semipalmated Sandpiper
Red Phalarope	Western Sandpiper
	Baird's Sandpiper
	Pectoral Sandpiper
	Dunlin
	Long-Billed Dowitcher
	Northern Phalarope

Table 8. Species - pair correlations of annual variation in post-breeding densities.

	Breeding	Post-Breeding
Within Habitat Groups	6	18
Between Habitat Groups	12	2
X^2 - Test	$P = .14$	$P<.005$

HABITAT STUDIES

We approached the important questions of shorebird habitat use on four different habitat levels. First, the broad division of tundra vs. littoral habitats determines some limits to exposure of each species to developments concentrated offshore or onshore. Second, we focused on activities in the littoral zone and grouped littoral transects into three general habitat categories. We evaluated the relative use of these three habitat groups for each species, since development effects within different littoral habitats will vary by species. Third, using 6 variable descriptions of each 50 meter by 50 meter plot, we examined the responses of species to these more detailed descriptions of littoral zone habitats and were able to relate in the same habitat space transects at geographically different sites. Finally, we examined the foraging habitat preferences on a microhabitat scale for several species.

Tundra vs. littoral habitat

Species vary widely in their relative use of these two major habitat classes during breeding aand post-breeding periods. Red Phalaropes (Figure 11 A,B) nest on the tundra but move to shorelines as breeding activities finish in successive waves of adult females, adult males, and finally juveniles. Peak densities in littoral habitats are many times higher than on the tundra. Other species such as American Golden Plover, (Figure 12A) are almost restricted to tundra habitats throughout the season. This difference in habitat selection should have a marked effect on the relative susceptibility of these two species to potential effects of offshore oil development. Phalaropes may be extremely sensitive to oil spills which would have almost no effect on Golden Plover populations. Other species show intermediate patterns. Dunlins (Figure 12B) shift from tundra to littoral habitats in late summer, but not to the same extent as Phalaropes. Adults remain at Barrow throughout August and early September and both juveniles and adults occur on tundra as well as littoral habitats. Semipalmated Sandpipers (Figure 35) show a fourth pattern utilizing some littoral habitats (slough edges and littoral flats) during the breeding season where these occur in the vicinity of tundra nesting sites. Use of littoral habitats increases with late summer but this species remains common on tundra as well.

We have classified the common Barrow shorebirds into four categories based on seasonal differences in the relative use of these two habitat classes (Table 9). These are general patterns which tend to gloss over distinctions between species within groups but they indicate some of the major differences in seasonal habitat use patterns which result in differences in species susceptibility to oil development. As another step in this process we have calculated the relative littoral zone use, taking into account the differences in areal extent of these habitats in the Barrow vicinity for each of the species (Figure 13;

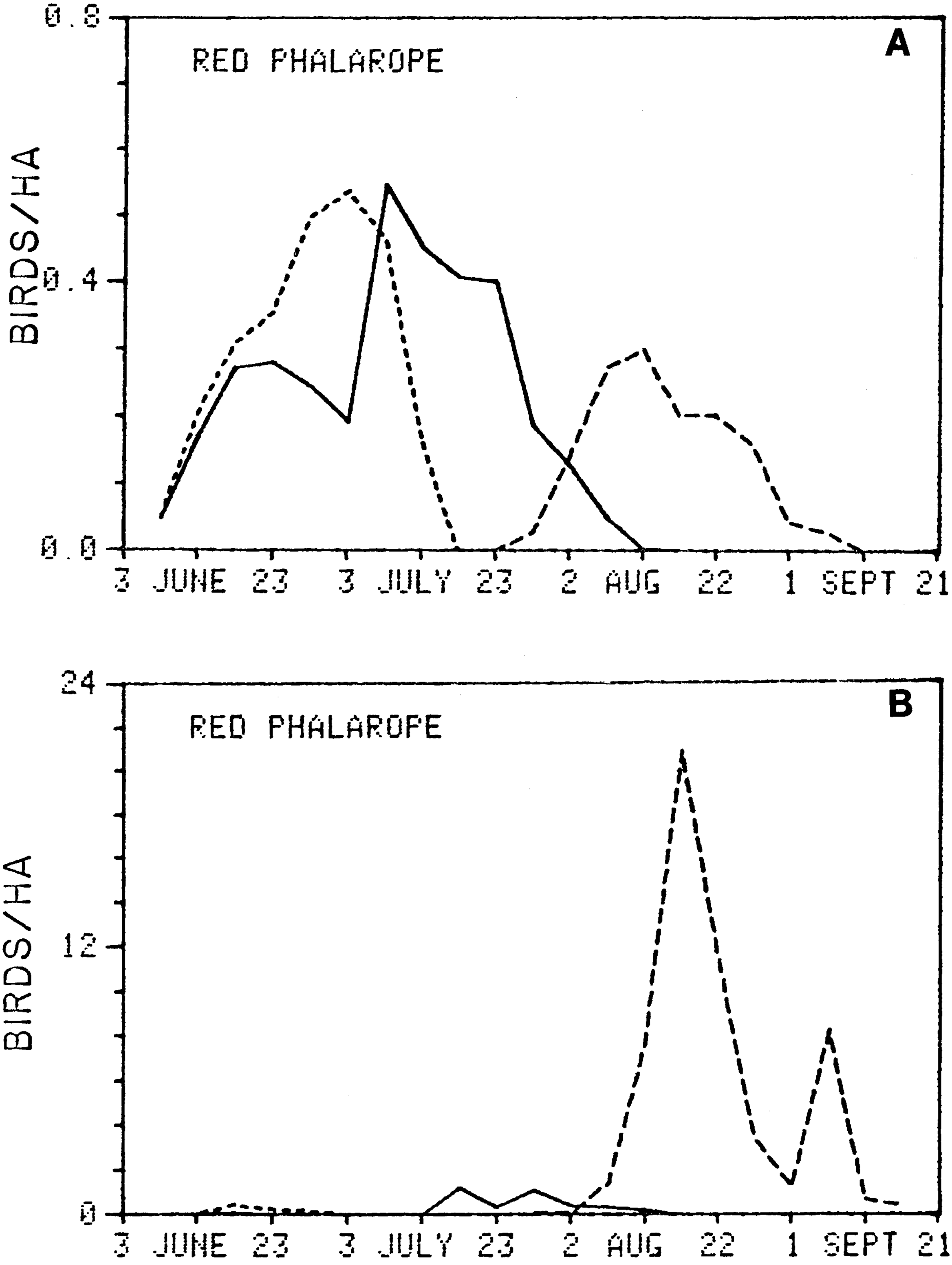

Figure 11. Red Phalarope densities on (A) tundra transects, (B) littoral transects. Short dash line, adult females; solid line, adult males; long dash line, juveniles. Note difference in scales.

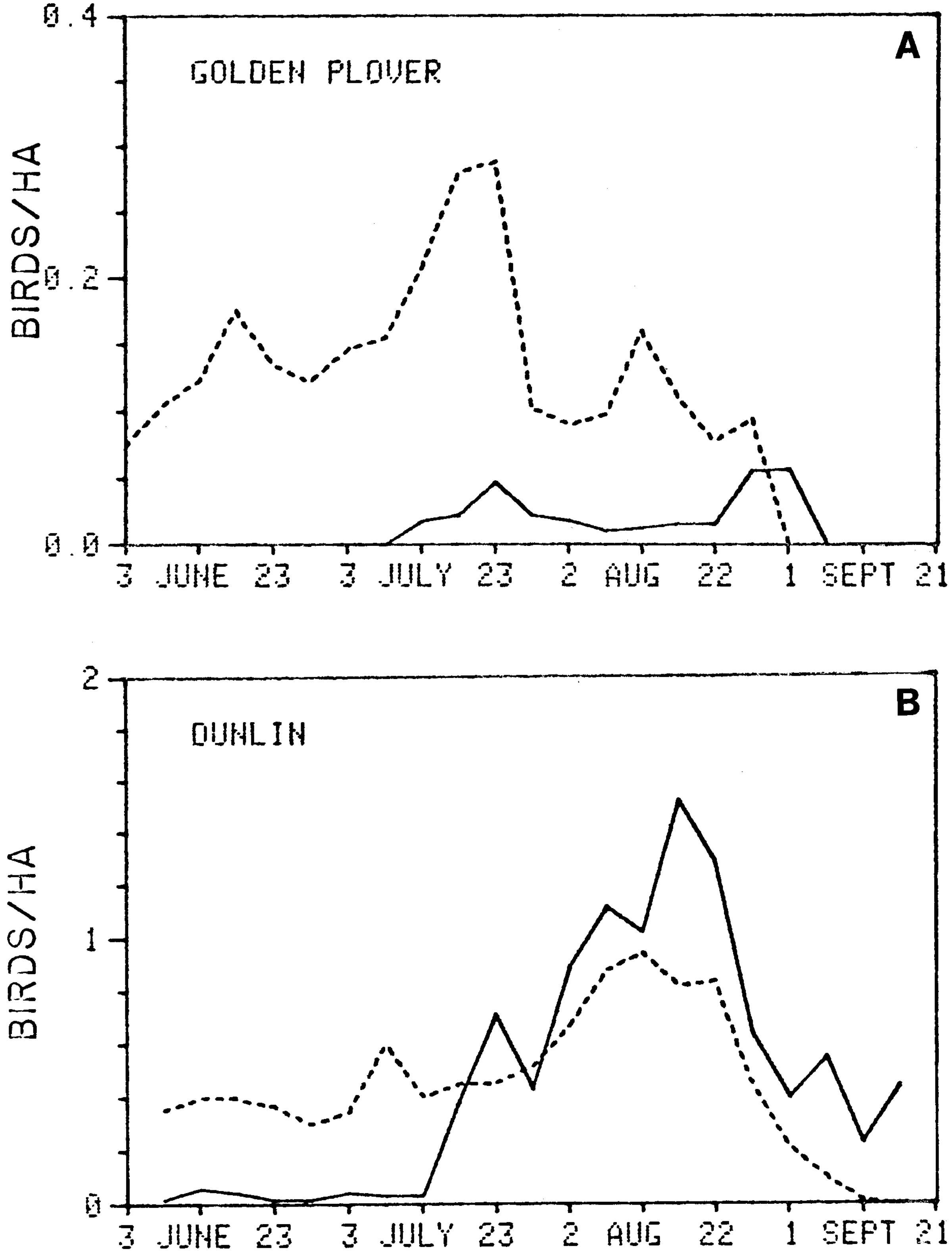

Figure 12. Densities of (A) American Golden Plover and (B) Dunlin on tundra transects (dashed line) and littoral transects (solid line).

Table 9. Seasonal habitat use patterns of common Barrow shorebirds. (T = Tundra; L = Littoral).

Category	Breeding	Post-breeding Adult	Post-fledging Juvenile	
I	T	T	T	Golden Plover, Pectoral Sandpiper
II	T	T+L	T+L	Dunlin, Long-billed Dowitcher
III	T+L	T+L	T+L	Western, Semipalmated, Baird's Sandpipers
IV	T	T+L	L	Red Phalarope, Ruddy Turnstone, Sanderling

Table 10. Principal component correlations for the habitat variables. Correlation coefficients and per cent of total variance associated with first and second principal components.

VARIABLE	PC I	PC II
DSHORE	.91	-.20
NORFLZ	.79	-.07
MAXFLZ	.75	-.49
WATCOV	-.76	.32
SUBSTR	-.66	-.70
VEGCOV	.67	.59
TOTAL VARIANCE	58.1	78.8

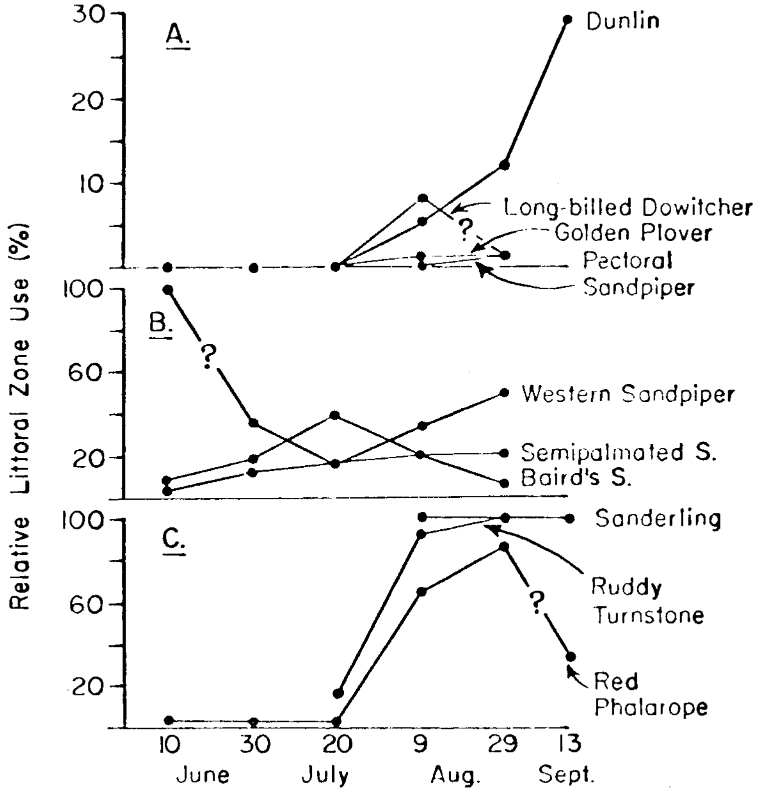

Figure 13. Relative use of littoral habitats by shorebird species in the Barrow area. (A) includes species from categories I and II, Table 9; (B) corresponds to category III, (C) to category IV.

Connors et al., 1979). These patterns in relative littoral zone use agree with the four categories of habitat use patterns listed in Table 9.

Littoral habitat groups

The principal components analysis based on six habitat variables assigned to each 50 meter by 50 meter square plot on each transect produced results shown in Table 10. The correlations indicate that the first principal component (PC I) should be interpreted as separating gravel beaches and lagoon and slough edges from mudflats and saltmarshes. PC II further separates gravel beaches from lagoon and slough edges. This produces groupings in a newly formed habitat space which correspond to the three categories - gravel beach, slough edge and littoral flat - into which we have subjectively grouped our transects (Figure 14). Although overall agreement between the two grouping systems is high, a few transects appear misplaced. In particular, the transect BMW, denoted by an asterisk in Figure 14, is classed as a lagoon edge transect in our analyses because of its location on the shore of Middle Salt Lagoon, an almost closed lagoon

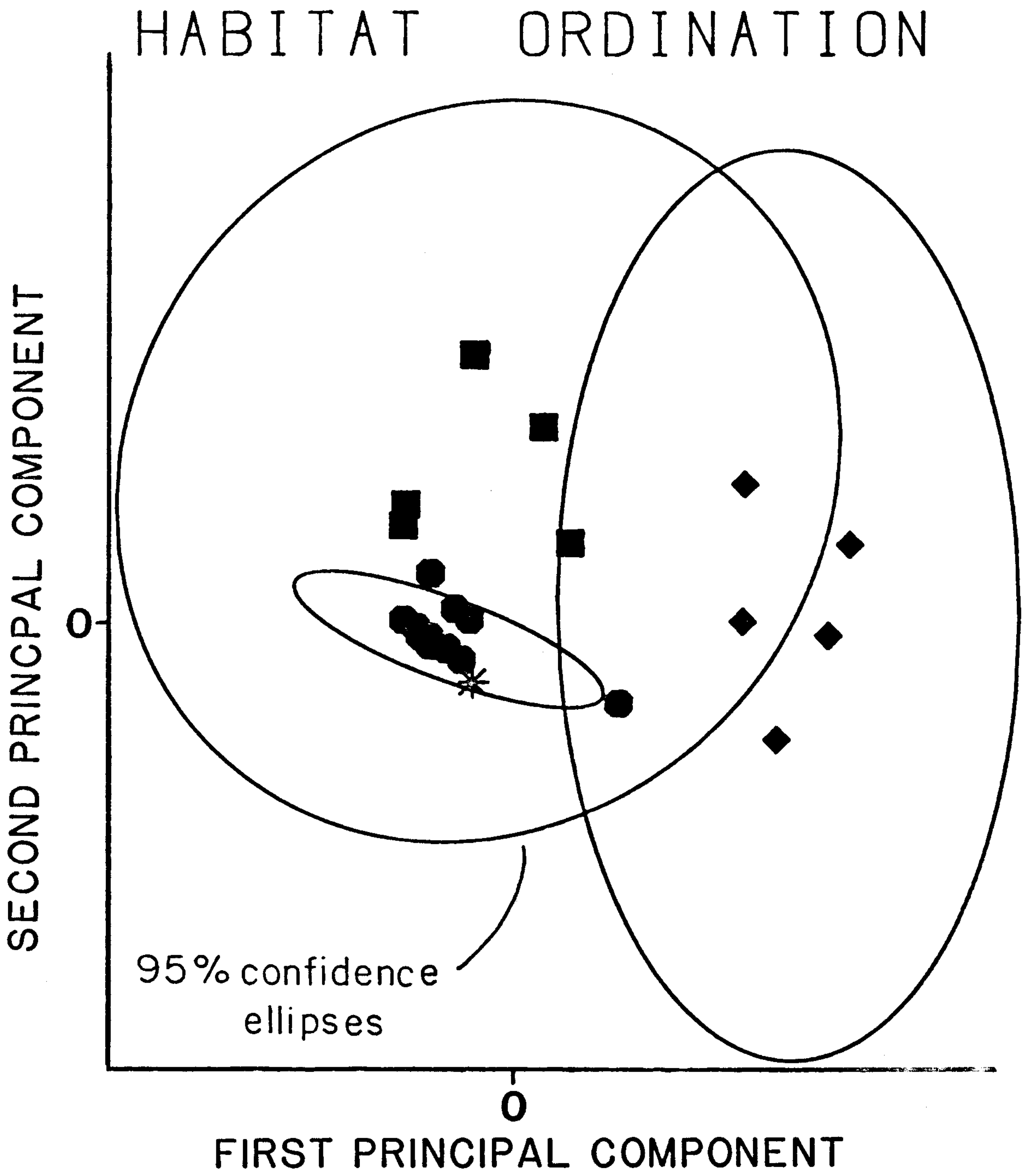

Figure 14. Locations of Barrow transects in principal component littoral habitat space. Gravel beaches (octagons), littoral flats (diamonds), and slough edges (squares). Asterisk denotes transect BMW. See text.

of 1.3 kilometer diameter at Barrow (Figure 2). In spite of this topographic feature, however, the habitat description variables do not distinguish it from a gravel beach because it is located near the mouth of the lagoon close to the inner edge of the wide gravel beach ridge. In fact, as will be noted below, several species responded to this transect and to the other middle salt lagoon transect (MSE) in a manner indicating intermediacy between gravel beaches and lagoon edges. Thus these transects show characteristics of both lagoon and marine beaches in physical description as well as in bird use.

The principal advantages of this habitat classification procedure are that it allows us to quantify aspects of habitat descriptions which otherwise remain too subjective for further analysis and that the procedure can be easily applied by field workers at other arctic sites. Assigning variables does not require extensive training. Multivariate techniques can then place newly described transects in habitat space with known transects for which bird density data are available. This permits comparison of areas studied by different researchers and may allow prediction of expected bird densities based only on habitat descriptions and geographic locality.

The essential question concerning these analyses is: do birds respond to the differences in habitats which we have described? They do, as is shown by the next two sets of analyses. Using as our data base the presence or absence of each of the thirty-one most common species on our transects (Table 11), we used a principal coordinate analysis (Gower, 1966) to separate transects in each of the four years on the basis of which species occurred on them (Figure 15). In interpreting these figures, changes in the position of transects between years is irrelevant. Concentrating on the relative positions of transects within each year, we find that in each year gravel beach transects cluster quite separately from other transects. The distinction between littoral flat and slough edge transects is less clear, however, suggesting that many of the same species utilize both groups of habitats. As mentioned above, the lagoon transect BMW (1976, 1977, 1978) is classified on the basis of species occurrence as somewhat intermediate between gravel marine shores and other lagoon edges. The details of arrangements within groups also suggest other distinctions made by the birds. Gravel beach transects along the mainland shore always cluster somewhat differently than the gravel shores along Barrow Spit (BCS in 1975; BCS, BCN, BBD in 1976 and 1977; BCS, BCN, BBD, BBV in 1978). These analyses show clearly that species occurrence varies among habitats and that groups of species apparently respond to habitat differences which are correlated with the variables we have measured. It also suggests that on the basis of species occurrence alone, the similarities between littoral flats and lagoon and slough edges are greater than between these habitat classes and gravel beaches.

Table 11. Common bird species on littoral transects during four post-breeding seasons at Barrow, Alaska.

COMMON NAME	SCIENTIFIC NAME	SPECIES CODE
Yellow-billed Loon	*Gavia adamsii*	YBLO
Arctic Loon	*Gavia arctica*	ARLO
Red-throated Loon	*Gavia stellata*	RTLO
Black Brant	*Branta bernicla*	BLBR
Pintail	*Anas acuta*	PINT
Oldsquaw	*Clangula hyemalis*	OLDS
Steller's Eider	*Polysticta stelleri*	STEI
King Eider	*Somateria spectabilis*	KIEI
Semipalmated Plover	*Charadrius semipalmatus*	SEPL
Golden Plover	*Pluvialis dominica*	GOPL
Ruddy Turnstone	*Arenaria interpres*	RUTU
Pectoral Sandpiper	*Calidris melanotos*	PESA
Baird's Sandpiper	*Calidris bairdii*	BASA
Dunlin	*Calidris alpina*	DUNL
Semipalmated Sandpiper	*Calidris pusilla*	SESA
Western Sandpiper	*Calidris mauri*	WESA
Sanderling	*Calidris alba*	SAND
Long-billed Dowitcher	*Limnodromus scolopaceus*	LBDO
Red Phalarope	*Phalaropus fulicarius*	REPH
Northern Phalarope	*Lobipes lobatus*	NOPH
Pomarine Jaeger	*Stercorarius pomarinus*	POJA
Parasitic Jaeger	*Stercorarius parasiticus*	PAJA
Long-tailed Jaeger	*Stercorarius longicaudus*	LTJA
Glaucous Gull	*Larus hyperboreus*	GLGU
Black-legged Kittiwake	*Rissa tridactyla*	BLKI
Sabine's Gull	*Xema sabini*	SAGU
Arctic Tern	*Sterna paradisaea*	ARTE
Black Guillemot	*Cepphus grylle*	BLGU
Snowy Owl	*Nyctea scandiaca*	SNOW
Lapland Longspur	*Calcarius lapponicus*	LALO
Snow Bunting	*Plectrophenax nivalis*	SNBU

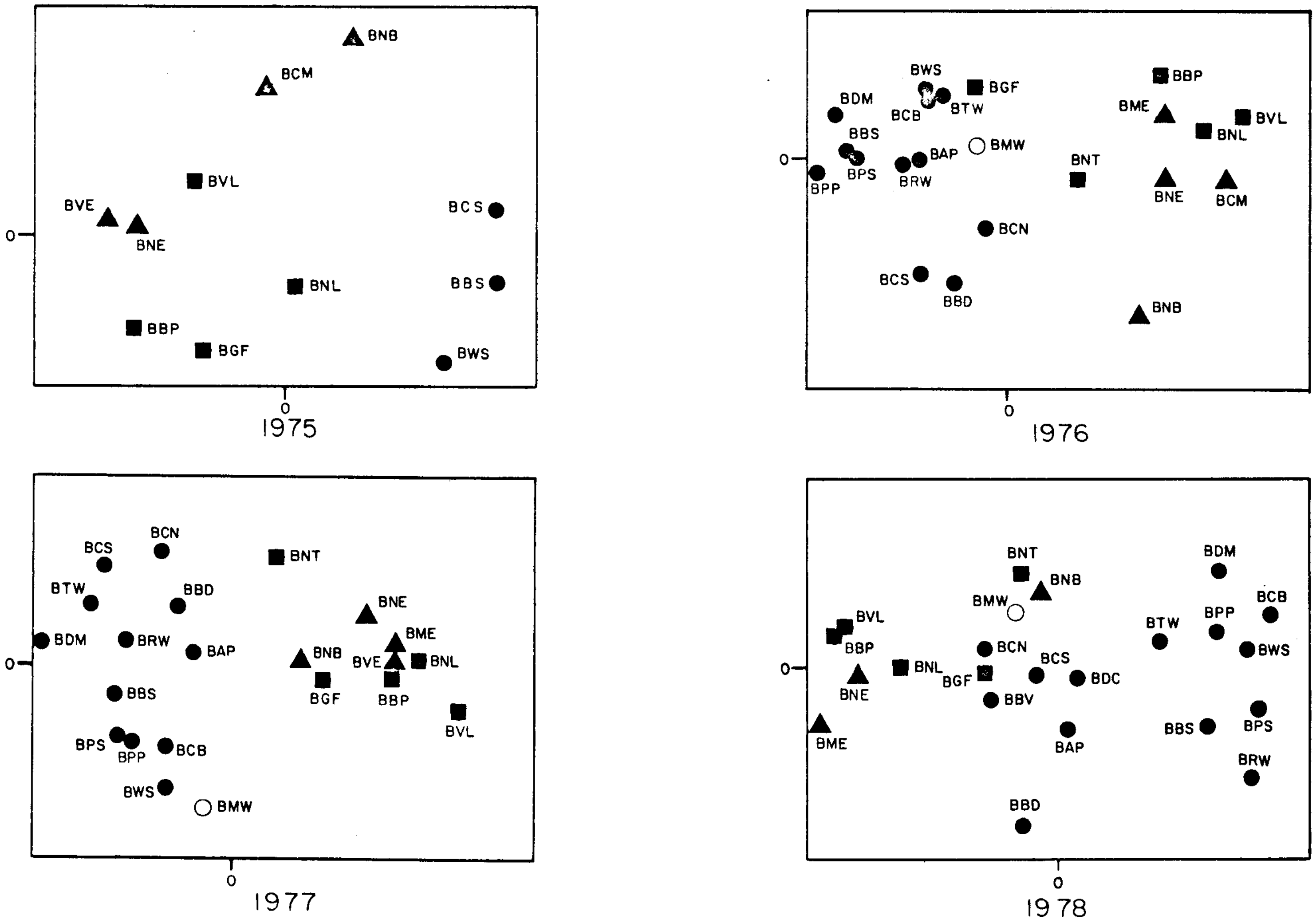

Figure 15. Ordination of transects according to birds species occurrence. Gravel beach transects (closed circles), littoral flats (squares), slough edges (triangles), beach-like lagoon transect (open circle). See text.

We can also ordinate all of the species according to which transects they occur on during each year (Figure 16). These plots are more obscure but groups of species showing similar habitat use can be distinguished and these tend to be consistent from year to year. Among shorebirds, Red Phalarope and Ruddy Turnstone occur together in each of four years and these are joined by Sanderling in 1975 and 1976. The two passerines, Lapland Longspur and Snow Bunting, show very close correspondence in the three years they were censused. A cluster of sandpipers (Semipalmated, Western, Pectoral, Baird's and Dunlin) usually occur close together. Among other groups, the jaegers show a similar habitat distribution in most years, as do the loons.

Species details of habitat use

Considering the habitat space defined by our principal component analysis (Figure 14) we can assign values to cells of that space representing the relative density of use by each species for habitat represented by that cell in habitat space. We display the results for a few species in Figure 17. This gives a detailed look at the differences in distribution of use within habitat space for each species. The relative heights of peaks indicate the relative use of different areas of habitat space. Zero height can indicate total absence of the species from a cell in habitat space, or lack of a transect sampling that cell. Regions characterized by gravel beaches (G), littoral flats (F), or slough edges (E) are indicated. Semipalmated and Western Sandpipers, two ecologically similar and closely related species, display similar general patterns differing in the relative height of just a few peaks. Both species occur in very low densities on gravel beaches and much higher densities on littoral flats and slough edges. Red Phalaropes show a markedly different pattern, occurring in high densities on gravel beach transects. Dunlins show an intermediate pattern.

The next series of plots demonstrates annual variation in patterns for three species (Figures 18, 19, 20). In this case the densities are expressed as deviations from the mean density; areas of lower than average use occur as depressions in the plain of habitat space. The many details of these plots are not critical to our discussion but a few points are important. In general, we can say that there is variation from year to year within a usually consistent species pattern. In all four years Red Phalaropes (Figure 18) show a distribution of habitat use markedly different from the other two species displayed. However, variation from year to year within a species can be large. For both Semipalmated Sandpiper and Dunlin (Figures 19 and 20), 1977 appeared to be an unusual year in terms of habitat use. Both species showed patterns in that year which are distinct from the other 3 years. However, the patterns for these two species in 1977 are remarkably similar. Dunlins in 1977 occurred in habitats more similar to those used by Semipalmated Sandpipers in 1977 than to those used by Dunlins in other years. This suggests

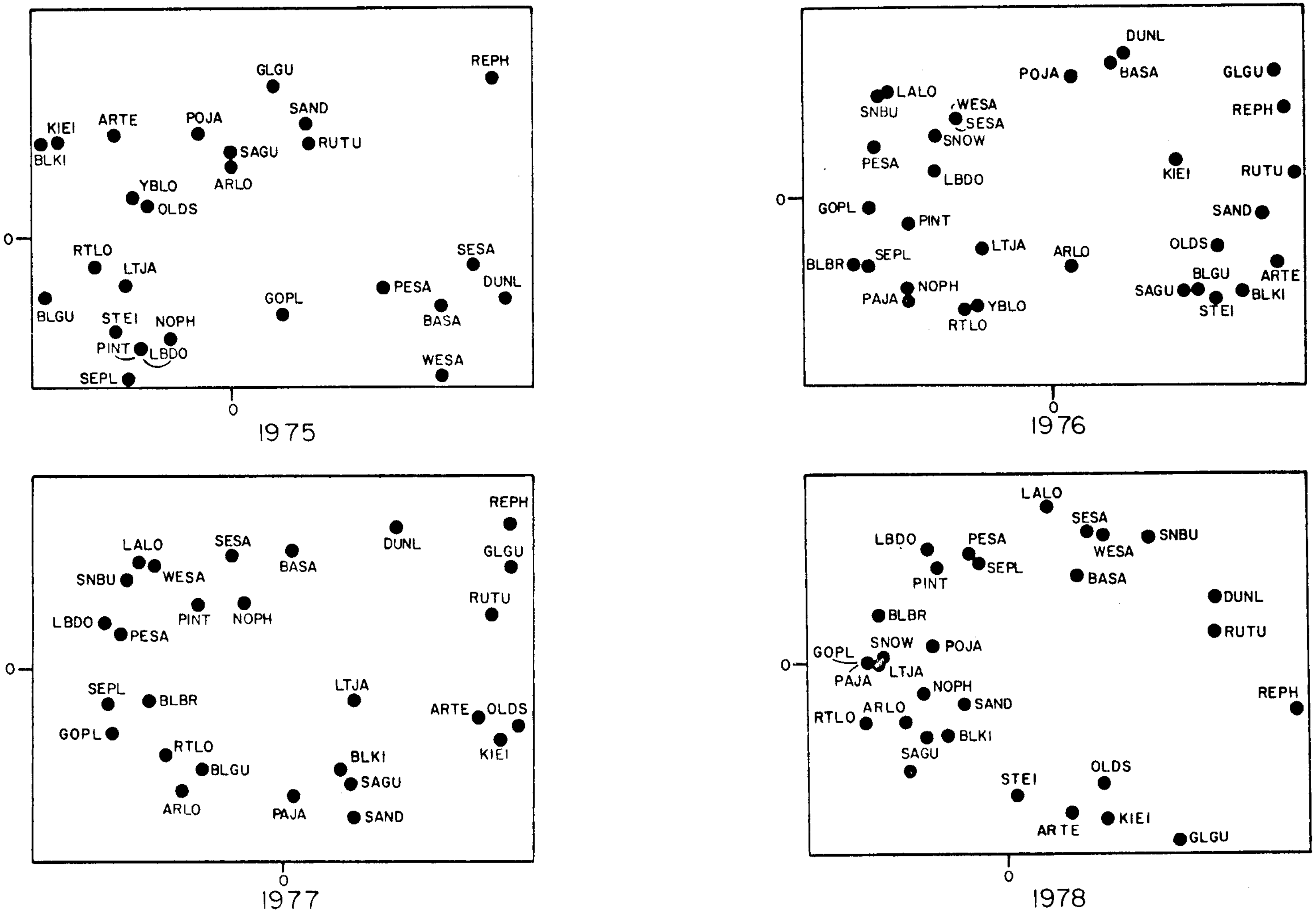

Figure 16. Ordination of species (Table 11) according to transect occurrence. See text.

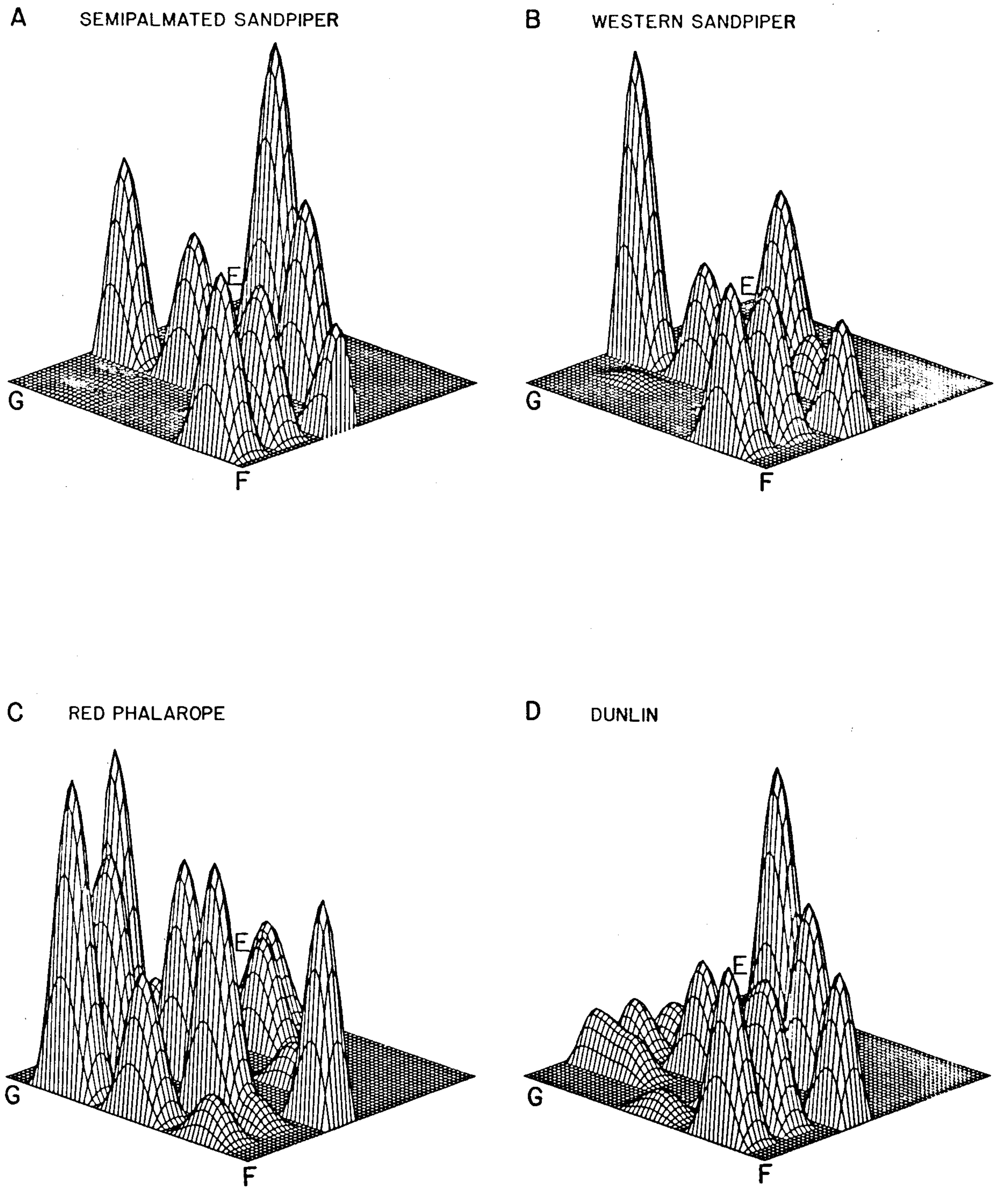

Figure 17. Littoral zone habitat use patterns of 4 species. Plane represents principal component habitat space of Figure 14. Gravel beach (G), littoral flat (F), slough edge (E).

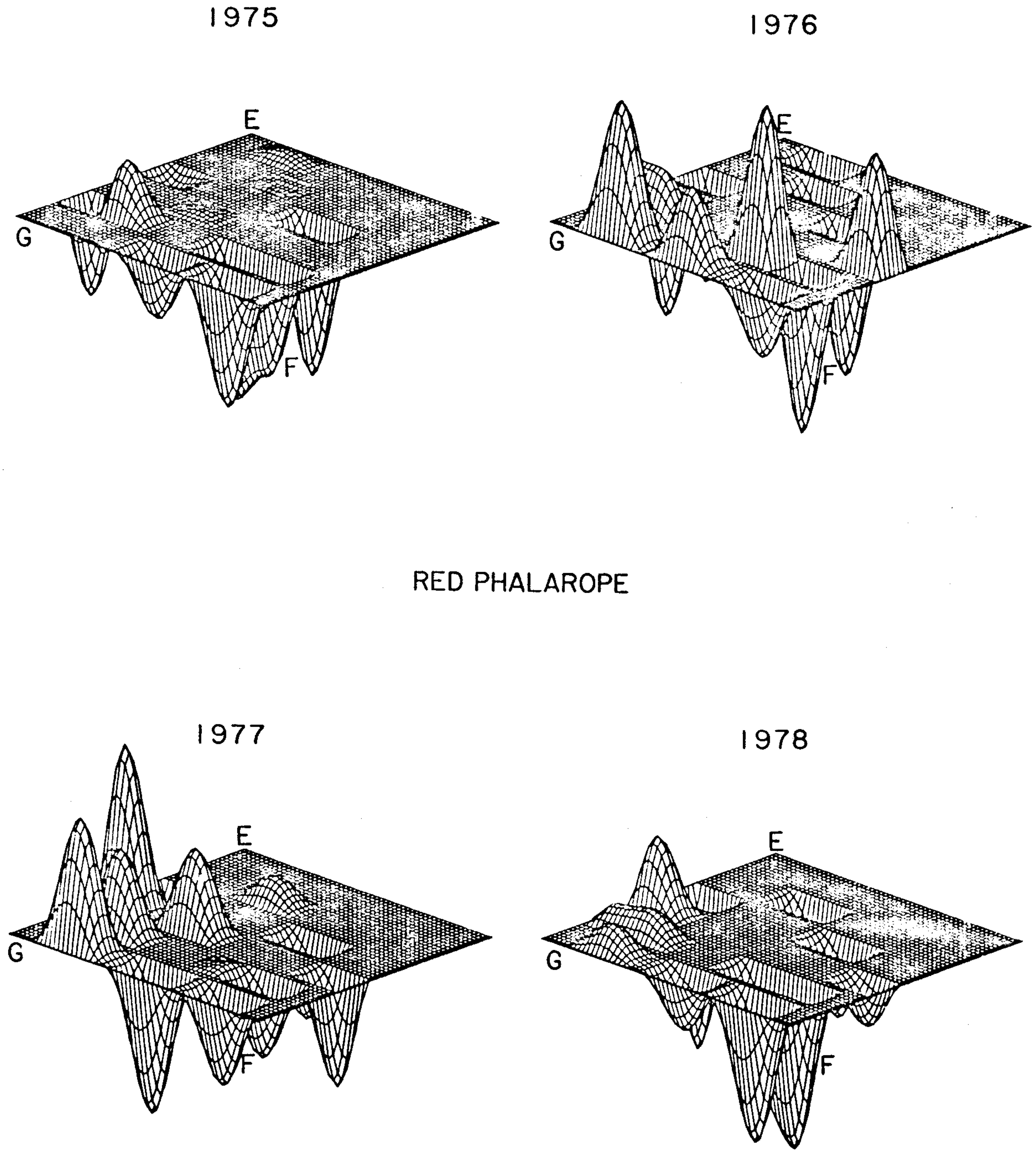

Figure 18. Annual variation in littoral habitat use. Plane represents principal component habitat space of Figure 14. Peaks above and below plane represent cumulative bird dinsities above or below mean densities over all habitat space.

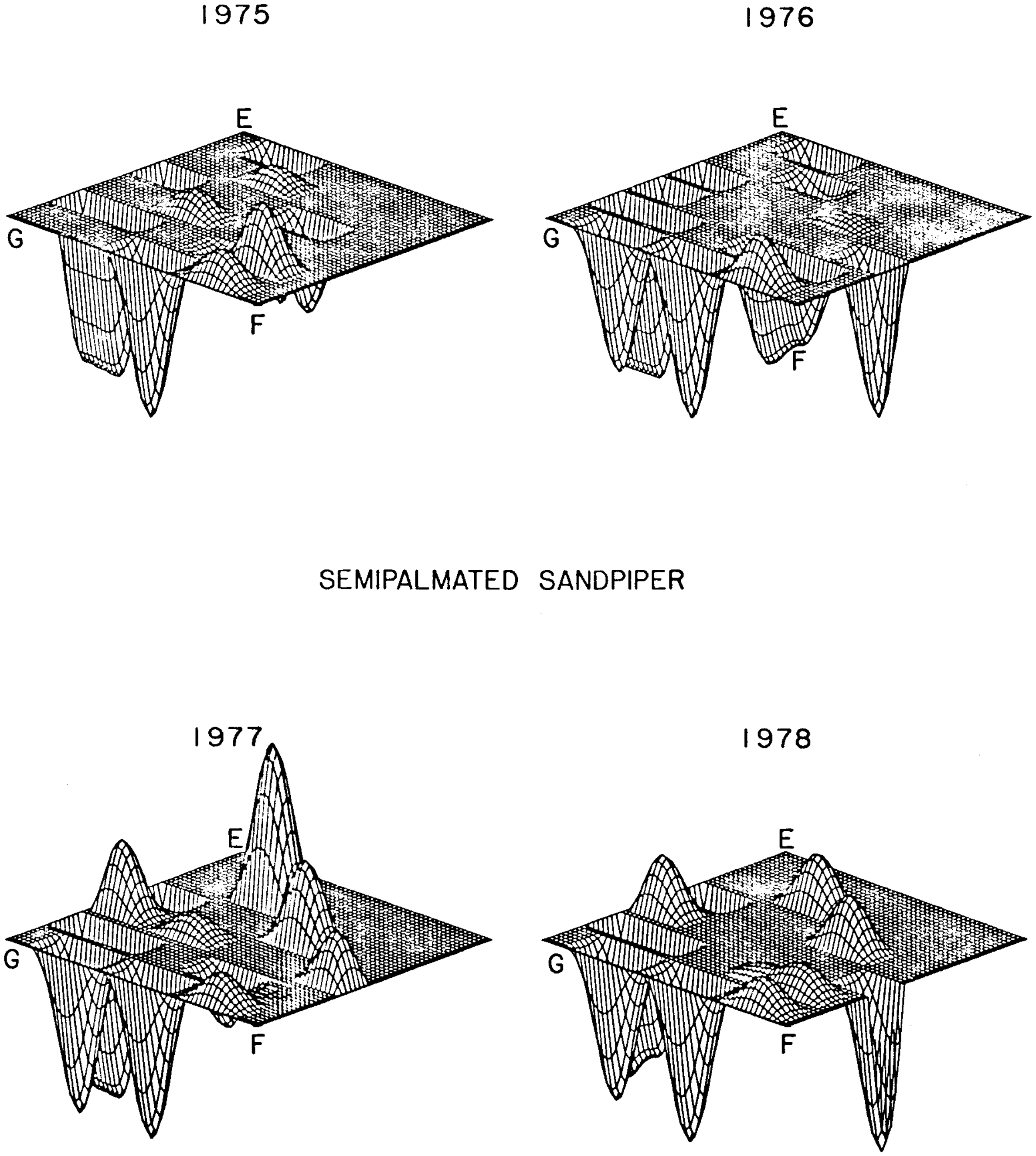

Figure 19. Annual variation in littoral habitat use. See Figure 18.

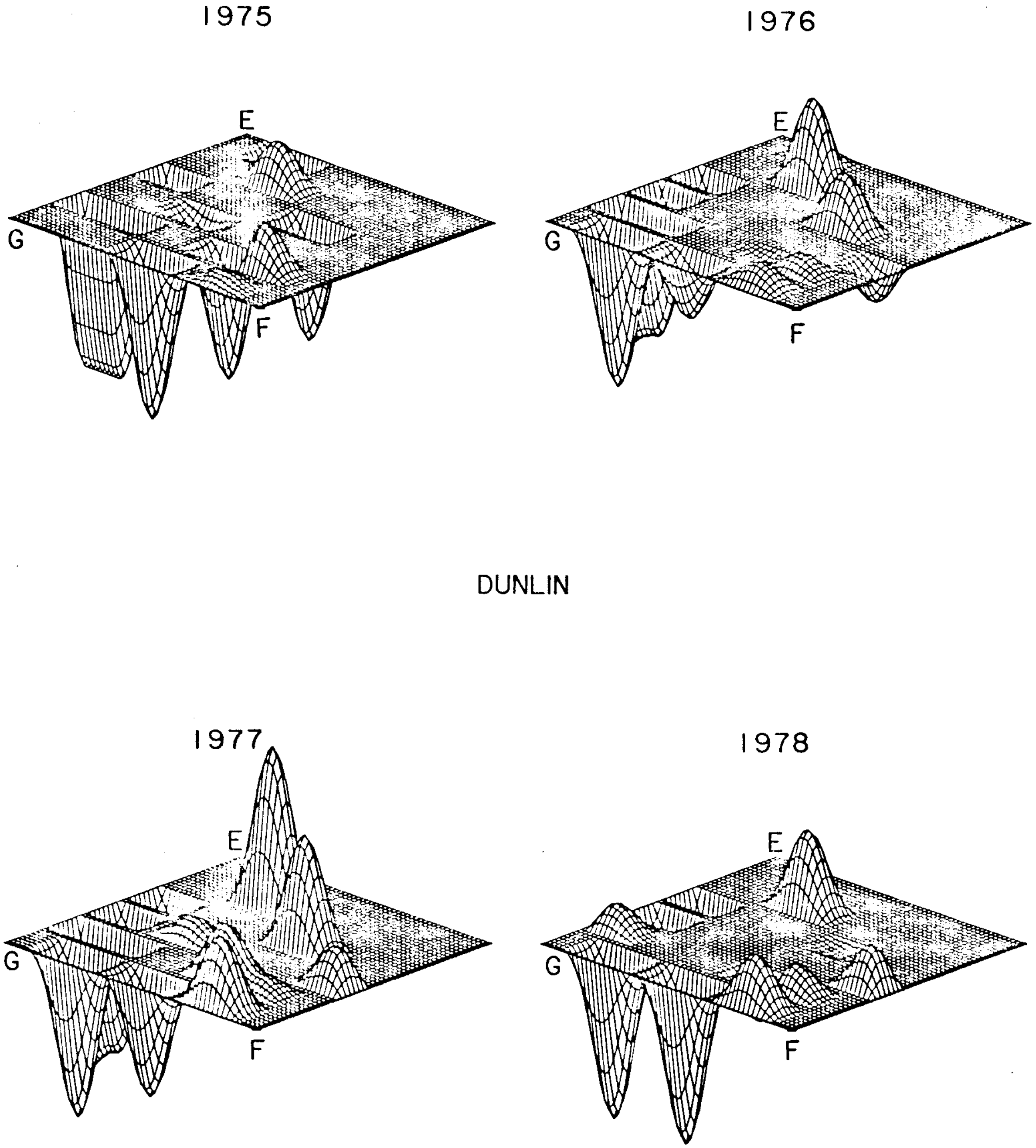

Figure 20. Annual variation in littoral habitat use. See Figure 18.

that variability in species habitat use patterns from year to year occurs in response to environmental conditions, such as water levels or availability of prey species of different types. If both species have similar prey items (discussed below) and prey conditions vary drastically from year to year, both species can be expected to alter their habitat selectivity or foraging behavior. In the event of an oil spill greatly altering foraging conditions, several species might shift their habitat use patterns to take advantage of alternate food sources. This apparent flexibility of species with respect to habitat preferences may bode well in the event of environmental perturbations, but it may also indicate a sensitivity of species to changes in trophic conditions under the influence of natural fluctuations.

Foraging microhabitat preferences

The results of microhabitat foraging measurements on 1210 individuals of nine species of Barrow shorebirds were presented in Connors and Risebrough (1977). To briefly summarize these results, factor analysis of the six microhabitat variables (see Methods) separated species along microhabitat gradients. Table 12 presents ordered lists of species on each of the first two factors running from positive to negative scores. The lines to the left of each ranking show groups of species defined along each gradient using a Tukey B *a posteriori* multiple comparison test: each line brackets a set of species whose mean values are not significantly different at the .05 level. Factor 1 is correlated most closely with distance to water's edge and water depth. Long-billed Dowitcher and Red Phalarope forage in significantly deeper water than any of the other species. Factor 2 shows a positive correlation with grain size and a negative correlation with bill penetrability, indicating that Sanderlings, Ruddy Turnstones and Red Phalaropes forage in habitats with large grain size and low bill penetrability compared to the other groups of species shown. These species groupings, especially along Factor 2, agree with groupings of species by habitat preference on the broader scales discussed above. The significance of this microhabitat analysis for assessing species susceptibilities to oil-related damage lies in the probability that a species' preferred microhabitat will be affected by oil spillage, either directly through the presence of oil or indirectly through detrimental effects on the food chain. We assume that preferred microhabitats below the water line are more suseptible than those above, at least to damage from oil spills transported on the water. The oil's distribution will be controlled by water transport and thus will spread only as far as water carries it. Second, we assume that increasing grain size indicates increased exposure to wave action. This means that sites characterized by large grain size are more likely to be impacted because of the increased rate of water transport in these areas. However, the duration of impact may be less than in areas of smaller grain size once the latter are hit, for the same

Table 12. Shorebird rankings along microhabitat gradients. Lines bracket groups with similar factor scores.

Factor I	Factor II
Long-billed Dowitcher	Sanderling
Red Phalarope	Ruddy Turnstone
Pectoral Sandpiper	Red Phalarope
Dunlin	Dunlin
Western Sandpiper	Semipalmated Sandpiper
Baird's Sandpiper	Western Sandpiper
Sanderling	Baird's Sandpiper
Ruddy Turnstone	Pectoral Sandpiper
Semipalmated Sandpiper	Long-billed Dowitcher

reason; oil will be more likely to be carried away in large grain size, high energy environments. Given these qualitative assumptions, we argue that species using microhabitats falling high along Factor 1 and high along Factor 2 are those which will be most frequently exposed to oil damage. Red Phalaropes, Sanderlings and Ruddy Turnstones stand out in this respect. Their foraging style and habitat choice expose them to conditions where they are likely to be contaminated with oil.

However, the decreased rate of transport, which may be inversely correlated with Factor 2, must also be taken into account, particularly in light of our evidence on trophic dependencies. Birds foraging in protected areas (usually small grain size) tend to rely on benthic infauna, especially insect larvae which complete their life cycle in these habitats. Birds foraging in areas characterized by large grain size typically feed on wave washed zooplankton either in the water column or along the water line. Long-term effects of oil spills may therefore be more pronounced in protected areas since birds are using a resource originating *in situ*. Plankton feeders in contrast utilize a resource which may be replenished from outside the local area. Such questions of bird susceptibility through secondary trophic and habitat effects are complex and cannot be answered without knowledge of the effects of oil on different food sources and the recovery rates within different environments.

Relative habitat use within the littoral zone

On the basis of the habitat analyses discussed above we classified all Barrow transects into one of three groups representing gravel beaches, littoral flats, and lagoon edges (Table 2). We calculated densities within each habitat group of transects for each period of each year for each species. This permits us to assess relative density within the three habitat types for different species averaged over four years of study (Figures 21 and 22). The results, expressed as a proportion of the total density summed over three habitats, show several distinct patterns of relative habitat use. Figure 21A shows the results for groups of species. Considering all shorebirds combined, all three habitats were heavily used but densities were lowest in gravel habitats. It is relevant however that in the Barrow area gravel beaches represent the largest component of littoral habitat available to birds. The solid line represents a four year average; the dotted line indicates an average for the years 1975, 1976, and 1978. In 1977, densities of Red Phalaropes, Northern Phalaropes and Arctic Terns were extremely high on one lagoon edge transect (MWE) for a brief period in August. Densities of a small calanoid copepod were also high at that time and probably attracted these plankton foragers from other habitats, more so than in the other three years. The habitat use pattern for these three species was therefore significantly different in 1977 than in the other 3 years. We are unable to say whether the 3 or the 4 year average is a better representation of a long term mean in relative habitat use and therefore report them both. Passerines, in this case only two common species, Lapland Longspur and Snow Bunting, show a significantly different pattern, with extremely low densities on gravel beaches and highest densities on littoral flats. The three common species of gulls plus arctic terns occurred in all three habitats but at highest densities along gravel beaches in all years except 1977.

Within the shorebirds, several distinct patterns of relative habitat use were evident. We have separated them into five groups, all significantly differently by a chi-square test. Group B includes the same three species, Sanderling, Ruddy Turnstone and Red Phalarope, which constitute a species group formed on the basis of tundra vs. littoral zone habitat use (see above discussion). These species occur almost entirely in the littoral zone in late summer where they forage principally along gravel beaches on marine zooplankton. Group C, Baird's Sandpiper and Dunlin, occur in all three habitats but densities in non-gravel habitats are considerably higher. The other seven shorebirds and two passerines occur in much lower densities along gravel shores and are grouped here somewhat arbitrarily according to their relative use of littoral flats and lagoon edges. A few of these species require further comment. In Group D, Semipalmated and Western Sandpipers display almost identical relative habitat use patterns. These two species have been discussed above as demonstrating remarkably similar annual fluctuations in numbers. This similarity of habitat pattern is another indication of how ecologically similar these two related species are and is consistent with our suggestion that annual variability in post-breeding numbers is determined in some way by conditions in post-breeding littoral habitats.

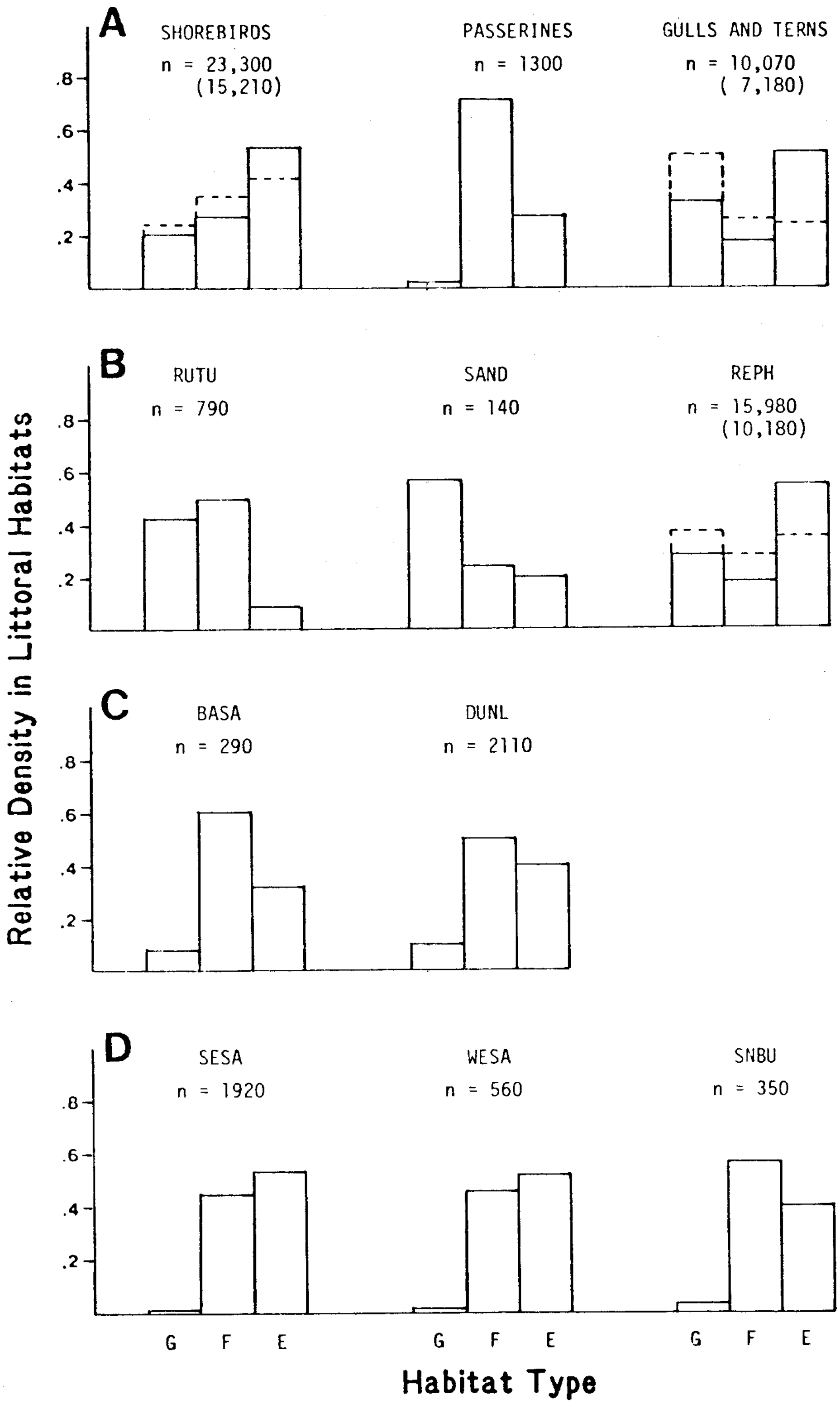

Figure 21. Relative use of littoral habitats: gravel beach (G), littoral flat (F), slough edge (E).

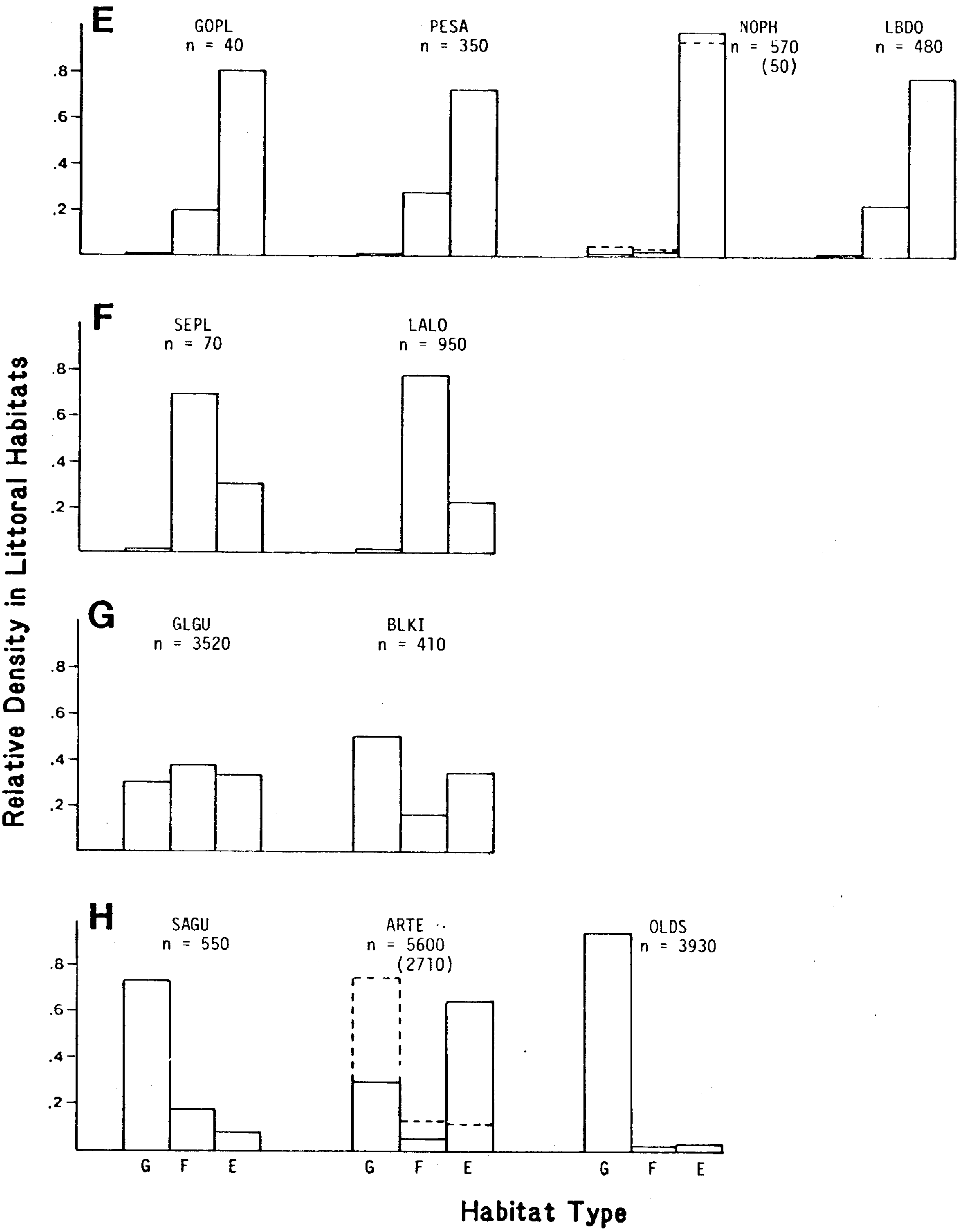

Figure 22. Relative use of littoral habitats: gravel beach (G), littoral flat (F), slough edge (E).

The apparent heavy association of Northern Phalaropes (Figure 22, Group E) with lagoon and slough edges may be somewhat misleading. Northern Phalarope densities are quite low at Barrow in most years but several flocks have been recorded while foraging on small calanoid copepods in Middle Salt Lagoon. In fact, most of the Northern Phalaropes recorded in four years of censusing at Barrow consisted of a single flock during one census of transect MSE. At sites to the east such as Prudhoe Bay, where Northern Phalaropes are much more common, they forage also along gravel beaches in a manner similar to most Red Phalarope foraging at Barrow. The results shown here suggest however that given the same set of available habitats and food sources, the choices of Northern Phalaropes differ from those of Red Phalaropes.

Although we present the relative habitat use patterns in several groups, we caution that differences in these data sets may be significantly different statistically but not biologically. The large sample sizes for most species make the chi-square test quite sensitive to differences in relative use of different habitats. In view of shifts in the use levels of different transects from week to week or year to year, however, and keeping in mind the ordination analyses discussed above, we are not certain that the differences shown here in relative use of littoral flats and slough edges are as important as may appear. We therefore retain the possibility that Groups D, E and F might better be presented as one group characterized by high use of non-gravel habitats relative to gravel beaches. Finally, we note the close similarity in habitat use pattern between the passerine species and several shorebird species, indicating that some passerines and shorebirds might be affected in similar ways by changes in littoral habitats arising from oil development.

GEOGRAPHIC VARIATION IN SHOREBIRD LITTORAL ZONE USE

Results presented above reflect the local distribution of shorebirds and habitat near Barrow. In general the conclusions from these site-specific studies apply quite well to a large region of the northern Chukchi and Beaufort coasts of Alaska. However, two sets of factors affect the applicability of specific results to other sites. First, the habitat use information reflects to some extent the availability of habitats in the local Barrow area. From Icy Cape west of Barrow to Prudhoe Bay east of Barrow (Figure 1) there is no clear geographic cline in littoral zone habitat types, but local sites vary depending on such factors as presence or absence of spits and barrier islands, elevation of tundra adjacent to the shore, and extent of local river deltas. A second set of factors, the changing distribution of individual species, follows a primarily longitudinal gradient along the coast.

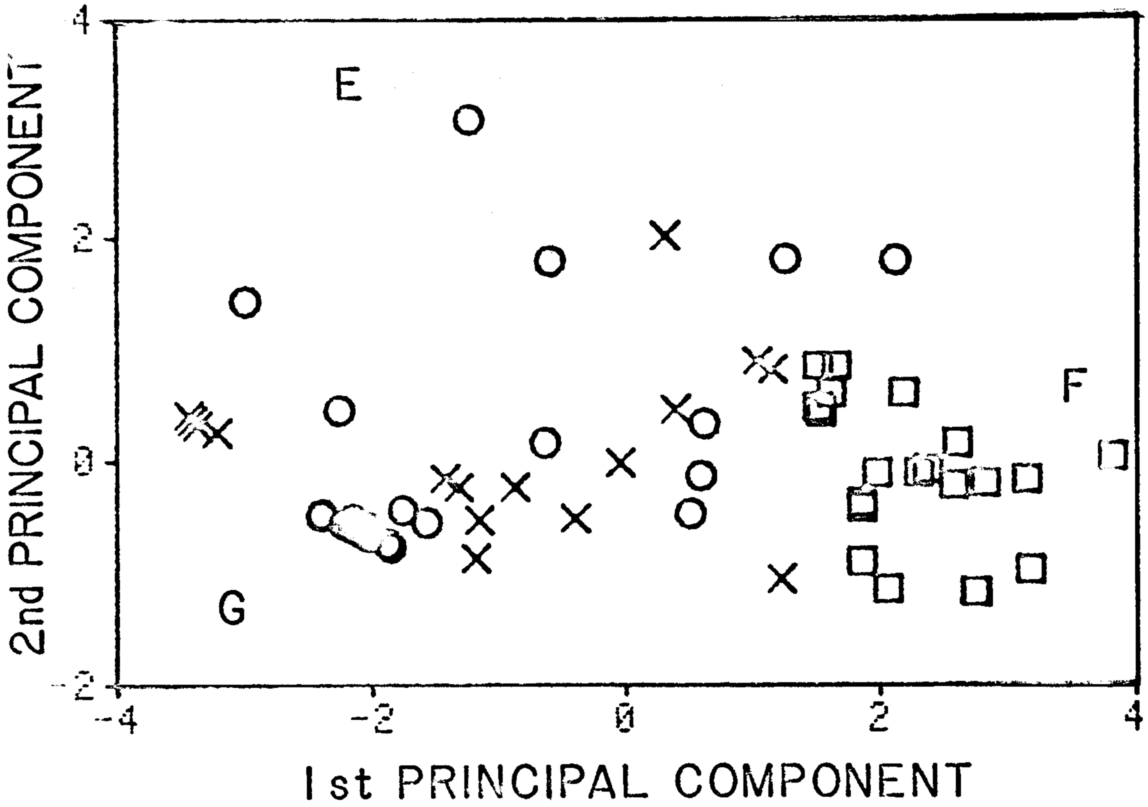

Figure 23. Locations of transects in principal component littoral habitat space. Barrow transects (circles), Prudhoe Bay (X's), Fish Creek Delta (squares). Letters indicate habitat types: gravel beach (G), littoral flat (F), slough edge (E).

Habitat availability

Figure 23 shows the placement of our littoral zone transects at Barrow, Prudhoe Bay and Harrison Bay (Fish Creek Delta) study sites in a habitat space defined by the first two principal components. This analysis is similar to that discussed for Barrow transects alone (Figure 14) but with measured distances replaced by their logarithms. This change was made because the pool of all transects from three sites has a much wider range of distance measurements. As in the Barrow analysis, gravel beach transects are represented by low values on both axes, while littoral flats score high on PC I and lagoon edges score high on PC II. Both Barrow and Prudhoe Bay transects represent a similar range of littoral zone habitat types with the principal difference being the much higher frequency of gravel beach transects at Barrow. At Fish Creek Delta, however, located between the other two sites (Figure 1), all transects are in one class of habitat space (saltmarsh and mudflat) with positions more extreme than any recorded from the other two sites. This difference relates primarily to the more extensive areas of littoral flats at Fish Creek Delta compared to the other two sites. Saltmarsh occurs farther from the shoreline at Fsh Creek Delta. These transects are characterized by wider flood zones, lower slopes, more vegetation and muddier substrates than transects censused at Barrow and Prudhoe Bay. Shorebird use of mudflat and saltmarsh habitats was very similar at all three sites, but the overall pattern of shorebird use varied among the sites because of the different mix of habitats available.

Species distributions

The relative abundance of different shorebird species at the three principal study sites varied partly in response to the changes in local habitat mix. Thus, for example, Ruddy Turnstones, Sanderlings and Red Phalaropes were almost absent from Fish Creek Delta in 1980 but this arises primarily from the absence of gravel shorelines which these species preferentially frequent during migration. However, longitudinal gradients in species distribution also affected local densities. The major changes in species abundance in littoral habitats over the regions studied affect four species. Western Sandpipers at Barrow are near the eastern limit of their breeding range. Densities of Western Sandpipers at Harrison Bay were an order of magnitude less than densities of Semipalmated Sandpipers, and they did not occur at Prudhoe Bay. Stilt Sandpipers occur in very small numbers at Barrow as a late summer migrant but are common during this period at Prudhoe Bay where they forage on littoral flats and slough edges.

Finally, the two Phalarope species vary in relative abundance. At Barrow, the ratio of Red Phalaropes to Northern Phalaropes on our transects over four years was approximately 30:1. At Prudhoe Bay, the ratio is almost reversed, with nearly all phalaropes along shoreline transects being Northerns in 1978. At Herschal Island at the western edge of the western edge of the Canadian Beaufort coast, Vermeer and Anweiler (1975) reported a ratio of about 40:1 favoring Northerns. On the Jones Islands just west of Prudhoe Bay, Johnson (1978) recorded 4:1 Red:Northern Phalaropes. At Harrison Bay, Red Phalaropes were almost absent but Northern Phalaropes were common on the littoral flats. This last difference may arise primarily from a difference in habitat selection by the two species which may also account for some of the difference between densities at Jones Islands and Prudhoe Bay. Red Phalaropes are most common along beaches on spits and barrier islands while Northern Phalaropes occur more frequently in sloughs and lagoons. The differential distribution of these two species in our study is apparently a result of the two factors of geography and habitat selection. This difference in Phalarope occurrence during the post-breeding period at Harrison Bay and at Barrow is demonstrated by Figures 24A and 39 A, B.

Figures 24B and 25A,B show the density comparisons for three other common species: Dunlin, Semipalmated Sandpiper and Lapland Longspur. Harrison Bay densities were comparable to somewhat greater than the four year average of Barrow densities. These species are all common on littoral flats at both sites; however, at Harrison Bay the relative and absolute amount of this class of habitat is much greater than at Barrow, so our figures represent a much larger number of birds in the littoral zone at Harrison Bay. Timing of the post-breeding peak of these species varies also, but in an inconsistent pattern, with Lapland Longspurs peaking much earlIer at Harrison Bay and Semipalmated Sandpipers peaking later. However, since these are based on only one year's data compared to four years at Barrow, they may represent a poor estimate of average timing of these movements.

Shorebird concentration areas

Areas considered sensitive because of high levels of use by birds of many species were identified in the Interim Synthesis Report: Beaufort/Chukchi (Weller et al., 1978). These include many of the areas where shorebird densities are high during late summer in the littoral zone. These regions correspond primarily to areas with gravel spits and barrier islands where densities of the gravel beach shorebirds are highest; and areas with extensive littoral mudflats, saltmarshes and slough edges, from Icy Cape in the Chukchi sea to Prudhoe Bay in the Beaufort sea. They include Icy Cape, Peard Bay, Point Barrow, the Plover Islands, Fish Creek Delta, Colville Delta and the Jones Islands (Figure 1). Smaller areas with heavily used shorebird littoral habitats occur at several other points along this coast and some rather extensive regions of coastline have not been adequately surveyed during the appropriate season.

SHOREBIRD DIETS AND FAT ACCUMULATION

Overlap in shorebird diets

Detailed lists of food items found in shorebird stomachs and of species composition and density of plankton samples have been reported in Connors and Risebrough (1976, 1977, 1978 and 1979). In this final report we summarize the major points arising from those collections but do not repeat the detailed data. Table 13 lists the numbers of each bird species collected at Barrow and a few nearby sites. These collections do not permit a definitive listing of average diets because of small sample sizes and because the diets of most species depend closely on the availability of prey species at the site sampled. The central conclusion of our shorebird diet studies is that the diets of most species correspond to the habitats in which they forage rather than to strong species differences in diet preference within habitats. The diets of many species overlap broadly while foraging in the same habitat type. In earlier reports, we cited numerous examples of shorebirds of two, three or four

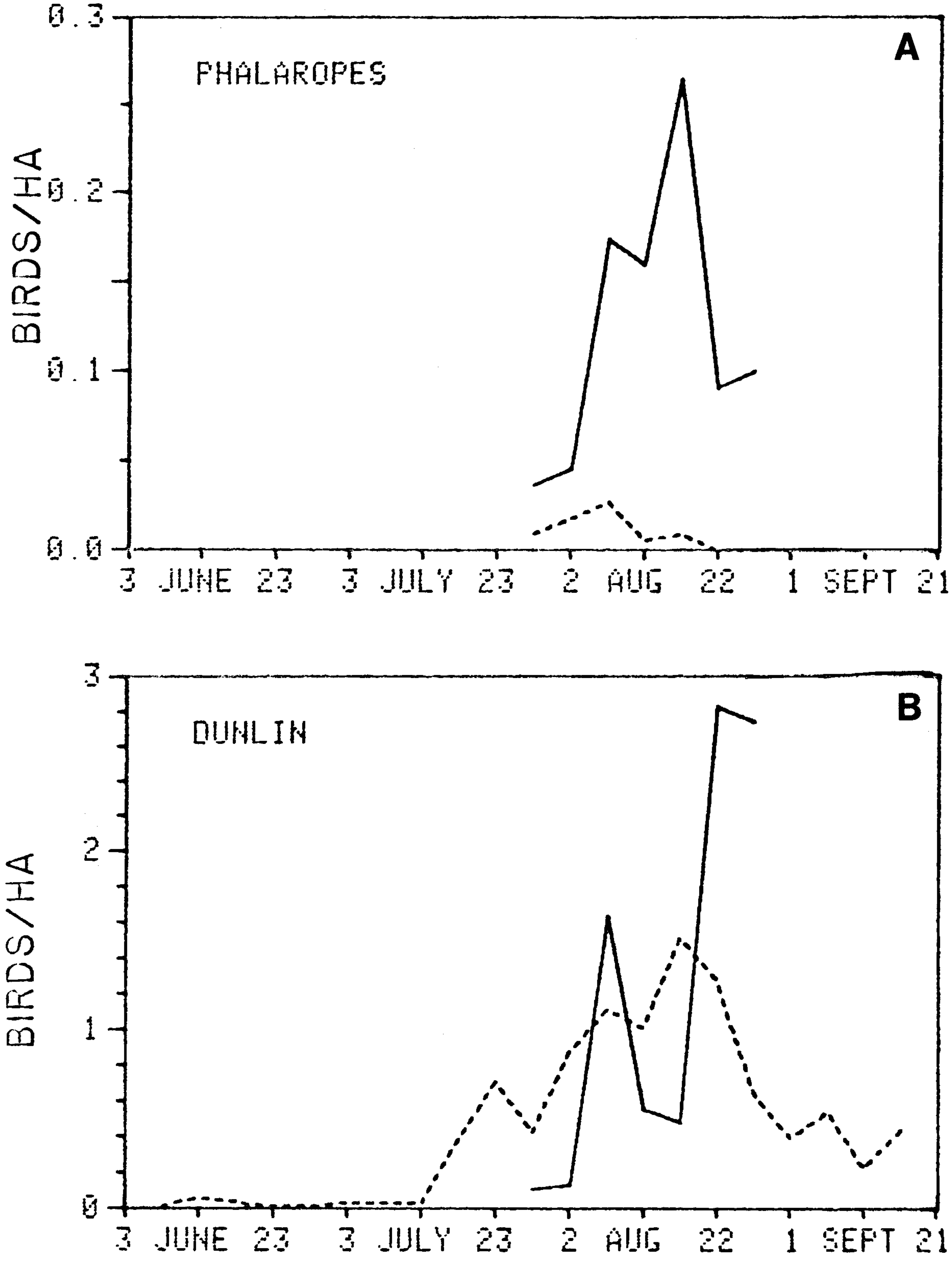

Figure 24. (A) Littoral zone densities of Red Phalarope (dashed line) and Northern Phalarope (solid line) at Fish Creek Delta.
(B) Comparison of littoral zone densities of Dunlin at Fish Creek Delta, 1980 (solid line) and Barrow 1975-1978 (dashed line).

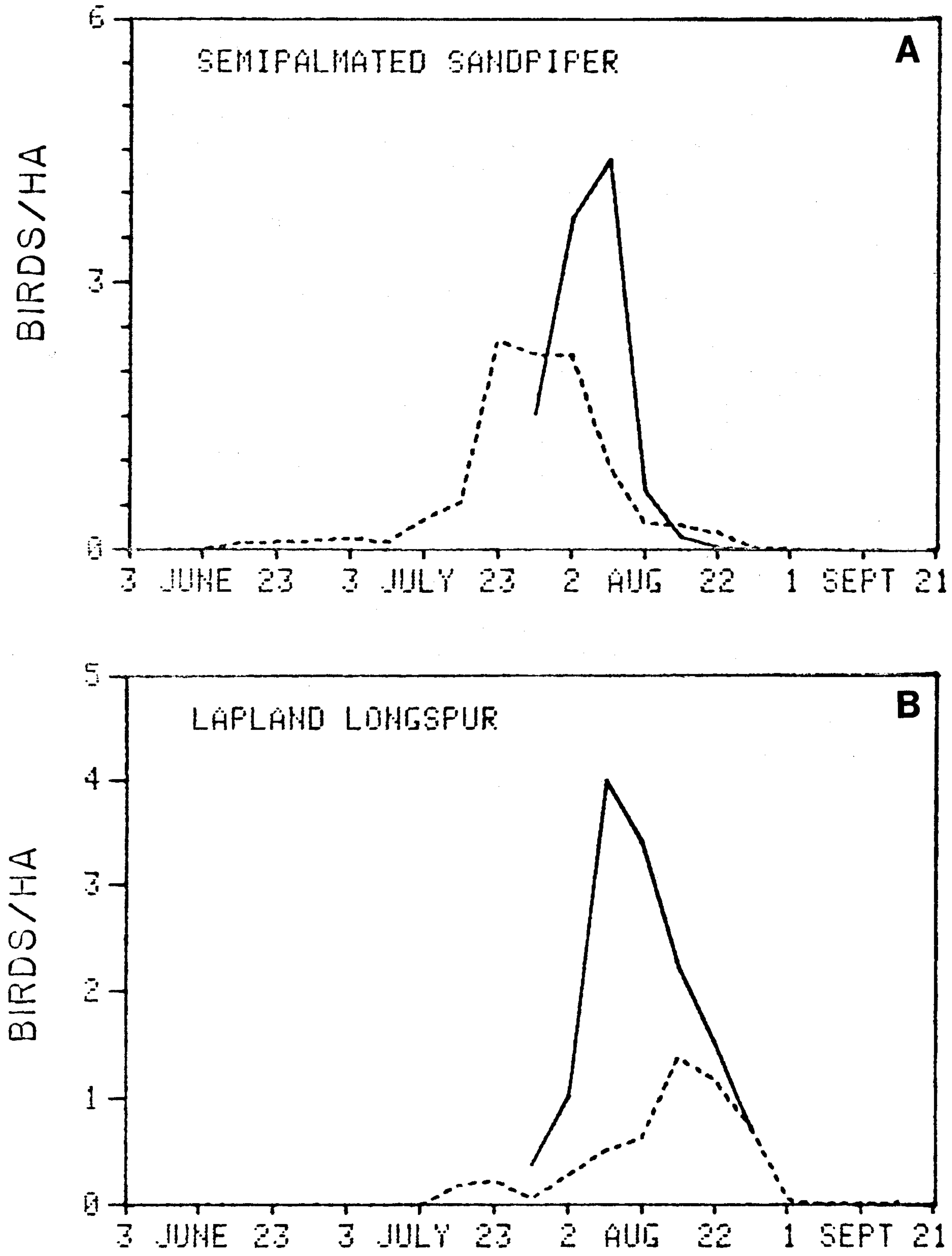

Figure 25. Comparison of littoral zone densities at Fish Creek Delta, 1980 (solid line) and Barrow, 1975-1978 (dashed line).

species foraging on very similar prey while together at one site. However, at other sites in different habitats or at different times within the same habitat the diets of all these species vary. There are of course exceptions; individual species do exhibit differences in foraging methods and some distinctions are imposed by species morphology. But in general the main differences in diet correspond to differences in habitat use. These can be summarized as follows: shorebirds foraging on littoral flats, in saltmarshes and along the shores of small lagoons and sloughs foraged principally on chironomid larvae in the substrate but in several areas small oligochaetes were also taken. Early in the post-breeding season (late July) adult chironomids are present and are taken by many species. Along gravel beaches on marine shores most species foraged on a wide variety of marine zooplankton and amphipods associated with the substrate or the under surface of ice. The actual species taken varied widely over time and place both within a season and between seasons, but the differences in prey between species at one time and place were relatively slight. This similarity of diet along arctic shores extends from Red Phalaropes who forage while swimming in shallow water along gravel beaches to Ruddy Turnstones, Sanderlings, Dunlin and occasionally a few other species which forage by walking at the water's edge. Phalaropes take zooplankton directly from the water column, while other shorebirds take the same prey species either washed up on the gravel or in the extremely shallow water right at the water's edge. All these species show a tendency to select larger sizes of zooplankton compared to sizes available in plankton tows (Connors and Risebrough, 1977), and the species favored included amphipods of the genera Apherusa and Onisimus, euphausiids (Thysanoessa), copepods (Calanus) and decapod zoea. We believe, however, that these apparent diet preferences vary widely depending on the availability of species within the zooplankton community.

Table 14 lists the groups of shorebird species which we believe have overlapping diets within habitat classes. This Table, when used in conjunction with Figures 21 and 22 summarizing relative littoral zone habitat use, will convey a good idea of the expected diet of each species in the Barrow area. The species listed as zooplankton predators may select some prey species preferentially; this distinction would require large sample sizes to identify; our samples only show considerable overlap. Among the group of species listed as foraging on chironomid larvae, species may differ in microhabitats or depths at which prey are taken, in prey size or prey species. Nevertheless, this is a very uniform prey base compared to tidal flat communities in temperate regions; the stomach samples indicated broad overlap.

Two other species which occur commonly on littoral flats and along lagoon and slough edges are passerines. Although they forage in the same habitat as many shorebird species our very limited collections suggest that they feed on the seeds

Table 13. Numbers of specimens from Barrow area examined for studies of diet and fat condition, 1975-1978.

Red Phalarope	2	Red Phalarope	76
Semipalmated Sandpiper	8	Northern Phalarope	3
Western Sandpiper	1	Sabine's Gull	2
Baird's Sandpiper	2	Arctic Tern	2
Dunlin	16	Lapland Longspur	2
Sanderling	12	Snow Bunting	2
Long-billed Dowitcher	2		

Table 14. Groups of species with overlapping diets in littoral habitats.

Habitat	Diet	Species
Marine shores, gravel beaches	Marine zooplankton, including copepods, euphasuiids, decapod zoea	Ruddy Turnstone, Dunlin, Sanderling, Red Phalarope, Northern Phalarope, Arctic Tern, Sabine's Gull
	Amphipods	Red Phalarope, Baird's Sandpiper
Small lagoons	Copepods	Red Phalarope, Northern Phalarope
Mudflats, saltmarsh, lagoon and slough edges	Adult chironomid flies	Ruddy Turnstone, Dunlin, Western Sandpiper, Red Phalarope
	Chironomid larvae	Ruddy Turnstone, Semipalmated Sandpiper, Western Sandpiper, Dunlin, Long-billed Dowitcher, Red Phalarope, Lapland Longspur
	Oligochaetes	Ruddy Turnstone, Dunlin
	Seeds	Lapland Longspur, Snow Bunting

of plants found in these areas but possibly also on chironomid larvae. At the other extreme of habitat and size the diets of Sabine's gulls and Arctic Terns overlap with gravel beach zooplankton foraging shorebirds, although these species also take fish.

There is a strong seasonal component to shorebird diets in the arctic. Many species take adult chironomid flies during July on the tundra, and birds of 4 species collected in late July in littoral habitats, including Red Phalaropes, contained adult flies. By mid-August these are no longer available, and these same bird species have shifted to other prey. Thus the diets of shorebirds change as species change foraging habitats and also as prey availability within habitats changes.

Red Phalarope diets and foraging behavior

The diets of shorebirds foraging on littoral flats are probably fairly consistent from year to year although little is known of the life cycles and ecology of the species of chironomid flies whose larvae develop in these littoral areas. In contrast, diets of birds foraging along the marine shorelines vary more widely from year to year because of annual variation and even within-season variation in relative abundance of different zooplankton species. Our Red Phalarope data provide the clearest example of this variation. In 1976, densities of marine zooplankton were strikingly lower than densities in 1975. Mean densities of the three prey species taken most commonly by shorebirds in 1975 were reduced by approximately 25 times. Diets of Red Phalaropes showed corresponding differences between the two summers, with copepods scarcer and amphipods more common in 1976 (Connors and Risebrough, 1977).

This change in diet reflected an observed difference in foraging behavior. In 1975, juvenile Red Phalaropes foraging along the shores of Barrow spit were most abundant in the shallow water zone 0 to 2 meters out from shore. Day to day distribution along the shores of Barrow spit and Plover spit varied considerably however. Using our census data of Red Phalarope distribution along shorelines which face in four different directions (Figure 2), we plotted the percent of birds present on each shore on seven days with wind speeds above 8 knots, against the deviation of wind direction from a full onshore wind (Figure 26A). The very restricted scatter of these data indicate that phalaropes rarely foraged on beaches with onshore winds (angles less than 90 degrees) if alternative shores were available. We repeated this analysis with strikingly different results for seven windy days in 1976 (Figure 26B). Clearly Red Phalaropes were responding differently in relation to wind direction in the two years. We suggest the following interpretation, related directly to the change in zooplankton conditions between the two seasons. In 1975 Phalaropes foraged on dense zooplankton in shallow water within 2 meters of shore almost exclusively. In this situation the protected shore probably provides increased

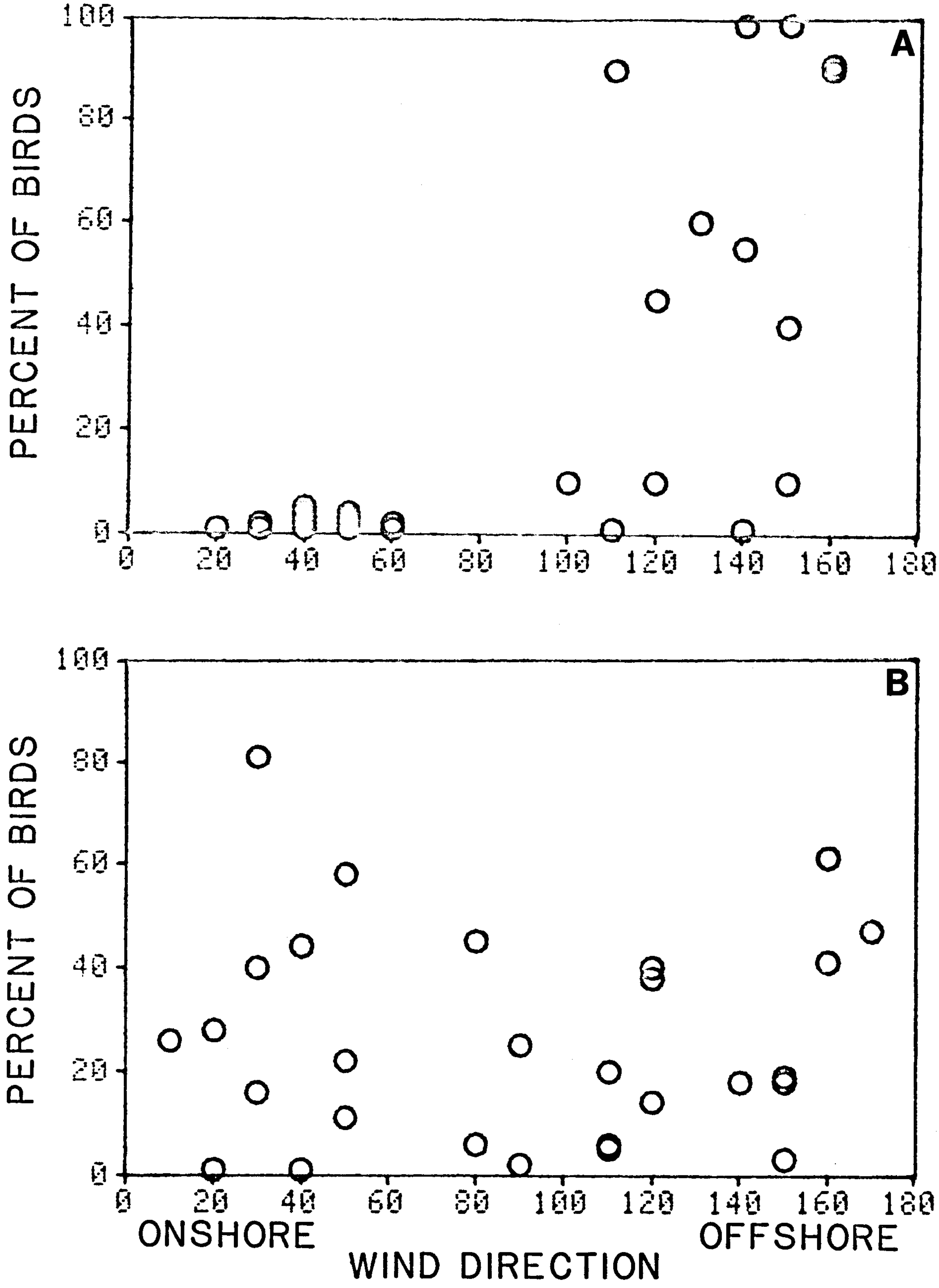

Figure 26. Distribution of foraging Red Phalaropes in relation to wind direction. (A) 1975. (B) 1976. See text.

foraging efficiency, possibly by improved surf and ice conditions and decreased turbidity and possibly through enhanced zooplankton density. In 1976, however, with drastically lower densities of the same zooplankton, Red Phalaropes also foraged on under-ice amphipods which became available on windy days when pieces of ice piled up on the windward shore. The absence of any wind related pattern in Figure 26B results from phalaropes utilizing multiple food sources with different responses to wind conditions.

Under conditions of either high or low zooplankton density our proposed explanation of Phalarope distribution in relation to wind direction suggests also an explanation of the large concentrations of phalaropes near spits and barrier islands. The complex shoreline topography of these sites provides a greater variety of foraging conditions with respect to wind direction than does a simple mainland shore. There is always a protected shore and a windward shore, permitting phalaropes to select the best foraging conditions, determined by the interacting factors of wind, water, ice conditions, and zooplankton densities.

Effect of oil spills on shorebird prey species

We discussed earlier the potential differences in oil spill effects on different microhabitats. These differences also apply to different prey communities. Spilled oil offshore might be expected to reach open water gravel shoreline areas first, where the possibility of toxicity to zooplankton communities or under-ice amphipods might reduce the densities of these food species. Littoral flats and slough edges might be affected by oil only if it occurs with storm flooding. However, oil spilled on beaches might be removed sooner, by subsequent wave action, than oil transported to protected littoral flats. In addition, zooplankton densities influenced strongly by water movements and phytoplankton activity might recover relatively soon after the initial phase of an oil spill. In contrast, oil spilled on muddy sediments within protected littoral areas might continue to affect chironomid life cycles and populations within the substrate. Assessing these differences will require studies of the sensitivity of various prey species to oil contamination and the recovery rates of prey populations in different habitats.

Premigratory fat deposition by shorebirds

We recorded fat conditions for all collected birds by assigning the OCS fat code to each specimen (Code 1 = no fat; Code 2 = little fat; Code 3 = moderate fat; Code 4 = very fat; Code 5 = excessive fat). Only two species showed any change in fat condition with date after August 1st. Both species showed an increase in fat levels during this period (Red Phalarope mean score $\bar{x} = 2.6$, Spearman correlation coefficient $r_s = .40$, $p<.01$ and Dunlin $\bar{x} = 2.5$, $r_s = .41$, $p<.05$). This suggests strongly that the long period in which these species forage in arctic habitats is important for the deposition of fat prior to southward migration. Arrival of these species at the latitude of California occurs in middle October or later in most years, considerably delayed compared to Sanderlings and Ruddy Turnstones. These latter species apparently accumulate higher fat reserves during August (Sanderling $\bar{x} = 3.8$, Ruddy Turnstones $\bar{x} = 3.3$) and migrate southward more rapidly. Juvenile Semipalmated Sandpipers leave the arctic much earlier, in late July and early August, but with lower fat levels than these two species ($\bar{x} = 2.6$). Semipalmated Sandpipers may migrate more slowly, replenishing fat supplies more frequently during migration. Johnson (1978) also found an increase in fat level of Red Phalaropes during August at Simpson Lagoon. His data suggest a difference in the fat deposition schedule of the two phalarope species: Northern Phalaropes had consistently higher fat levels throughout this period. Three Northern Phalarope juveniles we collected at Barrow over two years on 8 and 9 August had significantly higher fat levels than 20 Red Phalarope juveniles taken over four years 8 - 12 August (Mann-Whitney test, $p<.01$). We do not know what differences in foraging ecology or metabolism account for this surprising ability of Northern Phalaropes to accumulate fat more quickly than Red Phalaropes.

Unlike juvenile phalaropes, adult females and adult males, freed from nesting duties in late June and late July respectively, begin their southward migrations without a long post-breeding foraging period in the arctic. If juveniles require the long foraging period to build up energy reserves necessary for migration, have adults already achieved similar fat levels when they leave the tundra and depart southward? We compared fat levels in 14 adult male Phalaropes collected along shorelines from 15 July - 3 August, 1975 - 1978 with 20 juveniles taken 8 - 12 August, 1975 - 1978. The adult fat levels were significantly higher ($p<.02$, Mann-Whitney test). We believe this also indicates that juveniles require the late summer shoreline foraging period to build fat reserves necessary for southward migration.

DEVELOPMENT EFFECTS ON SHOREBIRDS

Effects of habitat changes on bird densities

In Table 15 we list the kinds of habitat alterations potentially associated with OCS development which might affect shorebirds. We addressed the first two listed factors, including several kinds of habitat changes as well as the effects of noise and activity disturbance, with sets of transects primarily at Prudhoe Bay and to a lesser extent at Barrow in 1978. We compared bird densities between transects of similar habitat differing in degree of habitat disturbance. The effects of a variety of habitat changes already accomplished at Prudhoe Bay were reported in Connors and Risebrough (1979). In this final report we present the comparisons indicating the greatest effects of habitat change on shorebird numbers.

Habitat removal. Habitat can be affected in varying degrees. At the crudest level, it is simply removed. Total loss due to gravel roads or construction pads for onshore facilities can be quantified in the Prudhoe Bay area. Our rough 1978 estimates of this tundra habitat loss within a 14 km x 26 km rectangle encompassing much of the oilfield amounted to about 10 sq km. This is only about 3% of the enclosed tundra, which sounds unimportant, but it implies a total loss of about 1000-2000 pairs of nesting shorebirds from this area, along with waterfowl and other species.

Road effects. Construction has other effects which also diminish usable habitat. A considerable dust shadow accompanies gravel construction, with vegetation coated to varying degrees with dust at distances measuring tens or hundreds of meters from all roads. This affects bird density.

A summertime prevailing wind direction from the northeast produces a more extensive dust shadow on the southwest side of roads at Prudhoe Bay. In Figure 27A we compare the seasonal changes in total shorebird density on the dust shadow transects, PG1 and PG2 (see Figure 28), with control transects, PG3 and PG4. Densities on the dusted tundra were significantly lower by a sign test ($p<.01$), especially during the breeding season. Comparing the inner and outer pairs of transects separately, densities are lower on PG1 than PG3 ($p<.01$) and lower on PG2 than PG4 ($p<.05$). The cross comparison of PG2 and PG3, transects with similar dust effects (Table 16) was not significant ($p>.05$). A similar effect is evident for passerines (Lapland Longspur and Snow Bunting; Figure 27B).

Before we interpret these differences in shorebird densities as the results of dust deposition on the tundra, we must establish that other habitat differences are unlikely to have produced the differences. The four transects were chosen in early June in a level area of superficially uniform tundra with respect to topography, vegetation, and surface water area and distribution. More detailed measurements of habitat parameters made during the summer indicate that this initial assessment was substantially accurate. Some distinguishable differences do exist, however (Table 16). Water cover decreased on all transects during June and between June and August, as expected. Average water cover in June on the four transects fell in a narrow range, with the

Table 15. Potential effects of oil development on arctic shorebirds.

1. Habitat changes
    a. Loss of habitat
    b. Change in quality of habitat
    c. Construction of new habitat
2. Activity disturbance
3. Changes in prey resource
4. Direct oil spill effects

Table 16. Characteristics of dust shadow and control transects.

	Dust		Control		
	PG1	PG2	PG3	PG4	n
June water cover[1]	18	25	25	21	6
August water cover[2]	4.4 ±11.4	13.0 ±12.0	7.0 ±7.1	5.9 ±4.1	20
Plant cover[3]	74±11	77±4	82±6	86±4	20
Relative disturbance[4]	60±10	15±5	25±5	0±0	20

[1] means of 6 census period estimates

[2] per cent of surface area. Means of 20 plots ± standard deviation

[3] per cent of non-water area. Means of 20 plots ± standard deviation

[4] scale of 0 to 100, means of 20 plots ± s.d.

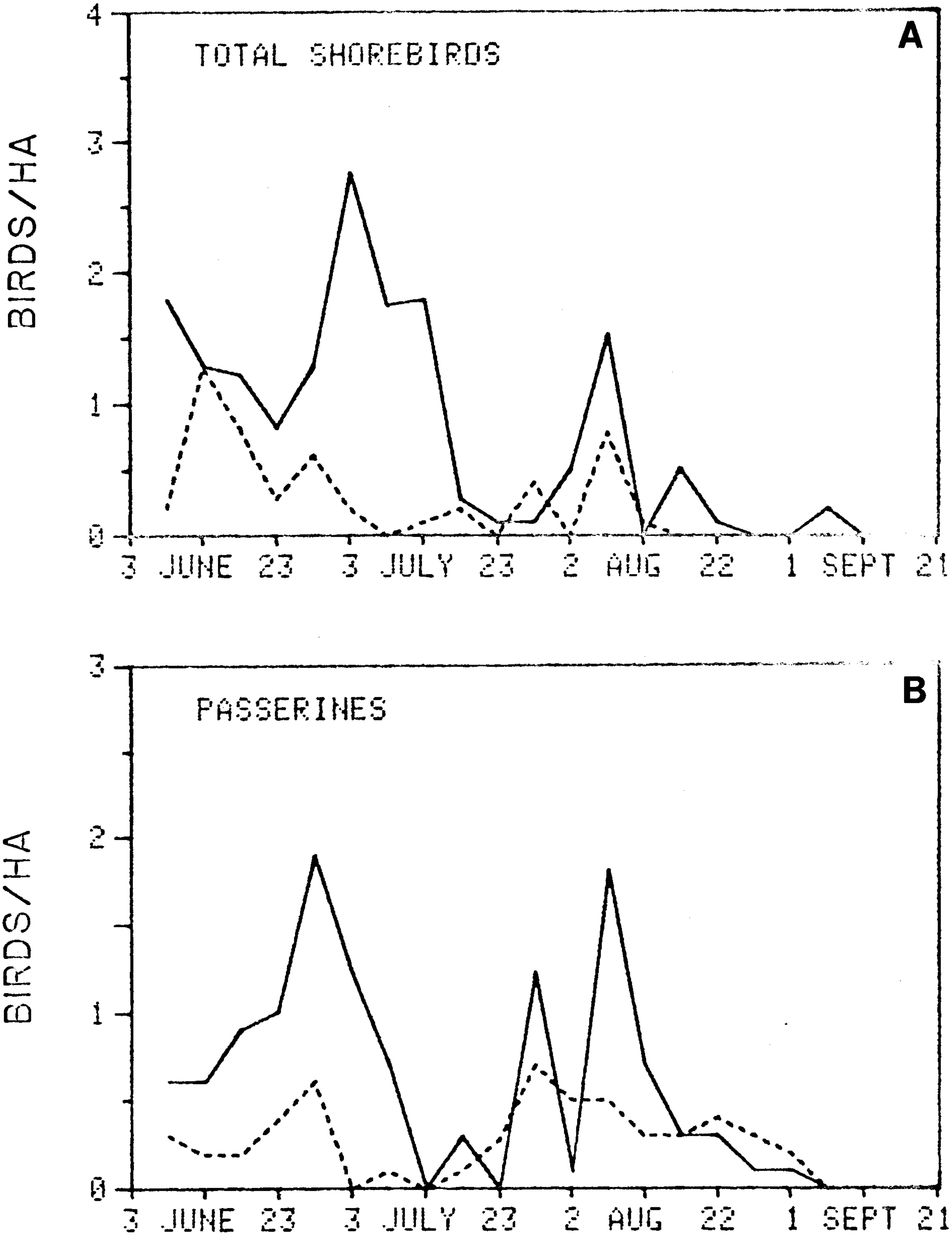

Figure 27. Comparison of bird densities on Prudhoe Bay dust shadow transects (dashed line) and on control transects (solid line).

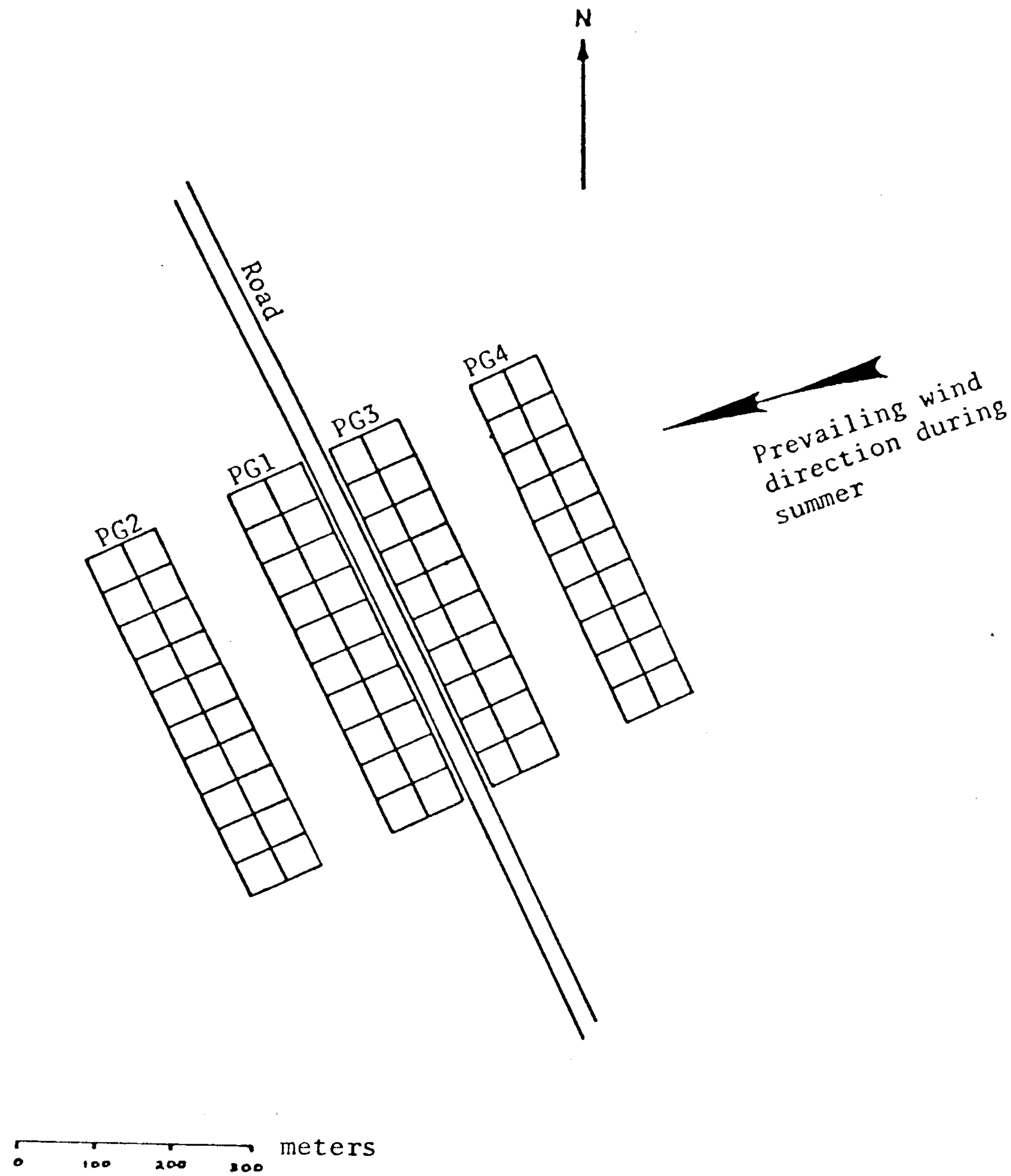

Figure 28. Diagram of Prudhoe Bay dust shadow transects (PG1 and PG2) and control transects (PG3 and PG4).

disparity increasing toward the end of the month. By August several plots had become dry or nearly so, and the relative range of average transect values had increased further. A Mann-Whitney test comparing the disturbed transects (PG1 and PG2) with undisturbed transects (PG3 and PG4) distinguishes between August water conditions on PG1 vs PG3 ($p<.002$) but not between PG2 and PG4 or between the combined PG1 and PG2 compared to PG3 and PG4. Thus, some differences do exist in August, but these differences are smaller in June. Furthermore, elimination of the driest 120 plots from transect PG1, which leaves a half transect indistinguishable in water content from PG3, still provides a comparison of bird densities which is significantly lower on the disturbed transect. Finally some of the habitat difference may, in fact, derive from the disturbance: the heavier deposition of dust on PG1 compared to PG3 may have reduced the surface water content of that transect, and may be responsible for the slightly lower per cent plant cover on the dust shadow transects (Table 16).

The upwind transects are, of course, not completely dust free. The full effect of dust on bird densities may therefore be greater than that shown in Figure 27. A possible additional effect, that of noise and activity disturbance associated with the road, is difficult to measure in the presence of the dust effect. We think there is such an effect, but that it is smaller than the dust effect.

The net result of these road effects is to increase the effective disturbance zone associated with the road. Instead of losing only the 30 m wide strip which is covered by gravel, the total loss of nesting habitat may be equivalent to a 60 m to 200 m wide strip. This change will multiply our total habitat loss by a factor of several times. In other words, the estimate of 1000-2000 pairs of shorebirds lost in the Prudhoe Bay oilfield increases to 3000 to 6000 pairs.

Drainage changes. Tundra construction frequently affects drainage patterns, either by increasing or diminishing local drainage, and these changes, by altering water levels and areas, can greatly influence habitat use by shorebirds and waterfowl. We show one example of an altered drainage effect in Figure 29A, comparing densities on pairs of transects differing principally in the effect of a road with an inadequate culvert system on drainage. The dotted line traces density of shorebirds on transects which remain flooded during early summer, but which drain considerably by late August. The area has been essentially eliminated as nesting habitat for shorebirds, but is very attractive to late summer migrants.

Human activity. We've also looked for effects of activity disturbance by people and machines along shorelines in late summer at Barrow, comparing densities on 7 shoreline transects, 3 with high disturbance (BBV, BBD, BDC) and four with low disturbance (BCS, BCN, BAP, BBS), scattered along 19 km of Chukchi coast. In general, most bird species occurred in higher densities along undisturbed shorelines, but the

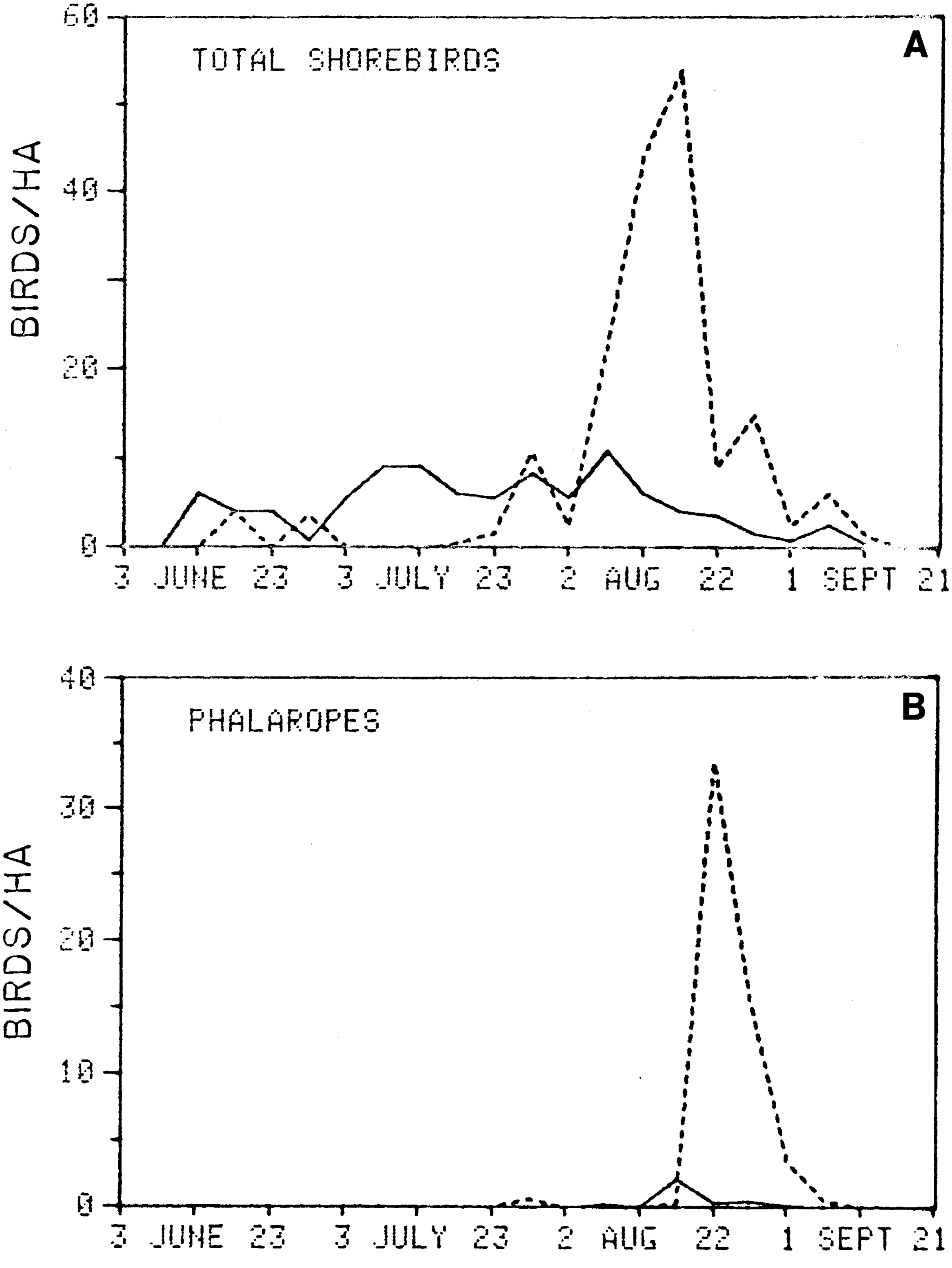

Figure 29. Prudhoe Bay bird densities on (A) altered drainage transects (dashed line) and control transects (solid line), and (B) artificial pier shorelines (dashed line) and mainland shores (solid line).

differences were not significant for any species. Two species were more common on the disturbed transects, however. Ruddy Turnstones and Glaucous Gulls are both preferential garbage foragers, occurring in higher densities on the transects where garbage was more frequent.

The extent of any deleterious effects of noise and activity disturbance will vary with the species involved and with their activities in the disturbed area. Colonies of nesting waterfowl will be very sensitive to disturbance during the breeding season. Our gravel shoreline transect comparisons indicate that the sensitivity of late summer migrant shorebirds and gulls is rather low, but that turnstone and gull populations might be locally enhanced if shoreline garbage becomes widespread.

Artificial causeways. Prudhoe Bay also offers a preview of what we might expect from the construction of artificial gravel shorelines -- drilling islands and causeways in shallow water -- in the form of the ARCO west dock, a gravel pier over 2 km long extending into the bay and used for unloading barges, and the shorter east dock. Our transects along these artificial spits indicate that zooplankton foraging birds -- phalaropes, gulls, terns and some other shorebirds -- will use these shorelines in preference to the adjacent natural mainland shores. In fact, densities of phalaropes (mainly Northern) were an order of magnitude higher along the artificial spits in August (Figure 29B). Shorebirds which are less dependent upon zooplankton during this period (especially Dunlins) were more common on the muddier mainland shores (Figure 30A). Lapland Longspurs and Snow Buntings, foraging on seeds and insects, were almost confined to the mainland shores (Figure 30B).

This result for zooplankton-foraging birds is just what we predicted based on the high density use of natural spits and barrier islands in 1975-1977 along the Beaufort-Chukchi coasts (Connors and Risebrough, 1978). Since the prey base is mainly marine zooplankton and under-ice amphipods, species more strongly associated with the water than with the particular shoreline substrate, the artificial spit apparently functions similarly to its natural counterpart. We don't know why spits and islands were more attractive than mainland shores during these 3 years, and a different result in 1978 calls this conclusion into question (Connors and Risebrough, 1979). We suspect that local current effects may be involved in producing occasional blooms of zooplankton along these shorelines. Extremely high densities of euphausiids, copepods, and chaetognaths occurred along Barrow Spit during the 4 years of this study, and a short but intense bloom of copepods along the ARCO dock in August 1978 attracted large numbers of phalaropes, gulls, and fish.

We have suggested above an additional hypothesis to explain apparently heavier use of spits and islands by phalaropes. The flexible foraging behavior of phalaropes in relation to wind direction and zooplankton densities indicates that spits and islands, with exposed and protected

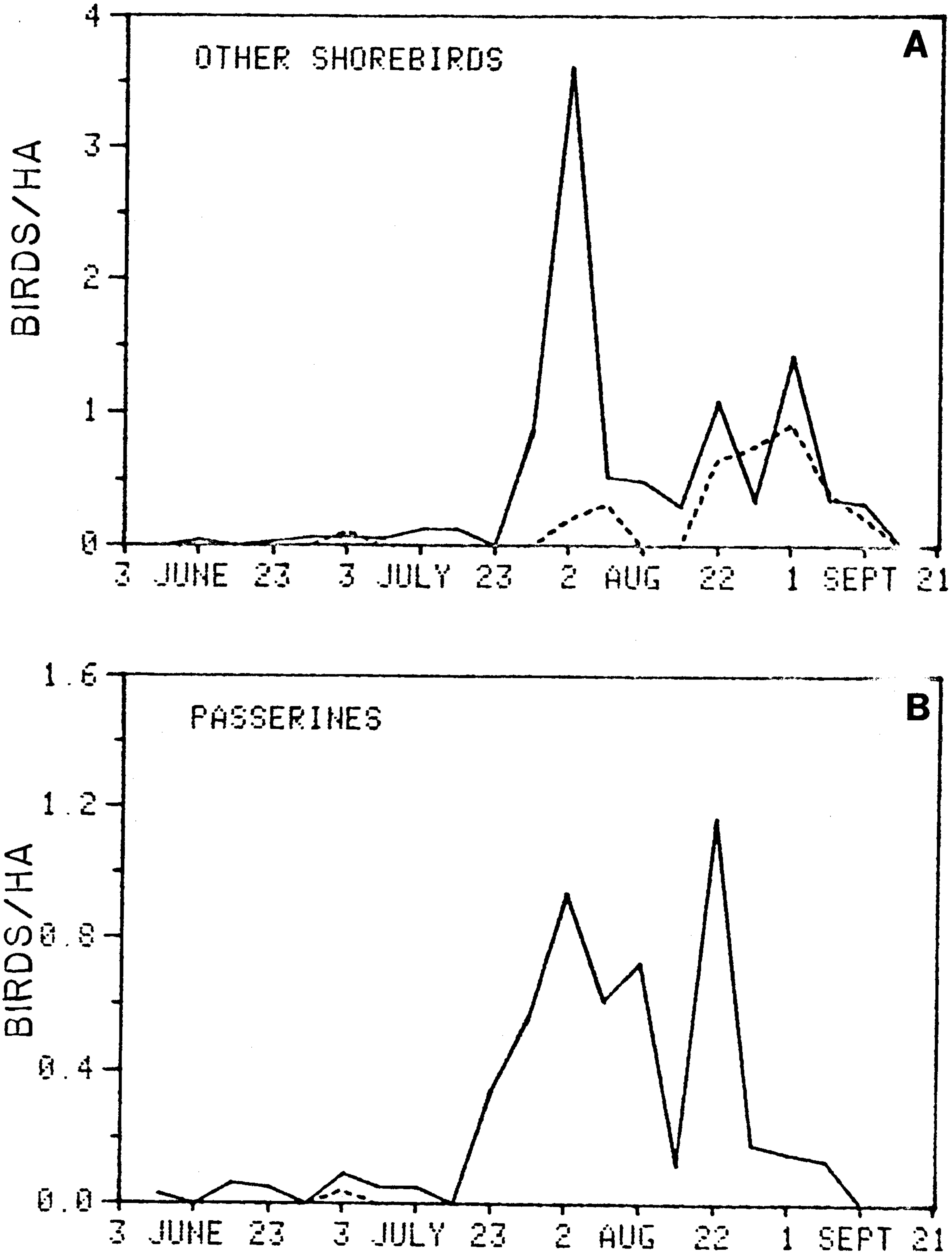

Figure 30. Comparison of bird densities on Prudhoe Bay artificial pier shorelines (dashed line) and on mainland shores (solid line).

shores in all wind conditions, offer more foraging options than do mainland shores.

Our Prudhoe Bay results suggest that artificial gravel piers and drilling platforms will be more heavily used than natural mainland shores by several species of shorebirds, gulls and terns, which on the surface sounds like an argument in their favor. However, the net effect will be one of attracting birds to precisely those habitats where oil spills will be most likely to occur, that is, where construction, barge traffic, and drilling activities will be most intense.

Responses of juvenile Red Phalaropes to thin oil films

The results of our foraging experiments and choice experiments to determine the effects of thin oil films on phalarope behavior were presented in full in Connors and Risebrough (1980). The results are of sufficient importance that we will repeat the main points in this report.

The initial results of the choice experiment are presented in Figure 31, comparing the number of choices made for clean pans and for oiled pans as a function of the sequence number of the choice. Of 12 birds making choices, all 12 made a first choice, 6 of them for oiled pans and 6 of them for clear pans. Only 10 of them made a second choice, 8 made third choices, and so forth, with only one bird making a twelfth choice. There is no suggestion of any discrimination in that first choice; birds were as likely to choose oiled as clear pans. But on subsequent choices, behavior changed. After the second round of choices, birds were able to make a distinction and were opting for clear pans rather than oiled. Of the last 33 choices, only 2 were for oiled pans. The birds seem to have learned something of the effects of the oil very quickly. They apparently can make the distinction and do learn to avoid the oil.

Figure 32A addresses a possible alternative explanation for these results: that any birds entering the oil on the first or second choice might be so damaged by the oil that they failed to make any subsequent choices, and that all later choices were made by birds who chose clear pans consistently. This explanation does not apply. Figure 32A is a comparison of the total number of choices made by all 12 individuals split up into two groups depending on whether they chose oil or clear on the first choice. It demonstrates that birds choosing oil initially did continue to make subsequent choices; most of these choices were for clear pans.

The duration of foraging periods also differed between oiled and clear pans, as indicated in Figure 32B. The frequency histograms contrast markedly. A Mann-Whitney comparison of the duration of foraging periods on oiled vs. clear was significant ($p<.01$). The median duration on clear pans was 33 seconds, compared with a median time of only 5 seconds on oiled pans, an indication that once the birds get on the oil, they quickly respond to something and on average get out early.

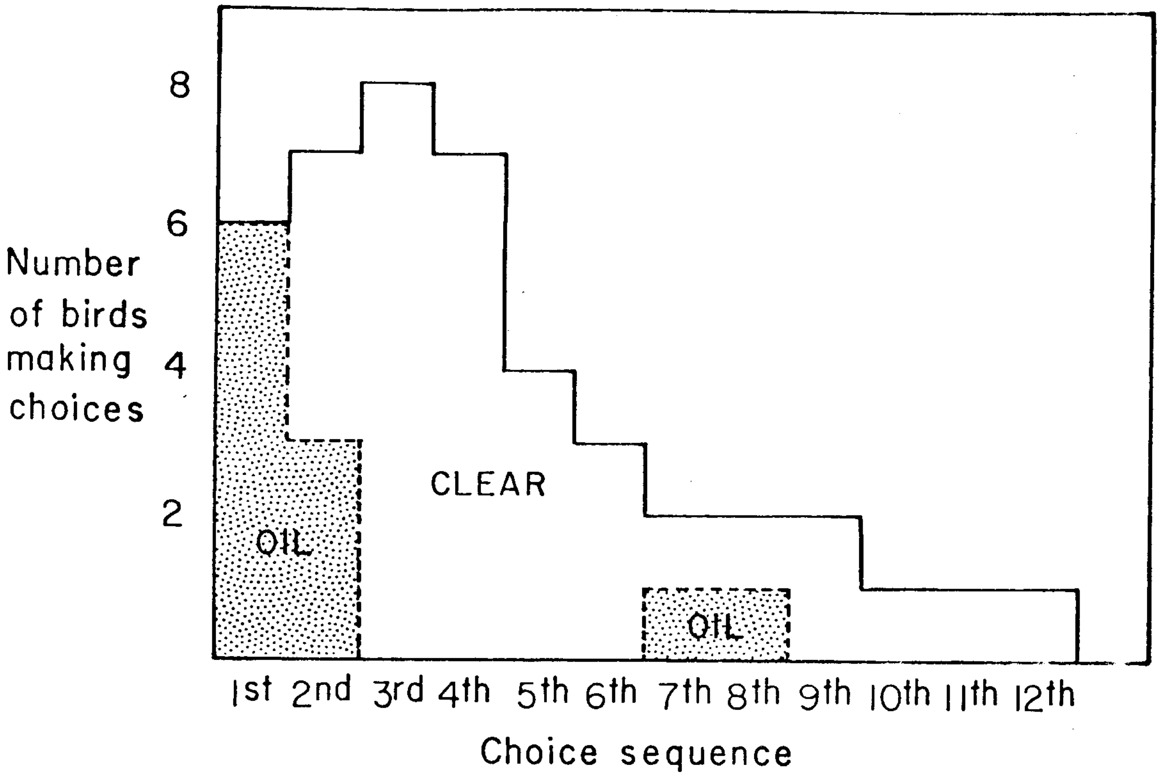

Figure 31. Comparison of phalarope choices for oiled versus clear surfaces.

The aquarium experiments support this conclusion. Phalarope behavior was recorded as foraging, resting, and escape behavior. This latter category includes swimming hard against the side of the aquarium, swimming rapidly from one side of the aquarium to the other, and occasionally attempting to fly. The percent of time spent by phalaropes in these escape behaviors varied widely, but increased strongly with increasing oil film thickness (Figure 33). In the presence of even these extremely thin oil films, the birds quickly sensed the difference and responded by trying to avoid the oil.

What is the relevance of these results to OCSEAP? Admittedly these experiments present artificial situations and small sample sizes. Nevertheless, the statistical tests take into account the samll sample sizes and judge the results significant. Naive juvenile Red Phalaropes apparently do not distinguish between oiled and clear surfaces for foraging before they have any experience with the oil. However, upon contact they have a fairly consistent and very quick response to try to get away from the oil, and subsequently they can and do distinguish between clear and oiled surfaces, and they avoid the oiled surfaces. This suggests that phalaropes may reduce the impact of an oil spill by behavioral adjustments after a brief learning period, but some questions remain.

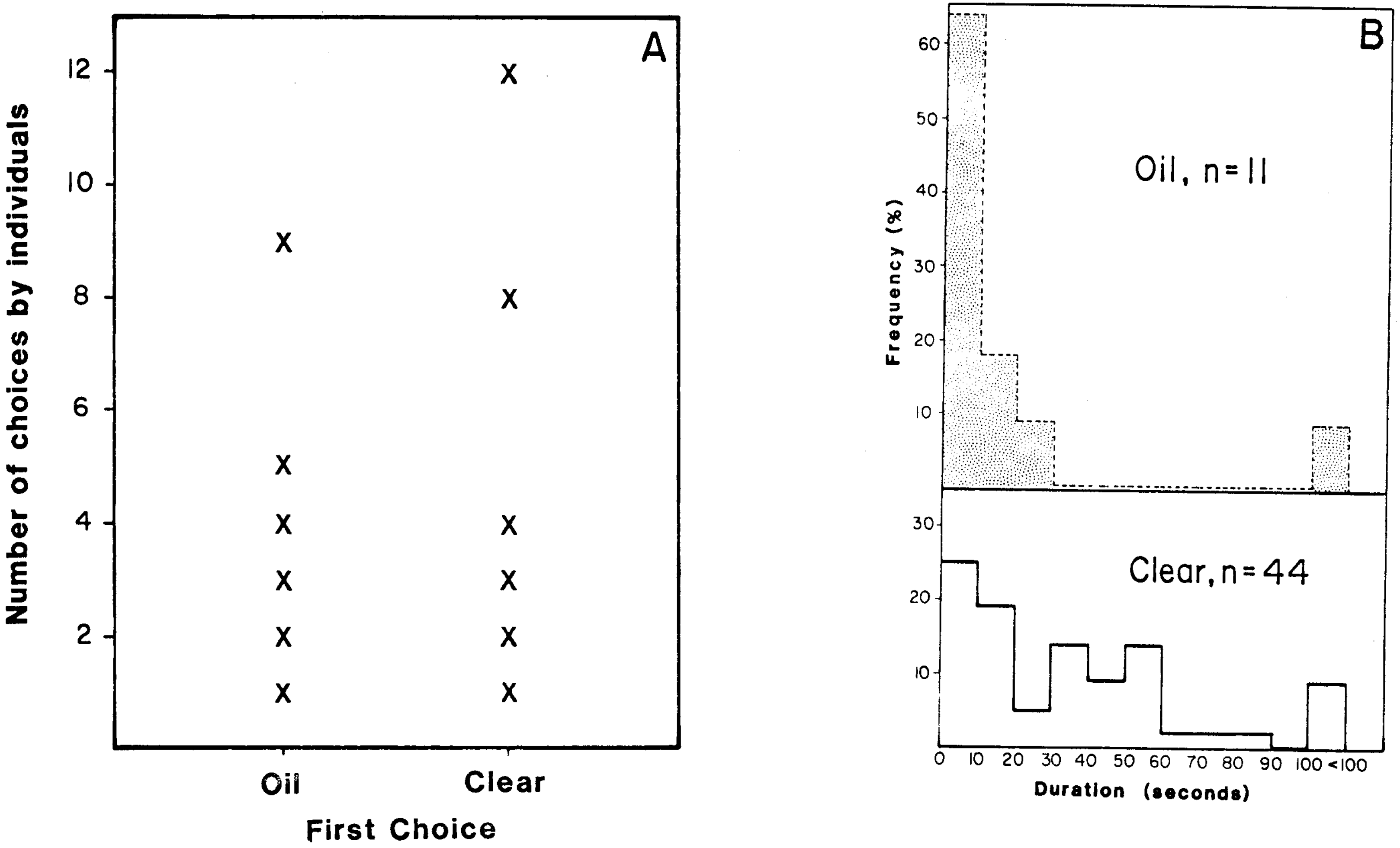

Figure 32. (A) Numbers of total choices by phalaropes after initial choice for oiled or clear pans.
(B) Frequency of swimming periods of different durations on oiled or clear surfaces.

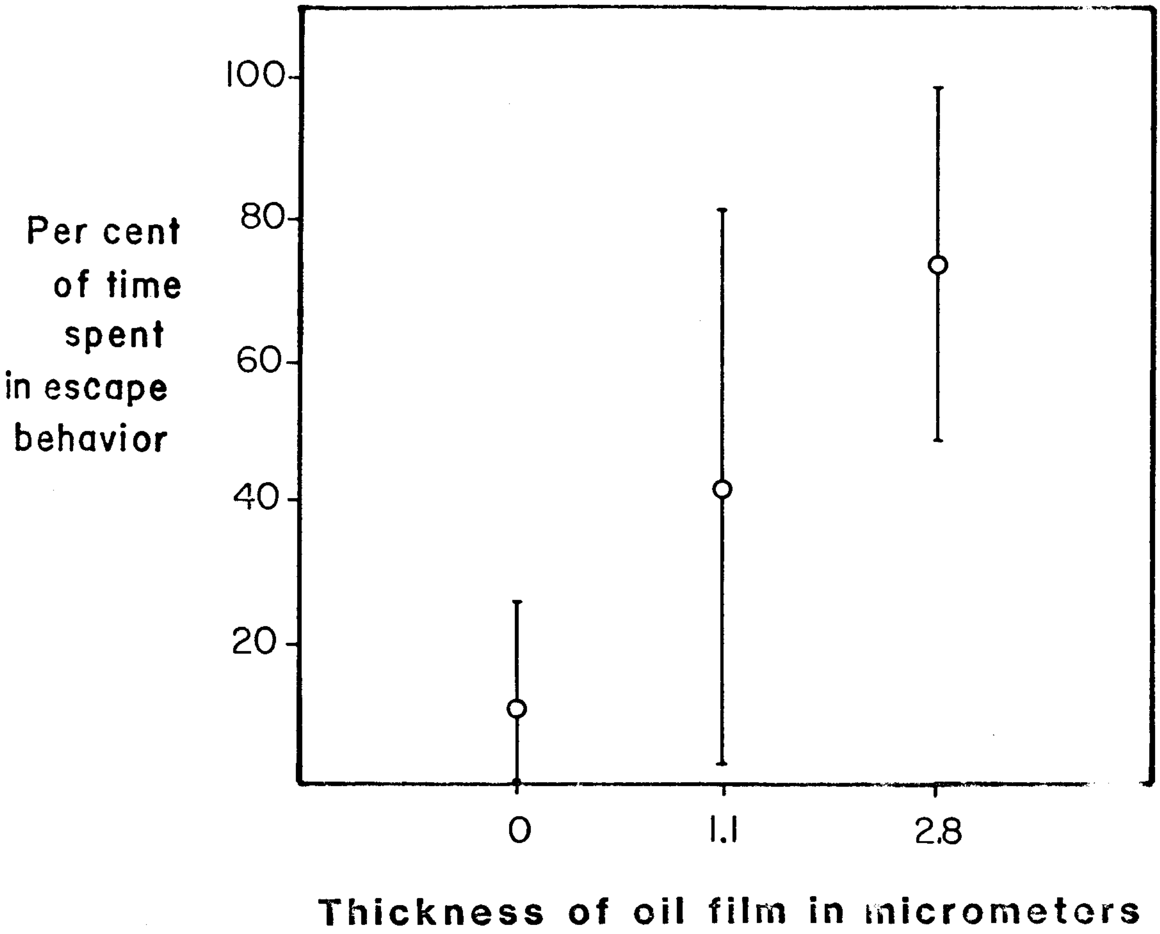

Figure 33. Escape response of Red Phalaropes in the presence of thin oil films.

For one thing, the bird can only avoid the oil if it has some alternative. In a very large, widespread, thick spill, the birds may not have nearby alternate choices of clean water. We have not tested whether they will fly long distances along the coast to avoid an extensive continuous spill. We suspect, however, that they will try to avoid small slicks if they have a clean nearby alternative, as might be the case in a small or patchy, broken-up oil slick.

The other critical question which remains is whether a bird after contact with oil for 5 seconds can be saved by subsequent behavior. Is that already too late? Within our experiment, we cleaned most of the birds after oil contact. Five seconds on one of the small pans was enough time to pick up a considerable amount of oil. On three of the individuals who had been in very briefly we did not do any cleaning. We merely returned them to their wire holding cage, outside at Barrow. They had plenty of food but may well have been under other stresses due to captivity. In each case these birds had, within a matter of a few hours, reworked all their plumage and had changed wet, sticky smears on their underparts to a dry and very uniform buffy color on all the plumage. The feathers were in good fluffy condition so the birds were probably able to control their temperature while out of the water. In experiments within the next few days these birds appeared able to swim reasonably well, so they had their plumage back in apparently functional shape, although the buffy color betrayed the lingering presence of oil residue on the feathers.

Whether a bird in the wild after this kind of brief exposure to a thin film could regain a healthy condition will depend on a wide variety of factors. Survival will depend on the type and thickness of the oil film, degree of contact, stress due to environmental factors - weather and foraging conditions - and the physiological state of the bird. We are presently unable to assess this. However, our guess now is that in many circumstances, phalaropes with this brief exposure (5 seconds or less to a thin film) would have a good chance of recovery and survival.

V. CONCLUSIONS

Many of the detailed conclusions of our studies have been presented in the preceding section. We summarize here our rankings of relative sensitivity to oil development for species, habitats, areas, and seasons.

Relative sensitivity of shorebird species

We have classified the common Beaufort coast shorebirds with respect to each species' relative sensitivity to littoral zone disturbances associated with oil development (Table 17). The principal disturbance being considered in this assessment is of course the threat of oil spills along the coast. The factors employed in making the assessment included primarily habitat use patterns of the various species. We gave primary weight to the relative use of tundra vs. littoral habitats, determined for each species by our transect work, but modified this with information on the choice of littoral habitat (gravel beaches, littoral flats or lagoon edges), the choice of foraging microhabitat within littoral habitats, and individual species foraging methods and behavior, to arrive at the final categorization. This assessment does not take into account, however, the possible duration of effects of an oil spill in different kinds of habitats as discussed above. The species with high sensitivity, Red and Northern Phalaropes, Sanderlings and Ruddy Turnstones, spend almost all of their time in late summer foraging in littoral habitats and usually in relatively exposed areas which would be the first hit by an oil spill. If however, oil is deposited on littoral flats and within lagoons and sloughs where it might affect prey densities and habitat conditions for several seasons, other species classed as moderately sensitive would also be strongly affected.

Relative sensitivity of habitats

Since the most effective method of managing bird populations is frequently a habitat management approach, we will summarize our results in terms of the littoral habitats we have studied. Table 18 summarizes this sensitivity ranking for six general descriptions of Beaufort coast littoral habitats. These categories emphasize the habitat features which correspond to major differences in bird use in terms of species composition and densities of shorebirds. The ranking also takes into account relative amounts of each habitat along the Beaufort coast.

Sensitive coastal areas

Results of mapping the Beaufort coast regions of highest bird use have been published in the Interim Synthesis Report: Beaufort/Chukchi (Weller *et al.*, 1978) with information added for the Harrison Bay area in the Synthesis Report for Lease Sale #71. For shorebirds, the sensitive areas correspond to the main concentration areas at spits and barrier islands - Peard Bay, Pt. Barrow, Plover Islands, Jones Islands, and

Table 17: Relative sensitivity of common shorebirds to littoral zone disturbances.

HIGH	MODERATE	LOW
Red Phalarope	Semipalmated Sandpiper	American Golden Plover
Northern Phalarope	Western Sandpiper	Pectoral Sandpiper
Sanderling	Baird's Sandpiper	
Ruddy Turnstone	Dunlin	
	Long-billed Dowitcher	

Table 18: Relative sensitivity of Beaufort littoral habitats. (Listed in order of decreasing sensitivity)

1. Littoral flats and saltmarsh
2. Sloughs and small lagoons (water surface and shorelines)
    1. with broad muddy margins
    2. with narrow margins
3. Spits and barrier islands
4. Mainland shorelines with broad beaches
5. Mainland shorelines with narrow beaches

perhaps other less studied barrier islands - and regions of extensive littoral flats or sloughs and lagoons - Fish Creek Delta, Colville Delta, and other sites less extensive or less studied (perhaps Pitt Point and Cape Halkett areas; see Figure 1). These are the main areas where highest total numbers of shorebirds are likely, but heavily used habitat areas are present along many other regions of the Beaufort coast. In these cases habitat protection will be most profitable.

Sensitive seasons

Shorebirds are present along the Beaufort coast from the end of May to late September. During June most birds are confined to tundra habitats, but densities in littoral areas are high from mid-July through early September. This is the period during which habitat disturbances will have the greatest impact on shorebird numbers. Most habitat disturbances will last through many seasons regardless of the time of initiation. Nevertheless, the winter period, when shorebirds are absent, corresponds to the frozen period, when habitats are less sensitive to alteration: we recommend that development take place during winter months whenever possible.

VI. APPENDIX

SEASONALITY OF LITTORAL ZONE USE - COMMON SPECIES

1. Semipalmated Plover (Charadrius semipalmatus). Figure 34A. Densities of this species are probably very low throughout the Alaskan arctic. They nest in sparsely vegetated gravel areas, conditions which occur frequently near gravel beaches. Most of the individuals recorded on our transects had nests nearby. An oil spill along the Beaufort coast washing into gravel areas along the edge of lagoons and sloughs or behind beaches might affect a large percentage, but few individuals, of the small population of this species.

2. American Golden Plover (Pluvialis dominica). Figure 12A. Of all common Barrow shorebirds, this species is the most nearly restricted to tundra habitats. Figure 12A shows the four-year mean density in littoral zone transects compared to densities on tundra transects over five years (Myers and Pitelka, 1980). Littoral zone use is almost insignificant even after all littoral habitats are ice-free. This pattern in Golden Plovers suggests they would not be readily affected by developments along the shoreline or by accidents involving spilled oil. Our observations at other sites along the Beaufort coast corrobrate this habitat use pattern. However, along the southern Chukchi coast near Kotzebue, Golden Plovers show a very different habitat distribution. In August the extensive salt marsh and flooded tundra areas of this region support large numbers of juvenile Golden Plovers. This may be a response to differences in the availability of habitats in the Beaufort compared to the southern Chukchi or to differences in the availability of prey within these habitats in the two areas; or it may relate to differences in the behavior of the two subspecies, P. d. dominica, the Barrow breeding race and P. d. fulva, the race which becomes more common in the southern Chukchi (Connors, in prep). At any rate our Barrow data suggest that along the Alaskan Beaufort coast the Golden Plover is relatively insensitive to disturbance by offshore oil development.

3. Black-bellied Plover (Pluvialis squatarola). A regular breeder inland and east of Barrow, this plover shifts to littoral habitats during migration more than does its congener, but numbers seen on our transects have been low at all Beaufort sites.

4. Ruddy Turnstone (Arenaria interpres). Figure 34B. Common breeder and migrant. Adult Turnstones breed on the tundra at Barrow in low densities (approximately .024 pairs per hectare; Myers and Pitelka, 1980) but shift to littoral habitats as nesting duties are finished. Adults depart Barrow in early August but juveniles remain in the littoral zone throughout August; densities here are much higher than on the tundra. This shift in late summer habitat agrees with

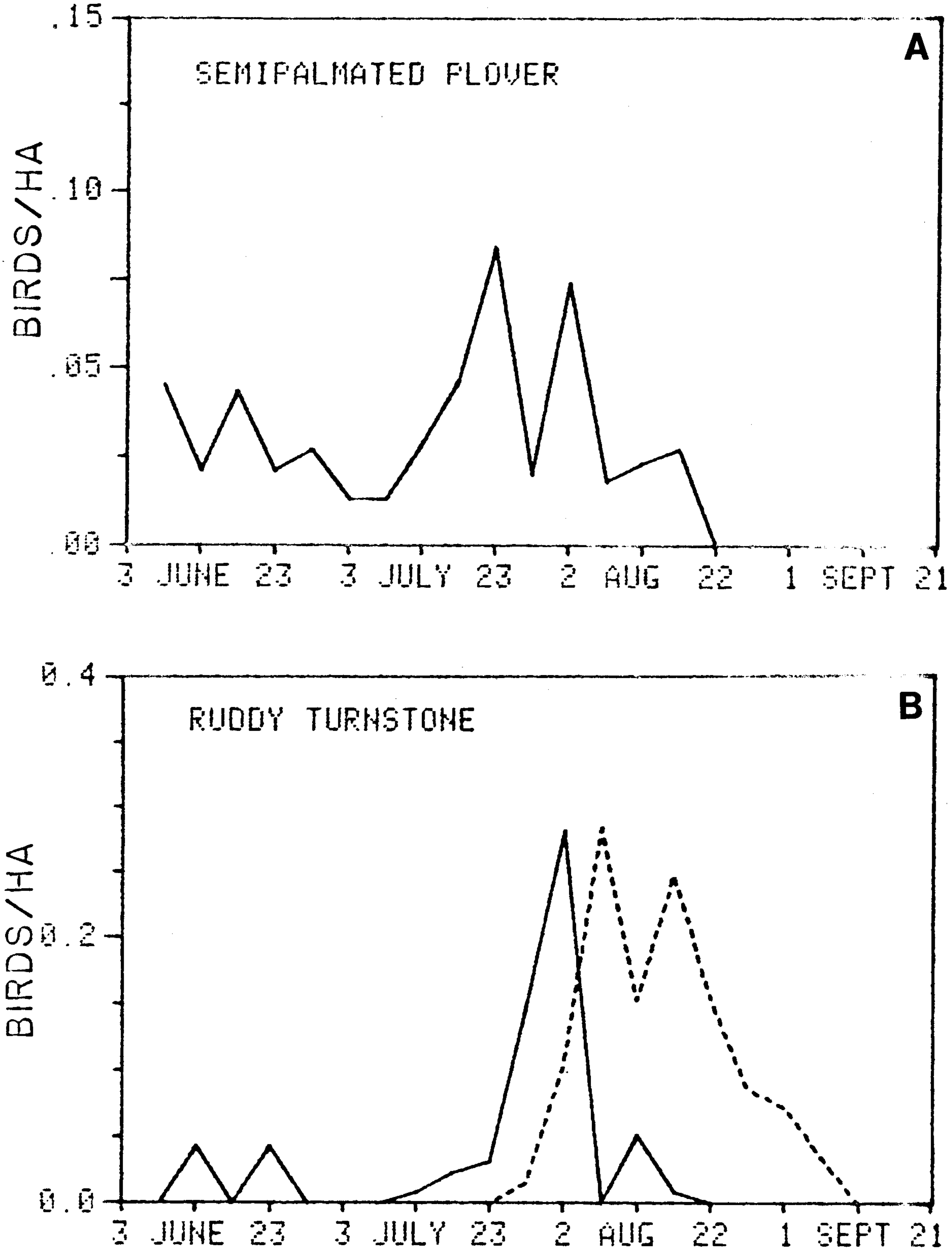

Figure 34. Mean shorebird densities at Barrow 1975-1978. (A) Semipalmated Plover. (B) Ruddy Turnstone. Adults (solid line) and juveniles (dashed line).

a report by Nettleship (1973) for an area in the Canadian arctic where fledged juveniles began foraging on the shores of a large cold lake.

5. Semipalmated Sandpiper (Calidrus pusilla). Figures 7, 8A, 25A, 35A, 35B. This species is a common breeder along the Beaufort coast. Adults nest on tundra but often forage on stream margins or mudflats adjacent to the nesting areas. Adults are therefore fairly common in littoral habitats throughout the early part of the season, in contrast to most of the Barrow sandpipers. As juveniles fledge in late July however, we observe a sudden and striking movement of this species into littoral areas (Figure 35B). This juvenile peak occurred at Barrow in all four years (Figure 8A) as well as at Fish Creek Delta (Figure 25A), Prudhoe Bay, Icy Cape and Wainwright. It is very short lived but may be important to juveniles for accumulation of fat reserves prior to southward migration.

6. Western Sandpiper (Calidrus mauri). Figure 8B, 36A. This species is an uncommon breeder at Barrow and becomes more rare eastward along the Beaufort coast. It is a fairly common migrant at Barrow however, with a seasonal habitat use pattern quite similar to that of Semipalmated Sandpiper. Adults occur on tundra and in littoral areas in early summer with a peak in late June or early July of most years followed by a juvenile littoral zone movement slightly later than, and of less magnitude than, Semipalmated Sandpiper.

7. Baird's Sandpiper (Calidris bairdii). Figure 36B. Seasonal habitat use by this species contrasts with most of the other Calidris sandpipers. Baird's Sandpipers nest frequently near lagoon edges, in tundra near brackish pools and on or near gravel beaches. One nest on Barrow spit was located in drift material 5 meters from the edge of Elson Lagoon on the gravel beach. The young hatched out several hundred meters from the nearest small patch of tundra vegetation. We located another brood near Nuwuk Lake on Point Barrow. These downy young, approximately one week old, were foraging directly on live zooplankton in the shallow water of a brackish flood pool. This species also nests commonly on coastal tundra in non-littoral areas. Departure of Baird's Sandpipers occurs earlier in August than that of most other Sandpipers, and densities of juveniles prior to departure remain low, indicating no movement of birds from distant areas through the Barrow area. The densities of individuals on littoral transects compare to a mean breeding density of .06 pairs per hectare at Barrow (Myers and Pitelka, 1980).

8. Sanderling (Calidris alba). Figure 37A. This species occurs in small numbers as adults at Barrow in early June, primarily in littoral areas near lagoons. In August and early September it is fairly common on gravel shores of Barrow Spit but much less common along mainland shores and

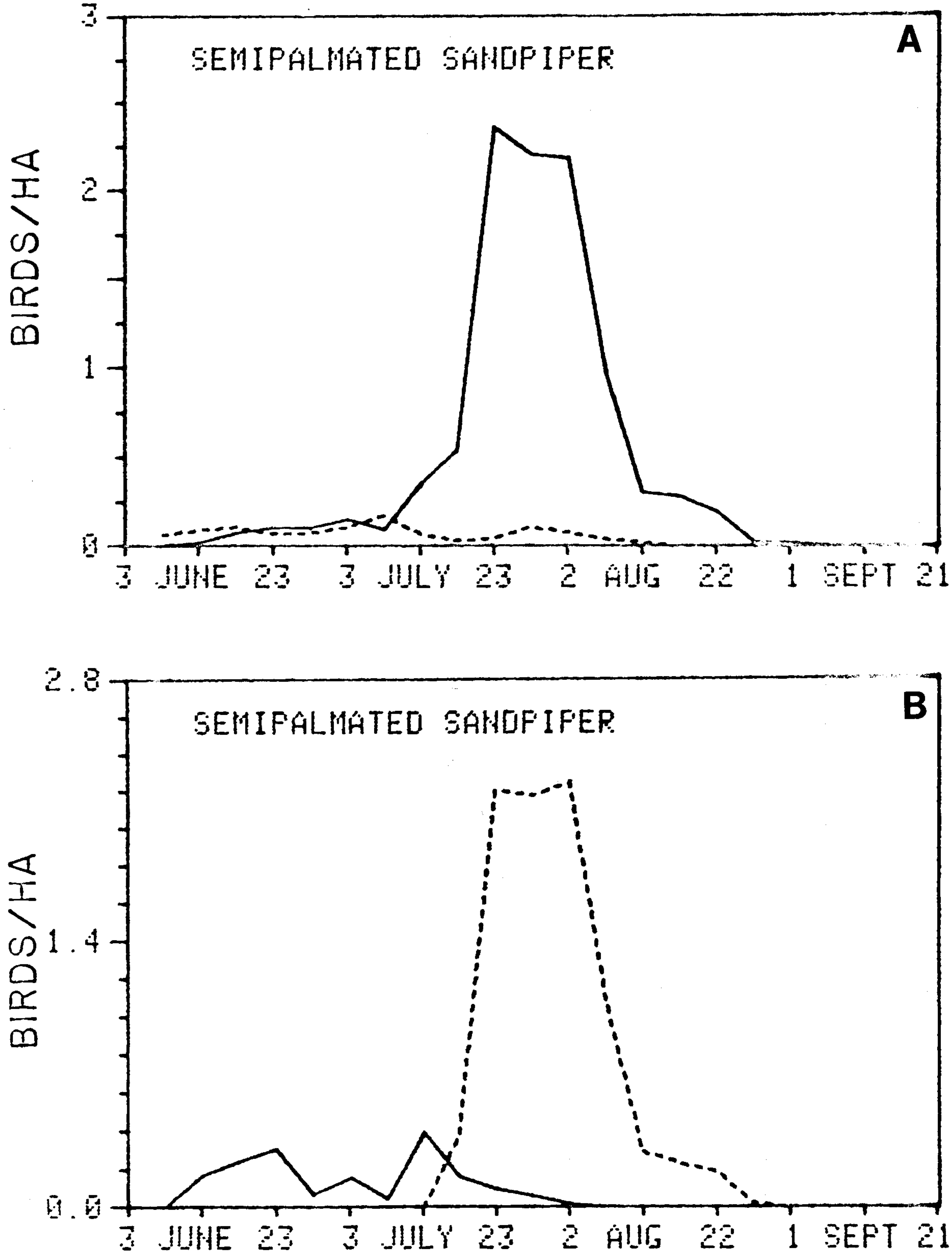

Figure 35. Mean Semipalmated Sandpiper densities at Barrow, 1975-1978. (A) Tundra (dashed line) vs. littoral (solid line). (B) Littoral transects: adults (solid line) vs. juveniles (dashed line).

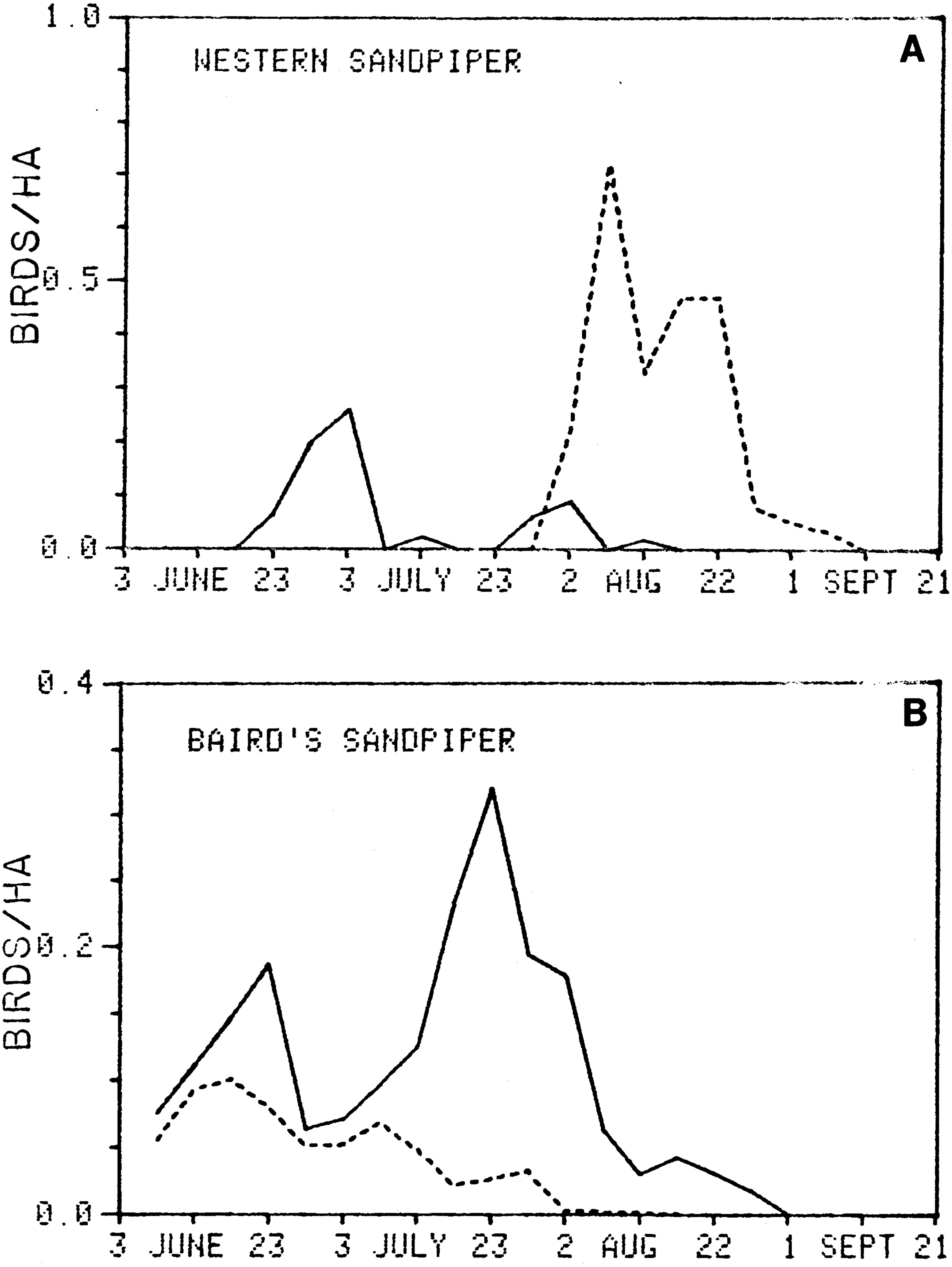

Figure 36. Mean shorebird densities at Barrow, 1975-1978. (A) Western Sandpiper, littoral habitats. Adults (solid line) vs. juveniles (dashed line). (B) Baird's Sandpiper, tundra (dashed line) vs. littoral (solid line).

almost absent from other littoral habitats. Essentially all late summer Sanderlings at Barrow are juveniles, foraging on marine zooplankton along the water's edge and accumulating heavy fat reserves prior to migration.

9. Pectoral Sandpiper (Calidris melanotos). Figure 37B. This species remains common on tundra in late summer, with limited movement to the littoral zone, primarily in muddy habitats near wet tundra or in salt marshes. Flocks occur irregularly in these areas as first post-breeding males and later females and juveniles begin southward migration.

10. White-rumped Sandpiper (Calidris fuscicollis). This species nests uncommonly at Barrow and probably at other sites along the Beaufort coast. We encountered only a few individuals on littoral zone transects.

11. Dunlin (Calidris alpina). Figures 12B, 24B, 38A. This common and widespread arctic sandpiper occurs in moderate to high densities on tundra throughout the summer but forages commonly in littoral habitats in late summer. At this time both adults and juveniles occur in tundra and littoral habitats. Juveniles appear to be somewhat more common in littoral areas, especially during late August, but this distinction is not as clear as earlier observations had indicated (Holmes, 1966a, b). We also suspect a distinction between the types of habitat used by adult and juvenile Dunlin within the littoral zone. Adults appear more likely to forage in mudflat and brackish pool margin habitats, whereas juveniles are more likely on gravel shores where they forage on plankton.

12. Stilt Sandpiper (Micropalama himantopos). A rare migrant at Barrow, nesting near Prudhoe Bay and farther east, where it is fairly common in littoral areas with shallow brackish pools.

13. Buff-breasted Sandpiper (Tryngites subruficollis). An irregular breeder at Barrow, more common eastward toward Prudhoe Bay. Restricted to tundra during the breeding season and occurring in migration on tundra near shorelines.

14. Long-billed Dowitcher (Limnodromus scolopaceus). Figure 38B. Juveniles of this species occur in high densities on tundra and in littoral areas (mudflats, saltmarsh, slough edges) at Barrow in mid to late August every year. This is a sudden, heavy migrational movement of juveniles beginning southward migration, probably from nesting areas inland on the north slope.

15. Red Phalarope (Phalaropus fulicarius). Figures 11A, 11B, 24A, 39A. This common nesting species at Barrow and along the Beaufort coast becomes abundant in littoral areas during late summer migration. Several aspects of Red

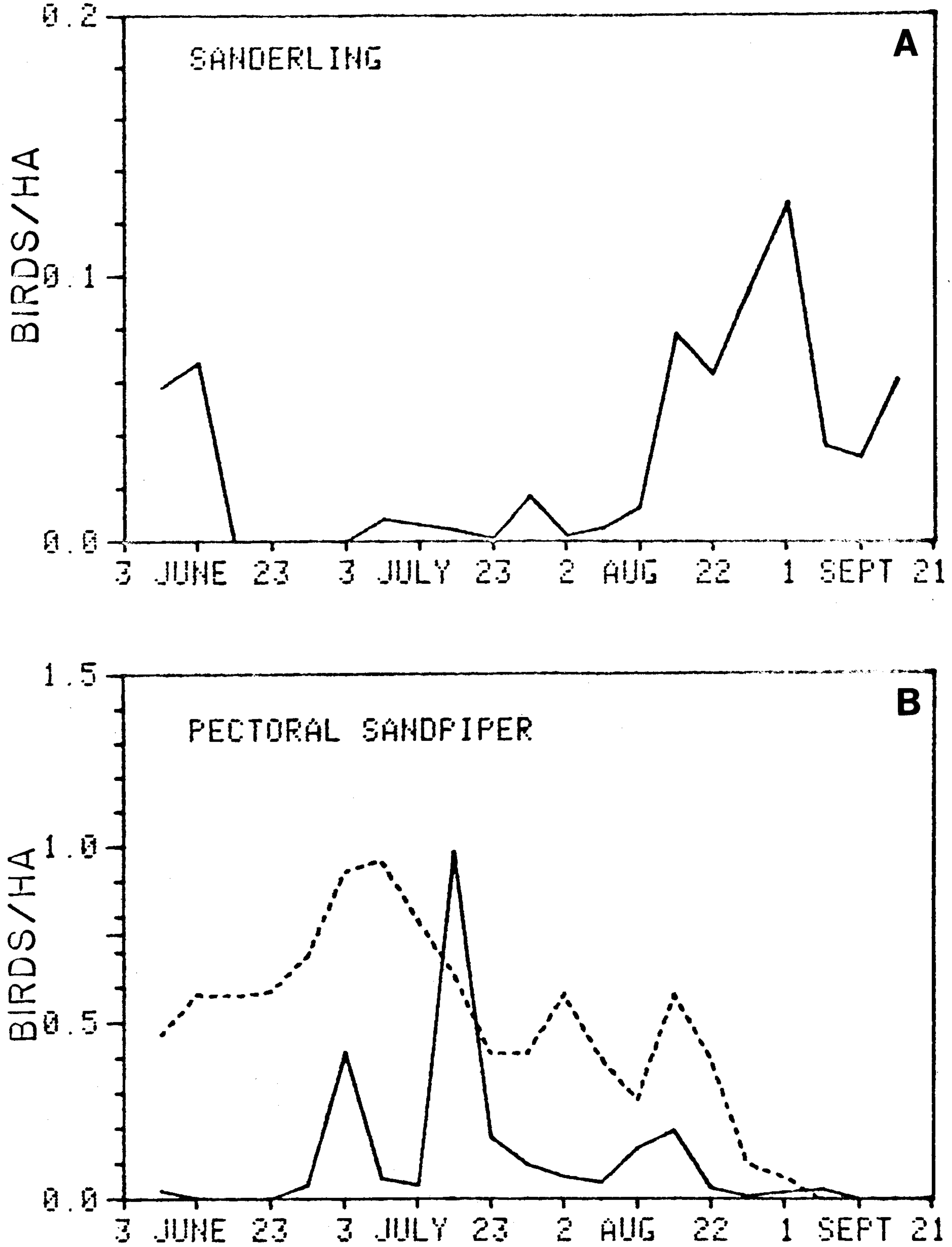

Figure 37. Mean shorebird densities at Barrow, 1975-1978. (A) Sanderling, littoral habitats. (B) Pectoral Sandpiper, tundra (dashed line) vs. littoral (solid line).

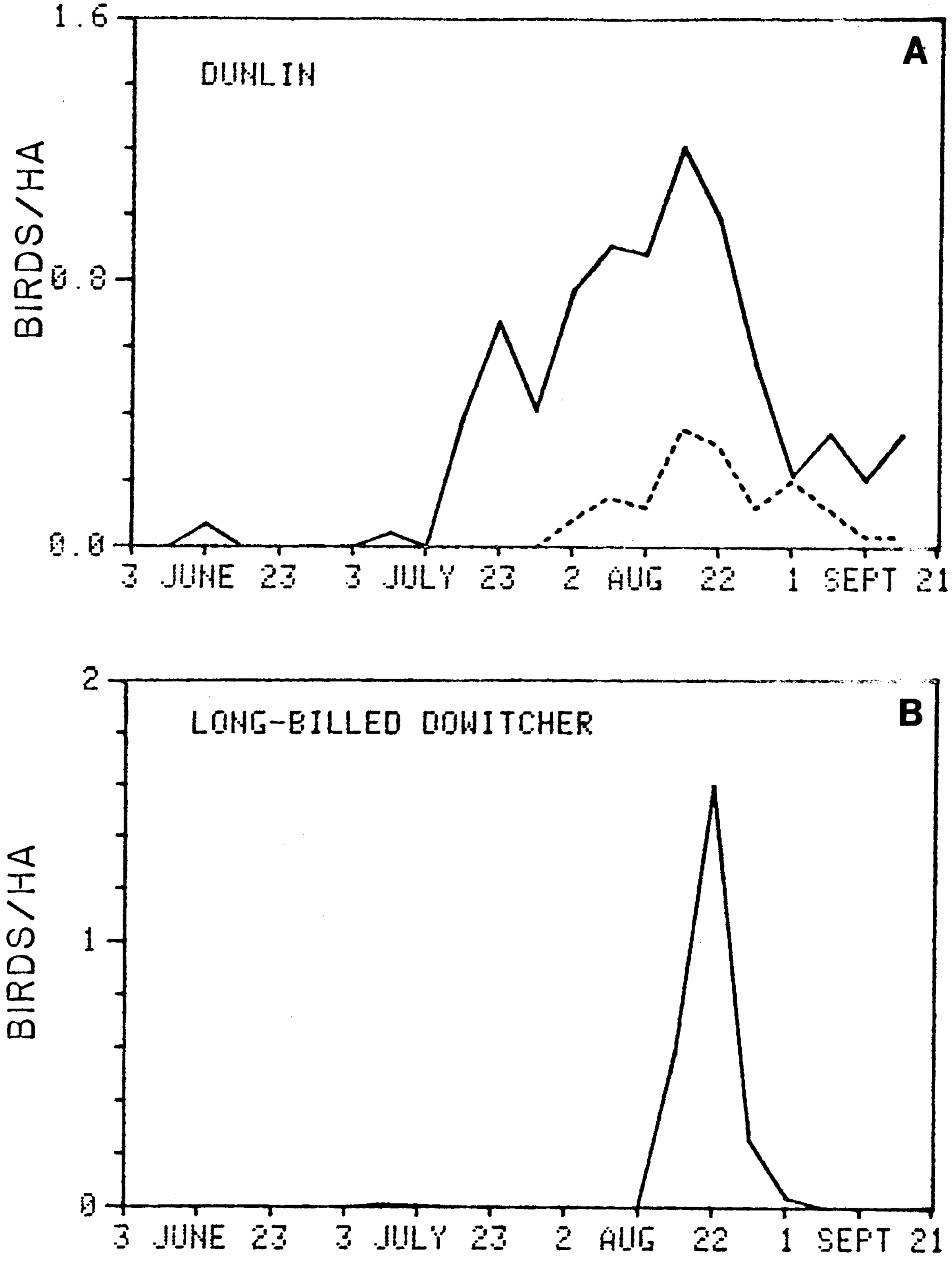

Figure 38. Mean densities at Barrow 1975-1978. (A) Dunlin, littoral transects. Adults (solid line) vs. juveniles (dashed line). (B) Long-billed Dowitcher, littoral transects.

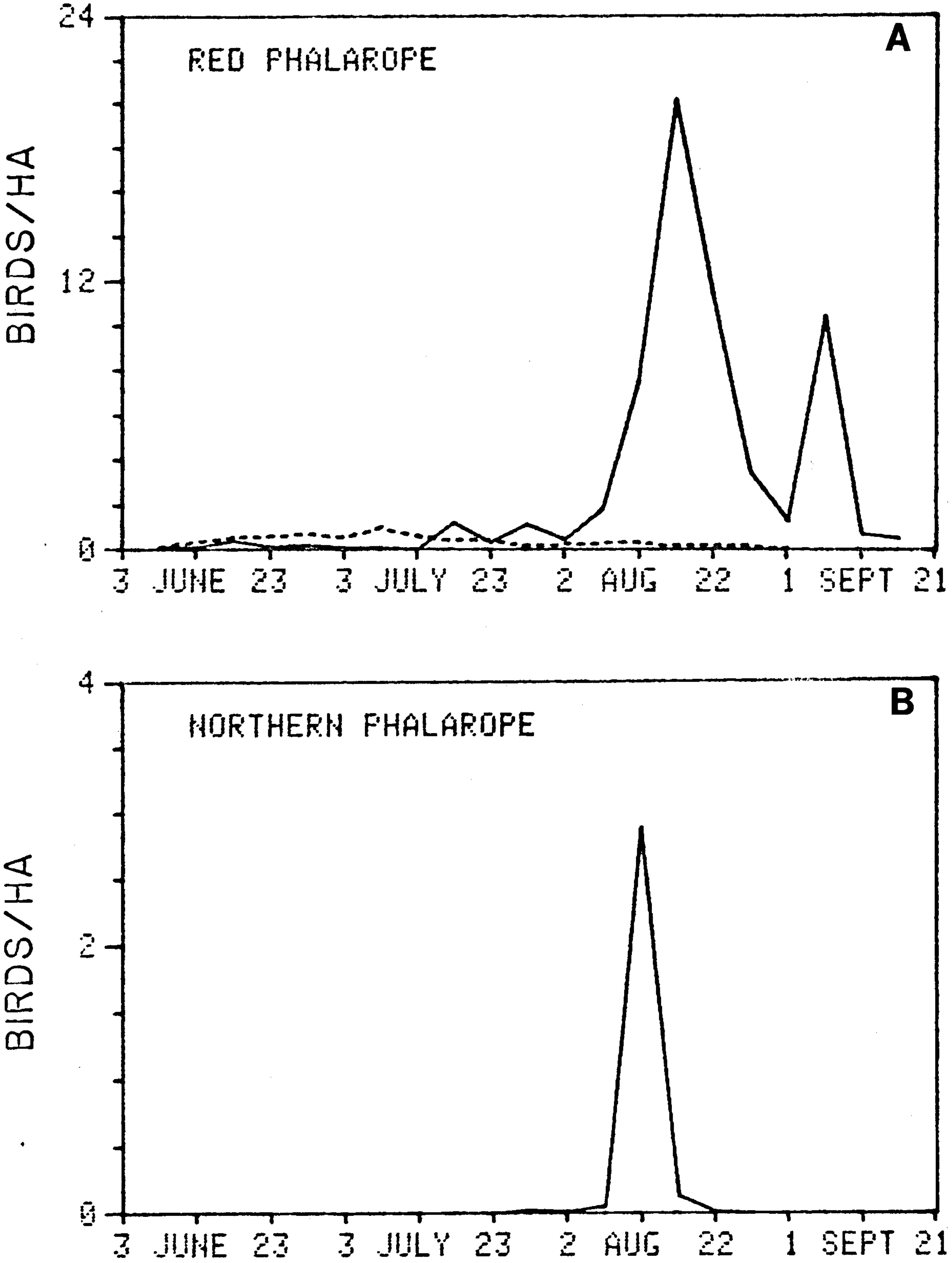

Figure 39. Mean shorebird densities at Barrow, 1975-1978. (A) Red Phalarope, tundra (dashed line) vs. littoral (solid line). (B) Northern Phalarope, littoral transects.

Phalarope movements and foraging ecology have been discussed within Results. Briefly, males and females nest on tundra in June. After clutch completion, females flock and begin migration, spending some time in ice-free littoral areas in late June or early July. Adult males tend the young, moving to some extent into littoral habitats in late July before they migrate southward. In early and middle August a flood of juveniles reaches the littoral zone, mainly along gravel shorelines where they forage on marine zooplankton. Densities in areas of gravel spits and barrier islands become extremely high, where phalaropes will be highly susceptible to damage from oil spills.

16. Northern Phalarope (Lobipes lobatus). Figure 24A, 39B. Uncommon but erratic at Barrow and increasingly common eastward along the Beaufort coast. Ratios of Red to Northern Phalaropes vary at different sites along the Beaufort, as discussed in Results. Northerns were much more common than Reds along the coast at Prudhoe Bay in 1978.

17. Glaucous Gull (Larus hyperboreus). Figure 40A. This largest and most common gull at Barrow occurred in highest densities along two of our transects because of proximity to the Barrow dump; nevertheless this species appears to be widespread along shorelines at all arctic sites.

18. Sabine's Gull (Xema sabini). Figure 40B. Fairly common along the shores of Barrow Spit during August, usually foraging on marine zooplankton with Arctic Terns and phalaropes.

19. Black-legged Kittiwake (Rissa tridactyla). Figure 41A. This species occurs commonly along Barrow spit shorelines in August but is also present as a non-breeder along shorelines beginning early June.

20. Arctic Tern (Sterna paradisaea). Figure 41B. Sporadically present in very high numbers in the Barrow spit area throughout August and early September. Large numbers of terns forage and roost on several areas of gravel spits and barrier islands in the Beaufort. They forage on small fish and marine zooplankton and therefore occur at Barrow on the same transects as phalaropes, Sabine's Gulls and Sanderlings.

21. Lapland Longspur (Calcarius lapponicus). Figures 25A, 42. The most common tundra nesting passerine along the Beaufort coast. During the breeding season it is essentially confined to tundra habitats but in August flocks of migrating birds, predominately juveniles, occur in areas of saline pools, lagoon edges, and saltmarsh flats. Their diet probably overlaps somewhat with that of shorebirds in these habitats but two juveniles collected at Barrow had been feeding principally on seeds.

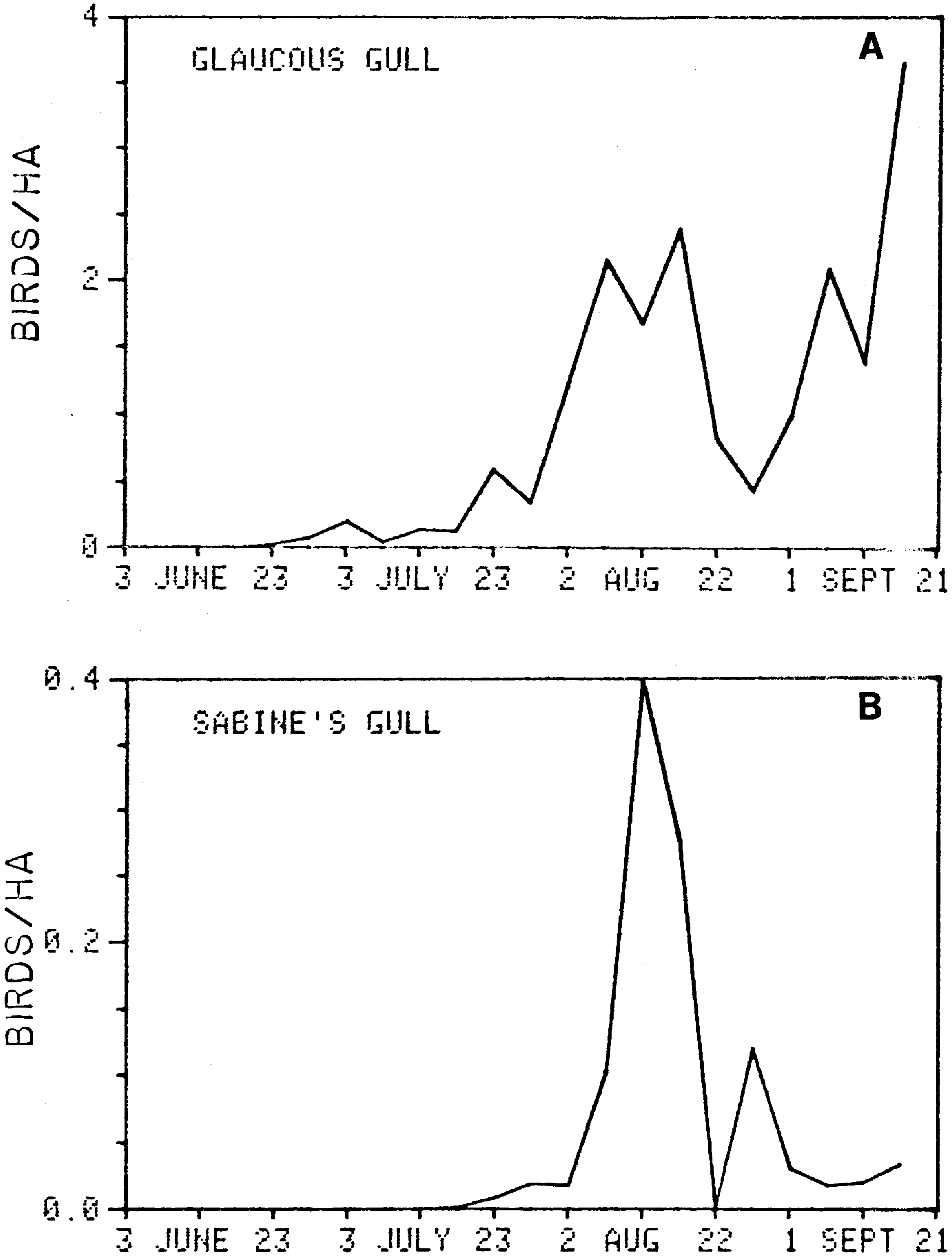

Figure 40. Mean densities on littoral transects, Barrow, 1975-1978.

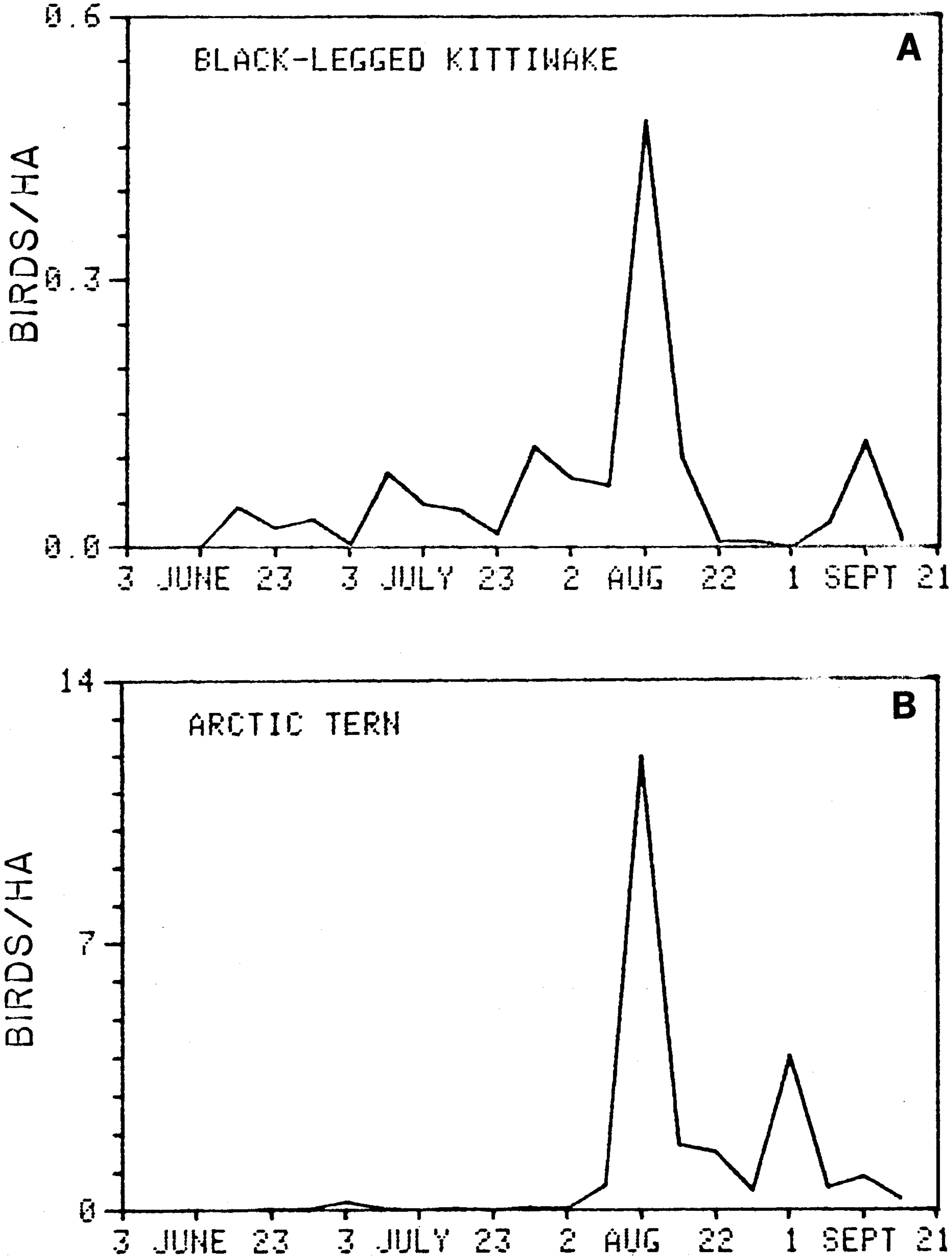

Figure 41. Mean densities on littoral transects, Barrow, 1975-1978.

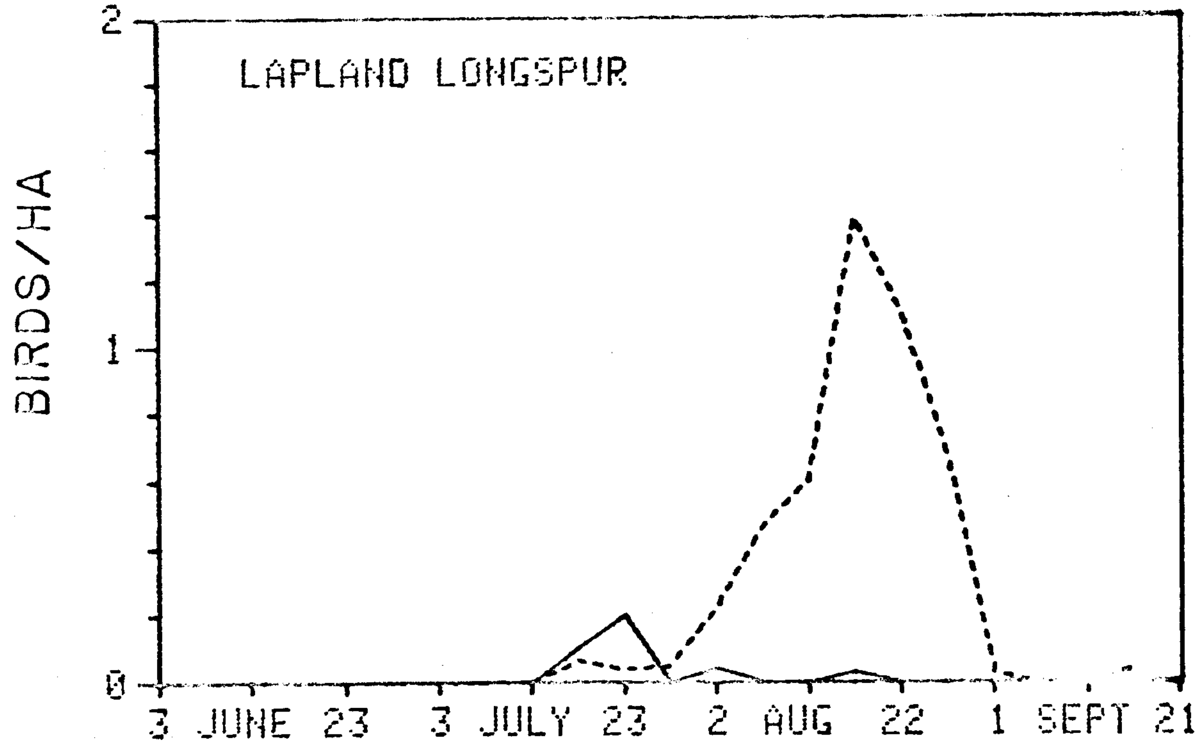

Figure 42. Mean densities on littoral transects at Barrow, 1976-1978. Adults (solid line) vs. juveniles (dashed line).

22. Snow Bunting (Plectrophenax nivalis). Snow Buntings are less widespread than Longspurs and individuals nesting near the littoral zone frequently forage in these habitats during the breeding season. In August there is a similar movement of juveniles and some adults into saltmarsh areas.

VII. ACKNOWLEDGEMENTS

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THE PELAGIC AND NEARSHORE BIRDS OF THE ALASKAN BEAUFORT SEA

by

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Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 196

January 1983

TABLE OF CONTENTS (Continued)

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I. Summary of objectives, conclusions and implications with regard to OCS oil and gas development

In order to delineate large scale patterns of seabird distribution and abundance in the Alaskan Beaufort Sea, bird observations were conducted on nine cruises during the period of maximum bird abundance (early August through mid-September). The six pelagic (waters deeper than 20 m) cruises and three nearshore (waters inside the 20 m contour) cruises produced over 500 hr of observation and censused over 1400 sq. km. The pelagic and nearshore regimes were divided into longitudinal sections (five for the pelagic and six for the nearshore) in order to demonstrate the bird use of the resulting eleven regions. The activities of birds were examined by analyzing migration rates and the number of birds sitting on the water so that bird density data could be better interpreted.

The pelagic regime was found to consist primarily of surface feeding species (gulls, terns, phalaropes and jaegers) with almost no use by diving species, except as a migratory area. The extreme western Beaufort was found to have high bird densities, apparently due to increased productivity caused by the Bering Sea Intrusion.

Nearshore waters contained large numbers of Oldsquaw, loons and migrant eiders with low densities of surface feeders approximating those found in pelagic waters. All nearshore regions have rather similar densities of diving species, with the exception of Harrison Bay which had consistently low densities. Like pelagic waters, surface feeding species were most abundant in the extreme western Beaufort.

Stomach contents indicate that the primary prey for species in the pelagic regime is Arctic Cod. In the nearshore diving species prey primarily on epibenthic crustaceans while surface feeding species prey on zooplankton.

This report shows the nearshore Beaufort to have a bird community that would be quite vulnerable to oil spills in that it contains high densities of diving species. Pelagic waters, with their low densities in most areas and lack of diving species, have a bird community that is much less likely to be affected by a spill.

A broad scale survey of this sort is perhaps most important in allowing site and region specific studies to be put into perspective with regard to distributions and activities throughout the Beaufort. This permits the resource manager to determine the importance of an area in the framework of a much large area.

II. Introduction

A. General nature and scope of study

OCSEAP Research Unit 3/4 was originally intended to deal primarily with birds associated with sea ice, specifically ice edges. The lack of a well-defined ice edge in the Alaskan Beaufort, and the minor role that sea ice plays in affecting large scale distributions during the period of maximum bird abundance (late July through early September) were factors in changing the scope of our research in this region. We attempted instead to document the large scale distributions and abundances of seabirds in the pelagic and nearshore Alaskan Beaufort and to determine those factors affecting these distributions. While OCSEAP was conducting such large area surveys in sub-arctic waters, primarily through the U.S. Fish and Wildlife Service, no such survey was specifically planned for the Beaufort.

With bird densities obtained on six pelagic and three nearshore cruises the large scale distribution patterns of the numerically important seabird species were determined. Information on the birds' activities, especially feeding and timing of migration was gathered to assist in the interpretation of the distribution and abundances.

While the time period covered by these cruises is limited (early August through mid-September), it covers the time of post-breeding staging, dispersal and migration, when densities of almost all species could be expected to be at their maximum for Beaufort marine waters. The large scale distributions presented here are valuable for interpreting the many site and region specific ornithological studies conducted in the last ten years.

B. Specific objectives

1. To determine the large scale patterns of distribution and abundance of seabirds in the pelagic and nearshore Alaskan Beaufort Sea during the post-breeding period (August through mid-September).

2. To determine, whenever possible, the major factors affecting these distributions and abundances.

3. To describe the activities of the numerically important bird species during their residency in the Beaufort Sea.

4. To identify the areas of critical importance to seabirds in the two regimes.

C. Relevance to problems of OCS petroleum development

The impacts that oil exploration and exploitation can have on birds are by now well known. They include direct mortality from oiling, degradation of critical habitats resulting in the disruption of annual cycles and depletion of prey populations. Specific potential impacts of oil development on birds in the Alaskan Beaufort Sea have been discussed in Weller *et al*. (1978). The characterization of the Beaufort avifauna presented here allows state and federal administrators to predict the species and approximate numbers of birds that would be impacted by development. With a knowledge of seabird distribution over much of the Alaskan Beaufort, these impacts can be put into a better perspective than is provided by a site specific study.

Seabirds occupy the terminal end of marine trophic systems and are usually more easily and efficiently sampled than other components of the system. For this reason areas we have identified as having high densities of feeding birds can be expected to be areas of high biological productivity. This is useful to the resource manager who is attempting to minimize the impacts of oil development. It also provides insights into which areas and systems would be most fruitful for further development-related studies.

III. Study Area.

A. Physical Setting

The Beaufort Sea is usually defined as that part of the Arctic Ocean east of the Canadian Arctic Archipelago and west of Point Barrow with its northern boundary being a line from Point Barrow to Land's End on Prince Patrick Island, N.W.T. This report will treat all sightings north of Alaska and east of Point Barrow (156°30'W) as being in the Alaskan Beaufort.

A good appreciation of the Beaufort Sea's position in the world's oceans is not afforded by a map of the State of Alaska which, unfortunately, is the way it is most frequently viewed. A much better perspective is provided by a polar projection where the Beaufort is seen to be part of the rim of the Arctic Basin (Figure 1). The Gulf of Alaska and Bering Sea are clearly part of the Pacific Basin, and the southern Chukchi, although part of the Arctic Ocean, has its physical and biological oceanography dominated by Bering Sea water. The Beaufort is the most truly "arctic" of the seas adjoining Alaska. This is true not only in its geographic setting but in its oceanography as well. The surface waters of the Beaufort are comprised almost entirely of pure polar water making it high arctic (Tuck, 1960). Only in the extreme western Beaufort do subarctic waters mix at the surface with polar water making that area low arctic. The boundary between high and low arctic areas corresponds well with the 5°C surface isotherm in August. The productivity and biota of the Beaufort reflect the high arctic characteristics seen in its physical oceanography.

The coastal features of the land adjacent to the Beaufort have played a role in determining the seabirds that utilize its waters. Rock cliffs and talus slopes that support large seabird colonies over much of the Alaskan coast are absent from the Beaufort. They are found in the Chukchi as far north as Cape Lisburne in Alaska (480 km southwest of Pt. Barrow) and at Herald and Wrangel Islands in the western Chukchi. The only colony of cliff nesting seabirds in the Beaufort is the small Thick-billed Murre (Uria lomvia) colony at Cape Parry, Banks Island, N.W.T. (600 km east of the Alaskan Beaufort).

While the Beaufort lacks the large seabird colonies that Alaska is famous for, it is an important migratory pathway and staging area for large numbers of tundra nesting species. The North Slope of Alaska, much of the Canadian Arctic Archipelago and the adjacent Canadian mainland have major expanses of moist and wet tundra that support large numbers of breeding waterfowl, gulls and shorebirds (Pitelka, 1974; King, 1979; Bergman et al., 1977; Porsild, 1943). Many of these species use the Beaufort as a migratory pathway and staging area (Frame, 1973; Watson and Divoky, 1974; Richardson and Johnson, 1981; Connors et al., 1979).

B. Marine Zones and Geographic Subdivisions

The Alaskan Beaufort is divided into two regimes, pelagic and nearshore, with the 20 m isobath as a boundary (Figure 2). Bird observations made by R.U. 196 fall into three groups that correspond well with three distinct habitats used by birds. These are:

Pelagic: Waters deeper than 20 m and extending out to the slope of the continental shelf. Most of our observations in the pelagic regime are in the waters from 20 to 200 m.

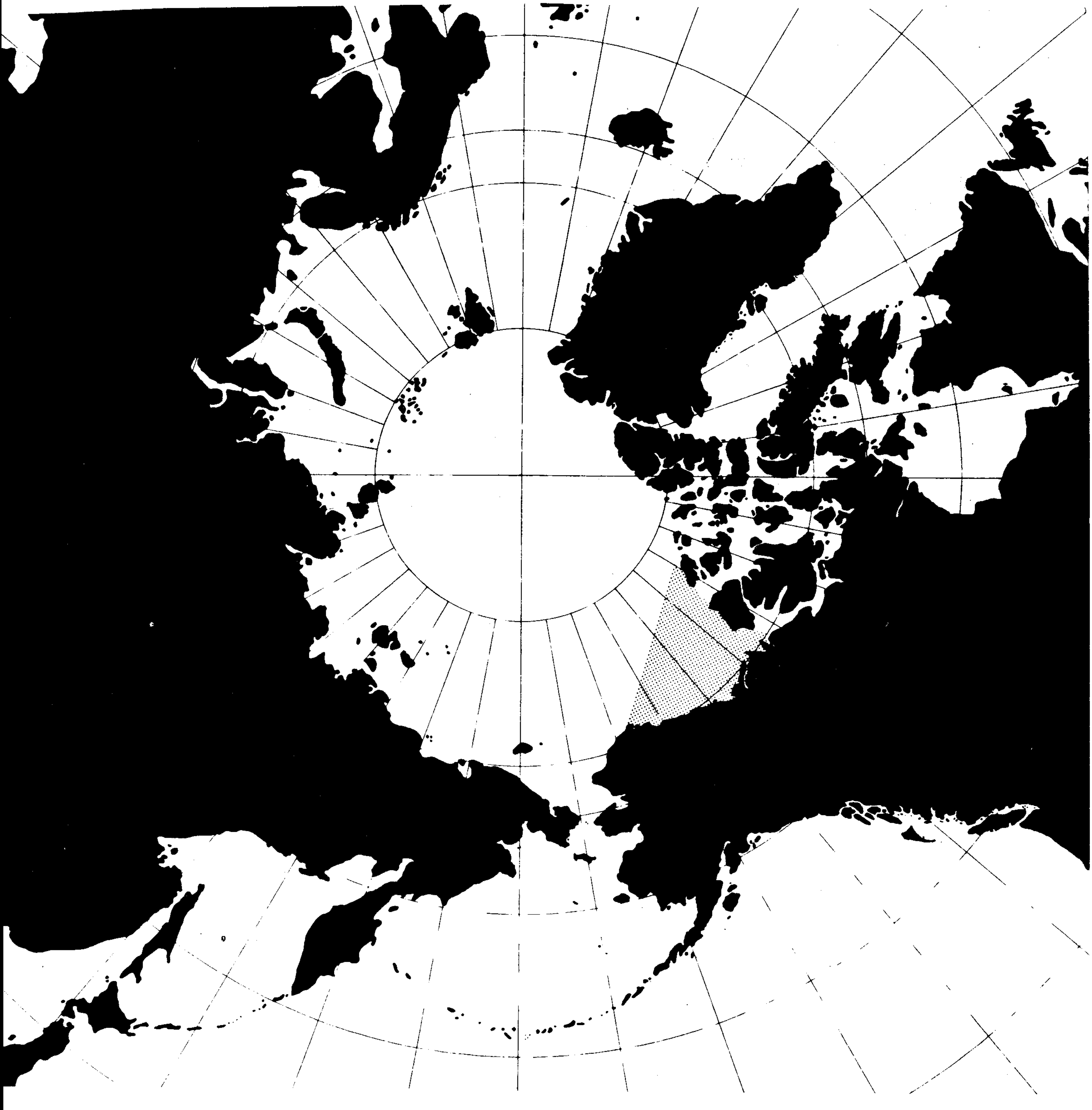


Figure 1. Polar projection showing the location of the Beaufort Sea.

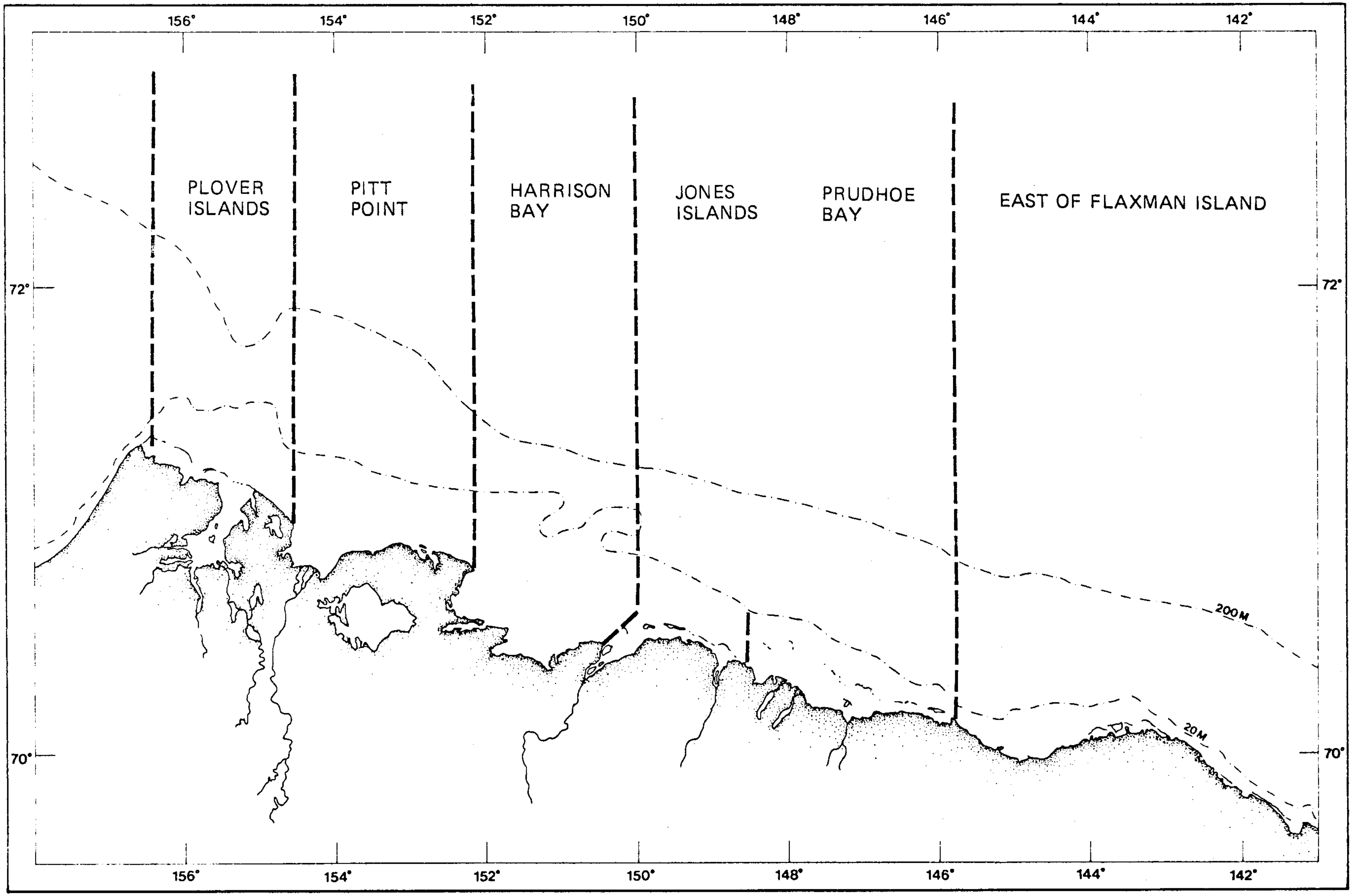


Figure 2. The five pelagic and six nearshore regions of the Alaskan Beaufort Sea. The pelagic and nearshore regimes are separated by the 20 m contour.

Nearshore: Waters shallower than 20 m but not within 300 m of land. Most of our nearshore observations are in waters less than 10 m. In the western Beaufort the 20 m contour is 35 km from shore and in the eastern Beaufort as close as 10 km from shore.

Littoral: Beach habitats including water and land habitats within 300 m of the land/water interface. These observations have been summarized in Divoky (1978a) and Divoky (1979 b). They will be mentioned in this report only when they relate to nearshore and offshore observations.

Pelagic and nearshore areas are sampled by icebreaker and small boat respectively, while the littoral zone is censused by observers on foot. Each of these zones also has characteristics that separate them from the others. The documentation of the characteristics and differences of the bird communities of the pelagic and nearshore regime is the goal of this report.

The bulk of the Alaskan Beaufort coast is composed of four major chains of barrier islands and three major bays. For purposes of this report we have divided the Beaufort into five longitudinal sections. This was done to provide a stratification of our Beaufort data that will allow us to show differences between regions, and also to provide information for those concerned with birds in a specific part of the Beaufort. The five sections are based on oceanographic and coastal features. These sections are shown in Figure 2 and listed below. The name we have given to each area is in quotes and is taken from a prominent coastal feature. More information on each section is presented in the data presentations and discussions.

Section A - "Plover Islands" - Point Barrow to Cape Simpson (156°30'W to 154°30'W). The coast is composed primarily of the Plover Islands which enclose Elson Lagoon. The lagoon is unlike others in the Beaufort in that it has no major rivers entering it. Meade River enters into Dease Inlet, which is connected with Elson Lagoon, but the Meade River Delta is some 30 km from Elson. The offshore waters regularly have the highest sea surface temperatures in the Alaskan Beaufort due to the Bering Sea Intrusion (Johnson, 1956). An eddy of Bering Sea water is also frequently present (G. Hufford, pers. comm.). It is in this section where the surface effects of the Bering Sea Intrusion can be expected to be most pronounced. The Plover Islands are named after the H.M.S. Plover which anchored near them and has no direct connection to the shorebirds known as plovers.

Section B - "Pitt Point" - Cape Simpson to Cape Halkett (154°30'W to 152°10'W). This section lacks barrier islands and lagoons and is rather featureless except for Smith Bay and the adjacent Ikpikpuk River Delta in the western part of the section. Sea surface temperatures in the offshore area frequently show the effects of the Bering Sea Intrusion.

Section C - "Harrison Bay" - Cape Halkett to Thetis Island (152°10'W to 150°10'W). This section encloses Harrison Bay, the largest embayment on the Alaskan Beaufort coast. It also has the largest river, the Colville, flowing into it.

Section D - "Jones Islands" - Thetis Island to Egg Island (150°10'W to 148°30'W). The coast from Thetis Island to Egg Island consists of a chain of barrier islands enclosing Simpson Lagoon and Gwydyr Bay. One major river, the Kuparuk, enters into this section as do a number of small streams. The mainland to the south is land owned by the State of Alaska and has already seen much oil related development.

Section E - "Prudhoe Bay" - Egg Island to Brownlow Point (148°30'W to 145°50'W). For presentation of pelagic data, this area is lumped with the Jones Islands region to the west. This pelagic region frequently has ice near the 20 m contour in August when areas to the west and east are ice free. For nearshore data the two regions are treated separately for the following reasons. The Jones Island region has a shallow (2 to 3 m), narrow (less than 9 km wide) lagoon, while the Prudhoe Bay region has a deeper (maximum 7 m), broader (maximum 20 km) inshore area. The barrier islands in the Prudhoe Bay area are not in a coherent chain and the only area that is strictly a lagoon is the area south of Flaxman Island.

Section F - "East of Flaxman Island" (145°50'W to 141°00'W). The western part of this region is comprised of Camden Bay, a poorly defined bay with rather high vertical relief near the shore where the foothills of the Brooks Range come within 35 km of the coast. In the east a narrow, discontinuous lagoonal system is present from Barter Island to the Canadian border. The 20 m depth contour is as close as 7 km from land in the eastern part of this region. Thus, what we refer to as the pelagic regime, in this report (waters deeper than 20 m), is quite close to the shore and the barrier islands. The mainland and islands in this region are part of the Arctic National Wildlife Refuge. Both the waters of the refuge and the refuge itself have been the objects of much interest from the oil and gas industry in recent years.

Sections A through C all border the Naval Petroleum Reserve in Alaska (NPR-A), a federal oil reserve. The eastern boundary of the Reserve is the west bank of the Colville River. Section D is adjacent to State of Alaska lands, much of which have been exploited for oil. Section F is adjacent to the Arctic National Wildlife Refuge, administered by the U.S. Fish and Wildlife Service.

C. Ice

1. General Effects

Sea ice is such a constant and dominant presence in the high arctic marine system that all seabird species that are regularly found in the high arctic have had at least part of their life histories influenced by the effects of sea ice. Ice can have a number of effects on seabirds and productivity that affects seabirds. These have been discussed previously (Divoky, 1979a)but will be summarized here. Effects of sea ice on seabirds can be grouped into negative and positive effects.

Negative Effects

a. Decreases the surface area of the water.

Sea ice acts as a barrier on the ocean's surface restricting the access of birds to prey in the water column and benthos. Surface feeders are most severly affected, since their potential feeding area is directly reduced by the amount of ice cover. Diving species can still have access to much of the potential prey in the water column and benthos, if open water is scattered throughout the ice.

b. Reduces primary productivity in the water column.

Ice inhibits phytoplankton blooms in the water column by decreasing light penetration of the water column and increasing the stability of the water column. The decrease of light penetrating the water column is caused by light being reflected by ice and snow and light being absorbed by algae in the ice. This reduction in light reduces the depth of the euphotic zone. Ice stabilizes the water column by preventing wind mixing and by forming a surface layer of meltwater in the spring and summer (Dunbar, 1968). This stabilization of the water column prevents nutrients from being upwelled to the euphotic zone.

c. Reduces benthic and intertidal biota.

In shallow waters ice freezes to the bottom for much of the year and prevents the establishment of plant and animal populations. In addition, keels on ice floes can scour the bottom as they move through the water (Reimnitz and Barnes, 1974). Sessile benthic populations are reduced in areas where ice scour is intense, although motile species can migrate into scoured areas during ice-free periods. Mollusk, kelp and eelgrass (*Zostera marina*) beds are all important food sources for birds in areas south of the pack ice. They are greatly reduced in the Alaskan arctic due to ice scour.

d. Provides terrestrial predators access to breeding sites.

In the spring before water surrounds the nearshore islands of the Beaufort and Chukchi seas, Arctic Fox (*Alopex Lagopus*) can visit the islands by traveling over the ice. Their presence can greatly reduce breeding success. For this reason islands near river mouths have the highest breeding populations, since river runoff surrounds them early in the year and hastens ice decomposition (Divoky, 1978b).

Positive Effects

e. Provides a matrix and substrate for an in-ice algae bloom and an associated under-ice fauna.

An in-ice algae bloom occurs in sea ice in spring. The importance of this bloom in the energy budgets of arctic and subarctic seas has only recently been recognized (Alexander, 1974; McRoy and Goering, 1974). An under-ice zooplankton fauna composed of copepods and amphipods is found directly under the ice throughout much of the year (Mohr and Geiger, 1968). Two species of fish, polar cod (*Arctogadus glacialis*) and arctic cod (*Boreogadus saida*), are also found directly under ice feeding on the zooplankton.

f. Provides hauling out space for marine mammals.

Marine mammals can provide scavenging opportunities to seabirds by leaving feces, placentas and carcasses on the ice. This does not, however, appear to be an important food source in the Beaufort Sea. Walrus could be expected to provide the best scavenging opportunities and they are present in the Beaufort only as stragglers.

g. Provides roosting sites.

Ice provides hard substrate that allows seabirds to leave the water to roost. This allows such species as the *Larus* gulls, which typically roost on hard substrates, to occur in numbers well offshore.

h. Reduces wind chill.

The upper surface of pack ice typically has many ridges which act to reduce wind speed directly over the ice. This provides a microhabitat with a reduced wind chill for birds sitting on or next to the ice.

i. Decreases wave action.

Surface disturbance of the water by wind is reduced by the presence of ice. Although swells pass through areas with ice cover, waves do not. In addition, the lee side of ice floes and cakes usually has little surface disturbance. These reductions in surface disturbance may allow surface feeders to more easily locate prey.

2. Yearly cycle of ice in the Beaufort

The ice environment of the Beaufort Sea is best described by discussing the yearly cycle from complete ice cover in winter and early spring, through decomposition, to formation of new ice in fall. The ice features and events discussed will be those of most importance to birds. More detailed information on ice features and dynamics can be found in Weeks and Kovacs (1977). In the following discussion and the remainder of the report two primary ice zones will be recognized: shorefast ice and pack ice. Shorefast ice is that part of the nearshore ice that is in continuous contact with the bottom (bottomfast ice) and the seaward extension of this ice (floating fast ice), that extends out to approximately the 15 m isobath (Shapiro and Barry, 1978). All ice seaward of the floating fast ice will be called pack ice.

Maximum ice cover

Ice cover is complete or nearly so from late fall (approximately 1 November) through late May. The time of freeze up or extensive ice cover varies greatly from year to year (Brower et al., 1977). From December through

April the pack ice edge is in the central to southern Bering Sea and birds are essentially absent from the Chukchi and Beaufort seas due to ice cover. During winter leads in the ice form as winds and currents act on the pack ice but, typically, they quickly refreeze. In areas where conditions cause leads to form on a constant and regular basis a predictable area of open water can develop. Such a chronic lead system can provide stable wintering habitat since some open water will almost always be available as leads constantly form and refreeze in a given area. Such a system exists in the Chukchi Sea from Wainwright to Point Barrow (Nelson, 1969) and extends to a small extent into the Beaufort. This is the only location where seabirds could be expected to regularly winter in the Alaskan Beaufort.

Ice decomposition

The first major event of importance to birds in the decomposition of ice is the formation of a lead extending from the central Bering Sea through the Bering Strait, north to Cape Lisburne and then northeast to Point Barrow. The lead is a flaw lead, being formed between the shorefast ice and the pack ice. It forms at Point Barrow from early to mid-May and is an important migratory pathway for certain species of marine mammals and seabirds that winter at the edge and to the south of the Bering Sea pack ice (Woodby and Divoky, 1982). While the lead is well defined as far north as Point Barrow it does not extend any distance into the Beaufort. Instead, a diffuse system of leads extends to the northeast. These leads are less well defined than the flaw lead and are much further offshore. The nature of the lead system in the Beaufort also makes it more likely to refreeze and can result in spring migrants being unable to find open water (Barry, 1968).

The first important event that occurs in the decomposition of shorefast ice in the Beaufort is the breakup of the North Slope rivers. Rivers usually begin to flow in the last week of May. When the river runoff reaches the sea it runs both over and under the shorefast ice adjacent to the river mouth or delta. The water's weight, temperature, movement and the detritus it leaves on the ice all act to hasten shorefast ice decomposition near rivers. The river runoff remains on top of the ice for as long as two weeks before it flows down through the ice. Runoff contains much detritus which is left on top of the ice and decreases the albedo increasing melting. The flow of the water under the ice also weakens the ice and further increases decomposition. Because of these effects nearshore waters near river mouths can be ice free in early to mid-June, up to one month before areas without rivers or large streams. This is important to species that feed and rest in nearshore waters and those that breed on barrier islands. Barrier islands near river deltas are surrounded by water earlier and thus isolated from Arctic Fox predation.

Nearshore areas without major river input have ice decomposition occur at a slower rate. Solar radiation absorbed by the mainland beach and the barrier islands melts the adjacent ice forming moats of open water that first appear in mid-June and increase in width during June and early July. At the same time meltponds form on the surface of the shorefast ice as the snow and surface ice are melted by the sun. In time, some of these meltponds become continuous with the seawater below the ice. Over half of the surface of the ice can be covered by meltponds before large cracks appear in the ice in late June or early July. Once cracks are large enough to allow waves to form, ice decomposition can be quite rapid. This is due in large part to most of the nearshore ice being first-year ice that is not as dense or thick as multi-year ice. Areas behind barrier islands usually become ice free between early and mid-July. Shorefast ice directly outside barrier islands usually decomposes about two weeks later than ice inshore of the islands. Once much of the shorefast ice has decomposed, cakes or small floes from the pack ice can be blown into nearshore areas. Such ice is usually discernible from shorefast ice by its vertical relief and blue color that identifies it is multi-year ice and distinguishes it from the flat, white first-year ice. All but the large floes of pack ice blown into nearshore waters decompose within a few days and many of the small pieces are carried onto the beach by swells. At Cooper Island, an island unaffected by river runoff, where we have done our most intensive and long term field work we recognize four ice periods. These periods are based on observations made from the island from June through September.

> <u>Shorefast ice</u> - the period of time when moat formation and meltpond formation are occurring and no major areas of open water are present.
>
> <u>Shorefast breakup</u> - from the first formation of major cracks in the ice to the period when all shorefast ice has either decomposed or been carried out of the nearshore area by currents or wind. This period typically lasts from the first week of July to the third week of July.
>
> <u>Drifting pack ice</u> - after the shorefast ice decomposes, the predominant NE winds can then move the pack ice into the nearshore area. The presence and concentration of ice in the nearshore area during this time depends to a great extent on wind and the ice conditions in the offshore Beaufort. This period typically begins the last week in July and lasts for from one to three weeks.
>
> <u>Open water</u> - the open water period typically occurs after the drifting ice is no longer present in the nearshore zone either due to wind or melting. Pack ice is frequently present on the horizon during this time (approximately 13 km from shore) and is apparently grounded. This period can begin as early as late July but typically begins the second to third week of August.

Decomposition of the pack ice is less dynamic than the shorefast ice. There is a steady, slow melting from June through September. In June and July ice cover is usually 90 percent in all areas. Areas northeast of Point Barrow, typically, are open earlier due to the flaw lead extending in from the Chukchi. By early August the southern edge of the pack ice has moved offshore leaving a strip of water adjacent to the coast. The width of the zone depends on wind conditions and the degree of melting. The pack ice can be next to the shore for the entire length of the Alaskan Beaufort as it was in 1975, or as much as 200 km offshore as it was in 1977. In August of the years 1976-78 pack ice was close to the 20 m contour in the area from Harrison Bay to Flaxman Island. The offshore areas to the east and west typically have the ice further from shore apparently due to the Bering Sea Intrusion to the west and the Mackenzie River outflow to the east. Annual average ice conditions are summarized in Brower et al. (1977).

Ice formation

Ice typically begins to form in the Beaufort in October although it may occur as early as mid-September. Inshore areas protected by islands or spits have faster ice formation since there is less wave action. Offshore there is freezing and subsequent breaking into pancake ice caused by the action of swells. Once ice cover becomes extensive enough to stop the formation of swells ice cover becomes complete.

IV. PREVIOUS ORNITHOLOGICAL STUDIES

While native eskimo knowledge of the birds of the Beaufort Sea and the adjacent mainland has been extensive for some time, western cultures have only recently begun to obtain information from this area. Knowledge of the occurrence and relative abundance of northern Alaskan birds has for a long time been based on their status at Barrow (Bailey, 1948; Pitelka, 1974). Unfortunately, the pelagic species seen near Barrow are more representative of the Chukchi Sea than the Beaufort. The discovery of oil at Prudhoe Bay in the late 1960's and the efforts to find more oil under the North Slope and nearshore Beaufort led to large scale surveys and site intensive studies east of Barrow that have provided much information on the status of birds east of Point Barrow.

The presence of ice in much of the Beaufort throughout the year has kept commercial and research vessel traffic to a minimum. Whaling vessels were common in the Beaufort in the late 1800's and early 1900's, but almost no published information on seabirds resulted from these cruises. Bodfish (1936), however, mentions incidental observations obtained while whaling in the Beaufort. All systematic observations of Beaufort pelagic seabirds comes from oil-related studies. Frame (1973) observed birds following the U.S.C.G. Staten Island in August 1969. A series of Western Beaufort Sea Ecological Cruises were initiated by the U.S. Coast Guard in 1970 when it appeared that supertankers might be entering the Beaufort to transport oil from Prudhoe Bay. Ice cover prevented the U.S.C.G.C. Glacier from entering the Beaufort in 1970 and a survey of the northern Chukchi Sea was done instead (Watson and Divoky, 1972). In August 1971 and 1972 cruises in the Beaufort did occur, with the observations being summarized in Watson and Divoky (1974). Results from these cruises are presented in this report. No other pelagic censusing of the Alaskan Beaufort was conducted until the initiation of OCSEAP in 1975. Other than this research unit (R.U. 196) the only OCSEAP project to conduct pelagic censusing of the Beaufort was R.U. 337 which conducted aerial surveys in 1975 and 1976 (Harrison, 1977).

Shore based studies have primarily centered on tundra habitats but the littoral zone inshore waters have received much attention in recent years. The following summary of coastal and tundra bird research proceeds from west to east.

Point Barrow to Oliktok Point

Bailey (1948) reported on his extensive work in the Barrow area as well as all previous information. Pitelka (1974) summarizes the avifauna of the Barrow region and North Slope in an excellent review of knowledge to 1973. King (1979) conducted aerial surveys on the Naval Petroleum Reserve south of Barrow from 1977 to 1979. Derksen et al. (1979 and 1981) studied waterbirds and wetland habitats in the same area during the same period.

Connors (OCSEAP R.U. 172) conducted surveys of shorebirds in the littoral zone at Barrow from 1975 - 1978 and at Pitt Point (adjacent to the Lonely DEWline site) in 1976 and 1977 (Connors et al., 1979). He studied bird use of a salt marsh adjacent to Harrison Bay in 1980 (Connors, in prep.). James Helmrichs (Colville Village, c/o Barrow, AK 99723) a bush pilot living on the Colville River delta has made incidental but regular observations in the course of his work.

Oliktok Point to Brownlow Point

This section of coast has been the site of numerous studies following the discovery of oil at Prudhoe Bay and in anticipation of the Joint State-Federal Lease Sale of 1979. Hall (1975) made incidental observations of birds while conducting oceanographic studies in Simpson Lagoon. Flock (1973) conducted radar observations of coastal bird movement at Oliktok Point as well as other northern Alaska coastal locations from 1969 to 1972.

Schamel spent the summers of 1971 and 1972 on Egg Island (13 km west of Prudhoe Bay) studying Common Eider (Somateria mollissima) breeding biology (Schamel, 1974). In 1972 he also gathered information on bird use of the Gwydyr Bay - Egg Island area, which was analyzed through OCSEAP (R.U. 215) (Schamel, 1978).

An extensive survey of bird use of Simpson Lagoon was conducted in 1978 and 1979 (R.U. 467) as part of an ecological process study (Johnson and Richardson, 1981 and 1982; Richardson and Johnson, 1981). At Point Storkerson (13 km west of Prudhoe Bay) the U.S. Fish and Wildlife Service conducted a number of studies in the early 1970's. Their primary emphasis was on coastal wetlands with incidental observations of nearshore birds (Bartels, 1973; Bergman et al., 1977; Bergman and Dirksen, 1977).

Prudhoe Bay has been the site of a number of studies. Norton et al. (1975) studied inland tundra avifauna as part of the Tundra Biome Program. Gavin (1979 and unpublished) has conducted surveys of the Prudhoe Bay area and adjacent nearshore Beaufort since 1969. Connors (1979) studied use of littoral zone at Prudhoe Bay in 1978.

Brownlow Point to Demarcation Point

The U.S. Fish and Wildlife Service has conducted a number of studies in this area as part of a biological assessment of Arctic National Wildlife Range. Aerial surveys of nearshore waters have been conducted by Spindler (1981). Spring and fall migration past Nuvagapak Point and bird use of Beaufort Lagoon were studied by J. Levison (in prep.) in 1980. C. Moitoret (in prep.) studied bird use of shoreline habitats on the Canning River delta in 1980. Andersson (1973) studied habitat preferences of birds in the Nuvagapak Point area. Birds on coastal tundra habitats were studied by Schmidt (1973), Spindler (1981) and Philip Martin (in prep.).

Canadian Studies

As in Alaska, studies of Canadian Beaufort seabirds have only begun in recent years in response to the promise of oil. Johnson et al. (1975) present a summary of all previous Beaufort bird information (Alaska and Canada) as well as information on the spring 1975 migration on the Canadian coast.

V. Sources, methods of data collection

A. Sources

A total of six pelagic and three nearshore cruises are reported on here. The dates of these cruises, the names of the vessels, and the three numeral designation used to identify the cruises in this report are given in Table 1. The number of observation intervals (20-minutes intervals for 1971 and 1972 and 15-minutes intervals for 1976-78) are given in Tables 2 and 3. A composite of all the cruise tracks reported on in this report is presented in Figure 3. This composite is most useful in showing the extent of sampling in a given area. Specific cruise tracks from the 1976-78 cruises are presented in Divoky (1978a and 1979b)with information on bird densities.

B. Methods

Seabird censusing of the pelagic regime has been done from icebreakers while nearshore censusing has been done from small (< 50 feet) research vessels. Other than the difference in the height of the observer above the sea (18 m vs. 6 m), the sampling techniques are the same for both regimes. Censusing was done in 20-minute intervals on the cruises in 1971 and 1972 and 15-minute intervals in 1976-78.

All birds observed out to 300 m to one side of the vessel are identified to species or species group and counted, with notes taken on age, sex and activities whenever possible. The area censused in each transect (distance x .3 km) is computed and the density (birds per km sq.) obtained for each species. For the discussion of biomass density (kg per km sq.) the birds per km sq. is multiplied by the average weight of the species. Average weights of the species discussed in this report are presented in Table 4 and have been obtained from specimens collected for stomach contents or from the literature.

Ship followers, which can artifically inflate or deflate densities depending on the circumstances, can be a major problem in the pelagic Beaufort. An icebreaker can attract large flocks of ship followers when Arctic Cod (Boreogadus saida) are washed onto the ice by propwash and the shifting of ice during icebreaking. At such times it can become difficult to accurately census certain species, primarily Glaucous Gulls, Black-legged Kittiwakes, and jaegers. In addition, the large amount of garbage thrown overboard from icebreakers can attract large flocks of scavenging Glaucous Gulls. While every attempt is made to count only those individuals that would be present irrespective of the ship, the error in censusing these species in pelagic waters is larger than for others. Such problems do not occur in the nearshore since no icebreaking or major garbage disposal occurs.

Densities are most useful for those birds that are sitting, feeding or searching for prey and less valid for situations where active migration is taking place. Because migration is a function of time (birds per hr.) and our conversion factor for transect observations is based on area, a constant rate of migration will result in varying densities as the speed of the ship varies. Because of this migration phenomena have been separated from density discussions whenever possible. The density figures given by cruise and region for each species include all birds encountered on transects. It is mentioned

	Cruise	Dates	Vessel
Pelagic			
	871	18 Aug.-16 Sept. 1971	C.G.C. Glacier
	872	2 Aug.- 9 Sept. 1972	"
	876	17 Aug.- 3 Sept. 1976	"
	976	6 -18 Sept. 1976	"
	877	7 Aug.- 5 Sept. 1977	"
	878	26 Aug.-15 Sept. 1978	C.G.C. Northwind
Nearshore			
	876	19-30 Aug. 1976	R.V. Alumiak
	877	2-26 Aug. 1977	"
	878	5-29 Aug. 1978	" and R.V. Natchik

Table 1. Dates and vessels of cruises reported on in this report.

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
871	20	25	41	134	43
872	4	50	36	82	58
876	30	28	23	32	0
877	74	61	77	61	131
878	19	0	24	55	81
976	52	42	28	0	0
TOTAL	199	206	229	364	313

TOTAL FOR FIVE REGIONS = 1311

Table 2 . Number of 20-minute transects (1971-1972) and 15-minute transects (1976-78) with bird observations in the five regions of the Alaskan Beaufort sea pelagic regime.

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
876	11	8	14	45	27	28
877	47	32	29	34	23	37
878	50	36	39	53	78	-
TOTAL	108	76	82	132	128	65

TOTAL FOR SIX REGIONS = 591

Table 3. Number of 15-minute transects with bird observations in the six regions of the Alaskan Beaufort Sea nearshore regime.

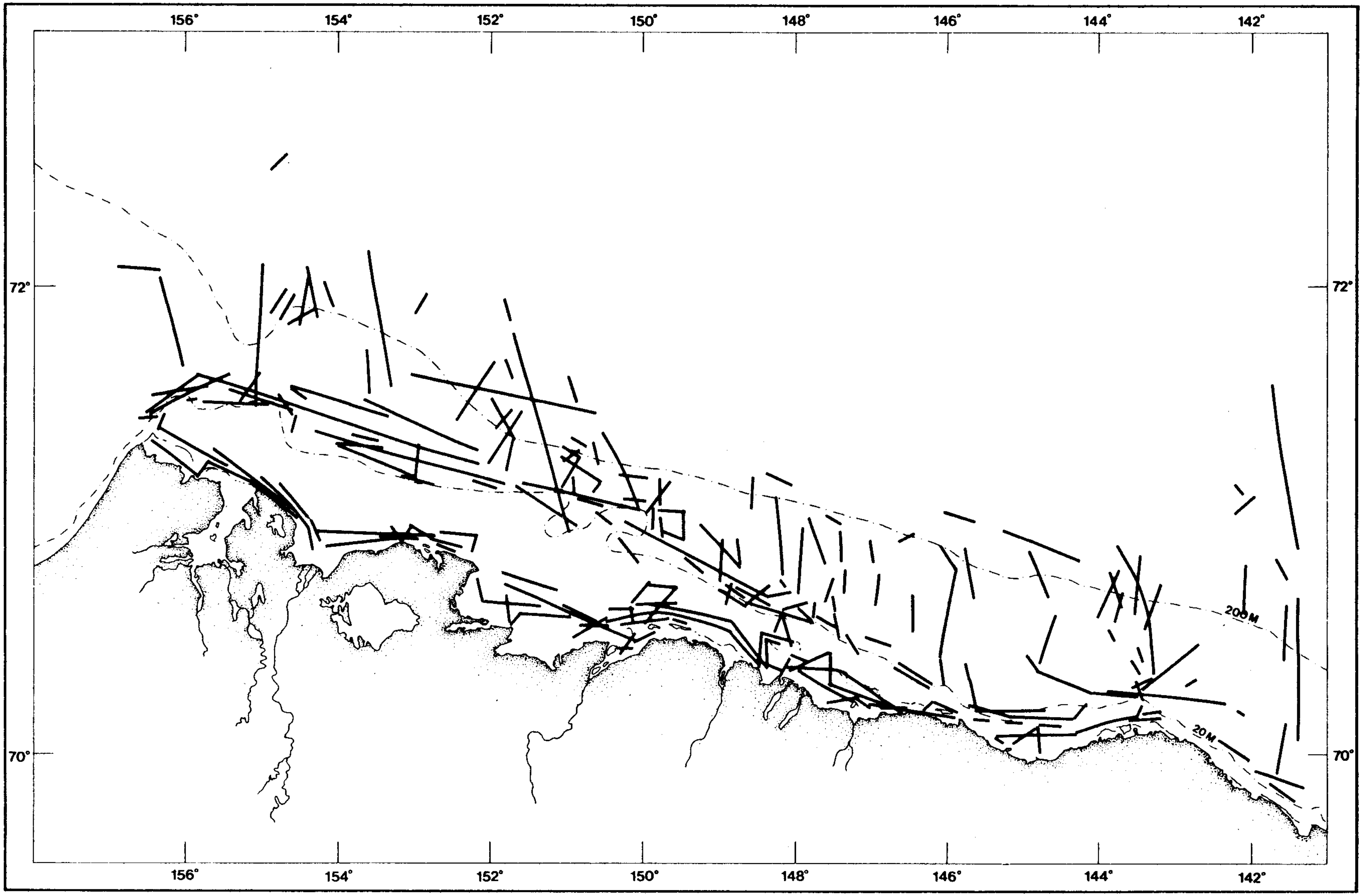


Figure 3. Locations of bird observations.

Table 4. Species regularly encountered in the pelagic and nearshore Alaskan Beaufort Sea and their average weights.

Surface feeding species	wt. (kg)
Red Phalarope	.05
Northern Phalarope	.05
Pomarine Jaeger	.7[1]
Parasitic Jaeger	.5[1]
Long-tailed Jaeger	.4[1]
Glaucous Gull	1.2
Black-legged Kittiwake	.4
Sabine's Gull	.2
Arctic Tern	.1
Diving species	
Arctic Loon	2.2[2]
Red-throated Loon	1.8[2]
Short-tailed Shearwater	.6
Oldsquaw	.8
King Eider	1.5[3]
Common Eider	2.5[3]
Thick-billed Murre	1.1
Black Guillemot	.5

1. Jaeger biomass computed using .6 kg for all sightings.
2. Loon biomass computed using 2 kg for all sightings.
3. Eider biomass computed using 2 kg for all sightings.

in the text when these densities principally represent birds that are migrating.

Stomach contents reported on here were presented earlier (Divoky, 1978c). For the purposes of this report the stomach contents of each species have been separated into two groups, pelagic and nearshore. Data on contents are presented by computing the percentage each prey species or species group contributes to the total weight and by computing the percentage of the stomachs in which the prey species or species group was found.

VI. Species Accounts

The following species accounts present data gathered on the nine cruises in the Alaskan Beaufort during the period of post-breeding dispersal and migration. In order to put these August and September densities and distributions in perspective the period of spring migration and breeding is briefly discussed.

The average densities for each region for each cruise are presented in the species accounts for the commonly encountered species. Averages by region for all cruises are combined and presented in Table 34 for pelagic observations and Table 35 for the nearshore. The average densities presented for each region by cruise are useful in demonstrating whether an area has consistently high or low densities and how much annual variation occurs. To interpret the data on a cruise by cruise basis the reader should be aware of the dates of observations for each cruise presented in Table 1. Pelagic cruises that sampled primarily in September could be expected to have lower densities of many species than cruises that sampled in early and mid-August.

Maximum densities (the highest density encountered in each region on each cruise) are also presented in the species accounts for the commonly encountered species. These figures demonstrate the degree to which a species can congregate in a given region. For many species the maximum density can result from a single flock. For those species that are utilizing an area for feeding or by sitting in the water (as opposed to flying migrants) the maximum density provides an indication of the maximum number of birds per km that could be expected to be impacted by an oil spill or other similar impact. Such information is useful when developing "worst case" scenarios.

In addition to average and maximum densities, the frequency of occurence is given for the regularly encountered species. Frequency of occurence is the percentage of transects in a region on which a species was encountered. Frequency of occurence helps in interpreting average density information by showing the degree to which a species is dispersed in a region. Species having a moderate average density and a low frequency of occurence in a region could be expected to have large numbers of birds occupying a small area of the region. Knowing the pattern of dispersion of a species is important when assessing potential impacts of development related activities. Average frequencies of occurrence for each region are presented in Table 36 for the pelagic regime and Table 37 for the nearshore regime.

When migration rates (bird per hour) are important in describing the activities of a species, the major features of our migration observations are presented. These include bird per hour and the direction of flight, shown by the percentage of the birds moving in each of the primary compass directions.

A. Loons

Loons are large diving birds that nest on freshwater habitats, but are found feeding in both the nearshore zone and freshwater during the breeding season. Outside of the breeding season, they are primarily marine, occupying coastal littoral habitats in ice-free areas of the subarctic and temperate zones. Three species of loons are regular in the Alaskan Beaufort; the Yellow-billed (*Gavia adamsi*), Arctic (*G. arctica*) and the Red-throated (*G. stellata*). The Common Loon (*G. immer*) is a rare migrant (Bailey, 1948).

The Arctic Loon is the most abundant breeding loon in northern Alaska. King (1979) found that 70 to 80 percent of all loon sightings on aerial censusing of NPR-A were this species. Seventy-five percent of all loon broods encountered by Derksen et al. (1981) on ground surveys of the same area were Arctic Loons. Red-throated Loons comprise the bulk of the remainder of loons in northern Alaska. Yellow-billed Loons are frequently seen at coastal and inland sites but no records of nesting densities or abundance are available. It is safe to say that Yellow-billed Loons comprise much less than ten percent of the loons utilizing the Alaskan Beaufort Sea and adjacent tundra.

Because loons usually migrate singly or in small flocks, estimates of population sizes are harder to obtain than for many other Beaufort species. King (1979) estimated 20 thousand loons breed on NPR-A. Timson (1976) estimated the number of fall migrants passing Pt. Barrow between 27 August and 16 September to be over 50 thousand. Much loon migration takes place after her observations and it is reasonable to assume that the total number of loons that use the Alaskan Beaufort Sea is well in excess of 100 thousand.

1. Spring migration

Loons migrate to the Beaufort Sea in spring from wintering areas in the northern Pacific. Observers in coastal locations in northern Alaska have found most migration to occur from early to mid-June (Bailey, 1948; Richardson and Johnson, 1981; Woodby and Divoky, 1982). The extent that loons utilize marine habitats in the arctic during spring migration is not known, but it is likely that the flaw lead in the Chukchi and offshore leads in the Beaufort are used primarily as migratory pathways with few birds sitting or feeding in the leads except when held up by weather. Spring migration observations from a number of coastal localities indicate that Yellow-billed Loons are either an earlier migrant than Arctics and Red-throateds or that some inland migration of the latter two species may occur. Yellow-billed Loons comprise the majority of loons observed at a number of coastal sites and a large percentage at others. Flock and Hubbard (1979) found that Yellow-billed Loons were the commonest loon passing Cape Prince of Wales (Bering Strait) from 20 May to 3 June with lesser numbers of Red-throateds and only one sighting of Arctics. At the flaw lead at Pt. Barrow this research unit saw 28 loons and of the 9 identified, all were Yellow-billed Loons (Woodby and Divoky, 1982). Aerial censusing of the flaw lead during the same time (5 June) produced sightings of nine Yellow-billed Loons. No other loons were seen on that flight. 5 June can be assumed to be a date when much loon movement is occurring based on dates of arrival at mainland sites (Bergman et al., 1977).

The high percentage of Yellow-billeds observed could be related to an earlier migration for this species than for Arctics. Richardson and Johnson (1981) found that the peak period of abundance for Yellow-billeds passing

Simpson Lagoon to be 3-9 June whereas Arctics peaked from 9-13 June. The same authors estimated, however, that approximately equal numbers of both species passed Simpson Lagoon from 9 May - 25 June. This supports the view that Yellow-billeds, as a species, are more coastal in spring migration than Arctics.

2. Breeding

Arctic Loons breed primarily on lakes that contain fish while Red-throated Loons nest on ponds and fly to marine habitats or lakes to feed (Bergman and Derksen, 1977). For this reason during the breeding season the Red-throated Loon could be expected to be relatively more common in the Beaufort than the Arctic Loon. Schamel (1978) found that total loon densities in nearshore waters surrounding a barrier island peaked on 16 June and decreased steadily until 7 August when his study ended. We found loons to be uncommon during the breeding season in the nearshore Beaufort based on aerial surveys but ground observations from islands and beaches during the same period have found them to be regular and not uncommon (Divoky, 1978a Divoky , 1979b). Loons complete breeding activities on the tundra in mid-August and move to marine habitats at that time.

3. Post-breeding dispersion and fall migration

a. Pelagic observations

While loons are common in the nearshore Beaufort during the entire summer, they are not found in pelagic waters until post-breeding dispersion and fall migration begin. Of the 475 loons we have seen in the pelagic Beaufort only eight percent have been sitting on the water and thus rates of movement are more important than densities when describing these observations.

Only 33 percent of the loons seen in the pelagic zone were identified to species. Of those identified, Arctics comprised 80 percent, Red-throateds 17 percent and Yellow-billeds 3 percent. Most of the Red-throateds were seen within 30 km of shore while Arctics and unidentified loons were common to 70 km from shore.

Loons were essentially absent from the pelagic regions in early August (Table 5). The one bird that was seen was adjacent to the nearshore zone, 7 km from shore. Beginning on 14 August loons became much more common with .2 per hour being observed. The flight directions during the 14-23 August period indicate that loons are dispersing to pelagic waters but that westward migration is not yet the major activity. After 24 August the number of loons in the pelagic regime increases greatly with an average passage rate of 1.7 per hour and major westward movements. Migration rates increase steadily until 18 September when our observations cease (Figure 4) and it is possible that loon use of the pelagic Beaufort is highest after that date.

Because the fall migration of loons occurs over a broad front in pelagic waters, densities showed only minor differences from one region to another (Table 6). The limited use of densities when describing migration phenomena makes Table 6 of little utility except to provide "potential densities" should migrating birds sit on the water. One area which regularly had higher passages of migrants was the 20 m isobath from north of the Jones Islands westward to north of Pitt Point. In 1971, 1977 and 1978 migrant individuals and flocks were regularly encountered in this area. On 16 September, 1977 a migratory rate of 42 birds per hour (n = 1.5 hr.) was observed.

Dates:	2-13 August	14-23 August	24 August-18 September
Hr. of observation:	44	98	239
Total flying loons:	1	15	395
Loons/hr.:	.02	.2	1.7
Flight direction: (percent of total)			
N	-	-	4
NE	-	7	1
E	-	27	1
SE	100	7	2
S	-	11	6
SW	-	27	17
W	-	20	64
NW	-	-	6

Table 5. Rates of movement and direction of flight of loons observed in the pelagic zone of the Beaufort Sea.

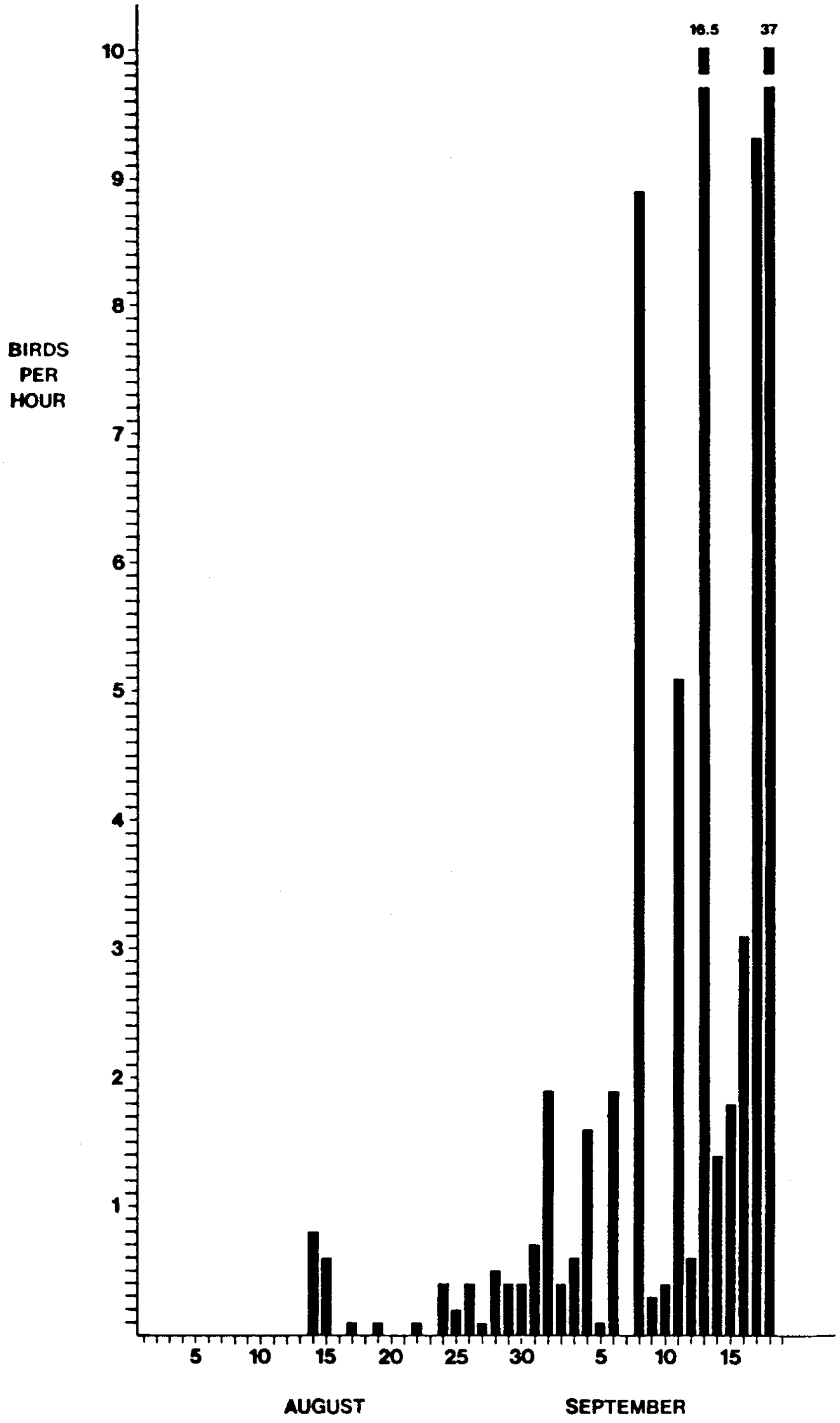


Figure 4. Migration rates of loons in the pelagic regime of the Alaskan Beaufort Sea.

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
AVERAGE DENSITY (birds/km^2)					
871	.1	.1	.2	.5	0
872	0	< .1	0	0	0
876	< .1	.2	0	< .1	-
877	.2	.1	.3	.1	.1
878	.6	-	2.9	.4	.9
976	.6	1.8	1.6	-	-
PERCENT TRANSECTS WHEN PRESENT					
cruise					
871	05	04	17	11	0
872	00	06	00	00	00
876	07	11	00	09	-
877	17	08	17	07	02
878	42	-	29	15	36
976	25	26	17	-	-
MAXIMUM DENSITY (birds/km^2)					
cruise					
871	1.4	2.4	3.0	13.6	0
872	0	.9	0	0	0
876	1.6	3.7	0	1.8	-
877	4.3	2.1	2.4	2.9	.8
878	2.4	-	29	4.4	10.4
976	7.0	22.8	43.8	-	-

Table 6 . Average densities, percent transects when present and maximum densities of Loons in the five regions of the Alaskan Beaufort Sea pelagic regime.

b. Nearshore observations

Loons were found in the nearshore Beaufort during the entire month of August. Loons use the nearshore regime both for feeding and for migratory and dispersion movements. Birds sitting on the water accounted for 32 percent of the 457 loons seen in nearshore waters. Sixty-eight percent of all loons were identified to species with the species composition being essentially identical to pelagic waters. Arctics comprised 81 percent, Red-throateds 17 percent and Yellow-billeds 2 percent of all identified loons. These percentages are very similar to what has been found for breeding populations on the tundra (King, 1979).

Major changes occur during August in the activities of loons in the nearshore regime. From 2 through 18 August, .2 loons per km sq. are sitting on the water (n = 103 km sq.). After 18 August this increases to 1.4 loons per km sq. (n = 301 km sq.). The increase coincides with the approximate time when loons are completing breeding activities on the tundra and moving to marine waters.

The movement to nearshore waters precedes the start of the major fall migration by approximately a week. Loons flying over nearshore waters do not begin moving west in numbers until 26 August (Table 7). Surprisingly, the number of loons flying over the nearshore Beaufort is the same in both the dispersion and migration periods (1.8 per hr.) with only the flight direction changing. Our nearshore observations do not include the period of major westward migration of loons in September, however. Observations by Timson (1976) at Pt. Barrow indicate that rates of passage for nearshore areas are equal or greater than what we encountered in the pelagic zone.

Because loons both sit in and fly over the nearshore Beaufort the densities presented in Table 8 are of use in demonstrating differences between areas and years. Three areas had consistently high loon densities; the Plover Islands, Pitt Point and Harrison Bay. The higher densities and frequence of occurrence in these areas may be due to the large area of ponds and lakes to the south. Areas where tundra ponds and lakes are common could be expected to have higher loon populations than areas where less standing water is present. The amount of wet tundra and lakes and ponds adjacent to the Alaskan Beaufort decreases to the east and fewer loons would be moving to the coast east of Harrison Bay.

Similar densities of loons in nearshore waters were found in 1976 and 1978, but 1977 had lower densities and frequencies in almost all areas censused. King (1979) observed 2.5 as many loon broods in 1978 as in 1977 and the low densities we encountered inshore in 1977 may also reflect this low breeding productivity.

B. Northern Fulmar

The Northern Fulmar (Fulmarus glacialis) does not breed north of the Bering Sea but non-breeders are present in the Chukchi Sea in summer where they are uncommon south of Cape Lisburne and irregular from Cape Lisburne north to Pt. Barrow (Swartz, 1967; Divoky, in prep.). Our observations show that fulmars only rarely enter the Beaufort. An individual was seen on 5 September 1977 at 71°36' N, 155°55' W in the pelagic waters north of the Plover Islands. We have two records from Cooper Island; a fulmar recently killed by a Peregrine Falcon (Falco peregrinus) was found on 1 July 1981. On 4 September 1981 a number (less than 10) were observed north of the island associated with a flock of Short-tailed Shearwaters (Puffinus tenuirostris). All fulmars encountered have been dark phase.

Dates:	2-25 August	26-30 August
Hr. of observation:	106	47.3
Total flying loons:	195	86
Loons/hr.:	1.8	1.8
Flight direction: (percent of total)		
N	20	5
NE	7	-
E	9	2
SE	7	-
S	32	12
SW	7	1
W	14	73
NW	6	7

Table 7. Rates of movement and direction of flight of loons observed in the inshore zone of the Beaufort Sea.

AVERAGE DENSITY (birds/km^2)

Cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
876	2.3	1.6	2.1	.5	.8	.3
877	.5	.3	.9	.5	.4	.4
878	2.4	2.2	2.5	.6	1.0	-

PERCENT TRANSECTS WHEN PRESENT

cruise						
876	55	50	79	31	37	21
877	21	19	24	26	07	14
878	72	56	67	21	54	-

MAXIMUM DENSITY (birds/km^2)

cruise						
876	11.7	8.6	8.3	4.2	3.6	3.5
877	3.7	1.8	5.1	3.9	8.8	6.0
878	11.5	10.3	18.0	6.6	4.0	-

TABLE 8 . Average densities, percent transects when present and maximum densities of Loons in the six regions of the Alaskan Beaufort Sea inshore regime.

C. Short-tailed Shearwater

The Short-tailed Shearwater breeds in the southern hemisphere and spends the austral winter in the subarctic North Pacific. Sanger and Baird (1977) estimated that this species, along with lesser numbers of Sooty Shearwaters (*P. griseus*), number more than 10 million individuals in the Bering Sea in summer. Shearwaters are most abundant in the southern and central Bering Sea with lesser numbers north of St. Lawrence Island.

A very small percentage of the shearwaters present in the Bering Sea move north through the Bering Strait into the Chukchi from late July through September. They are most frequent north to Cape Lisburne and irregular and uncommon from Cape Lisburne to Pt. Barrow (Swartz, 1967; Divoky, in prep.). When shearwaters are in Alaskan seas they are not tied to nest sites and are thus good indicators of prey availability.

The occurrence of Short-tailed Shearwaters in the Beaufort is dependent on the oceanographic conditions in the northern Chukchi Sea and western Beaufort. The location of shearwater observations and oceanographic conditions at these locations indicate that most shearwaters in the Beaufort are associated with the Bering Sea Intrusion (Table 9). Shearwaters are irregular but sometimes abundant in the pelagic waters north of the Plover Islands in September (Table 10, Figure 5). On one cruise (1972) they were encountered in the Pitt Point region with our furthest east sighting at 71°40' N, 153°40' W. They have been reported as far east as Flaxman Island (Bodfish, 1936). On 6 September 1981 flocks were reported in the nearshore waters north of Pingok Island (L. Lowry, pers. comm.).

Because the area where we have encountered shearwaters has not been of interest for its potential oil reserves there is little physical oceanographic data to correlate with our sightings. In 1971 and 1972 physical oceanographic studies were conducted concurrent to our observations (Hufford et al., 1974) and allow some general comparisons between the two years. In 1971 when we failed to observe shearwaters the core temperature of the warm water layer in the Beaufort did not exceed 3°C. In 1972 when shearwaters were encountered, a large area of the pelagic Beaufort west of 150° W had a core temperature of 5°C or higher. Unfortunately no detailed oceanographic data is available from 1978 when we observed large numbers of shearwaters. The birds were seen in 1978 in an area where the sea surface temperature rose from 0°C to 3.3°C in 15 minutes. This was the highest sea surface temperature encountered in the Beaufort that year. Similar changes in temperature were recorded with the 1976 and 1977 sightings.

The presence of the Bering Sea Intrusion alone is not enough to guarantee that numbers of shearwaters move into the Beaufort. In 1977 when a major pulse of water warmer than 7°C was present north of the Plover Islands only one shearwater was encountered. Because shearwaters apparently follow pulses of Bering Sea water north from the southern Chukchi to the Beaufort, the presence of shearwaters in the Beaufort is probably related to the size and depth of these pulses and prey populations associated with them.

While the densities of shearwaters can be among the highest in the pelagic regime, the number of individuals in the Beaufort is very low when compared to many other species. This is related not only to the limited geographic area where shearwaters are found but also to the low turnover rate of shearwaters. While many species have much lower densities than shearwaters they maintain these low densities over an extended period of migration (from 6 to 8 weeks) so that the total number of birds moving through the Beaufort is quite high. The shearwater population of the Beaufort probably has little if any turnover.

Table 9. Short-tailed Shearwater sightings in the pelagic Alaskan Beaufort Sea.

1972

6-7 September
Total birds = 102
Transects when observed = 10
Average density (birds per km sq.) = 7.7
Oceanographic conditions: Sea surface temp. 3°C. On western edge of 6°C pulse at 10m depth extending from 153°30' W to 150°30' W (Hufford et al., 1974)

1976

14 September
Total birds = 2
Transects when observed = 2
Average density (birds per km sq.) = 4.8
Oceanographic conditions: Sea surface temp. 1.3°C. Highest temperature encountered on cruise.

1977

4 September
Total birds = 1
Transects when observed = 1
Average density (birds per km sq.) = 1
Oceanographic conditions: Sea surface temp. 6.7°C adjacent to area with 9.1°C.

1978

15 September
Total birds = 3659
Transects when observed = 13
Average density (birds per km sq.) = 225
Oceanographic conditions: Sea surface temp. 3.3°C adjacent to area with 0°C.

Table 10. Average densities, percent transects when present and maximum densities of Short-tailed Shearwaters in Plover Islands and Pitt Point regions of the Alaskan Beaufort Sea pelagic regime. No shearwaters seen east of the Pitt Point region.

cruise	871	872	876	877	878	976
Plover Islands						
Average density (birds per km sq.)	0	13.7	0	.1	106.9	.1
Percent transects when present	00	75	00	01	68	04
Maximum density	0	29.4	0	1.0	996	.9
Pitt Point						
Average density	0	.5	0	0	0	0
Percent transects when present	00	14	00	00	00	00
Maximum density	0	10.5	0	0	0	0

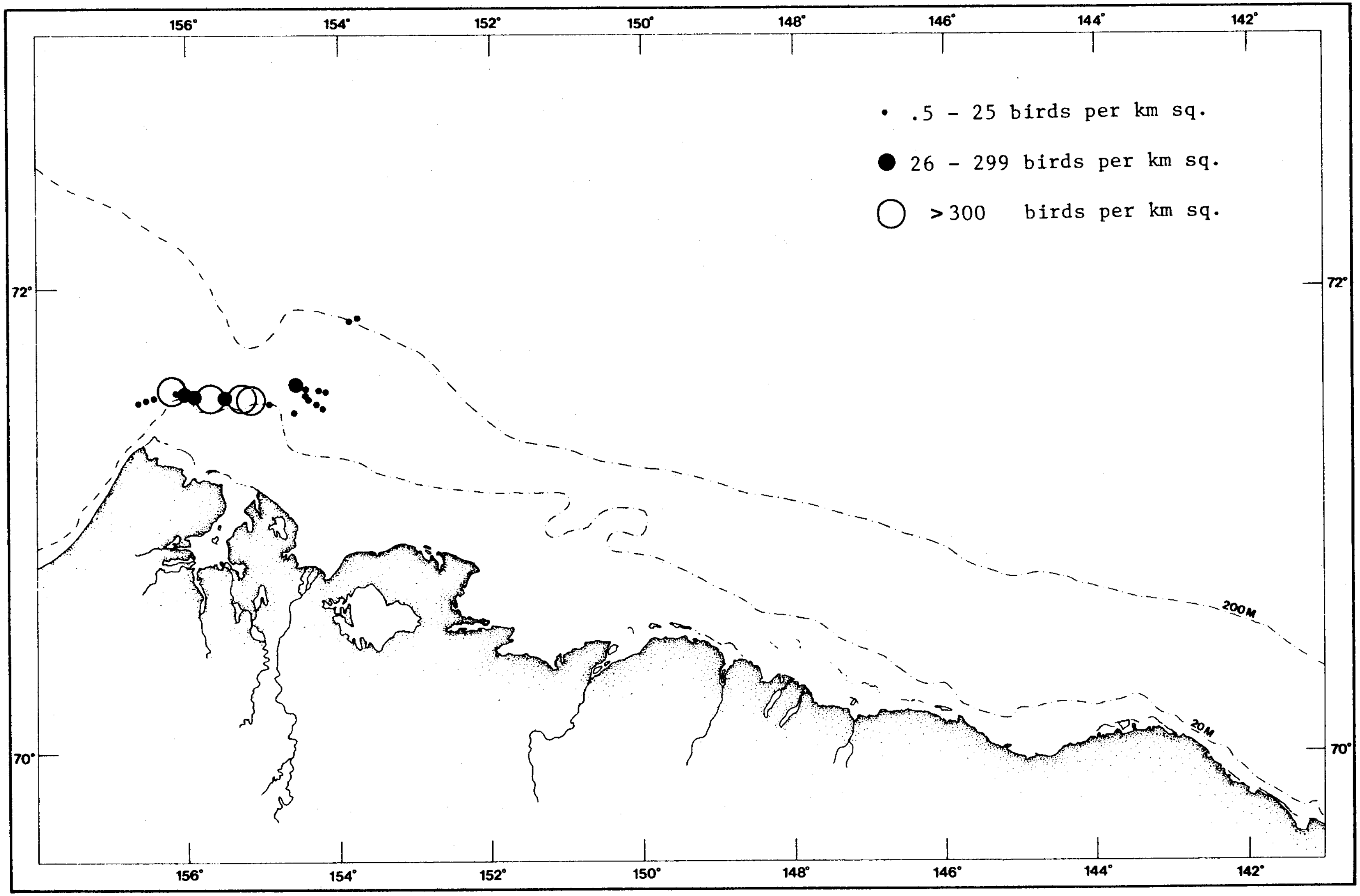


Figure 5. Densities of Short-tailed Shearwaters in the Alaskan Beaufort Sea.

We have not collected shearwater stomach samples in the Beaufort. The prey present in the Bering Sea Intrusion that attracts shearwaters is most likely the euphausiid *Thysanoessa raschii*, based on stomach contents of other species feeding directly on Intrusion waters. The area north of the Plovers occasionally has an abundance of euphausiids as is evidenced by the numbers that wash up on the beaches of the Plover Islands. Sanger (in prep.) found euphausiids to be the primary prey item of shearwaters in the Bering sea in summer.

D. Black Brant

Black Brant (*Branta bernicla nigricans*) are the most marine of the geese species present on the North Slope. They breed in small numbers on barrier islands. A total of 54 nests were found on the Alaskan Beaufort barrier islands in 1976 (Divoky, 1978b) Brant feed on grasses in salt marshes during pre-migratory staging and are common in the littoral zone where salt marshes are present. They could not be expected to occur in nearshore or pelagic habitats except as flying migrants. No Brant were seen in pelagic waters and they were present on only ten nearshore transects. Most of the sightings were south of Flaxman Island and in the area of Barter Island and all were adjacent to the mainland or barrier islands.

E. Oldsquaw

Oldsquaw are circumpolar in distribution and are a common to abundant breeder on the Alaskan North Slope (Bergman et al., 1979; Derksen et al., 1982). They are ubiquitous in nearshore habitats from the time moats and leads first appear in June until freeze-up (Schamel, 1978; Johnson and Richardson, 1981; Divoky, 1978 a)

1. Spring migration and early summer

Oldsquaw enter the Beaufort by way of the flaw lead in the Chukchi Sea. The bulk of the migration apparently takes place in June since observations at the lead at Pt. Barrow found few Oldsquaw passing until 3 and 4 June (Woodby and Divoky, 1982).

Oldsquaw numbers in the nearshore are low through most of June but start to increase in late June and then increase steadily through July (Schamel, 1978; Johnson and Richardson, 1981; Divoky, 1978a) Male Oldsquaws molt between 15 July and 15 August. During this time Oldsquaw are most abundant near lagoon systems where barrier islands provide roosting sites (Johnson and Richardson, 1981).

2. August and September

a. Pelagic observations

Aerial surveys and limited shipboard observations have shown that small numbers of Oldsquaw are present in pelagic waters in July (Harrison 1977; Divoky, unpubl.). They apparently leave by early August since our first sighting in pelagic waters is on 19 August and they remain uncommon until the last week of August.

Of the 1623 Oldsquaw observed in the pelagic regime 50 percent have been sitting on the water and of those sitting on the water, 92 percent were sitting on the 20 m contour. Densities of sitting Oldsquaw in the pelagic regime are as follows:

Dates	birds per km sq.
2-23 August	.01
24-31 August	.4
1-18 September	.8

Over 90 percent of the migrant Oldsquaw in the pelagic regime have been on or near the 20 m contour. Of the 810 migrant Oldsquaw, 80 percent were moving westward indicating that the birds are migrating over pelagic waters and not just dispersing from nearshore habitats.

The rates of movement by date are shown in Figure 6 and indicates that the highest rates of movement may occur after our last observations on 18 September.

The densities given in Table 11 must be interpreted with caution since half of the birds encountered were migrants. The percent transects when present show that Oldsquaw have been more commonly encountered in the western regions. It is unclear if this is due to the dates of sampling or if, as in many other species, the western pelagic regions support higher densities.

b. Nearshore observations

Oldsquaw are common to abundant in the nearshore Beaufort (Table 12). Because they are still molting in August they are most common in coastal regions containing lagoons and barrier islands where prey and roosting sites are available.

All flocks of Oldsquaw with more than 25 birds encountered in nearshore waters are shown in Figure 7. It should be noted that a flock of 25 Oldsquaw is not large. Oldsquaw flocks encountered on transects are rarely large, however, since only birds seen out to 300 m on one side of the ship are counted. Thus while the number of birds represented in Figure 7 is not large, the location of the relatively small flocks give an indication of where Oldsquaw are most abundant. Three lagoonal areas had flocks of over 300 birds and consistently had flocks over 25 birds: Elson Lagoon, Simpson Lagoon (including the area south of Thetis Island) and the lagoon south of Flaxman Island. In late August Oldsquaw become more common in non-lagoonal areas and our sightings of flocks in Smith Bay, north of Pitt Point, and Camden Bay are for the last few days of August when birds have moved away from molting areas and are beginning to migrate.

Observations of flying Oldsquaw in the nearshore have shown that the month of August can be divided into two parts, based on rates and direction of movement (Table 13). Until 23 August the rate of movement is not high (5.4 birds per hr) with 15 percent moving westward indicating that migration has not started. The majority of Oldsquaw seen flying during this period were in the area of Thetis Island and Simpson Lagoon and it is not known if the east and south movements observed there are typical for the rest of the coast.

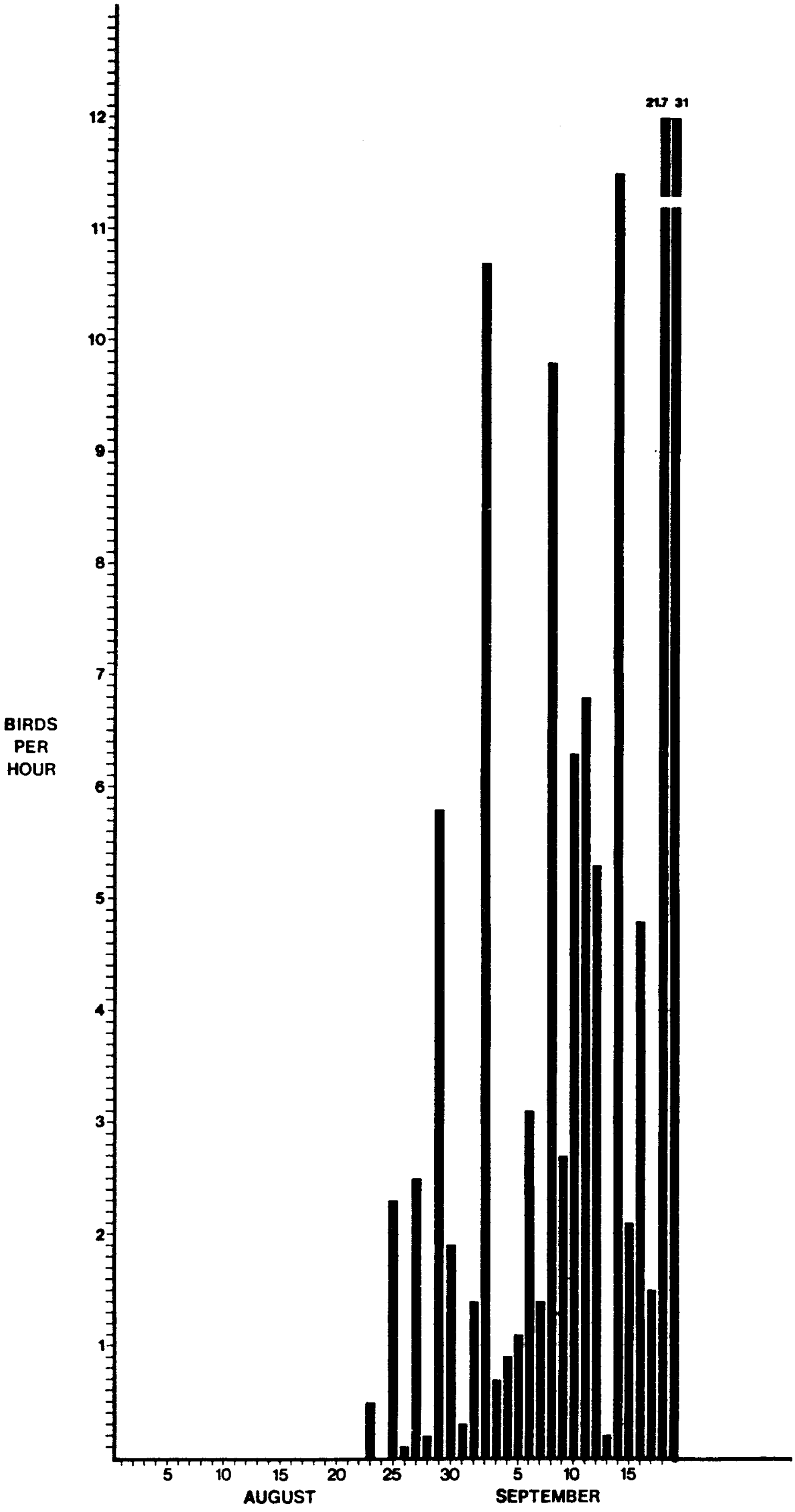


Figure 6. Migration rates of Oldsquaw in the pelagic regime of the Alaskan Beaufort Sea.

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
871	14	.4	.6	1.3	< .1
872	.9	7.2	0	0	0
876	.9	1.2	0	0	-
877	< .1	< .1	< .1	< .1	1.6
878	2.1	-	2.7	1.3	1.7
976	4.8	.7	.3	-	-

PERCENT TRANSECTS WHEN PRESENT

cruise					
871	10	08	15	10	02
872	50	24	00	00	00
876	13	11	00	00	-
877	04	02	01	02	11
878	42	-	13	22	10
976	19	19	07	-	-

MAXIMUM DENSITY (birds/km^2)

cruise					
871	280	7.8	17	77.4	.7
872	1.8	233	0	0	0
876	15.8	19.3	0	0	-
877	2.2	.7	.8	21	108
878	7.2	-	49	12	54
976	49.9	10.2	7.1	-	-

Table 11. Average densities, percent transects when present and maximum densities of Oldsquaw in the five regions of the Alaskan Beaufort Sea pelagic regime.

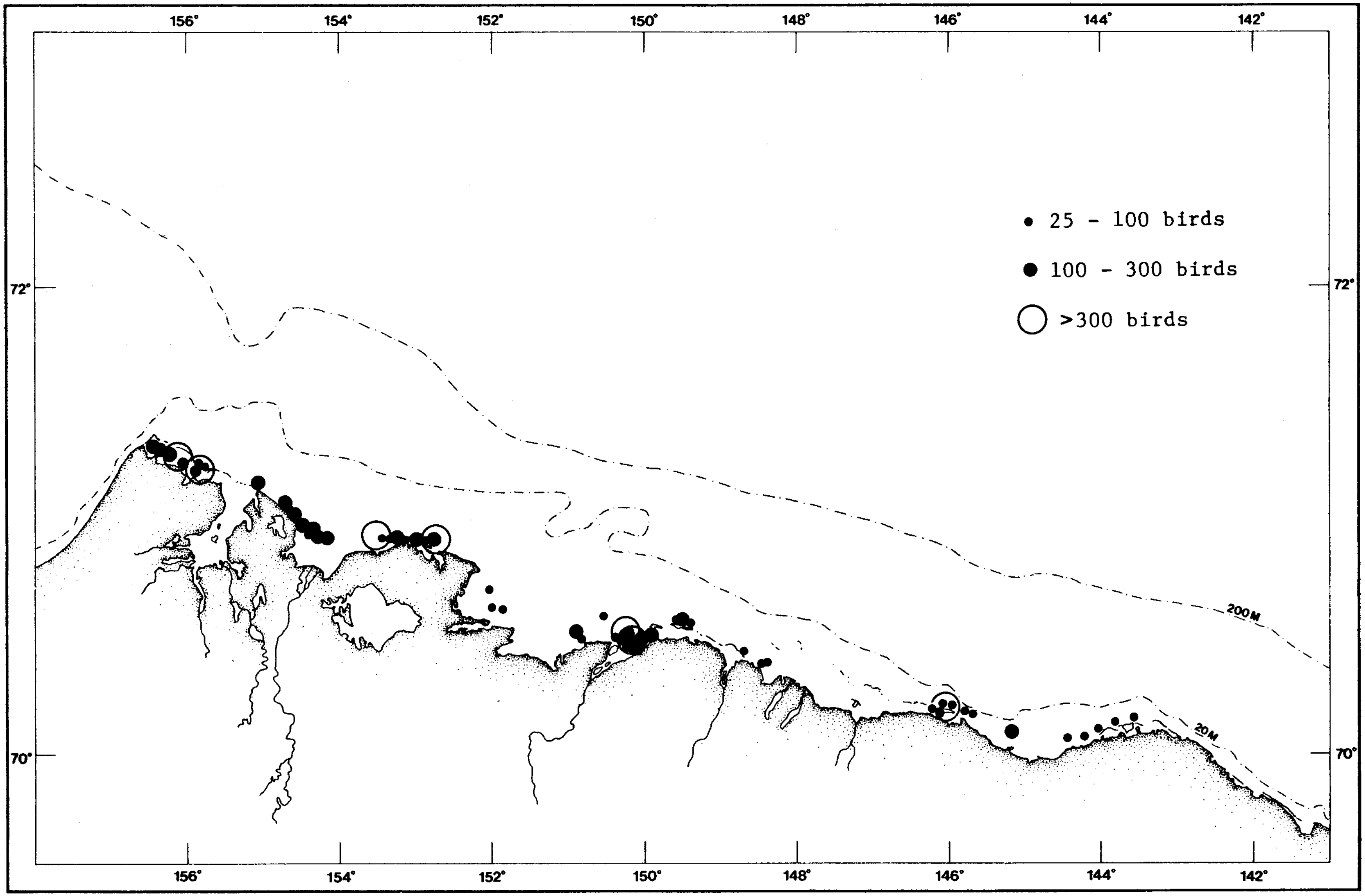


Figure 7. Location and size of all Oldsquaw flocks of more than 25 birds observed in the nearshore regime of the Alaskan Beaufort Sea.

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
876	3	3	2	45	114	42
877	26	7	.1	16	1	.4
878	76	120	20	100	31	-

PERCENT TRANSECTS WHEN PRESENT

cruise						
876	36	13	14	71	52	89
877	36	19	07	29	17	05
878	54	78	54	63	59	-

MAXIMUM DENSITY (birds/km^2)

cruise						
876	18	23	13	244	1218	189
877	191	167	3	247	15	13
878	629	1049	236	1907	418	-

Table 12. Average densities, percent transects when present and maximum densities of Oldsquaw in the six regions of the Alaskan Beaufort Sea inshore regime.

Dates:	2-22 August	23-30 August
Hr. of observation:	96	57.3
Total flying Oldsquaw:	521	1784
Oldsquaw/hr.:	5.4	31.3
Flight direction: (percent of total)		
N	2	10
NE	1	5
E	28	10
SE	38	17
S	16	16
SW	1	10
W	4	25
NW	10	6

Table 13. Rates of movement and direction of flight of Oldsquaw in the nearshore zone of the Beaufort Sea.

After 23 August Oldsquaw movement increases to 31 birds per hour with westerly movements constituting 41 percent of the total, indicating that some migration is taking place.

F. Eider

Two species of eider, the Common (Somateria mollisima) and King (S. spectabilis) are regular and common in the Alaskan Beaufort. Two other species, Steller's Eider (Polysticta stelleri) and Spectacled Eider (S. fischeri) are rarely seen in the Alaskan Beaufort though they are regular but uncommon breeders on the coastal North Slope tundra (Pitelka, 1974). Of the King and Common, the former is much more abundant with the total number migrating westward past Pt. Barrow estimated to be over one million birds (Thompson and Person, 1963). T.W. Barry (in Bellrose, 1976) estimated the Beaufort Sea Common Eider population to be 275 thousand birds. The two species differ in their breeding habits in that King Eiders breed on wet tundra, while Common Eiders breed on islands and at other coastal marine locations.

1. Spring migration

In late May eiders move north from the Bering Sea and other North Pacific locations to breeding grounds in the arctic. The lead that forms in the ice from the Bering Strait north to Pt. Barrow is a major migratory pathway for King and Common Eiders. This research unit conducted the first systematic observations at the edge of the lead at Pt. Barrow, from 6 May to 4 June 1976 (Woodby and Divoky, 1982). King Eiders were first seen at the lead on 16 May but were uncommon until 26 May when 360 thousand passed within a ten hour period with a projected total of 500 thousand for the 24-hour period. This large pulse of birds was associated with the first warm southwest (following) winds after a period of cold weather and north and east winds. The eiders observed on 26 May must have been staging south of Cape Lisburne since an aerial survey of the lead between Pt. Barrow and Cape Lisburne on 19 May revealed only 5 thousand eider in a narrow partially refrozen lead. The eiders were apparently in the southern Chukchi Sea or northern Bering waiting for suitable weather. King Eiders continued to pass Pt. Barrow until 4 June when our observations ceased. The projected passage for the 30-day sampling period was 800 thousand King Eiders. Males comprised the majority of birds in the major flight on 26 May with females more abundant towards the end of the observations. 65 percent of the birds seen on 4 June were females.

Common Eiders are later spring migrants than Kings. A projected total of 875 Common Eiders passed from 6 May to 3 June. On 4 June, 10 thousand passed north-eastward over the lead and it is likely much Common Eider migration took place after 4 June.

After passing Pt. Barrow eiders move in an ENE direction (Flock, 1973) rather than following the coast. The flaw lead that the eiders follow to Pt. Barrow ends northeast of the Point. A series of poorly defined offshore leads are present in the Beaufort and eiders continue their migration over them. No censusing of these leads in Alaska has been done but it is reasonable to assume that birds do not usually sit in them except when held up by weather or when in the vicinity of nesting grounds. Searing et al. (1975) found over 75 thousand Common Eiders in a single lead in the eastern Beaufort on 21 May 1974. In springs when unseasonably late freezing occurs the refreezing of these leads can cause major eider mortality as it did in 1964 when an estimated 100 thousand eiders starved (Barry, 1968).

2. Breeding

Because King Eiders breed on wet mainland tundra, the species has little or no contact with marine waters during breeding. Common Eiders, however, nest on islands and spits and are residents of the nearshore regime during breeding. In both species males leave the female shortly after eggs are laid and fly westward to molting areas (Johnson and Richardson, 1982).

Common Eiders are found breeding in the Alaskan Beaufort from Thetis Island east to Demarcation Bay on islands and spits that are surrounded by river runoff in late May and June. The number of nests in the Alaskan Beaufort is not large. A 1976 survey found 420 nests (Divoky, 1978 b).The area where Common Eider nests are most numerous (Jones Islands and Prudhoe Bay regions) can be expected to have regular use of nearshore waters during the breeding season by breeding Common Eiders, non-breeding females associated with the breeding colonies, and newly hatched young. Schamel (1974 and 1978) provides information on Common Eider numbers and habitat use in the vicinity of Egg Island.

3. Post-breeding dispersion and migration

Male King and Common Eiders begin their westward molt migration in late June and early July (Johnson and Richardson, 1982). Eiders passing Pt. Barrow are primarily males until approximately 15 August when females become the majority. Females and young of the year continue to pass Pt. Barrow until at least late October (Bailey, 1948).

Aerial surveys conducted by this research unit (Divoky 1979b) and others (Johnson and Richardson, 1981; Spindler, 1981) have shown that eiders are uncommon in the nearshore waters of the Alaskan Beaufort except as migrants. Prior to August, when our observations from vessels begin the only areas having numbers of sitting eiders are adjacent to islands with breeding colonies. It thus appears that eiders do little if any staging in the nearshore Alaskan Beaufort prior to their westward movement.

Our August and September vessel observations corroborate aerial data in showing that eiders use the Alaskan Beaufort primarily as migrants with few instances of resting or staging. More than any other species eiders move through the Alaskan Beaufort in a narrow migratory corridor so the frequency with which one encounters eiders is dependent on proximity to the migratory corridor. The location of this corridor will be discussed after some general comments about eiders in the pelagic and nearshore regimes.

a. Pelagic observations

Eiders in the pelagic regime are found almost exclusively adjacent to nearshore waters. Of the 2 thousand eiders we have observed in pelagic waters all but 100 (5 percent) were within 5 km of the 20 m isobath. Of the 2 thousand eider, 72 percent were actively migrating with movement being almost exclusively westward. Five flocks totalling 1380 birds comprised the majority of all eiders encountered. The presence of eider in the pelagic zone does not appear to vary with time during the period we sampled.

Table 14 presents eider densities for the five regions of the pelagic Beaufort. It should be remembered that those densities are principally of flying migrants. The low densities and frequencies demonstrate the few eiders present in the pelagic regime. All high densities are from areas directly adjacent to the nearshore zone.

b. Nearshore observations

As with pelagic observations eiders in the nearshore regime are primarily migrants. Of the 10 thousand eider observed on nearshore cruises, 87 percent have been actively migrating with almost all movement being westward. Table 15 shows that the densities and frequencies of eider in the nearshore regime are much higher than in the pelagic. High densities and frequencies are primarily indicative that censusing was conducted in the migratory corridor and thus comparisons between years and areas are of questionable value. Information on densities of eiders sitting on the water is presented after the discussion of the migratory corridor.

c. Migratory corridor of eiders

The path that migratory eiders take along the Alaskan Beaufort has been in question for some time. While the eider pass at Pt. Barrow is known to be major (Thompson and Person, 1963; Johnson, 1971) at other localities less movement is observed, i.e. Simpson Lagoon (Johnson and Richardson, 1981). Bartels (1973) used pelagic and aerial nearshore observations to attempt to locate migrating eiders, and believed most migration occurred 13 to 16 km from shore. The geographic location of Bartel's sightings are not given and thus they cannot be integrated with our data.

In order to locate the principal migration corridor of eiders in the Alaskan Beaufort we plotted all observations of migrating flocks of 25 birds or more that have been observed on pelagic and nearshore cruises (Fig. 8). These observations will be discussed on a west to east basis and will be supplemented by other observations when appropriate.

In the Plover Islands eiders pass westward on a relatively broad front. Observations from Cooper Island indicate that much movement occurs near the south shore of Elson Lagoon. Our 1978 censusing of Elson Lagoon confirmed this since most eiders were seen "off transect" to the south. This is also consistent with observations of where eiders cross the Pt. Barrow spit. "Duck Camp," where most eider hunting occurs, is located at the junction of the spit and the mainland. Most of our nearshore sampling from vessels has been just north of the Plover Islands and only minor movement has been observed there. Few observations in the pelagic waters north of the Plovers have been made but a flock of 500, 8 km from shore on 17 September 1976, indicates that flocks occasionally pass by well north of the islands. Flock's (1973) radar observations showed eider flocks passing both north and south of the islands before turning southwest into the Chukchi. Incidential observations of eider migration near Cooper Island in 1982 showed that eiders pass over the island most frequently when winds are from the southeast.

Observations of flocks made from Tangent Pt. to Cape Simpson show that eider pass within 5 km of the shore. Many apparently enter Elson Lagoon near

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
871	.5	0	.7	.7	1.2
872	0	0	.2	.9	15.3
876	0	0	0	< .1	-
877	< .1	< .1	.8	0	.3
878	0	-	0	.2	12.9
976	4.4	< .1	0	-	-

PERCENT TRANSECTS WHEN PRESENT

cruise					
871	05	00	02	03	09
872	00	00	03	02	10
876	00	00	00	03	-
877	01	02	01	00	02
878	00	-	00	02	11
976	10	02	00	-	-

MAXIMUM DENSITY (birds/km^2)

cruise					
871	10.2	0	30	63	48
872	0	0	6.6	42	478
876	0	0	0	1	-
877	5.8	3.6	57.6	0	28.8
878	0	-	0	11.5	828
976	200	3.5	0	-	-

Table 14. Average densities, percent transects when present and maximum densities of Eider in the five regions of the Alaskan Beaufort Sea pelagic regime.

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
867	9	.2	69	2	3	3
877	21	10	3	.1	111	8
878	15	146	5	6	9	-

PERCENT TRANSECTS WHEN PRESENT

cruise						
876	36	13	79	11	15	07
877	24	16	07	03	22	16
878	48	34	15	11	18	-

MAXIMUM DENSITY (birds/km^2)

cruise						
876	65	2	323	33	44	75
877	725	227	65	5	1370	90
878	198	1200	66	113	155	-

Table 15. Average densities, percent transects when present, and maximum densities of Eider in the six regions of the Alaskan Beaufort Sea inshore regime.

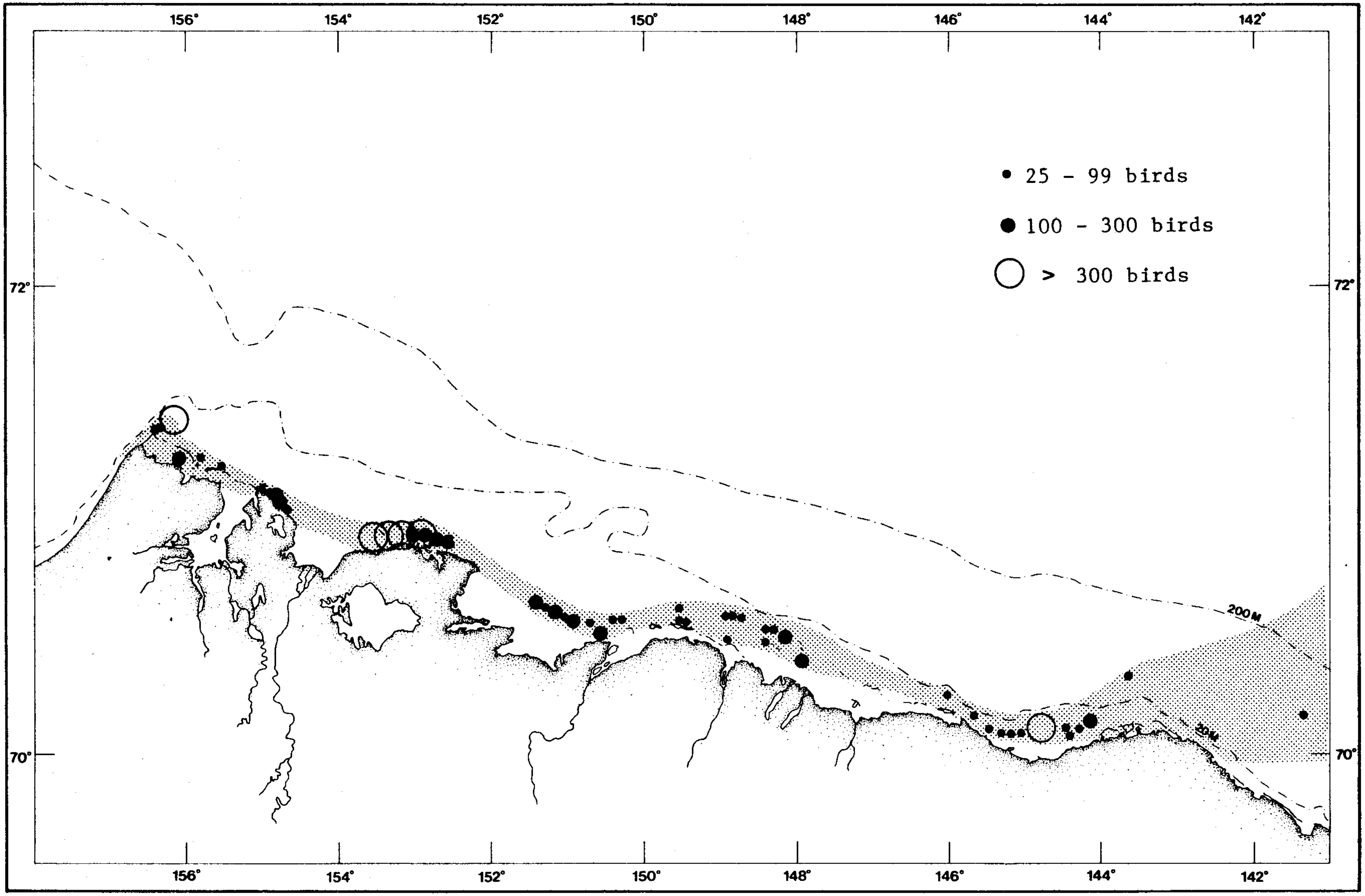


Figure 8. The location and size of all flying eider flocks of more than 25 birds. Shading delineates the apparent location of the migratory corridor used by eiders.

Tangent Pt. moving west past Christie and Scott Points.

Limited censusing has been done at the mouth of Smith Bay but there is little doubt that birds move northwest across the mouth. The area from Pitt Point to Cape Halkett has produced a number of sightings; some of very large flocks. On 8 August 1978 three hours of observation averaged over 15 hundred birds per hour. This includes only birds on transects within 300 m of the vessel. The migration was occurring 2 to 3 km from shore.

Censusing in Harrison Bay shows that migrating eider are absent from the bay's interior but move WNW on a line from Thetis and Spy Islands to Cape Halkett. While extensive sampling of the lagoonal areas in the Jones Islands and Prudhoe Bay regions has been conducted from vessels, we have not observed a migrant eider flock of over 25 birds inside of the islands. Censusing done outside of the islands show that eiders migrate between the barrier islands and the 20 m isobath. Observations in Camden Bay show birds are commonly passing along the 20 m isobath. Far fewer eiders are seen to the north and south.

East of Barter Island we lack nearshore censusing and have not seen eider on pelagic transects at the 20 m isobath. The 20 m isobath is so close to shore in this area (5 to 6 km) that large eider flocks in the nearshore regime would be obvious from some of the pelagic transects. Two sightings offshore west of Barter Island are of interest. The only two eider flocks larger than 25 birds we have seen well offshore have both been in this area. Both flocks were moving southwest. This indicates that some eider from the Canadian arctic islands are moving southwest to the area of Camden Bay. That an offshore migration occurs that bypasses the section of the southeastern Beaufort adjacent to the Mackenzie River Delta is supported by the observation of large numbers of eiders seen passing Cape Bathhurst (on the eastern edge of the Mackenzie River Delta) (Anderson, 1937) and from the paucity of sightings from further west in Canada (Johnson and Richardson, 1982; Salter et al., 1980).

It is possible that some eiders move over the eastern and central Beaufort at high altitudes (out of sight of observers) and descend in the western Beaufort where they then pass Pt. Barrow. On 8 August 1978 during a day of particularly intense eider migration, a flock of 200 eider was observed at an altitude of 1 to 2 km just north of Pitt Point. Almost all observations of eiders migrating through the Beaufort are of birds between 1 and 10 m high. Our sighting of a flock migrating at quite a high altitude suggests that some eiders may move over the eastern and central Beaufort at altitudes where they are too high to be detected by observers. This would help to explain the difference between the large eider flocks seen at Pt. Barrow and the lesser numbers to the east. This difference is partially explained, however, by our delineation of the migratory corridor.

d. Sitting Eiders

Of all eiders seen on cruises in the nearshore and pelagic Beaufort the percentage seen sitting on the water is 28 percent in the pelagic regime and 13 percent for the nearshore. The locations of all sitting eider flocks of more than 10 birds are shown in Figure 9. These flocks account for all but 6 percent of our observations of eiders on the water. Over 99 percent of the eiders sitting on pelagic waters are on or adjacent to the 20 m isobath. These observations are merged with nearshore censusing in Table 16. Regions listed correspond to the six nearshore regions used throughout this report but certain regions have been subdivided to provide greater resolution.

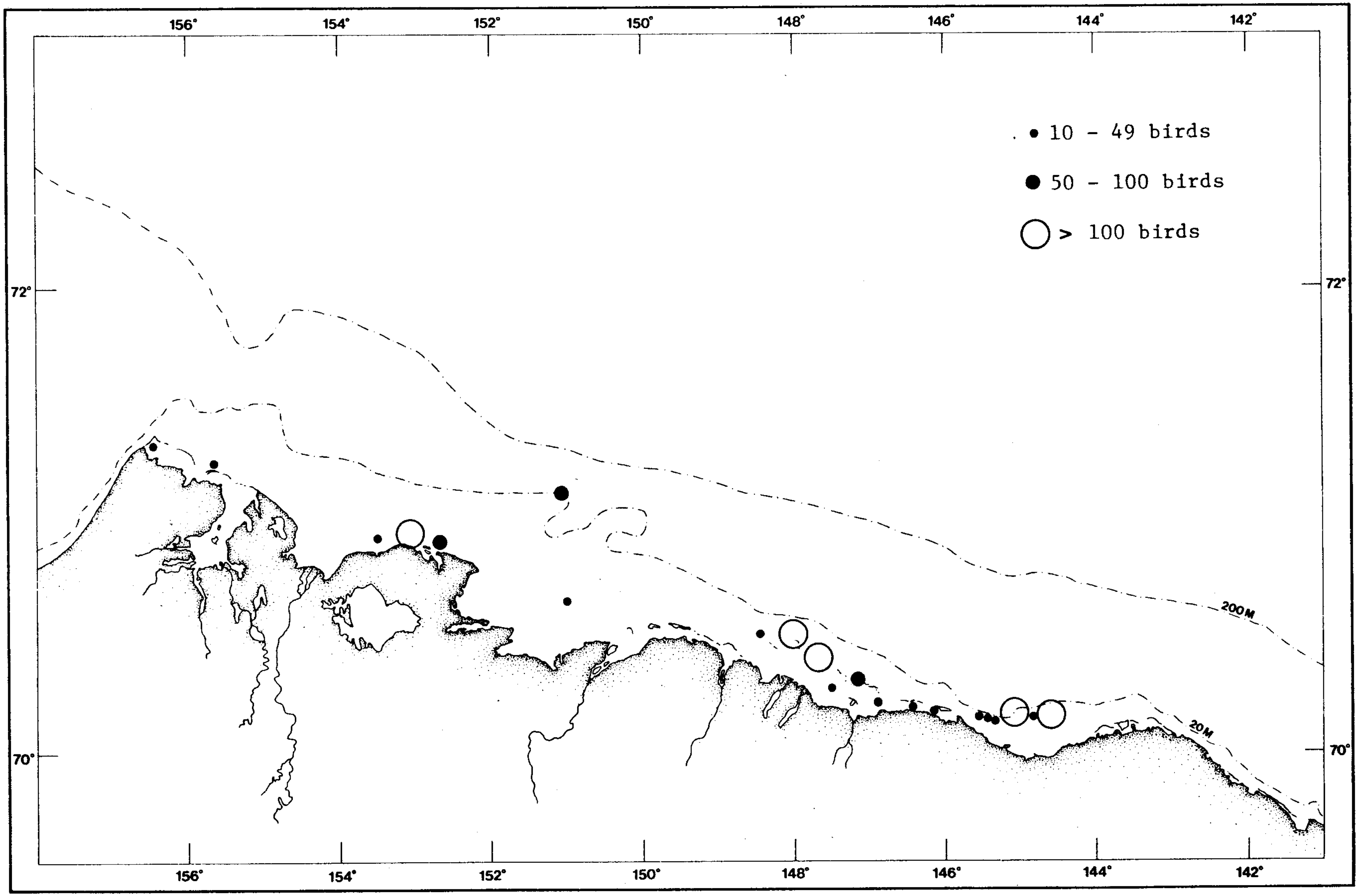


Figure 9. The location and size of all sitting eider flocks of more than ten birds.

	1976	1977	1978
North of Plover Islands	1.7	0.2	3.7
Elson Lagoon	-	-	.5
Smith Bay	-	0	.9
Pitt Point	.8	8.5	.4
Harrison Bay	3.1	0	0
North of Jones Islands	.1	1.2	.6
Simpson Lagoon	0	0	0
Prudhoe Bay	2.9	61.8	2.7
Camden Bay	1.0	0	36.0
Barter Island	0	0	-

Table 16. Densities of eiders (birds per km sq.) sitting on water in the nearshore Beaufort Sea.

Regular but low densities of sitting eiders were found north of the Plovers each year. Observations from Cooper Island show that a small number of King Eider (usually less than 50) are present on and north of the island during August. No flock larger than 15 birds has been observed on the water in this region. The Pitt Point region has regular low to moderate densities on what we have delineated as the principal migratory corridor in the area. While eiders cross the mouth of Harrison Bay in numbers they rarely sit there since we have recorded only two flocks. Many of the eider encountered east of Harrison Bay are associated with breeding colonies on barrier islands. Our sampling in the Jones Island/Simpson Lagoon area shows that birds are regular and uncommon north of the islands and absent from the lagoon. The Prudhoe Bay area consistently had eiders on the water both landward and seaward of the islands. While most of these birds are associated with breeding colonies, "migrant" flocks of 350 and 370 have been seen resting seaward of the islands.

In Camden Bay we have encountered two large eider flocks, one of 120 birds in 1972 and one of 300 in 1978, associated with a pingo-like shoal. The flock in 1978 appeared to be feeding. If eiders are moving west and southwest over the offshore Canadian Beaufort to the Alaskan coast, Camden Bay may be their first landfall and thus possibly a staging area before moving west down the coast.

In summary, the areas near eider breeding islands in the Jones Island and Prudhoe Bay regions have regular and moderate numbers of eiders on the water during August. Because migrating eiders occasionally sit down in the Beaufort large sitting flocks can be expected anywhere in the migratory corridor, although we have found them to be more common in the eastern Alaskan Beaufort. The Plover Islands, where eiders do not breed and no large sitting flocks have been encountered, has small numbers of molting males that use the islands as roosting sites.

G. Scoters

Sightings of scoters have been made on only 11 transects, all in nearshore waters. Surf Scoters (Melanitta perspicillata) have been seen on nine transects and White-winged Scoters (M. deglandi) on two. All sightings, but one, have been confined to a remarkably small region encompassing the area south of Thetis Island and western Simpson Lagoon, all within 20 km of Oliktok Pt. All these sightings were of less than five birds. The only sighting out of the Oliktok Pt. area is of a flock of 33 birds near Barter Island. Six of our sightings are from 1978 when Johnson and Richardson (1982) found them to be common molt migrants in the Simpson Lagoon area. Surf Scoters are abundant further east in the Canadian Beaufort where large numbers molt near Herschel Island (Vermeer and Anweiler, 1975).

H. Phalaropes

Phalaropes are the smallest seabirds present in the pelagic Beaufort, weighing approximately 50 g. Both Red (Phalaropus fulicarius) and Northern (P. lobatus) Phalaropes occur in the Alaskan Beaufort. Red Phalaropes are the most commonly encountered species although Northerns may be occasionally common in the littoral (Connors, 1979). Northern Phalaropes are common in nearshore habitats in the Canadian Beaufort (Vermeer and Anweiler, 1975). Phalaropes are frequently difficult to identify to species when observed from vessels and all sightings presented here are treated simply as phalaropes. There seems little doubt that Red Phalaropes constitute the majority of phalaropes we have observed. Collecting from small boats during cruises has produced only Red Phalaropes. Phalaropes breed circumpolarly on tundra and winter, in temperate and tropical marine waters.

1. Spring migration and breeding season

Phalaropes move through the Bering Sea in late May (Divoky, in prep.) and arrive on the coastal tundra of the Alaskan Beaufort the first week in June (Bergman et al., 1977). They are not observed in numbers over the flaw lead in the Chukchi (Flock and Hubbard, 1979; Woodby and Divoky, 1982) and it is likely the final stages of migration are overland. Some birds may move offshore, however, since Schamel (1978) saw phalaropes approaching the Beaufort coast from the north. Female phalaropes leave the breeding grounds shortly after egg-laying and in late June and early July small numbers of females are seen near barrier islands (Schamel, 1976; Divoky, 1978a). Phalaropes remain uncommon in the nearshore until late July and early August when large numbers of males and young are present in the littoral (Connors, 1979; Divoky, 1978a).

2. Post-breeding dispersion and migration

a. Pelagic observations

Phalaropes are common and regular in the Plover Islands region averaging 16.5 birds per km sq. and present on 40 percent of the pelagic transects (Tables 17, 34 and 36) Regions to the east have overall densities of <1 bird per km sq. with the exception of Pitt Point which averages 1.1 per km sq. Frequencies of occurrence for regions east of the Plovers are <13 percent. The large numbers of phalaropes present in the pelagic waters north of the Plovers and the lesser numbers to the east may indicate that 1) phalaropes move westward in nearshore areas until they reach the Plovers and then move offshore to feed, or 2) phalaropes migrate quickly through most of the pelagic Beaufort until they reach the Plover Island area where they then begin feeding. Densities of phalaropes in the Plover Islands pelagic region can exceed 300 birds per km sq. (Table 17).

b. Nearshore observations

The average phalarope density in the nearshore Plover Islands region approximates that for the pelagic area of same region (17.9 vs 16.5 birds per km sq.)(Tables 18 and 35). Three regions to the east (Pitt Point, Jones Islands and Prudhoe Bay) have substantially higher nearshore than pelagic densities. Both Harrison Bay and the East of Flaxman regions have little difference in their nearshore and pelagic densities. Our nearshore censusing east of Flaxman Island is primarily in Camden Bay and higher phalarope densities could be expected east of Barter Island near Icy Reef. Harrison Bay and the East of Flaxman region have low frequencies of occurrence for phalaropes (11 and 8 percent respectively) while the other four regions have higher frequencies (29 to 37 percent) (Tables 18 and 37).

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
871	45.7	0	.5	.7	0
872	2.7	1.1	.7	< .1	.7
876	38.5	.6	0	0	-
877	2.1	.1	1.1	4.8	.1
878	1.8	-	0	0	.5
976	19.5	3.3	.2	-	-
PERCENT TRANSECTS WHEN PRESENT					
cruise					
871	40	00	02	04	00
872	25	18	11	02	17
876	53	11	00	00	-
877	27	11	17	20	05
878	32	-	00	00	09
976	54	19	04	-	-
MAXIMUM DENSITY (birds/km^2)					
cruise					
871	366	0	20	12	0
872	10.8	19.6	8.8	2.8	13.5
876	301	8.8	0	0	-
877	32.4	.7	26.4	94.3	6.5
878	13.6	-	0	0	10.4
976	166.8	66.5	5.8	-	-

Table 17. Average densities, percent transects when present and maximum densities of Phalaropes in the five regions of the Alaskan Beaufort Sea pelagic regime.

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
876	114	53	.3	4	1.4	.8
877	12	4.6	.8	2	.2	.5
878	2.3	.9	.5	7	13	-

PERCENT TRANSECTS WHEN PRESENT

cruise						
876	72	100	14	42	15	11
877	38	31	14	12	04	05
878	14	28	08	28	44	-

MAXIMUM DENSITY (birds/km^2)

cruise						
876	883	201	2	32	34	16
877	99	14	15	70	4	9
878	36	7	11	156	720	-

Table 18. Average densities, percent transects when present and maximum densities of Phalaropes in the six regions of the Alaskan Beaufort Sea inshore regime.

I. Jaegers

The three species of jaegers, Pomarine (Stercorarius pomarinus), Parasitic (S. parasiticus), and Long-tailed (S. longicaudus) all occur in the Beaufort Sea. When at sea the first two species regularly pirate prey from other birds (kleptoparasitism). The Parasitic also regularly eats small birds, such as phalaropes. The Long-tailed eats primarily aquatic prey which it obtains directly. All three species winter offshore in tropical and temperate waters and breed on tundra habitats where they are linked to terrestrial and freshwater systems (Ashmole, 1970).

1. Spring migration and breeding season

Jaegers become common in the Bering Sea in late May (Divoky, in prep.) and arrive in the Alaskan arctic in the last days of May (Bailey, 1948). Migration to arctic breeding grounds apparently takes place largely overland (Dean et al., 1975). Few are seen in migration over the flaw lead at Pt. Barrow (Woodby and Divoky, 1982) but coastal locations further east in the Beaufort have sizeable jaeger migrations (Richardson and Johnson, 1981).

The number of jaegers breeding in a given year is dependent on lemming cycles (Pitelka et al., 1965) with large fluctuations being common. The jaeger population for NPR-A was found to be between 54 and 65 thousand in 1977 and 1978 (King, 1980). Unlike many other species, jaegers were as common in the southern (well drained) area of NPR-A as in the coastal sections with large areas of wet tundra, demonstrating the jaegers' dependence on terrestrial prey during the breeding season.

Observations at nearshore locations show that jaegers are typically present in low numbers in June and July (Divoky, 1978a; Schamel, 1978). In certain years (apparently when low prey densities prevent many birds from breeding) rather large westward movements can occur in late June and early July (Divoky, in prep.). At Cooper Island, Parasitic Jaegers regularly pirate fish from terns and prey on eggs of terns and Oldsquaws. Jaegers can be expected to occur offshore in small numbers in June and July wherever gulls and terns provide opportunities for piracy. Limited shipboard censusing in July found small numbers of Parasitic Jaegers (Divoky, unpubl.). Aerial surveys in June and July did not find jaegers offshore, however (Harrison 1977).

2. August and September

a. Pelagic observations

Jaegers are attracted to icebreakers because of the large numbers of gulls feeding in the wake and the cod made available by icebreaking. For that reason jaeger densities obtained in the pelagic regime may be somewhat inflated(Table 19). Jaegers are well distributed in the pelagic regime (Table34) with each region having an overall average of .1 bird per km sq. or higher. The Plover Islands have the highest average density (.3 birds per km sq.). Jaegers are present on 20 percent of all transects in the Plover Islands and between 7 and 13 percent of the transects in regions to the east. Jaegers are nowhere abundant with 6.7 birds per km sq. the highest density encountered.

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
871	.8	.2	< .1	.2	< .1
872	0.0	< .1	.1	.3	.2
876	.7	.3	.3	.2	-
877	.2	< .1	< .1	< .1	.1
878	< .1	-	0.0	.2	.1
976	.3	.5	.2	-	-

PERCENT TRANSECTS WHEN PRESENT

cruise					
871	55	24	05	17	05
872	00	04	08	16	16
876	27	11	09	06	-
877	12	02	09	10	09
878	05	-	00	09	09
976	22	24	07	-	-

MAXIMUM DENSITY (birds/km^2)

cruise					
871	3.4	1.4	1.4	3.1	2.1
872	0.0	2.2	1.4	2.8	2.8
876	6.7	5.0	4.4	4.0	-
877	3.8	.8	1.2	1.5	3.6
878	.8	-	0.0	2.2	2.4
976	3.1	5.3	3.5	-	-

Table 19. Average densities, percent transects when present and maximum densities of Jaegers in the five regions of the Alaskan Beaufort Sea pelagic regime.

b. Nearshore observations

Unlike the pelagic regime where jaegers are rather evenly distributed, the nearshore of the Plover Islands region has a high average density (.6 birds per km sq.) and a high frequency of occurrence (20 percent) while regions to the east all average .1 bird per km sq. with the exception of the East of Flaxman region where no jaegers were seen. Frequency of occurrence in the four central nearshore regions averaged between 4 and 8 percent(Tables 20, 35 and 37.).

J. Glaucous Gulls

The Glaucous Gull is the common "Larus" gull found in arctic Alaska. It is circumpolar in its breeding distribution and breeds as far south as the Yukon-Kuskokwim Delta. Glaucous Gulls are a ubiquitous part of wet tundra habitats on the North Slope and much of the Beaufort Sea. The species is highly opportunistic in its feeding habits (Ingolfsson, 1967) which include scavenging on natural carrion and human garbage; preying on fish, zooplankton and small birds and mammals. Plentiful food sources can attract large flocks (i.e. the garbage dump at Barrow).

1. Spring migration

Glaucous Gulls winter as far north as Kotzebue Sound (Swartz, 1966) but are most common in subarctic waters from the Bering Sea ice edge (Divoky, in prep.) south with vagrants seen as far south as California.

Glaucous Gulls are early migrants. Observations at the flaw lead at Pt. Barrow (Woodby and Divoky, 1982) conducted by this research unit showed that Glaucous Gulls were present on 6 May when observations began and that 50 percent of the 3500 birds seen between 6 May and 4 June had passed by 23 May. Richardson & Johnson (1981) found most movement past Oliktok and Milne Pts. occurred in late May and early June. Sub-adult birds do not move into Beaufort waters until the latter part of the migration.

2. Breeding

Glaucous Gulls breed on both tundra habitats and barrier islands. King (1979) found between 12 and 19 thousand "gulls" breeding on NPR-A in 1977 and 1978. This included both Glaucous and Sabine's Gulls but Glaucous Gulls comprised over 85 percent of the total. Breeding on barrier islands occurs primarily between Harrison and Camden Bay on islands surrounded by river runoff. A 1976 census of all Beaufort islands found a total of 445 nests. Glaucous Gulls are early nesters with eggs being laid in the first week of June. Successful adults remain in nesting areas until late August(Divoky, 1978b).

Glaucous Gulls do not breed until at least their third summer and have thus had a large non-breeding population. The size of the sub-adult population is determined by recent breeding success and mortality of young. It is likely that most Glaucous Gulls seen in the pelagic regime in August and, with the exception of the Prudhoe Bay, the nearshore region, are part of this non-breeding population or are failed breeders. The age composition of Glaucous Gulls seen on two pelagic and three nearshore cruises shows that the majority of birds we have observed have obtained adult plumage, indicating that many birds do not breed their first year after having obtained adult plumage(Table 21). The Glaucous Gull

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
876	.4	0	< .1	.1	.2	0
877	.4	.1	.2	0	0	0
878	.9	< .1	< .1	< .1	.1	-

PERCENT TRANSECTS WHEN PRESENT

cruise						
876	27	00	07	04	15	00
877	11	06	10	00	00	00
878	26	06	03	06	08	-

MAXIMUM DENSITY (birds/km^2)

cruise						
876	1.8	0.0	.9	3.6	3.0	0.0
877	9.4	1.8	2.4	0.0	0.0	0.0
878	10.1	1.2	1.6	1.6	2.4	-

Table 20. Average densities, percent transects when present and maximum densities of jaegers in the six regions of the Alaskan Beaufort Sea nearshore regime.

	Pelagic		Nearshore		
	1977	1978	1976	1977	1978
Total aged	383	295	33	102	133
Percent adult	76	74	91	60	67
Percent sub-adult	23	26	9	40	31
Percent hatching year	0	1			2

Table 21. Age composition of Glaucous Gulls observed on two pelagic and three nearshore cruises.

non-breeding population is not tied to nest sites and is able to respond to locally abundant food resources.

3. August and September

a. Pelagic observations

Aerial censusing in June and July shows that Glaucous Gulls are present offshore in densities of $<$.1 per km sq. (Divoky 1979b;Harrison 1977). Densities during this time are almost certainly dependent on the amount of open water available. Glaucous Gulls are, however, able to feed in areas with complete ice cover by scavenging marine mammal feces and carrion.

More than any other species, except perhaps the Black-legged Kittiwake, Glaucous Gulls are attracted to the icebreakers that we use for observation platforms in the pelagic regime. During icebreaking operations where Arctic Cod are made more available as they are washed onto the ice and brought to the surface in the ship's prop wash, large flocks of Glaucous Gulls will gather to feed behind the ship. The amount of cod made available and the number of birds following the ship depends on the method of icebreaking. For this reason counting only ship followers, as Frame (1973) did, gives values that are greatly affected by the ice conditions and the activity of the ship. In addition, garbage thrown from the ship is a substantial food source when one considers the more than 200 crewmen aboard most icebreakers. Because Glaucous Gulls are attracted to icebreakers, the densities obtained for them are less reliable than for most other species. There is little doubt that in certain cases densities are exaggerated, but the attraction of the ship can also result in deflated densities. A ship sitting on station for 24 hours can attract many of the Glaucous Gulls that are usually dispersed over a large area. When the ship steams away from the garbage and bird observations begin, few if any Glaucous Gulls would be encountered since they are all behind the ship preying on cod or have remained with the garbage.

Densities of Glaucous Gulls in the pelagic regime are presented in Tables 22 34. In August densities are between .2 and .8 birds per km sq. with maximum densities of less than 7 birds per km sq. On the two cruises that censused to mid-September (878 and 976) densities were higher than 1 bird per km sq. in the central and western Alaskan Beaufort and a high of 14.4 birds per km sq. Like many surface feeding species the Glaucous Gull is most abundant in the western Alaskan Beaufort. The average density for the Plover Islands region is twice that for the East of Flaxman Island region (.8 vs. .4 birds per km sq.). The frequency of occurrence of Glaucous Gulls is rather constant throughout the Beaufort being found on approximately one quarter of the transects in each region (Tables 22 and 36).

The movements of Glaucous Gulls in pelagic waters can be divided into two periods (Table 23). From 7 to 27 August the rate of bird movement is low (.4 per hr.) and not primarily westerly. Movements during this period are predominantly to the south and east, the significance of which is not clear. From 28 August to 18 September movement was 1.8 birds per hour and 62 percent of these were moving westward. Movement from 14 - 18 September was 2.5 birds per hour and it appears that rates of a movement offshore are highest after our observations cease. Bailey (1948) mentions major movements past Barrow

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
871	.2	.3	.3	.7	.4
872	.4	.7	.6	.4	.3
876	.8	.5	.4	.4	-
877	.2	.3	.4	.4	.2
878	1.2	-	.9	.5	.6
976	1.7	1.1	1.0	-	-
PERCENT TRANSECTS WHEN PRESENT					
cruise					
871	25	36	22	41	26
872	25	42	25	17	16
876	27	15	09	09	-
877	12	18	21	17	10
878	37	-	46	22	38
976	52	33	29	-	-
MAXIMUM DENSITY (birds/km^2)					
cruise					
871	1.4	1.4	4.2	12	1.8
872	1.4	5.6	5.5	5.4	5.4
876	6.0	3.5	6.6	4.0	-
877	2.4	4.3	7.2	3.0	7.2
878	14.4	-	3.6	4.8	3.6
976	10.4	7.3	9.6	-	-

Table 22. Average densities, percent transects when present and maximum densities of Glaucous Gulls in the five regions of the Alaskan Beaufort Sea pelagic regime.

Dates:	7-27 August	28 August-18 September
Hr. of observation:	71	121.5
Total Glaucous Gulls recorded with flight direction:	28	214
Glaucous Gulls/hr:	.4	1.8
Flight direction: (percent of total)		
N	7	5
NE	0	3
E	21	6
SE	32	4
S	14	9
SW	4	10
W	21	43
NW	0	9

Table 23. Rates of movement and direction of flight of Glaucous Gulls in the pelagic zone of the Beaufort Sea.

after mid-September.

b. Nearshore observations

Glaucous Gulls are present in the nearshore in June and July both in areas with breeding colonies (Schamel, 1978; Johnson and Richardson, 1981) and in areas without colonies (Divoky, 1978a, Divoky, 1979b) The numbers present in the latter areas depend on food resources. On Cooper Island in 1978, numbers of dead *Parathemisto libellula* washed onto the island during moat formation in July and over 100 Glaucous Gulls congregated at this food source. In most areas there is a steady increase in Glaucous Gull numbers peaking in early and mid-September (Divoky, 1978a; Johnson and Richardson, 1981) and being most abundant in the littoral zone.

Nearshore observations of Glaucous Gulls from vessels are not complicated by the factors discussed for pelagic observations from icebreakers. The 30 to 60 foot vessels used in the nearshore do not break ice or dump large quantities of garbage. For that reason the values obtained for the nearshore are more reliable than for the pelagic regime.

Nearshore observations from vessels (Table 24 and 35) show that the Plover Islands region has the highest densities for the Beaufort with an average density of 3.0 birds per km sq. All other regions average less than 1 bird per km sq. with the exception of Prudhoe Bay when in 1978 a large flock was present near the "West Dock." Large flocks are uncommon except in the Plover Island region with most areas having maximum densities of 10 birds per km sq.

The three western regions had Glaucous Gulls present on an average of 26 to 39 percent of all transects. The three eastern regions had frequency percentage averaging between 13 and 22 percent. (Tables 24 and 37)

The analysis of movements in the nearshore is complicated by the large numbers of birds encountered in the Plover Island region. Table 25 shows that from 2 to 16 August there is little westerly movement. The rate of movement during this period is high (1.5 per hr.) because of sampling in the Plovers where large numbers of gulls have congregated and are searching for food. Westward movement appears to begin on 17 August with 54 percent of all birds seen past that date moving in a westerly direction. This indicates birds in the nearshore begin to move west before those in the pelagic regime.

Our nearshore observations do not occur in September when Glaucous Gulls are at their highest densities on spits and barrier islands (Divoky 1979) and areas containing spits or barrier island chains have their highest Glaucous Gull densities at that time.

K. Other *Larus* gulls

While the vast majority of *Larus* gulls seen in the Alaskan Beaufort are Glaucous Gulls, some gulls with dark wing-tips are encountered. Both Herring Gulls (*Larus argentatus*) and Thayer's Gulls (*Larus thayeri*) are present in the Beaufort but many birds cannot be identified to species. *Larus* gulls with dark wing-tips have been seen on 3 percent of the pelagic transects and 1 percent of nearshore transects. The majority of our sightings have been in late August and early September.

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
867	1.5	.5	.8	.2	.4	.5
877	2.0	.7	.7	.1	.9	.2
878	4.4	.5	.8	.6	1.5	-

PERCENT TRANSECTS WHEN PRESENT

cruise						
876	36	25	57	13	30	11
877	40	31	38	09	39	14
878	36	22	33	21	15	-

MAXIMUM DENSITY (birds/km^2)

cruise						
876	6.3	1.9	4.2	3.3	3.0	9.5
877	24.3	5.4	2.4	1.7	2.6	1.7
878	126.7	3.6	5.4	9.4	85.2	-

Table 24. Average densities, percent transects when present and maximum densities of Glaucous Gulls in the six regions of the Alaskan Beaufort Sea inshore regime.

Dates:	2-16 August	17-30 August
Hr. of observation:	52.3	100.3
Total Glaucous Gulls recorded with flight direction:	80	72
Glaucous Gulls/hr:	1.5	.7
Flight Direction: (percent of total)		
N	18	11
NE	21	8
E	5	17
SE	15	3
S	18	7
SW	6	12
W	11	31
NW	6	11

Table 25. Rates of movement and direction of flight of Glaucous Gulls in the nearshore zone of the Beaufort Sea.

L. Ivory Gull

The Ivory Gull (Pagophila eburnea) is a circumpolar high arctic breeder that is typically associated with pack ice throughout the year. Breeding has been recorded on the Canadian Arctic Archipelago (MacDonald and Macpherson, 1962) and apparently some of these birds move through the Beaufort to and from wintering areas in the Bering Sea (Divoky, in prep.).

1. Spring migration

Ivory Gulls enter the Chukchi Sea in early May and are regular at Wainwright during mid and late May (Bailey, 1948). The number that move northeast past Pt. Barrow into the Beaufort is not known. Brower (in Bailey, 1948) considered them common at Barrow in the spring but observations at the lead in 1976 from 6 May to 4 June failed to produce any sightings (Woodby and Divoky, 1982).

No sightings of Ivory Gulls have been made in the Alaskan Beaufort in June and July (Divoky 1979b; Harrison, 1977).

2. August and September

a. Pelagic observations

Ivory Gulls are rare in the pelagic Alaskan Beaufort during the period of our shipboard observations (Table 26). They have been seen on 2 percent of all transects with a total of 19 sightings. In two of the five years none were seen. No influx into the Beaufort in September, as one would expect, was observed. All sightings were between 10 and 31 August. Thus the birds we encountered may be non-breeders summering in the Beaufort. All were in adult plumage, however. Frame (1973) saw two Ivory Gulls in the Beaufort in early August. No Ivory Gulls have been seen in the nearshore or littoral zones.

M. Black-legged Kittiwake

The Black-legged Kittiwake (Rissa tridactyla) is the most truly pelagic of the gulls found in arctic Alaska. It nests on rock cliffs as far north as Cape Lisburne (Springer et al., 1982) and winters in subarctic waters from the Bering Sea ice edge south. The bulk of the kittiwakes encountered in the Beaufort Sea are apparently non-breeders, based on their presence in the Beaufort during the breeding season, although approximately half have obtained adult plumage. Banding studies in Great Britain have shown that some non-breeding birds from British colonies spend the summer at the ice edge off Greenland (Coulson, 1966) and our observations at the Chukchi and Beaufort ice edge show a similar pattern for western arctic kittiwakes. The kittiwakes present in the Beaufort Sea in summer are not tied to nest sites and their distribution and abundance is related almost solely to prey availability.

In most situations kittiwakes are not a common ship follower since they do not eat garbage. In the ice-covered areas of the Beaufort, however, large flocks of kittiwakes will gather behind the ship to feed on Arctic Cod made available by the icebreaking activities of the ship. These flocks reduce the

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
871	0.0	< .1	.1	< .1	0.0
872	0.0	0.0	0.0	< .1	< .1
876	0.0	0.0	0.0	0.0	0.0
877	< .1	0.0	< .1	0.0	< .1
878	0.0	0.0	0.0	0.0	0.0
976	0.0	0.0	0.0	0.0	0.0
PERCENT TRANSECTS WHEN PRESENT					
cruise					
871	00	04	07	06	00
872	00	00	00	01	02
876	00	00	00	00	-
877	02	00	01	00	02
878	00	00	00	00	00
976	00	00	00	00	-
MAXIMUM DENSITY (bird/km^2)					
cruise					
871	0.0	1.4	2.4	3.4	0.0
872	0.0	0.0	0.0	3.6	1.4
876	0.0	0.0	0.0	0.0	-
877	2.8	0.0	1.0	0.0	.8
878	0.0	0.0	0.0	0.0	0.0
976	0.0	0.0	0.0	0.0	-

Table 26. Average densities, percent transects when present and maximum densities of Ivory Gulls in the five regions of the Alaskan Beaufort Sea pelagic regime.

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
871	.5	.3	.1	.2	.1
872	7.0	1.8	.2	.3	< .1
876	1.6	3.2	.6	.5	-
877	.9	< .1	.4	< .1	.1
878	1.0	-	0.0	< .1	.1
976	.8	1.4	.5	-	-

PERCENT TRANSECTS WHEN PRESENT

cruise					
871	25	20	10	12	05
872	75	42	19	13	05
876	48	14	17	09	-
877	35	06	33	05	02
878	53	-	00	02	04
976	33	45	21	-	-

MAXIMUM DENSITY (birds/km^2)

cruise					
871	3.4	3.0	.8	11.2	1.4
872	15.3	16.8	1.4	5.4	1.8
876	3.5	30	5.0	7.0	-
877	14.4	1.3	3.3	1.5	3.6
878	5.6	-	0.0	2.9	1.4
976	5.6	7.0	4.8	-	-

Table 27. Average densities, percent transects when present and maximum densities of Black-legged Kittiwake in the five regions of the Alaskan Beaufort Sea pelagic regime.

	Pelagic	Nearshore
Dates:	7 August - 18 September	2 - 30 August
Hr. of observation:	228.8	153.3
Total Kittiwakes recorded with flight direction:	120	33
Kittiwakes/hr.:	.5	.2
Flight direction: (percent of total)		
N	10	6
NE	7	0
E	19	3
SE	19	6
S	22	15
SW	9	3
W	9	27
NW	5	39

Table 28. Rates of movement and direction of flight of Black-legged Kittiwakes in the pelagic and nearshore Beaufort Sea.

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
867	1.7	0.0	0.0	< .1	0.0	0.0
877	.3	.2	0.0	.1	0.1	0.0
878	.9	.3	0.0	0.0	.2	-

PERCENT TRANSECTS WHEN PRESENT

cruise						
876	82	00	00	02	00	00
877	09	06	00	03	04	00
878	16	14	00	00	03	-

MAXIMUM DENSITY (birds/km^2)

cruise						
876	3.8	0.0	0.0	1.8	0.0	0.0
877	5.8	4.8	0.0	1.9	1.8	0.0
878	11.5	10.8	0.0	8.4	-	

Table 29. Average densities, percent transects when present and maximum densities of Black-legged Kittiwakes in the six regions of the Alaskan Beaufort Sea inshore regime.

quality of our bird density data from pelagic waters. Densities can be increased due to birds flying into the transect as they are attracted to the feeding flock, or decreased since all the birds from an area may be attracted to the ship, reducing the frequency with which kittiwakes are encountered. The type of icebreaking and the amount of cod made available has a marked effect on the number of ship followers (especially kittiwakes) and thus comparisons of ship followers between areas and/or years is not possible. Nearshore densities are not affected by icebreaking problems.

1. May through July

Black-legged Kittiwakes are present in the Beaufort as early as May. Observations in May at the flaw lead at Pt. Barrow show that small numbers move into the Beaufort during that month (Woodby and Divoky, 1982). Kittiwake numbers probably gradually increase in June and July as more open water becomes available, Single birds and small flocks are regular but infrequent in the Plover Islands region during this time period (Divoky, in prep.). Harrison (1977) encountered them in July north of the Plovers.

2. August and September

a. Pelagic observations

August and early September, the period with least ice cover, can be expected to be the time of maximum abundance for Black-legged Kittiwakes in the Beaufort. As with many other surface feeding species kittiwakes are most regular and abundant in the western Beaufort (Table 27&34)But unlike most surface feeding species the Plover Islands and Pitt Point regions are equally important with overall average densities of 1 bird per km sq. The three regions to the east have overall densities of .3 birds per km. Kittiwakes are most frequently encountered in the Plover Island region being on almost 40 percent of all transects with frequencies of 20 percent for Pitt Point and Harrison Bay, Jones Island/ Prudhoe Bay and the East of Flaxman Island region have frequencies of 9 and 4 percent respectively. Maximum densities of kittiwakes are not exceptionally high in any region. The largest flock encountered on transect was a feeding flock of 20 associated with a convergence line north of the Plovers. Flocks of ship followers can become quite large. During a day of much icebreaking in the Pitt Point region a flock of over 200 birds was following the ship throughout the day.

The 120 kittiwakes recorded with a flight direction (Table 28) demonstrate that there is little directed movement and that a considerable percentage of birds are moving east and south. This indicates that westward movement out of pelagic waters occurs after our observations cease in mid-September.

b. Nearshore observations

As one would expect for a highly pelagic species, nearshore densities are less than for pelagic waters (Tables 29 and 35). The Plover Island region is the only area where kittiwakes are common in the nearshore, averaging .7 birds per km sq. and present on 20 percent of the transects (Table 37). While not uncommon in the Pitt Point region (averaging .2 birds per km sq. and on 9 percent of the transects), regions from Harrison Bay east have densities of $<.1$ bird per km sq. with kittiwakes seen on 3 percent of all transects.

Littoral zone observations show that as many as 400 kittiwakes can congregate at Cooper Island. Few are seen in the littoral zone to the east (Divoky, in prep.; Johnson and Richardson, 1981).

Kittiwake movements in the nearshore are less than in pelagic waters (Table 28) and 69 percent of all birds are moving westward. This directional movement may be due to kittiwakes moving westward with feeding flocks of terns and other surface feeding species, rather than being actual migration.

N. Ross' Gull

Ross' Gulls (Rhodostethia rosea) breed primarily in northern Siberia (Dementiev and Gladkov, 1969) although small numbers breed sporadically in high arctic locations in Canada and Greenland (MacDonald, 1978; Hjort, 1980). Although they breed and feed on freshwater habitats during the summer they occupy marine habitats for the remainder of the year. Ross' Gulls move from their Siberian breeding grounds eastward into the Chukchi Sea (Pleske, 1928). They begin arriving in small numbers in mid-August (Divoky, in prep.) and are present in large numbers by late September (Watson and Divoky, 1972). From early September through October, Ross' Gulls are commonly seen in the littoral and nearshore areas from Wainwright to Pt. Barrow (Bailey, 1948). Little is known of their movements or distribution after October.

1. Pelagic observations

Ross' Gulls do not enter the pelagic Beaufort until mid-September. Our earliest sighting is on 11 September and it appears they are probably most common after 18 September when our observations cease. Our sightings show them to be abundant in the Plover Islands region. If they are moving eastward they could be more widely distributed in the Beaufort later in September and in October. On the only mid-September cruise that adequatley censused the pelagic waters north of the Plovers (976), Ross' Gulls were found on 15 percent of all transects and averaged .5 birds per km sq. The Pitt Point region had a frequency of 2 percent and an average density of .1 birds per km sq. Only two other sightings of Ross' Gull have been made, both in 1971; one bird in the Harrison Bay region and two in the Pitt Point region.

Since nothing is known of Ross' Gulls movements once they pass the Pt. Barrow area it is not possible to say how long they may remain in the Beaufort. It is possible that some birds could stay until open water becomes severely limiting in November.

2. Nearshore observations.

Our vessel observations in the nearshore do not extend into September when Ross' Gulls are present in the Beaufort and thus we have no density information for that regime. Infrequent observations of Ross' Gulls have been obtained from Cooper Island in late August and early September (Divoky, in prep.).

O. Sabine's Gull

Sabine's Gull (Xema sabini) is a small black-headed gull that breeds circumpolarly primarily on tundra habitats. It winters in biologically productive offshore areas in the southern hemisphere. Pacific Basin birds are found in the Humboldt Current on the west side of South America (Chapman, 1969). Migration to and from wintering areas usually occurs well offshore. Sabine's Gulls have been little studied compared to most arctic species due to a small total population, localized breeding, and migrating and wintering offshore.

1. Spring migration and breeding

Sabine's Gulls arrive in arctic Alaska the last week in May. Little information is available on Sabine's Gull movements in the spring and, like Arctic Terns, they appear to complete their migration to the arctic at high altitudes. There are few Bering Sea records for late May (Divoky, in prep.) and they have not been observed at the flaw lead in late May or early June at Cape Prince of Wales (Flock and Hubbard, 1978) or Pt. Barrow (Woodby and Divoky, 1982). Late migrants, presumably non-breeders, may migrate at lower altitudes since Bailey (1948) saw many passing Cape Prince of Wales on 16 June. Once in the Beaufort some low altitude coastal migration does occur as evidenced by observations in Canada (Richardson and Johnson, 1981).

Sabine's Gulls breed primarily on mainland tundra habitats. King (1979) found an estimated 2 to 3 thousand breeding on NPR-A. Brower (in Bailey, 1948) states that they are uncommon on the coast but found in colonies on lakes further inland. Sabine's Gulls are rare on Alaskan Beaufort barrier islands with a total of three nests being found in 1976 on a census of all islands (Divoky, 1978b). There is little use of nearshore habitats during the breeding season (Divoky , 1979b)and probably virtually no use of the pelagic regime (Harrison ., 1977). In June and July on Cooper Island, small numbers (<10) of breeding and non-breeding Sabine's Gulls feed primarily in brackish tundra ponds where spring-tails (Collembolla) are a major food source.

2. Post-breeding dispersion and migration

a. Pelagic observations

Sabine's Gull appears to be one of the few species that migrates westward through the Alaskan Beaufort primarily in pelagic waters. Both densities and rates of movements are higher for that regime than for the nearshore. As with many other surface feeding species the pelagic waters north of the Plover Islands have the highest densities, averaging 2 birds per km sq. (Tables 30 and 34). The three central regions have overall average densities between .4 and .5 birds per km sq. The East of Flaxman region has an overall density of much less than .1 birds per km sq. Sabine's Gulls are found on 11 percent of all transects in the Plover Islands region. Frequencies to the east decline from 6 percent in the Pitt Point region to <1 percent in the East of Flaxman Island.

Data on the pelagic movements of Sabine's Gulls have been obtained only on the last four cruises (all those after 1972). Movement was 1.5 birds per hour and of the 332 birds recorded with a flight direction, 71 percent were moving westward. Migration was most pronounced in the last week of August and the first week of September.

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
871	.5	0	.3	.1	0
872	0.0	.3	.1	.2	< .1
876	8.9	.9	< .1	.2	-
877	.1	< .1	1.0	0.0	0.0
878	0.0	-	0.0	0.0	0.0
976	2.2	.8	.6	-	-

PERCENT TRANSECTS WHEN PRESENT

cruise					
871	15	00	05	01	00
872	00	08	06	07	05
876	37	07	04	13	-
877	04	02	03	00	00
878	00	-	00	00	00
976	10	14	11	-	-

MAXIMUM DENSITY (birds/km^2)

cruise					
871	6.8	0	6.8	13	0
872	0	11	3.3	5.6	2.8
876	112	12	1.2	2.0	-
877	7.2	3.6	40.	0.0	0.0
878	0.0	-	0.0	0.0	0.0
976	49.6	24.7	0.0	-	-

Table 30. Average densities, percent transects when present and maximum densities of Sabine's Gulls in the five regions of the Alaskan Beaufort Sea pelagic regime.

b. Nearshore observations

Sabine's Gulls show a marked affinity for the nearshore Plover Island region compared to the regions to the east. The Plovers have an average of .8 Sabine's Gulls per km sq. with sightings on 14 percent of all transects from that region. Regions to the east all average .1 per km sq. with no region having Sabine's Gulls on more than 3 percent of the transects (Tables 31 and 35).

Littoral zone observations also demonstrate the marked difference between the Plover Islands and regions to the east. In years when drifting pack ice provides large quantities of zooplankton, linear densities of Sabine's Gulls at Cooper Island are over 80 birds per km sq. (up to a total of 900 birds). Few Sabine's Gulls are seen in the littoral zone to the east (Johnson and Richardson, 1981; Divoky , 1979b).

Movement of Sabine's Gulls in the nearshore is .3 birds per hour. Of the 48 birds recorded with direction only 46 percent are moving westward indicating that while some migration is occurring there is also much dispersion.

P. Arctic Tern

Arctic Terns (Sterna paradisaea) breed circumpolarly in the arctic and subarctic. They nest both on inland, freshwater habitats and coastally on spits and barrier islands. Outside of the breeding season marine habitats are used exclusively. The species winters at the edge of the Antarctic pack ice and migrates in the offshore waters of both the Atlantic and Pacific Oceans (Salomonson, 1967).

In northern Alaska breeding occurs primarily on tundra ponds and lakes. King (1979) estimated the tern population of the coastal tundra of NPR-A to be between 45,000 and 50,000 birds, based on aerial surveys. Few breed on Alaskan Beaufort barrier islands with a 1976 census finding less than 100 pairs (Divoky, 1978b).

1. Spring migration and breeding season

Arctic Terns arrive in arctic Alaska in the last days of May through the first week in April (Bailey, 1948; Bergman et al., 1977). Arctic terns make little use of the Alaskan Beaufort Sea during spring migration. They apparently do not pass over coastal waters for the last part of their migration since observations in late May and early June at the edge of the flaw lead at Cape Prince of Wales (Bering Strait) and Pt. Barrow have failed to observe migrating terns (Flock and Hubbard, 1978; Woodby and Divoky, 1982). Shipboard observations in the Bering Sea in May have failed to find them in numbers (Divoky, in prep.) and it is likely they complete their migration to the high arctic at very high altitudes. Brower (in Bailey, 1948) commented on their sudden appearance in the spring with no migration being noted (Bailey, 1948). There are records of coastal movements in the Canadian Beaufort, however. Johnson et al. (1975) saw terns moving east past coastal locations on the west side of the Mackenzie River Delta as did Searing et al. (1975) on the east side.

During the period of shorefast ice and shorefast breakup, terns are breeding and are uncommon in the nearshore regime in most areas (Divoky, 1979b; Johnson and Richardson, 1981) except near islands with breeding colonies (Divoky, 1978a; Schamel, 1978). Use of pelagic areas is also low based on aerial surveys in July (Harrison , 1977).

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
876	2.9	1.0	0.0	0.1	.2	< .1
877	.9	0.0	0.0	0.0	0.0	0.0
878	.3	< .1	0.0	0.0	< .1	-
PERCENT TRANSECTS WHEN PRESENT						
cruise						
876	45	13	00	02	07	04
877	11	00	00	00	00	00
878	10	03	00	00	03	-
MAXIMUM DENSITY (birds/km^2)						
cruise						
876	15.4	7.6	0.0	3.3	3.8	.9
877	19.7	0.0	0.0	0.0	0.0	0.0
878	6.0	1.2	0.0	0.0	2.4	-

Table 31. Average densities, percent transects when present and maximum densities of Sabine's Gulls in the six regions of the Alaskan Beaufort Sea inshore regime.

2. Post-breeding dispersion and fall migration

Flying juvenile Arctic Terns appear in the nearshore Beaufort as early as the last week in July (Divoky and Boekelheide, in prep.) although some young do not fledge until the last week in August (Divoky, in prep.). Movement of adults and young occurs from late July until mid-September and is eastward to Pt. Barrow and then south to the Pacific Basin. There are areasin the Alaskan Beaufort where terns concentrate because prey and roosting sites are most available. Terns gather in these areas to build fat reserves before continuing their migration (Divoky, in prep.). Thus the Beaufort is not used only as a migratory pathway but also a staging area.

a. Pelagic observations

Arctic Terns are uncommon migrants over much of the pelagic Beaufort (Fig. 10). Densities in all regions east of the Plover Islands average 1 bird per km sq. (Tables 32 and 34), with the lowest densities being east of Flaxman Island. The Plover Islands have an average density of 2.5 birds per km sq., but tern distribution in that area is patchy. In two years they were not encountered and overall have been seen on only 14 percent of the transects in that area. This patchiness is probably linked to the Bering Sea Intrusion and associated eddies.

Terns were most common within 70 km of shore although they were encountered as far as 250 km offshore over the Arctic Basin.

The movements of terns in pelagic waters provides more indication that the area affected by the Bering Sea Intrusion is important for feeding. In the area east of where the Bering Sea Intrusion directly affects sea surface temperatures (east of 152° W), 79 percent of the 267 terns seen were moving westward. In the area where sea surface temperatures are frequently affected by the Intrusion only 31 percent of 157 terns were moving westward indicating that birds are searching for and responding to food sources.

Only 53 Arctic Terns seen in pelagic waters were aged with the following percentages being found:

Dates	Percent adult	Percent juvenile
2 - 17 August	94	6
18 August - 1 September	76	24
2 - 18 September	47	53

These ratios agree with those observed at Cooper Island where the percentage of juvenile birds increases steadily during migration and can constitute over 90 percent of early September flocks (Boekelheide, 1980; Divoky, in prep.).

b. Nearshore observations

Nearshore censusing shows that the difference between tern densities in the Plover Island region and the remainder of the Alaskan Beaufort is even

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	E. of Flaxman Island
871	2.8	.4	.7	.1	.2
872	0.0	< .1	1.0	.6	.2
876	2.2	.4	.2	.7	-
877	4.2	1.5	1.1	.3	< .1
878	0.0	-	0.0	.3	0
976	1.3	0.0	< .1	-	-

PERCENT TRANSECTS WHEN PRESENT

cruise					
871	20	12	02	01	03
872	00	02	08	07	07
876	22	07	04	25	-
877	16	16	04	02	<01
878	00	-	00	05	00
976	10	00	04	-	-

MAXIMUM DENSITY (birds/km^2)

cruise					
871	49.0	6.8	30	6.8	6.4
872	0.0	2.4	12.6	17.6	5.2
876	30.2	7.4	4.8	7.4	-
877	216.	10.8	45.6	18	3.6
878	0.0	-	0.0	11.3	0.0
976	31.2	0.0	1.8	-	-

Table 32. Average densities, percent transects when present and maximum densities of Arctic Terns in the five regions of the Alaskan Beaufort Sea pelagic regime.

AVERAGE DENSITY (birds/km^2)

cruise	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
876	20.4	1.1	.1	.5	3.9	.2
877	10.9	1.2	.3	1.0	.2	.4
878	6.1	.3	.1	.8	.4	-

PERCENT TRANSECTS WHEN PRESENT

cruise						
876	100	18	07	09	15	04
877	49	13	03	09	09	11
878	30	08	03	06	09	-

MAXIMUM DENSITY (bird/km^2)

cruise						
876	85.0	7.6	1.1	9.9	57.7	4.2
877	133.0	14.4	9.5	26.9	2.1	6.4
878	88.7	5.2	3.3	26.3	8.3	-

Table 33. Average densities, percent transects when present and maximum densities of Arctic Terns in the six regions of the Alaskan Beaufort Sea inshore regime.

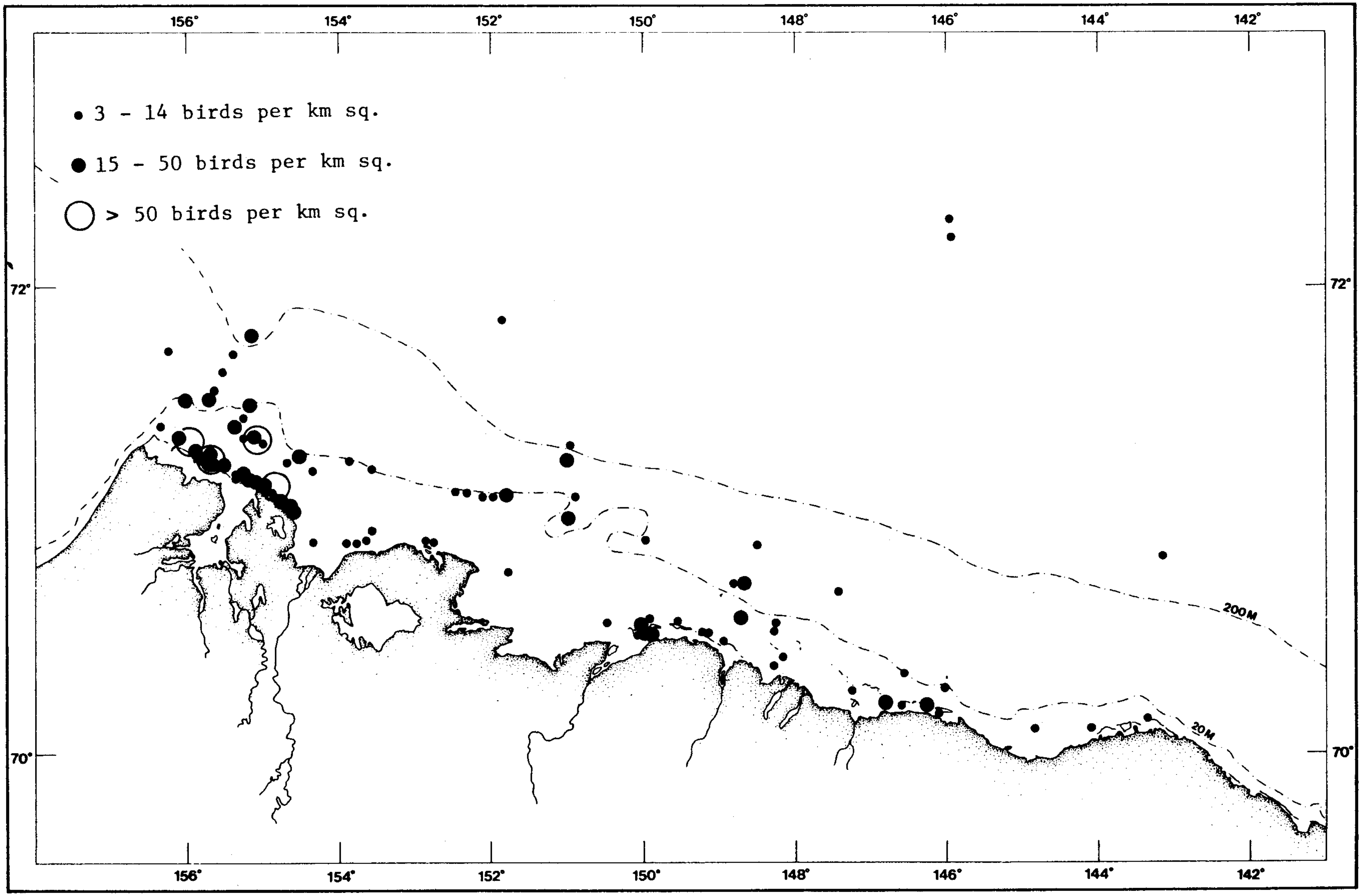


Figure 10. The location and density of all Arctic Tern densities of more than 3 birds per km sq.

more marked in the nearshore than in the pelagic regime (Tables 33 and35). The average density in the Plover Islands is 9.6 birds per km sq. and to the east it averages < 1 bird per km sq. The maximum densities for each year were always found in the Plover Islands region. Terns are well distributed in the nearshore Plover Islands being seen on 45 percent of all transects. They are present on < 11 percent of transects for the regions to the east.

Tern movements in the nearshore show that birds are moving primarily to the west in all areas with 66 percent of the 325 directional birds moving westward. That this percentage is not higher indicates that many terns are dispersing and/or looking for food sources rather than just migrating.

Because terns do not regularly sit on the water staging areas have to provide spits and islands near productive waters with high prey densities. The Plover Islands and Pt. Barrow spit appears to be the only area in the Beaufort that fulfills these requirements. Icy Cape and Pt. Franklin in the Chukchi are also important staging areas. Observations from the Plover Islands in 1979 when apparently little prey was available for surface feeding species show that the islands were still important roosting sites even though birds were feeding well offshore when they were feeding at all.

Q. Murres

The two murre colonies closest to the Alaskan Beaufort are at Cape Parry (600 km to the east)(Hohn, 1955) and Cape Lisburne (480 km to the southwest) (Springer et al., 1982). The approximately 150 Thick-billed Murres (*Uria lomvia*) that breed at Cape Parry pass through the Beaufort from wintering grounds in the Pacific Basin. Apparently far more birds than the Cape Parry breeding population enters the Beaufort in the spring. Hendee (*in* Bailey, 1948) saw many hundreds passing Wainwright and moving toward the Beaufort. Lesser numbers were seen by Woodby and Divoky (1982) at Pt. Barrow, but their findings corrobate the view that the number of murres entering the Beaufort is not minimal. Once in the Beaufort the movements of the birds is not known but it is likely they follow offshore leads to the Canadian Beaufort. Apparently some of the birds leave the Beaufort shortly after they arrive. In mid-June 1981 a flight of over 1000 murres passed westward over Cooper Island (Divoky, in prep.). This major emigration may indicate that murres that enter the Beaufort but do not breed at Cape Parry do not remain in the Beaufort.

There is little evidence of murres in the Alaskan Beaufort in June and July. Aerial surveys have failed to see them (Harrison ., 1977) and they are regular but rare stragglers near the Plover Islands (Divoky, in prep.).

1. Pelagic observation

Murres were found to be rare in the pelagic waters of the Alaskan Beaufort being seen on 1 percent of all transects. Eight of our sightings are from 1977 when the pack ice was far offshore indicating that ice cover may play a role in reducing murre numbers. No east-west trend is present and the average for all regions combined is .01 birds per km sq.

2. Nearshore observations

It is surprising that murres, a species usually found in offshore waters, are more common in the nearshore than the pelagic Beaufort. Murres were regular in the Plover Islands region being present on 15 percent of the transects and averaging .8 birds per km sq. Pitt Point had a density of .1 per km sq. and a 6 percent frequency. East of Pitt Point densities are .05 birds per km sq. and frequencies less than 3 percent.

R. Black Guillemot

The Black Guillemot (Cepphus grylle) is a circumpolar species that nests in cavities and is typically associated with rock cliffs and talus. Because they are able to exploit a wide range of cover for nest sites (Storer, 1958) guillemots have been able to breed on the Alaskan Beaufort coast by utilizing man-made debris (Divoky et al., 1975; Divoky, 1978b). While the number of nests on the Plover Islands is approximately 200, there are probably less than 10 pairs between the Plover Islands and the Canadian border.

Black Guillemots winter in leads in the ice from the northern Bering Sea north. They are known to occur in the chronic lead system off Wainwright and Pt. Barrow in winter (Nelson, 1970; Bailey, 1948). The lead system extends slightly into the extreme western Beaufort and Black Guillemots are one of the few species that can be expected to winter in the Beaufort. The bulk of the Alaskan Beaufort lacks chronic lead systems, however, and the number of guillemots present in winter can be expected to be low and their distribution restricted.

Because Black Guillemots winter relatively near their breeding sites, little migration occurs. Observations at the lead off Pt. Barrow in spring show that guillemots are present as early as 6 May and numbers increase in late May. Birds fly both north and south over the lead and no net movement northeast into the Beaufort is evident (Woodby and Divoky, 1982). In June and July Black Guillemots can be expected to be rare stragglers in the Alaskan Beaufort in June and July, except in the Plover Islands where they are common breeding birds arrive at breeding colonies in early June and non-breeders arrive in numbers in July.

1. August and September

a. Pelagic observations

Black Guillemots are rare offshore in the Alaskan Beaufort. They were seen on 1 percent of all transects with none seen east of the Harrison Bay region. The Plover Islands, Pitt Pt. and Harrison Bay regions had densities of .04, .02 and $<$.01 birds per km sq. respectively. While guillemots may be absent from the eastern Alaskan Beaufort, Frame (1973) saw scattered birds in the Canadian Beaufort.

Black Guillemots are much more regular in the pelagic waters of the Chukchi Sea than in the Beaufort and this may be an indication of the difference in prey availability in the two seas (Divoky, in prep.).

b. Nearshore observations

Guillemots are almost as rare in the nearshore as in the pelagic regime, being present on 2 percent of all transects. They are not uncommon in the Plover Islands (avg. density of .3 birds per km sq. and a frequency of 11 percent). There are only two sightings east of the Plovers; one in the Pitt Point region and one near Prudhoe Bay. Small numbers could be expected to be present anywhere where cover is available for nesting.

	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	East of Flaxman Islands
Loons	.3	.5	.6	.3	.3
Short-tailed Shearwater	10.5	.1	0.0	0.0	0.0
Eider	1.2	<.1	.4	.5	6.5
Oldsquaw	3.0	2.1	.4	.7	1.1
Phalaropes	16.5	1.1	.6	.9	.3
Jaegers	.3	.2	.1	.2	.1
Glaucous Gull	.8	.6	.5	.5	.4
Black-legged Kittiwake	1.0	1.2	.3	.2	.1
Ross' Gull	.1	<.1	0.0	0.0	0.0
Sabine's Gull	2.0	.4	.5	.1	<.1
Arctic Tern	2.5	.6	.7	.3	.1
TOTAL	38.1	6.9	4.1	3.7	9.0

Table 34. Average densities of numerically important species in the five regions of the Alaskan Beaufort Sea pelagic regime.

	Plover Islands	Pitt Point	Harrison Bay	Jones Island	Prudhoe Bay	East of Flaxman Islands
Loons	1.6	1.3	1.9	.5	.9	.4
Eider	17	73.4	15	3.1	26	5.9
Oldsquaw	46.8	60	9.9	59.6	43	18.3
Phalaropes	17.9	7.9	.6	4.7	8.3	.6
Jaegers	.6	.1	.1	.1	.1	0
Glaucous Gull	3.0	.6	.8	.3	1.2	.3
Black-legged Kittiwake	.7	.2	0	<.1	.1	0.0
Sabine's Gull	.8	.1	0	<.1	.1	<.1
Arctic Tern	9.6	.8	.2	.7	1.0	.3
Murres	.8	.1	0	<.1	<.1	<.1
B. Guillemot	<.1	<.1	<.1	0	0	0
TOTAL	98.9	144.6	28.6	69.2	80.8	25.9

Table 35. Average densities of numerically important species in the six regions of the Alaskan Beaufort nearshore regime.

	Plover Islands	Pitt Point	Harrison Bay	Jones Islands/ Prudhoe Bay	East of Flaxman Islands
Loons	18	11	14	08	10
Short-tailed Shearwater	09	03	00	00	00
Eider	01	01	01	02	07
Oldsquaw	14	13	05	08	08
Phalaropes	40	13	08	05	08
Jaegers	20	11	07	13	10
Glaucous Gull	29	29	24	26	21
Black-legged Kittiwake	38	25	20	09	04
Ross' Gull	04	01	00	00	00
Sabine's Gull	11	06	05	03	.1
Arctic Tern	14	08	04	05	04
ALL BIRDS	89	69	60	55	55

Table 36. Frequency of occurrence (percent transects when present) of the numerically important bird species and all birds in the five regions of the Alaskan Beaufort Sea pelagic regime.

	Plover Islands	Pitt Point	Harrison Bay	Jones Island	Prudhoe Bay	East of Flaxman Islands
Loons	48	40	53	26	42	17
Eider	36	24	23	09	18	12
Oldsquaw	44	46	30	57	50	41
Phalaropes	30	37	11	29	31	08
Jaegers	20	05	06	04	08	00
Glaucous Gull	38	26	39	15	22	13
Black-legged Kittiwake	20	09	00	01	03	00
Sabine's Gull	14	03	00	01	03	02
Arctic Tern	45	11	04	08	10	08
ALL BIRDS	99	96	71	85	86	64

Table 37. Frequency of occurrence (percent transect when present) of the numerically important bird species and all birds in the five regions of the Alaskan Beaufort Sea nearshore regime.

VII. Trophics

The stomach contents of birds collected in the Beaufort Sea were reported on earlier (Divoky, 1978c). For this final report, the same data is being presented, but with the data separated by regime for each species in order to delineate differences between the pelagic and nearshore.

A. Surface feeding species

The numerically important surface feeders in the Alaskan Beaufort include the phalaropes, jaegers, gulls and Arctic Tern. Stomach contents data for these species are presented in Tables 38 through 44.

All of the phalaropes collected have been Red Phalaropes. Phalarope stomach contents are frequently in the form of crustacean chyme weighing less than .1 g. Because of this percent, weight is difficult to compute and only frequency of occurrence is given (Table 38). The average length of whole prey items is also given. The eight stomachs collected in the pelagic regime did not differ from the 68 from the nearshore and the data were pooled. Gammarid amphipods, especially Apherusa glacialis, appear to be the primary prey items. Connors and Risebrough (1977) found copepods, Apherusa glacialis, and decapod zoea to be the major prey items in the littoral zone at Point Barrow. At Simpson Lagoon, phalaropes took primarily copepods, amphipods and mysids (Johnson and Richardson, 1981).

No jaeger stomach contents were collected. The two larger jaegers are frequent ship followers in the pelagic regime where they pirate Arctic Cod from Glaucous Gulls and kittiwakes. Long-tailed Jaegers could be expected to take Arctic Cod and zooplankton directly. Parasitic Jaegers will regularly take phalaropes.

Glaucous Gulls in pelagic waters were taking primarily small birds and Arctic Cod (Table 39). Because small birds (phalaropes) are uncommon over most of the pelagic Beaufort it is likely that cod is the primary prey in most areas. In nearshore waters cod are an important item but amphipods and euphausiids are frequent in stomachs. The Glaucous Gull is a highly opportunistic feeder (Ingolfsson, 1967) and could be expected to prey on whatever food source is most abundant and available.

Black-legged Kittiwakes, Sabine's Gulls and Arctic Terns all demonstrate similar differences between nearshore and pelagic stomachs contents. Birds in pelagic waters prey to a great extent on Arctic Cod with zooplankton usually being of less importance. Few cod are taken in the nearshore where zooplankton are of primary importance. This division is most extreme for kittiwakes and less marked for Sabine's Gulls (Tables 40 - 42).

B. Diving species

Because diving species are frequently harder to collect than surface feeders, we have fewer stomachs from most species. Two loons collected near Barrow in July contained only amphipods (Divoky, 1978c) but it is clear that cod are also important, at least as prey returned to chicks still on tundra ponds. Adult loons are frequently seen returning to the mainland with Arctic Cod in their bills.

No shearwaters have been collected in the Beaufort but they feed on both fish and zooplankton in the Bering Sea (Sanger, in prep.).

Oldsquaw were found to be feeding on a wide range of invertebrates (Table 43) with epibenthic species being of major importance. Johnson and Richardson (1981) found mysids and amphipods to be the primary prey in Simpson Lagoon. Common and King Eiders appear to have similar diets with large isopods being the major prey item (Table 44).

The stomach contents of birds collected in the Beaufort demonstrate two important points.

1) Arctic Cod is a major prey item in pelagic waters for surface feeding birds, with the exception of phalaropes, but these same species prey primarily on zooplankton in the nearshore.

2) The common diving species prey on epibenthic crustaceans and are restricted to the nearshore.

Both of these points demonstrate the differences in the pelagic and nearshore regimes. Arctic Cod are apparently the most available prey at the surface of pelagic waters while zooplankton is more available in nearshore waters. The diving species that prey principally on epibenthic crustaceans are limited to the nearshore indicating that their prey is less abundant or available in the pelagic regime.

These trophic differences in the two regimes and factors relating to them will be discussed later in this report.

	Percent frequency	Size of prey (mm)
Unidentified gammarid amphipods	31	5
Unidentified crustaceans	30	-
Apherusa glacialis	18	8
Mysis sp.	13	14
Copepods	11	2.5
Thysanoessa sp.	5	11
Larval fish	1	15

Table 39. Frequency of occurrence and average length of prey items in Red Phalarope stomachs collected in the pelagic and nearshore Beaufort. Number of stomachs = 76.

	PELAGIC n=9 wt=20g		NEARSHORE n=9 wt=98g	
	% wt	% freq	% wt	% freq
Arctic Cod	17	56	60	33
Small birds	75	22	--	--
Amphipods	1	22	1	22
Thysanoessa sp.	--	--	13	33
Saduria entomon	--	--	12	11

Table 39. Percent of total weight and frequency of occurrence of prey items in Glaucous Gull stomachs collected in the pelagic and nearshore Beaufort Sea.

	PELAGIC		NEARSHORE	
	n=25 wt=134g		n=14 =11.2g	
	% wt	% freq	% wt	% freq
Arctic Cod	95	92	5	27
Amphipods	--	12	67	7
Shrimp	--	04	--	--
Apherusa glacialis	--	--	14	28
Mysis sp.	--	--	11	14

Table 40. Percent of total weight and frequency of occurrence of prey items in Black-legged Kittiwake stomachs collected in the pelagic and nearshore Beaufort Sea.

	PELAGIC		NEARSHORE	
	n=6 wt=15g		n=32 wt=60.6g	
	% wt	% freq	% wt	% freq
Arctic Cod	13	67	4	3
Thysanoessa sp.	13	17	4	3
Parathemisto sp.	53	17	--	--
Shrimp	3	17	--	--
Apherusa glacialis	--	--	49	56
Mysis sp.	--	--	24	28
Unid. amphipods	1	17	6	19

Table 41. Percent of total weight and frequency of occurrence of prey items in Sabine's Gull stomachs collected in the

	PELAGIC		NEARSHORE	
	n=27 wt=40.4g		n=48 wt=78.6g	
	% wt	% freq	% wt	% freq
Arctic Cod	64	78	20	21
Thysanoessa sp.	35	22	23	23
Amphipods	1	4	22	38
Mysis sp.	--	--	13	29
Apherusa glacialis	--	--	9	17
Sand Lance	--	--	12	2

Table 42. Percent of total weight and frequency of occurrence of prey items in Arctic Tern stomachs collected in the pelagic and nearshore Beaufort Sea.

	OLDSQUAW	
	n=93 wt=317.8g	
	% wt	% freq
Amphipods	23	38
Molluscs	22	59
Mysis sp.	20	16
Thysanoessa sp.	17	13

Table 43. Percent of total weight and frequency of occurrence of prey items in Oldsquaw collected in the nearshore Beaufort Sea.

	COMMON EIDER		KING EIDER	
	n=3 wt=42g		n=16 wt=178.6g	
	% wt	% freq	% wt	% freq
Saduria entomon	83	67	89	63
Mysis	15	33	-	-
Molluscs	1	66	2	31
Amphipods	1	33	2	19

Table 44. Percent of total weight and frequency of occurrence of prey items in Common and King Eider stomachs collected in the nearshore Beaufort Sea.

VIII. Biomass Densities

The conversion of birds per km sq. to biomass per km sq. (obtained by multiplying the birds per km sq. by the average weight of the bird) allows one to compare regions and regimes with regard to the avian biomass supported by prey populations in an area. To do this it is necessary to consider only those species that are feeding or potentially feeding in an area. Because surface feeding species can search for prey while migrating, all surface feeding species are included in biomass densities. The common surface feeding species in the Beaufort include phalaropes, jaegers, gulls and terns. Of the diving species regularly encountered in the nearshore all loons and Oldsquaw observed are considered in biomass calculations because they are regularly seen sitting on the water. Because the majority of eider seen in the nearshore are flying, only sitting birds are used to compute biomass densities. In the pelagic regime loons, Oldsquaw and eider are absent until migration begins in late August and few birds are seen sitting on the water. Thus the only diving species considered in biomass calculations for the pelagic regime is the Short-tailed Shearwater. While loons, Oldsquaw and eider almost certainly do some feeding in pelagic waters the frequency of feeding is low and most of it occurs in close proximity to the 20 m contour.

Total biomass densities by region for the pelagic and nearshore regimes are shown in Table 45. Species biomass densities by region by regime are presented in Figures 11 through 13 .

The pelagic regime of the Alaskan Beaufort Sea is characterized by an almost complete lack of diving species in most areas and a marked east-west gradient in total biomass with the extreme western region having over ten times the biomass of the extreme eastern. Although diving species made up 69 percent of the biomass in the pelagic waters north of the Plover Islands, diving biomass was extremely low in all other regions. The high density of diving species in the Plover Islands is due primarily to one loose flock of Short-tailed Shearwaters seen on 15 September 1978. Short-tailed Shearwaters have been seen on only 9 percent of all transects conducted in pelagic waters of the Plover Islands region and most of the sightings are from 1978. For all other years the biomass density of diving species in the Plover Islands region was similar to the rest of the pelagic Beaufort. Biomass of surface feeding species was high for the Plover Islands region (3 kg km^{-2}) and low in the central and eastern regions ($\lesssim$ 1 kg km^{-2}).

Biomass of surface feeders in pelagic waters showed a marked east-west gradient. Glaucous Gulls constituted over 50 percent of the biomass of surface feeders. The extreme eastern Beaufort was found to support low biomass levels of all species.

Total avian biomass supported in the nearshore Alaskan Beaufort is over ten times the amount present in pelagic waters. Except for Harrison Bay and the area east of Flaxman Island the nearshore had rather consistent values of between 49 and 65 kg km^{-2}. The low values for Harrison Bay are probably valid since extensive sampling was done in that area. Our sampling east of Barter Island in the east of Flaxman Island region has not been as thorough, however, and the diving biomass data are partially based on Spindler's (1981) data which are not directly comparable to ours. The densities for this area should be considered minimum estimates. While no east-west trend is evident in diving species in the nearshore, surface feeding species had their highest total density in the Plover Island area (6.2 kg km^{-2}) with low values (.5 to 2 kg km^{-2}) for areas in the east.

	Plover Islands	Pitt Point	Harrison Bay	Jones Islands	Prudhoe Bay	E. of Flaxman Island
Pelagic						
surface	3.0	1.5	1.0	1.0		.6
diving	6.3	<.1	<.1	<.1		<.1
total	9.3	1.5	1.0	1.0		.6
Nearshore						
surface	6.2	1.3	1.0	.8	2.0	.5
diving	43.7	56.6	12.2	48.8	63.0	33.7
total	49.9	57.9	13.2	49.6	65.0	34.2

Table 45. Biomass densities (kg per km sq.) in the five pelagic and six nearshore regions of the Alaskan Beaufort Sea.

Oldsquaw constitute 80 percent of the diving biomass inshore with loons and eiders making up the remainder. While loons had their highest densities in the western portion of the Alaskan Beaufort, Oldsquaw and eiders showed no such trend. Murres were common in the Plover Islands in 1978 giving them a relatively high average biomass for that region. Guillemots were found only in the Plover Islands (.2 kg km^{-2}).

Surface feeding species present in the nearshore are the same as those found in the pelagic regime. All reach their highest densities in the Plover Islands. The decrease to the east in the total biomass of surface feeding species is similar to that found in pelagic waters with the exception of the Prudhoe Bay region having a density higher than any of the others east of the Plover Islands. As in pelagic waters Glaucous Gulls constituted more than 50 percent of the surface feeding biomass.

The avian biomass densities show the two regimes to differ greatly with a low biomass pelagic community composed primarily of surface feeders and a higher biomass nearshore community composed of diving species with a smaller surface feeding component. In both regimes surface feeding biomass showed a marked east-west gradient with the extreme western Beaufort having the highest densities. Diving biomass in the nearshore showed no such gradient and showed little variability between regions except for Harrison Bay which consistently had low diving biomass densities.

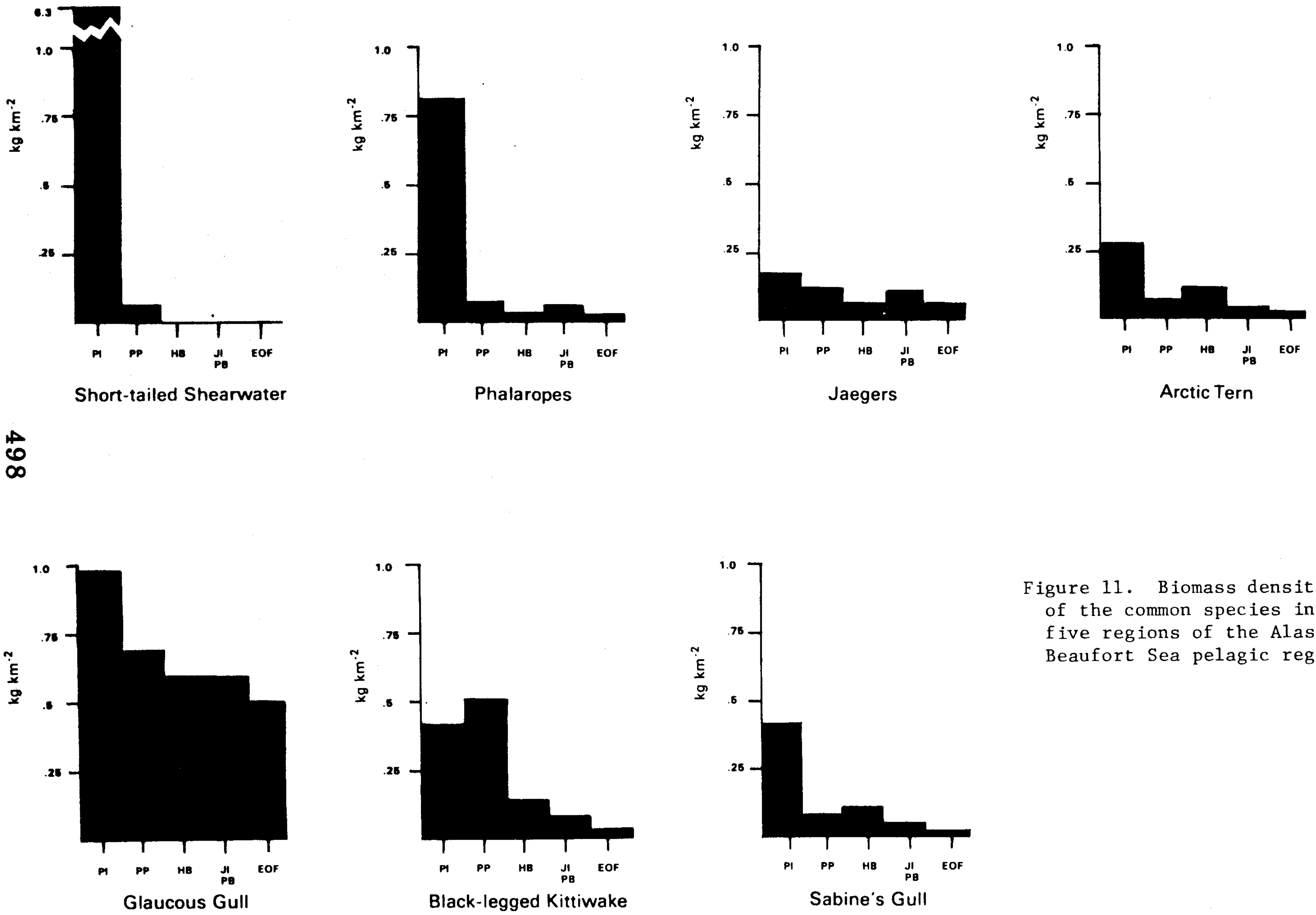


Figure 11. Biomass densities of the common species in the five regions of the Alaskan Beaufort Sea pelagic regime.

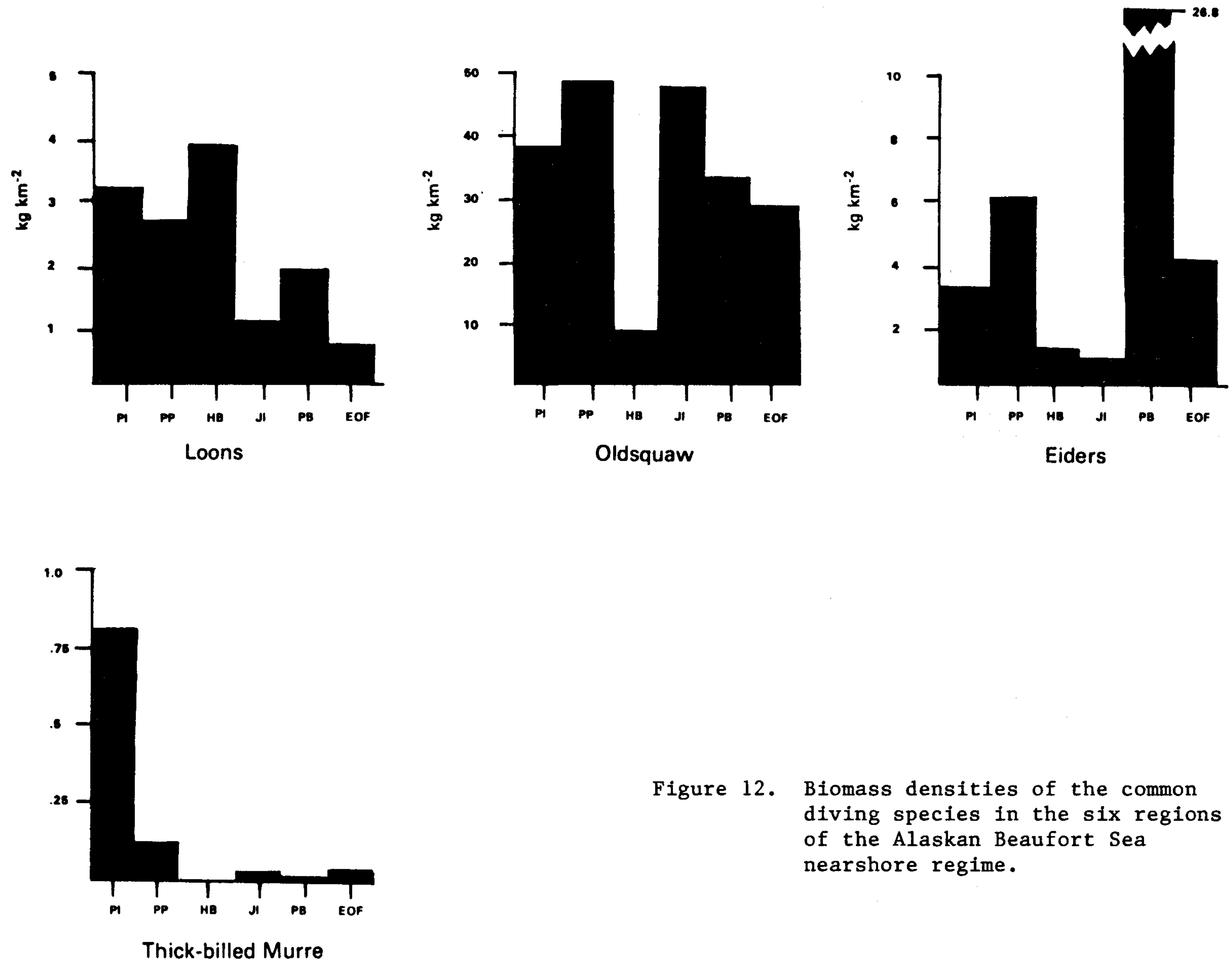
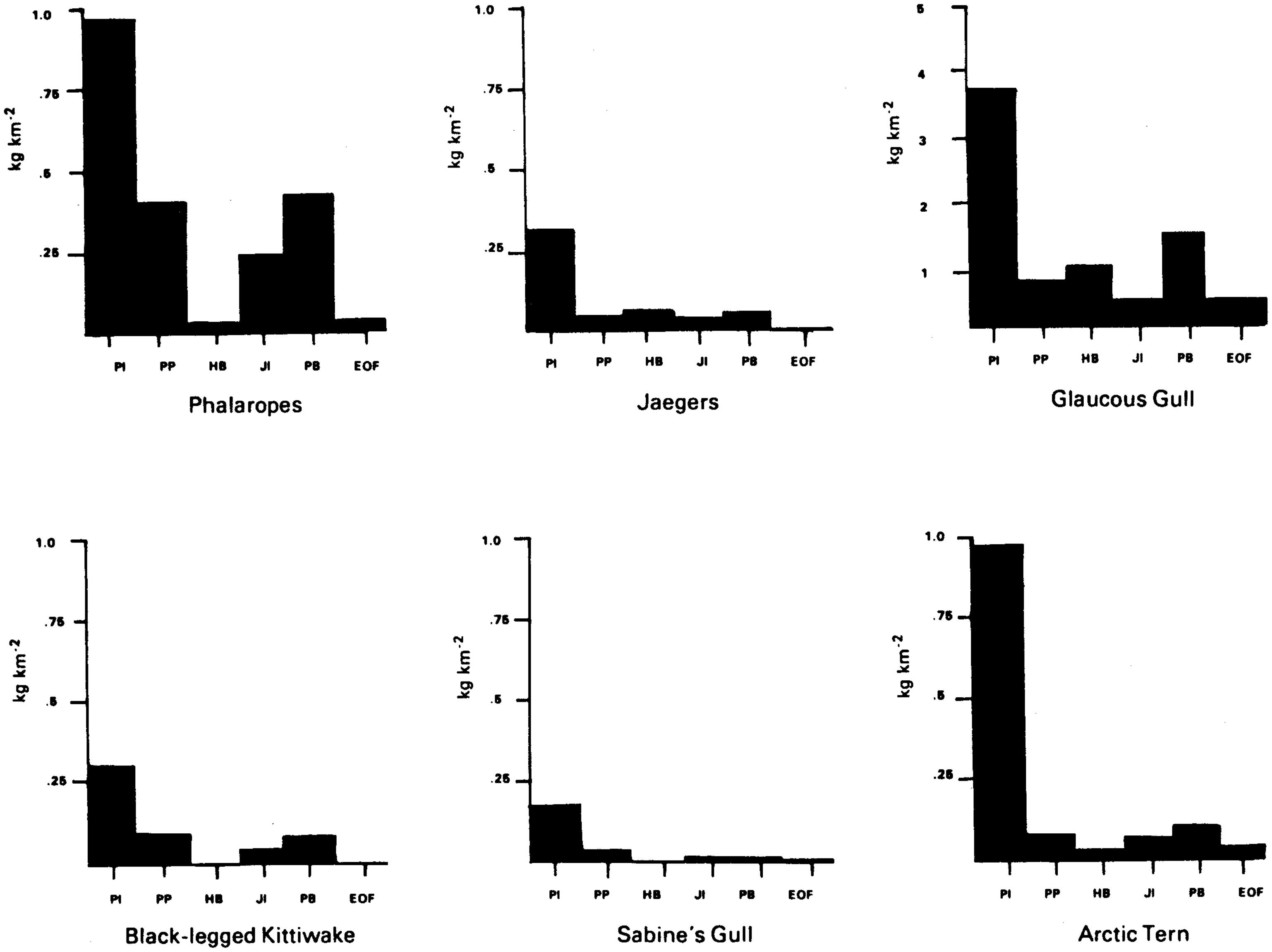


Figure 12. Biomass densities of the common diving species in the six regions of the Alaskan Beaufort Sea nearshore regime.



Phalaropes

Jaegers

Glaucous Gull

Black-legged Kittiwake

Sabine's Gull

Arctic Tern

Figure 13. Biomass densities of the common surface feeding species in the six regions of the Alaskan Beaufort Sea nearshore regime.

IX. Discussion

This report presents much species specific data that make important contributions to the knowledge of the distribution, abundance and activities of the species regularly encountered in the Beaufort. The major outcome of this research, however, has been the delineation of broad-scale trends and characteristics of the Alaskan Beaufort avifaund. These trends allow the many recent site and region specific findings to be put in perspective and also are important when considering the overall impacts of development-related activities in the Alaskan Beaufort.

These major findings are:

1) The nearshore and pelagic regimes are quite different in the amount of biomass of diving species present, and in the prey of surface feeders in each regime.

2) Surface feeders in both the nearshore and pelagic regimes show a marked last-west gradient, with the Plover Islands region having the highest densities of most species. The eastern regions have extremely low densities of many surface feeding species.

A. Characteristics of the two regimes

The Alaskan Beaufort was found to have a high biomass (> 45 kg km sq.) nearshore avian community composed primarily to diving species (loons, Oldsquaw, eider) feeding on epibenthos. The pelagic regime has a low biomass avian community composed almost exclusively of surface feeding species. While the same surface feeding species are present in both regimes, Arctic Cod are the main prey in pelagic waters while zooplankton are the primary prey in the nearshore.

In general the diving component of the nearshow varies little between regions. This indicates that the epibenthic system that supports these species (Johnson and Richardson 1982) varies little between regions (Table 45). This is consistent with the findings of benthic sampling (Carey et al. 1982). Harrison Bay is the one region with regular low biomass of diving species which is probably related to the shallowness of the bay (averaging < 10 m) and the major input of turbid fresh water from the Colville River that diving species feeding on epibenthos are essentially limited to the nearshore is probably primarily due to the energy required for diving more than 20 m. There is, however, a change in the benthic populations of amphipods and molluscs at 20 m (Carey et al. 1982) which may relate to the lack of epibenthic feeders in deeper water.

The pelagic regime is characterized by an almost complete lack of diving species and, for most regions, extremely low densities. The bird densities encountered are almost certainly the lowest for any of the shelf regions adjacent to Alaska.

The low numbers of birds supported by the pelagic waters can be at least partially attributed to the low annual primary productivity of the Beaufort, which averages between 15 and 30 g C per m sq. (Schell et al. 1982), and resulting low prey densities (Horner, 1981). The lack of diving species in most areas of the pelagic Alaskan Beaufort is another indication of low prey density. Surface feeders are able to feed where prey densities are low because they can search for food while flying, while diving species require more abundant and reliable food sources. In general, diving species in pelagic waters are over the continental shelf and the narrow shelf of the Alaskan Beaufort provides little suitable habitat.

The difference in prey consumed by surface feeders in the regimes is an indication that two separate systems are present. The difference can be partially explained by the greater ice cover of the pelagic regime. While no sampling has been conducted to demonstrate that Arctic Cod are more abundant in ice-covered waters, they are almost certainly more available to birds. Zooplankton could be expected to be more abundant in the nearshore which can average 5°C warmer than pelagic waters. Redburn (1972) estimated that zooplankton biomass in the warmer coastal waters is roughly an order of magnitude higher than for the colder central Arctic. The low percentage consumed by birds is due to both low densities and short residency time. Estimates of the total annual production of smaller fish consumed by large predators, including seabirds, was estimated to be 10 percent in the North Sea (Evans, 1971) and 8 percent in the North Pacific (Sanger, 1972).

Aside from low densities and a paucity of diving species in the pelagic regime the most striking aspect of the Alaskan Beaufort bird community is the difference between the relatively high densities of surface feeding species found west of Cape Halkett (Plover Islands and Pitt Point regions) and the low densities present to the east. During the period of observations there is a post-breeding movement of most surface feeding species west to Point Barrow and then southwest to the Pacific Basin. Many of these species undertake long migrations after leaving the arctic and require abundant prey resources that permit the accumulation of fat reserves before beginning those migrations. The results presented here, as well as other information on bird movements in pelagic waters (Divoky, in prep.), show that birds move west through the Alaskan Beaufort until they reach the area west of Cape Halkett where they begin to actively feed and search for food. Birds accumulate in this area, resulting in high densities, before continuing their post-breeding migration.

Three species, the Short-tailed Shearwater, Glaucous Gull and Black-legged Kittiwake have pelagic populations that are not involved in breeding activities and are able to respond to prey abundance during the entire summer and early fall period. These species show a similar distributional pattern with the highest densities occurring west of Cape Halkett.

It appears that the higher bird densities in the western Beaufort are due to the input of warm subarctic water resulting in higher prey densities for pelagic birds. The advection of Bering Sea water into Beaufort Sea (the Bering Sea Intrusion) has been discussed by Johnson (1956), Hufford (1974), Hufford _et al_. (1974) and Mountain (1974) and consists of two water masses, Alaskan Coastal Water and Bering Sea Water. The former water mass mixes with arctic surface water soon after it passes Point Barrow and is not clearly identifiable east of 148°W. The latter moves east to at least 143°W. Satellite photos indicate that when the Intrusion meets the water moving westward in the Beaufort Gyre and the nearshore regime, eddies are formed in the Plover Island and Pitt Point regions.

While the importance of the Bering Sea Intrusion to Beaufort Sea biological oceanography was recognized by Johnson (1956), the studies related to oil development in the central Alaskan Beaufort were usually too far from the major affects of the Intrusion to provide further information on it. Schell _et al_. (1982) in a synthesis of available annual primary producitivity data shows a tongue of high productivity (45 g C per m sq.) from Point Barrow east to 152°W along the 20 m contour and speculates that eddies north of the Plover Islands have annual production rates approaching 50 g C per m sq. Areas east of 151°W have annual productivity rates between 30 and 37.5 g C per m sq.

While zooplankton sampling has demonstrated the presence of Bering Sea species and higher densities of other species in the Intrusion, no clear evidence of higher total zooplankton abundance in the Intrusion is available. Johnson (1956) found the area from Point Barrow to 150°W to have copepods characteristic of the Bering Sea. The arctic copepod (Arcatia longiremis) was most common west of 150°W and barnacle larvae reached their highest densities directly north of Point Barrow. McConnell (1977) in an analysis of zooplankton collected in 1971 east of 150°W found only one species, a pteropod (Clione limacina), with a distinctly western distribution, but did find an area of high zooplankton diversity and abundance at 148°W which she attributed to a pulse of Bering Sea water. Data collected by Horner (1981) in 1973 and 1976-78 showed barnacle larvae to be most abundant in the Intrusion but failed to find any other affect of the Intrusion on zooplankton densities or larval fish. Lowry and Frost (1981) showed that Arctic Cod were most common west of 148°50'W although their data are from bottom tows and of use in explaining the densities of surface feeders only in showing a general trend. Marine mammal distribution reflects the influence of the Intrusion. Bowhead whales (Balaena mysticetus) concentrate in the fall in the area north of the Plover Islands (Braham and Krogman, 1977) as do Belukha Whales (Delphinapterus leucas) (J. Burns, pers. comm.). Seals present on the shorefast ice have been shown to be most common west of 153°W (Burns and Harbo, 1972; Burns and Eley, 1978).

The importance of Bering Sea water, and its associated higher productivity, to seabirds in the Chukchi Sea has been recognized by Springer et al. (1982) for cliff-nesting species and Divoky (in prep.) for pelagic populations.

If the Bering Sea Intrusion is the primary factor causing high prey abundance in the extreme western Beaufort, the distribution and abundance of prey could be expected to be patchy in space and time and poorly sampled by opportunistic zooplankton tows. Bering Sea water moves into the Beaufort in pulses and the strength of the Intrusion shows yearly variability (Johnson, 1956; Hufford et al., 1974). Physical oceanographic sampling in the Plover Island and Pitt Point regions demonstrate that certain stations show no effects of the Intrusion and that the temperatures and depth of the Bering Sea water varies greatly among stations where the Intrusion is observed (Horner, 1981). In addition the location of eddies would increase the patchiness of zooplankton. For these reasons it is not surprising that the available zooplankton data fail to agree with that for marine birds and mammals.

The patchiness of bird densities in the Plover Island region is demonstrated by observations made on 4 September 1977. Transects began at 72°10'N, 155°00'W and went south to 71°33'N. All transects were in ice-free waters. In the first 4.25 hr of observation the average biomass was .4 kg per km sq. Approaching the 20 m contour a feeding flock of 300 Arctic Terns, 20 Black-legged Kittiwakes, 10 Sabine's Gulls, five Red Phalaropes and two Pomarine Jaegers was observed. The flock was over a convergence line that caused enough chop for it to be clearly visible on the ship's radar as sea clutter. The east side of the convergence had a secchi depth of 9 m while the west side had a secchi depth of 6 m with both sides having 8°C water in the entire water column (27 m) (Horner, 1981). Stomach samples showed that Arctic Terns were taking primarily euphausids while Sabine's Gulls were taking hyperiid amphipods. Bongo tows on both sides of the convergence showed only moderate densities of either prey species. Bird censusing conducted next to and over the convergence produced an average of 6.9 kg per km sq. in 1.75 hr of observation with a high of 30.7 kg per km sq. directly over the convergence. Densities to the east and west of the convergence were low with .5 kg km sq. in 4.5 hr of observation.

The location of this feeding flock may regularly be a site of high bird densities since a flock of 300 Arctic Terns was observed there on 18 August 1976.

The processes by which the Intrusion increases prey abundance are not known but could include:

1. Increasing vertical mixing thus bringing nutrients to the surface and increasing primary productivity.

2. Bringing water with higher nutrient and/or phytoplankton levels into the Beaufort, thus increasing primary productivity and/or providing food for zooplankton.

3. Bringing water with high zooplankton standing stocks into the Beaufort, thus directly providing prey.

Major wash-ups of dead and dying *Thysanoessa raschii* that occur regularly on the Plover Islands (Boekelheide, 1980; Divoky, in prep.) may be composed of Pacific expatriates that perish as the Bering Sea water looses its integrity in the Beaufort. An integrated study of the physical and biological components of the extreme western Beaufort is needed in order to delineate the processes involved.

B. Vulnerability of species and areas

The following is a synopsis of the times and areas when Beaufort seabirds are most vulnerable to development related impacts (primarily oil spills). In general, during species are more vulnerable to oil spills since they can become oiled by diving through and surfacing in spills. Surface feeders are usually able to avoid spills.

Loons - During spring migration Yellow-billed Loons appear to be the primary loon species utilizing leads for migration. Yellow-billed Loons moving through the Chukchi to the Beaufort could be expected to be affected by a spill in the fl w lead in the Chukchi. When the first patches of open water begin to form in the nearshore in mid-June loons are regularly seen, and they continue to be common in the nearshore until at least mid-September. While loons are regular in most nearshore areas and for most of the summer and early fall, the number of loons impacted by any given spill could be expected to be low since loons do not gather into large flocks, unlike Oldsquaw and eiders. The period from mid to late August when most loons have left the tundra for nearshore waters and migration has not yet begun would probably be the time when loons as a group are most vulnerable.

Oldsquaw - Oldsquaw are present in the nearshore from the first moat formation in June until freeze-up. It is doubtful if a spill in the nearshore would not result in the oiling of a quantity of Oldsquaws. There are locations and times when the magnitude of the impacts on Oldsquaw would be large. In late June and early July a spill in the small areas of open water occupied by Oldsquaw could be expected to result in high mortality since the areas available to Oldsquaw is limited. In late July and for much of August, lagoonal areas have the highest Oldsquaw densities and because many of these birds are moulting, they are flightless and less able to avoid spills. Beginning in late August and, apparently through September, Oldsquaw move to non-lagoonal nearshore areas in numbers and during this time the species would be vulnerable in all nearshore areas.

Eiders - In spring migration the eiders moving to the Beaufort apparently wait in the Bering/Chukchi flaw lead for following winds. The location of this staging area isn't known but any oil spill in the area in May could be expected to greatly impact the Beaufort eider population. The spring migration in the Beaufort is probably too far offshore and too diffuse to be impacted by oil spills. From June through August the area between Harrison and Camden Bays, where breeding colonies are located, would be the primary area where eiders could be expected to be affected by oil spills. Migratory flocks appear to set down so infrequently in the Alaska Beaufort that they would be able to avoid spills.

Surface feeders - Phalaropes, jaegers, gulls and terns are all less likely to be directly oiled than diving species. They can be indirectly affected by the loss of habitat or through impacts on prey or the systems that provide the prey. Except for the terns and gulls breeding on barrier islands, surface feeding species do not concentrate in the nearshore or pelagic regimes until late July. They then remain common until late August. During this period the areas shown to have large numbers of surface feeding species (the Plover Islands nearshore and pelagic regions, and the Pitt Point pelagic region) are the locations where the largest number of surface feeding species would be affected by a spill.

Because the pelagic regime has lower bird densities than the nearshore and because diving species are essentially absent from the pelagic regime, while they are common to abundant in the nearshore, oil spills would have a far greater impact in nearshore than in pelagic waters. The impact of a spill in pelagic waters would depend on how far west the spill occurred. In pelagic waters east of Harrison Bay the affect of a spill on birds could be expected to be minimal.

While a spill in the nearshore would almost certainly impact numbers of birds wherever it occurred there are two areas that appear especially sensitive:

1) The Jones Island nearshore area containing Simpson Lagoon and the area south of Thetis Island appears to have the largest concentrations of Oldsquaw in the Alaska Beaufort.

2) The nearshore area north of the Plover Islands consistently has the highest concentrations of gulls, terns and phalaropes and maintains these high concentrations during much of August while birds feed and stage in this area. Both of the above mentioned areas contain important feeding areas for the species involved as well as roosting areas on barrier islands. Human activities on the islands and impacts to the marine system could both be expected to interfere with the birds in these areas.

X. Needs for further studies

A large scale survey of this sort(5 years of cruises and over 500 hours of observations) helps to delineate the major patterns of bird distributions in the Alaskan Beaufort. Areas where we consistently found low bird densities (such as the central and eastern pelagic regime) probably require little more in the way of bird surveys. Areas where higher bird densities have been found do need further study when it is anticipated that development related impacts might occur. Such studies have been conducted in Simpson Lagoon and are being conducted on the Arctic National Wildlife Range coast. Site or region specific studies allow small scale patterns of distribution and abundance to be determined. Such information allows development to occur with the minimum amount of disturbance to birds. The data presented in this report cannot take the place of such studies.

While our coverage of the Beaufort has been rather complete, given the problems of shipboard censusing in a sea like the Beaufort, Figure 3 shows a number of areas where censusing has not taken place. The nearshore east of Flaxman Island has already been mentioned as an area in need of further study. The bird studies currently being conducted there (1982) will hopefully fill that gap. The largest area that we have been unable to census is the broad nearshore area from Harrison Bay west. On the basis of observations north and south of this area it may be an important staging and feeding area for seabirds. This would be especially true in the Plover Islands area. A study in this area would also help to delineate the differences between the pelagic and nearshore regimes. Few of our observations have crossed the boundary between the two regimes (the 20 m contour) and a series of transect lines crossing the boundary would show how sharp the division is.

Further studies in the pelagic regime would be best done in the Plover Islands region. This is not only the area where birds are most vulnerable in the pelagic Beaufort, it also appears to be one of the most interesting in terms of biological oceanography due to the influence of the Bering Sea Intrusion and its associated eddies. The large number of higher vertebrates that are found in the Plover Island pelagic region would justify a study of prey populations in the area.

The short time that birds are present in the Beaufort and the even shorter time when vessels can effectively move through the Beaufort, means that a data base is built slowly through time. This is clear from the decade that has passed since the first cruise reported on in this report was conducted. The long time involved in effectively censusing the Beaufort was recognized by the OCSEAP Arctic Project Office when this study was first funded by OCSEAP in 1975.
The pace of development is now so fast that time will rarely permit data to be gathered on vessels, where fog and mechanical failures can greatly shorten the few ice-free weeks of available census time. Because of this it is good to mention that much of the information on bird activities

presented in this report (migration rates, flight directions, percent birds sitting on the water) could not have been obtained from aerial surveys. Biological oceanographers will continue to use icebreakers and smaller vessels for platforms when conducting research in the Beaufort and,although the amount of bird observations obtained on a given cruise might be small, those who are interested in Beaufort seabirds or in need of development related data would do well to put a bird observer on board.

XI. Acknowledgements

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Observers on pelagic cruises included the author, G. E. Watson, D. A. Woodby, K. Wilson, D. Forsell, T. Sharffenberg and M. Phillips. Nearshore observations were conducted primarily by A. E. Good, with some assistance from D. Forsell and the author.

The cooperation and assistance of the captains and crews of the vessels used as observation platforms was essential to the gathering of the large volume of data reported on in this report. Personnel aboard the U. S. Coast Guard icebreakers Glacier and Northwind and the Naval Arctic Research Laboratory's Alumiak and Natchik assisted in many ways.

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PREY SELECTION BY OLDSQUAWS (CLANGULA HYEMALIS L.) IN A BEAUFORT SEA LAGOON, ALASKA

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1. ABSTRACT

The feeding ecology of Oldsquaws (*Clangula hyemalis* L.) was investigated during July-September of 1977-1978 in Simpson Lagoon on the Beaufort Sea coast of Alaska. Few species of prey were available. Volumetric analyses of the stomachs of actively feeding birds collected systematically throughout both summers indicated that the diet consisted mainly of two mysids (*Mysis relicta* and *M. litoralis*)-70% and one amphipod (*Onisimus glacialis*)-15%. The remainder of the diet was mainly bivalves. Oldsquaws fed primarily in the portions of the lagoon that ranged from 2-3 m in depth, where prey densities were highest. Oldsquaws fed selectively on larger mysids and amphipods, and preyed most effectively (more food found in their stomachs) in areas where prey was most dense and biomass was greatest.

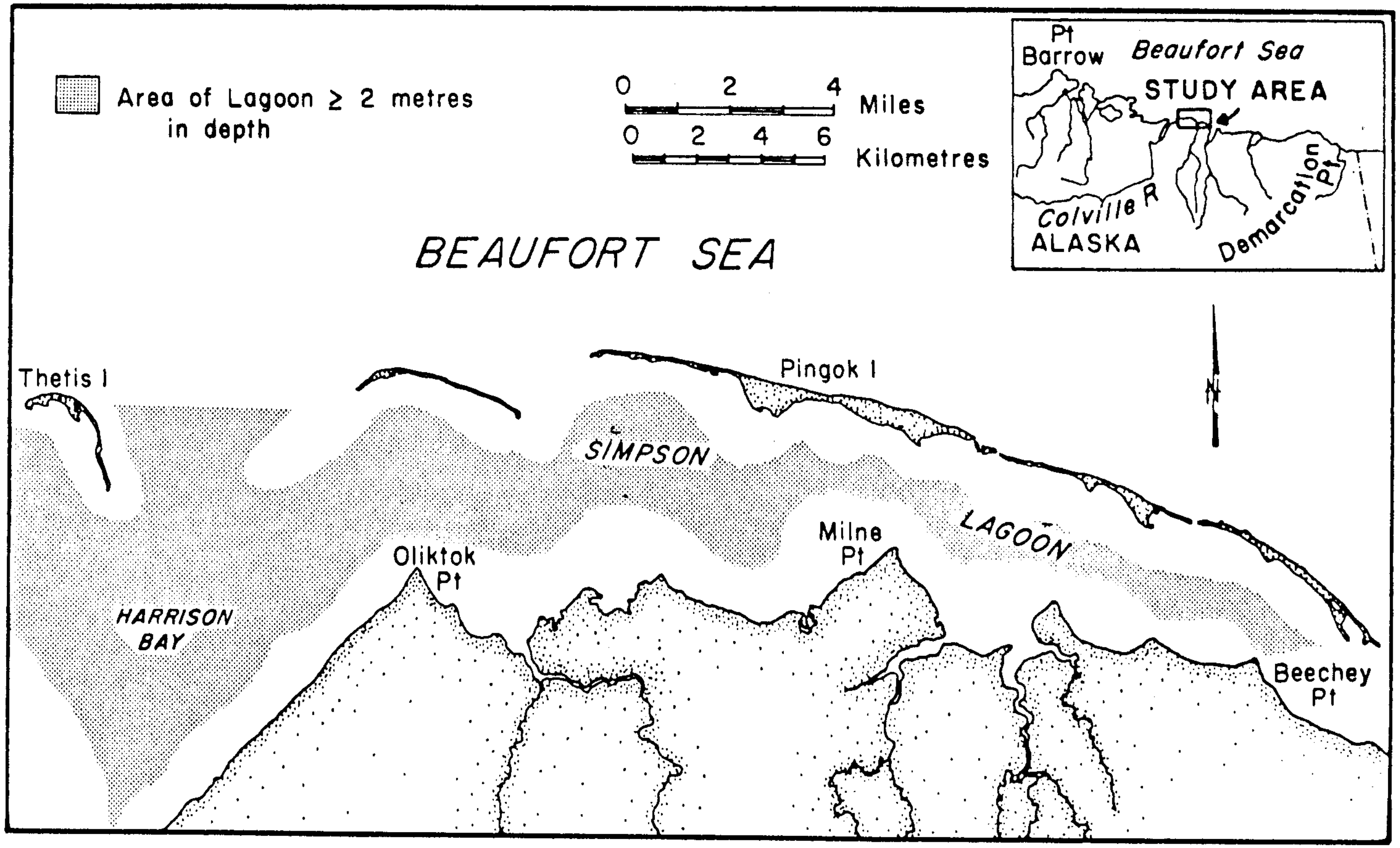

Figure 1. Simpson Lagoon, Alaska.

2. INTRODUCTION

Tens of thousands of male Oldsquaws, and a small number of non-breeding females, congregate in nearshore Beaufort Sea lagoons during July and August (Johnson and Richardson, 1982). In contrast, breeding female Oldsquaws remain with their broods on freshwater tundra lakes and ponds often until ice forces them to leave these for the coastal lagoons in mid- to late-September. This paper describes the feeding relationships between Oldsquaw ducks (Clangula hyemalis) and their invertebrate prey in Simpson Lagoon, one of a series of shallow lagoons on the north coast of Alaska (Figure 1).

The main purpose of this study was to determine which prey organisms formed the important components of Oldsquaw diets in the study area, and to determine the relationship between prey availability and prey selection by feeding Oldsquaws. Investigations of the feeding ecology of marine birds provide a key link in the interpretation of the relationship between biological productivity and abundance of birds. The studies of Oldsquaws were part of a larger interdisciplinary study of ecological processes (LGL 1981).

3. METHODS

3.1. Collection of Birds and Habitat Samples

The procedures for collecting Oldsquaws and Oldsquaw feeding habitat samples during 1977 were the following:

1. A flock of Oldsquaws was located and watched for 3-5 minutes to determine whether some birds appeared to be feeding by diving. An estimate was made of the flock size.
2. Observers then sped into the flock by boat (16 foot Zodiac with 35 hp outboard), dropped an anchored buoy into the water as the vessel slowed, and shot as many birds as possible (generally 3-8 birds).
3. Birds were retrieved and labelled. To mitigate post-mortem digestion, the gizzard, proventriculus and esophagus were injected immediately with absolute isopropyl alcohol. The esophagus was then plugged with paper.
4. Habitat sampling occurred after the collecting party returned to the buoy.
   a. For each set of birds collected, two zooplankton samples were obtained, one from the surface-water and another from the mid-water column. This was accomplished by towing both a surface-supported 14 x 10-cm neuston net (mesh size 0.079 mm) and a submerged (1 m deep) 0.25-m diameter macroplankton net (mesh size 0.239; see Griffiths and Dillinger 1981 for more details of sampling equipment).

b. One sample from the lagoon epibenthos (bottom community) was collected. From a stationary boat in the area of the buoy, the 0.25-m macroplankton net was towed manually across the bottom of the lagoon for a distance of approximately 10 m at a speed of approximately 0.5 - 1.0 m/s. The water depth at this location was measured with the buoy rope. Observations by SCUBA divers in this study indicated that the epibenthic community in Simpson Lagoon extended from the bottom surface upward to about 0.25 - 0.75 cm and included a suspension of detrital material several centimetres thick. The 0.25-m macroplankton net was a relatively crude device for sampling the epibenthos; no doubt many fast moving organisms (e.g., mysids) escaped from the net before it could be retrieved. The net often bounced along the bottom and scraped a thin layer of mud and accompanying infaunal organisms from the top 1 cm of bottom substrate.

c. Habitat samples were washed immediately from the sampling nets and preserved in 10% neutral formalin

During 1977, 31 collections of Oldsquaws ($\bar{x}$ = 2.8 birds/collection; total = 87) were made in Simpson Lagoon from 11 July through 14 September. During 1978, 45 collections ($\bar{x}$ = 2.4 birds/collection; total 108) were made in Simpson Lagoon from 10 July to 27 September. The same general procedures for collecting Oldsquaws were followed in both 1977 and 1978. Prior to making collections in 1978, however, some flocks were watched more carefully and longer (10-30 min) to determine whether they appeared to be feeding. Of the 81 feeding birds that were collected in 1978, 65 (80%) had identifiable food in their stomachs, whereas of the 27 birds that were taken indiscriminately with no prior observations of behaviour, only 26% contained some identifiable food. During 1977, 54 (62%) of the Oldsquaws collected had identifiable food in their stomachs; that proportion was similar to the overall value for the 1978 collections (67%). Thus, optimum use and least wastage of Oldsquaw specimens depends on adequate observation to determine that the birds are actively feeding and will be useful in prey analyses.

Studies during 1977 (Griffiths and Dillinger 1981, Johnson and Richardson 1981) indicated that Oldsquaws fed primarily on epibenthic invertebrates and bivalves found on or near the lagoon bottom. Therefore, during 1978 samples for analyses of food availability were collected only from this level of the lagoon. To minimize escapement of mobile epibenthic animals, the drop net method (mesh 1.0 mm; Fig. 2) of Griffiths and Dillinger (1981) was substituted in 1978 for the 0.25-m macroplankton net tows. The drop net sampled from the bottom surface of the lagoon (including approximately 1 cm of substrate) and also from the bottom 95 cm of the water column. Three to five drop net samples were collected immediately at each location where birds were collected.

3.2. Laboratory Techniques

Within 24 h of collection all birds were dissected in a field laboratory and food items were preserved. The esophagus, proventriculus and ventriculus (gizzard) were removed as a single unit from each bird. During 1978, this unit was slit lengthwise, and an arbitrary measure of

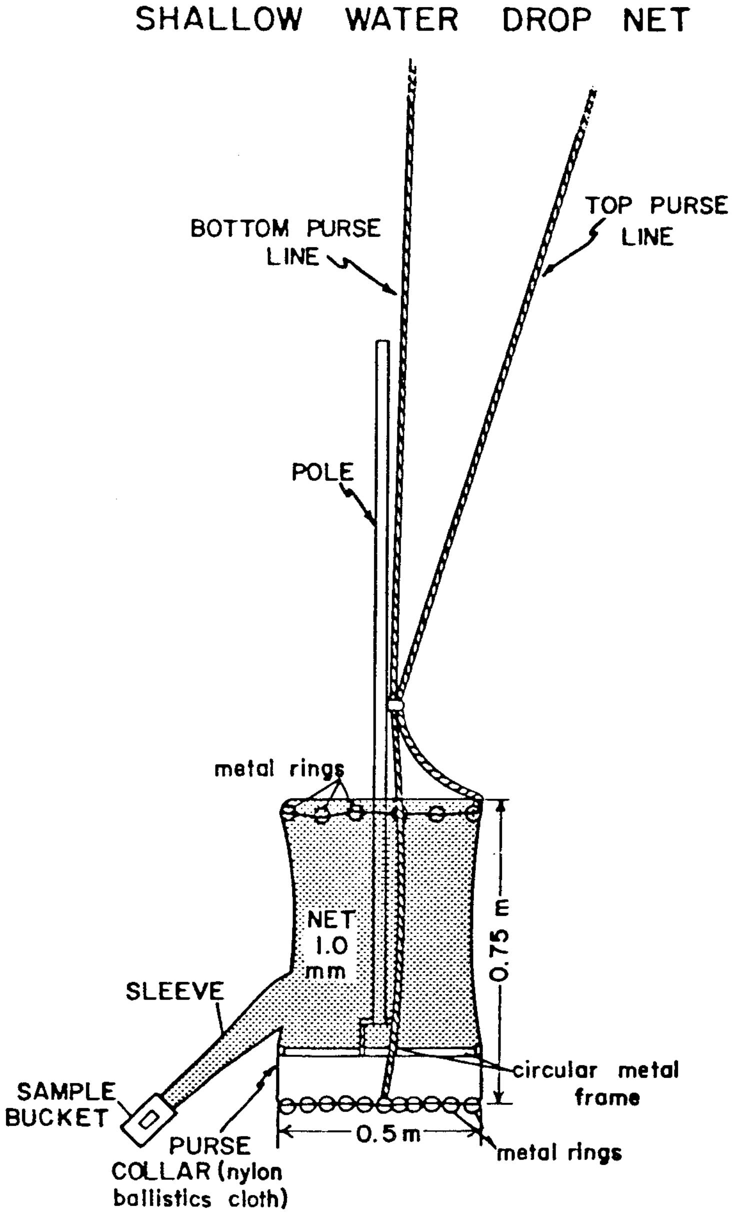

Figure 2. Shallow water drop net used to sample invertebrates in Simpson Lagoon.

fullness (Hynes 1950, and Griffiths et al. 1975; see below) was assigned to the total unit. A cursory and tentative description of the contents was also recorded. These contents were then washed with 10% neutral formalin into a 227 ml (8 oz) bottle for later reexamination. During 1977, no measure of fullness was assigned in the field, but all other procedures were the same.

To assess and compare the importance of various invertebrate taxa in the diet of Oldsquaws in 1977 and 1978, the preserved stomach contents were sorted by trained invertebrate zoologists and an estimate was made of the relative volume of each major taxon (e.g., amphipod, mysid, copepod, isopod, etc.) following the procedures developed by Hynes (1950) and modified by Griffiths et al. (1975). Twenty points were assigned to the fullest Oldsquaw stomach analyzed. The fullness of each other stomach was subsequently gauged against the fullest stomach and a corresponding number of points were assigned. After the sample had been sorted, and after each major taxon had been bottled, the total number of points thus assigned to each stomach was partitioned among the major invertebrate taxa present according to the relative volume of each. No distinction was made between whole organisms and fractions thereof. Pieces of unidentified organisms were classified as such.

During 1977 and 1978, each habitat sample was sorted and bottled by major taxon. Twenty points were assigned to the total volume of each sample and then an estimate of the relative proportions (volumes) of the total 20 points was assigned to the various major taxa in the sample.

During 1977 the two most important taxa (mysids and amphipods) present in the stomachs and habitat samples were sorted further, identified to the species level, and weighed (formalin wet weight). For a size comparison, 20 individuals each of mysids and amphipods were selected randomly from each Oldsquaw stomach and from its associated habitat sample; these individuals were measured to the nearest millimetre. During 1978 a much more detailed system of sorting and measuring was adopted; all individuals present in the stomachs and habitat samples were sorted to major taxa, identified to the species level, counted, weighed, and measured.

No studies were conducted to determine if the contents of the esophagus, proventriculus, and gizzard differed significantly. Therefore, as shown by Bartonek (1968), Bartonek and Hickey (1969), and Swanson and Bartonek (1970), some bias in prey analysis may have resulted because of differential digestion in these portions of Oldsquaw digestive tracts. Very few soft-bodied invertebrates were found in Oldsquaw digestive tracts or their feeding habitat (epibenthos), however, and our detailed laboratory analyses in 1978 confirmed that the broken shells of bivalves and the telsons and adjacent urosomes of mysids and amphipods remained identifiable and measurable in Oldsquaw gizzards. Reference collections were made of all Oldsquaw prey organisms, and regression equations were developed to relate the partial length of incompletely digested invertebrate organisms to total length, weight, and caloric value of whole organisms of the same species. Further details of the identifying, sorting, counting, weighing, and measuring procedures followed during 1977 and 1978 are described in Griffiths and Dillinger (1981).

All results presented are of the total seasonal diets of Oldsquaws. Cluster analyses (see Clifford and Stephenson 1975:134 for procedures) indicated no justification for further, more detailed categorizations of early, middle, and late season diets of oldsquaws.

4. RESULTS

4.1. Oldsquaw Diet

Of the 87 Oldsquaws collected during 1977, 15 had empty stomachs and 18 contained only unidentifiable material. The average diet of the remaining 54 birds included, on a percent estimated volume basis, 58.7% mysids, 14.2% amphipods, 8.1% bivalves, 2.3% isopods, 2.3% small fishes, and 14.2% unidentifiable material (Table 1).

The Oldsquaw diet during 1978 was similar to that in 1977 (Morisita Similarity Index, C = 0.74; Horn 1966). Of the 108 Oldsquaws collected during 1978, 34 had empty stomachs and 2 contained only unidentifiable material. The average diet of the remaining 72 birds, on a percent estimated volume basis, was 68.5% mysids, 15.5% amphipods, and 12.1% bivalves (Table 1). Unidentifiable material comprised a much smaller portion of the stomach contents in 1978 (1.5%) than in 1977 (14.2%), because of the availability of completed reference collections and improved identification procedures in the second year of study.

Table 2 provides a comparison of the proportions of major taxa found in Oldsquaw stomachs as determined by precise measurements of wet weight, ash-free dry weight, energy content (kilocalories) and abundance (total individuals) as well as by the qualitative, modified Hynes Point method. The Hynes Point method proved to be a relatively accurate indicator of the proportions and importances of various major taxa of prey organisms consumed by Oldsquaws.

The main prey species were the mysids Mysis litoralis and M. relicta, the amphipod Onisimus glacialis, and the bivalves Portlandia arctica and Cyrtodaria kurriana (Table 3).

4.2. Prey Availability

Gear used for surface and mid-water collections in 1977 probably provided a reasonably accurate indicator of prey availability there, but epibenthic invertebrates of the types important to Oldsquaws were especially difficult to sample quantitatively. Methods used to sample such animals in 1978 were much improved over those used in 1977. These problems must be recognized when interpreting the data concerning food availability.

Few mysids or amphipods were collected from the surface waters of the lagoon (Figure 3). This evidence, plus our observations and published information (see Discussion) on the diving behaviour of Oldsquaws, indicated that Oldsquaws probably rarely feed in this layer. The predominant invertebrate taxa present in this layer during 1977 were, on an estimated percent of total volume basis, copepods (68.1%)

Table 1. Volumetric comparison of Oldsquaw diet in relation to composition of epibenthic samples from Simpson Lagoon, Alaska.

	1977			1978		
	Oldsquaw Diet (n=54; total points*=443)		Epibenthic Samples (n=18; total points=160)	Oldsquaw Diet (n=72; total points=422)		Epibenthic Samples (n=39; total points=166½)
Prey	% Total	% Total Identifiable	% Total	% Total	% Total Identifiable	% Total
Mysids	58.7	68.4	28.1 (42.5)†	68.5	69.5	48.9
Amphipods	14.2	16.6	27.5 (41.5)	15.5	15.7	36.6
Bivalves	8.1	9.5	1.9 (2.8)	12.1	12.3	7.1
Isopods	2.3	2.6	0	1.0	1.0	1.4
Fishes	2.3	2.6	0	0.2	0.2	0.3
Copepods	0.1	0.1	33.8 ------	0.2	0.2	0.5
Polychaetes	0	0	1.9 (2.8)	0.7	0.7	2.4
Euphausiids	0	0	0	0.2	0.2	0
Priapulids	0	0	0	0.1	0.1	1.1
Tunicates	0	0	0	0.1	0.1	0.6
Cnidarians	0	0	2.5 (3.8)	0	0	0.8
Pteropods	0	0	3.1 (4.7)	0	0	0
Ostracods	0	0	0.6 (0.9)	0	0	0
Foraminiferans	0	0	0.6 (0.9)	0	0	0
Sponges	0	0	0	0	0	0.1

...continued

Table 1. Continued.

	1977			1978		
	Oldsquaw Diet (n=54; total points*=443)		Epibenthic Sample (n=18; total points=160)	Oldsquaw Diet (n=72; total points=422)		Epibenthic Sample (n=39; total points=166½)
Prey	% Total	% Total Identifiable	% Total	% Total	% Total Identifiable	% Total
Chaetognaths	0	0	0	0	0	0.1
Cumaceans	0	0	0	0	0	0.1
Unidentifiable	14.2	----	0	1.5	-----	0
TOTAL	99.9	99.9	100.0	100.1	100.0	100.0

*See Griffiths et al. (1975) for a description of the points method for assessing the relative importance of food organisms.

†Recomputed percentages after omitting copepods, whose appearance in epibenthic samples may have been an artifact of the sampling equipment.

Table 2. Diet of Oldsquaws in Simpson Lagoon during 1978 as determined by various measures.

	Volume		Abundance		Wet Weight		Ash-free Dry Weight		Energy Content	
Prey	Points*	%	No.	%	g	%	g	%	kcal	%
Mysids	289	68.5	6464	75.0	155.1	77.4	17.9	69.7	97.5	69.8
Amphipods	65 ¼	15.5	1845	21.4	23.7	11.8	4.2	16.3	21.3	15.3
Bivalves	51 ¼	12.1	260	3.0	13.3	6.6	2.6	10.1	14.7	10.5
Other Taxa	16 ½	3.9	48	0.6	8.3	4.1	1.0	3.9	6.1	4.4
Total	422	100.0	8617	100.0	200.4	99.9	25.7	100.0	139.6	100.0

*See Griffiths et al. (1975) for a description of the points method for assessing the relative importance of food organisms. Points listed in this table are only those of identifiable taxa.

Table 3. Identifiable prey consumed by Oldsquaws in Simpson Lagoon.*

Prey	1977 Oldsquaws (n=54)	1978 Oldsquaws (n=72)
Mysis litoralis and *M. relicta*	67.6	79.7
Apherusa glacialis	< 0.1	-
Onisimus glacialis	8.0	10.4
Gammarus setosus	1.7	0.8
Parathemisto spp.	4.9	0.3
Pontoporeia affinis	-	0.1
Pontoporeia femorata	-	< 0.1
Gammaricanthus loricatus	1.2	0.7
Copepods	1.2	< 0.1
Isopods	2.7	0.9
Cumaceans	-	0.1
Euphausiids	-	0.1
Fishes	2.7	0.4
Bivalves	9.6	6.2
Polychaetes	-	< 0.1
Pteropods	-	-
Others	-	0.3
Total	99.7	100.3

*Presented as % composition (wet weight).

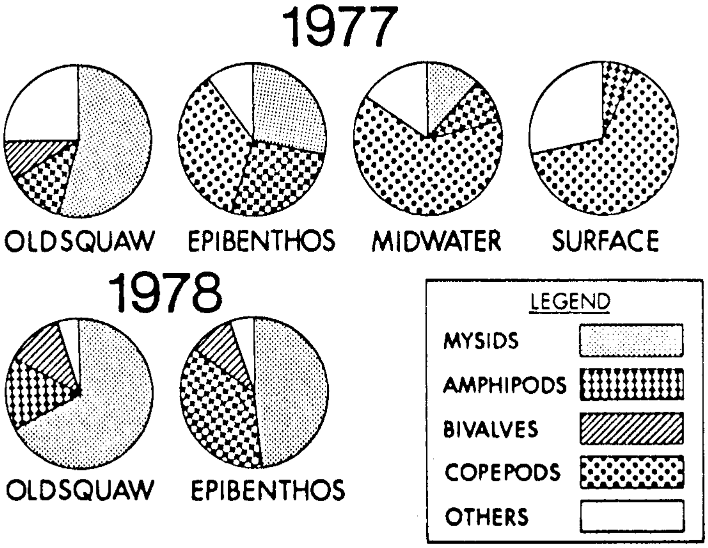

Figure 3. Volumetric composition of Oldsquaw diets and feeding habitat samples in Simpson Lagoon.

and cnidarians (16.7%). Most of the remainder of the organisms collected in this habitat were amphipods (5.7%) and chaetognaths (3.3%).

Copepods represented almost two-thirds (64.4%) of the total volume of invertebrate organisms present in the mid-water habitat samples (Figure 3); this proportion was similar to that found in the surface water samples. Mysids and amphipods comprised 11.7 and 9.4%, respectively, of the mid-water samples. Cnidarians, chaetognaths, and ctenophores represented a major proportion of the remainder of the mid-water samples during 1977.

Copepods, mysids, and amphipods comprised the major proportions (33.8, 28.1 and 27.5%, respectively) of the epibenthic samples collected during 1977 (Table 1). Observations by a SCUBA diver at several locations in Simpson Lagoon during 1977 and 1978, including a series of dives where flocks of Oldsquaws had been feeding, indicated that mysids and amphipods were the most conspicuous invertebrate organisms present in the epibenthos (Griffiths and Dillinger 1981). The relatively large volume of copepods in the "epibenthic" samples taken during 1977 was probably an artifact of the sampling equipment (0.25-m macroplankton net); they presumably were taken in the water column as the net sank and was retrieved.

Because both mysids and amphipods, the organisms that comprised the major proportions of the diet of Oldsquaws during 1977, were proportionately most abundant in the lagoon epibenthos, oldsquaws probably fed almost exclusively from this habitat rather than from either the surface or the mid-water layers where mysids and amphipods were relatively uncommon. The few copepods in the diet of Oldsquaws during 1977 may have been taken incidentally during the process of feeding on other epibenthic invertebrates (Table 1 and Figure 3).

Mysids and amphipods collectively represented 85.5% of the estimated volume of invertebrates in the 1978 epibenthos samples. Although the drop net sampling technique was not designed as an infaunal sampler, a notably larger proportion of the estimated volume of epibenthic samples consisted of bivalves in 1978 (7.1%) than in 1977 (1.9%). Differences in wet weights of bivalves in 1977 (9.6%) and 1978 (6.3%) were not as marked, however (Table 3). Perhaps because more effective sampling gear was used during 1978, the relative importance of copepods in the epibenthos was markedly lower in 1978 (0.5% of estimated volume) than in 1977 (33.8%).

4.3. Selectivity in Diet

The results from 1978, when more effective epibenthic sampling gear was used, show the close relationship between the relative volumes of major invertebrate taxa in Oldsquaw stomachs and in the epibenthic habitats (Table 1; Figure 3). Furthermore, the weights of invertebrates as a group and of mysids in particular in the stomach contents of individual Oldsquaws were positively and significantly correlated with the availability of these animals in the epibenthos at the place and time of collection (Figure 4). Diet was not totally parallel to food availability, however. In both 1977 and 1978 the relative proportions of mysids found in Oldsquaw stomachs were substantially greater than

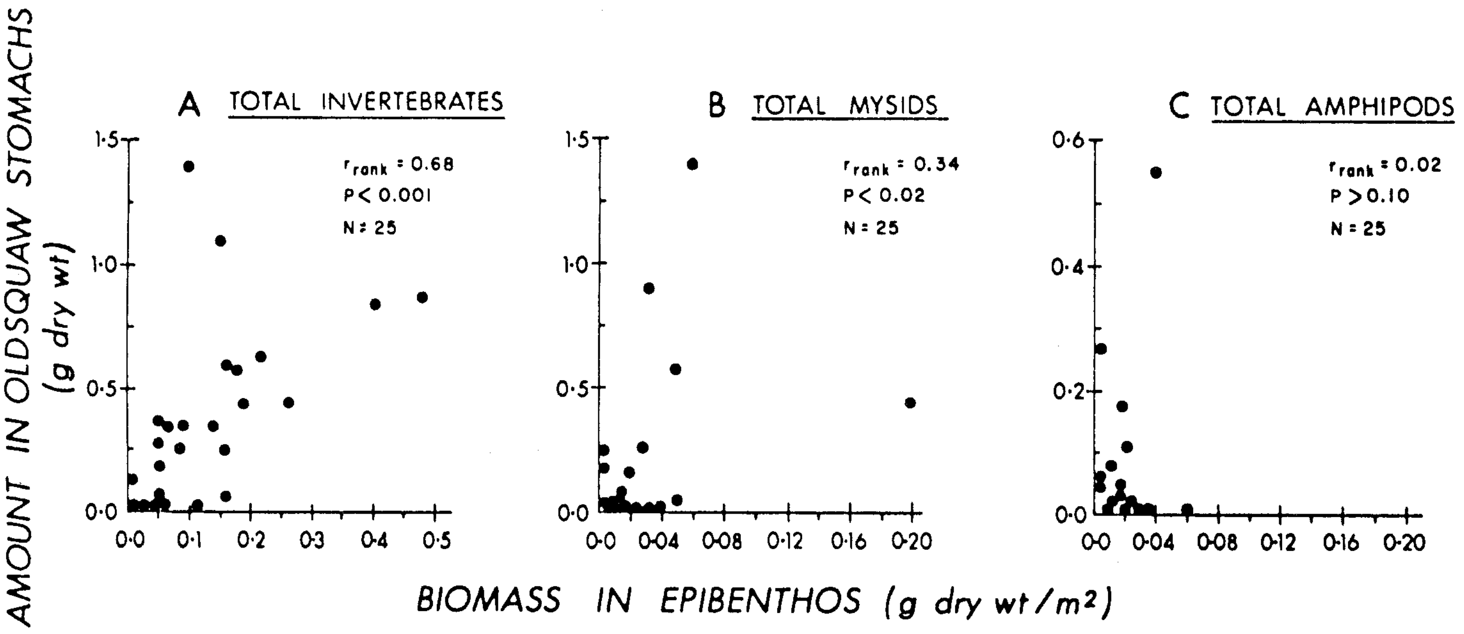

Figure 4. Relationship in Simpson Lagoon in 1978 between amount of prey in stomachs of feeding Oldsquaws and the biomass of prey in the epibenthos where feeding Oldsquaws were collected.

those found in feeding habitats (Table 1). The differences in 1977 between mysids in the diet and in the epibenthos remain substantial even if copepods are not considered in the epibenthos percentage computations.

In contrast to the mysids, the weights of amphipods in the stomachs in 1978 showed no positive nor signficant correlation with the availability of these animals in the epibenthos (Figure 3). During both 1977 and 1978, the proportions of amphipods in Oldsquaw stomachs were about half those found in feeding habitats (Table 1). Data from both 1977 and 1978 indicate that, on the basis of the total season diet, the average sizes of mysids and amphipods consumed by Oldsquaws were significantly larger than the average sizes of the same species found in the epibenthos (Table 4, Figure 5). Hence, in Simpson Lagoon, feeding Oldsquaws apparently tended to select larger individuals of at least the most common prey species, especially mysids, found in epibenthic feeding habitats. In 1978, this selection by Oldsquaws of the large size classes of invertebrates is most apparent during mid-July for all major prey consumed, and is less apparent later in the season, especially for *Mysis litoralis* (Table 5).

5. DISCUSSION

Oldsquaws in Simpson Lagoon, as at other locations, are largely opportunistic feeders -- they prey on those organisms most available to them. Hull (1914) and Ellarson (1956:215) recorded Oldsquaws feeding on

Table 4. Comparison of the sizes of the most important marine invertebrates taken from Oldsquaw stomachs and from the epibenthos in Simpson Lagoon.

Prey Species	Prey Length in Oldsquaw Stomach (mm)	Prey Length in Epibenthic Sample* (mm)	n	z[†]	p<
1977					
Mysis litoralis	13.28 ± 2.59[‡]	10.74 ± 3.42	20	1.97	0.06
Mysis relicta	12.72 ± 1.41	10.61 ± 1.51	20	2.91	0.01
Onisimus glacialis	5.64 ± 1.16	4.38 ± 1.68	20	2.35	0.03
1978					
Mysis litoralis	12.42 ± 2.21	8.92 ± 3.51	20	2.89	0.01
Mysis relicta	12.06 ± 1.94	8.83 ± 2.08	20	2.61	0.02
Onisimus glacialis	5.78 ± 0.96	4.24 ± 0.82	20	2.94	0.01

*Epibenthic samples were collected at the locations where birds were collected.

[†] Wilcoxon's matched-pairs tests.

[‡] Mean ± standard deviation.

Table 5. Comparisons of sizes of prey available and eaten by Oldsquaws in Simpson Lagoon during 1978.

Prey Species	Overlap Index* for Various Sampling Periods			
	Mid July n=8-14[†]	Early August n=5-12	Mid August n=5-13	Late August n=10-13
Mysis litoralis	0.12	0.90	0.82	0.83
Mysis relicta	0.21	0.64	0.85	0.71
Onisimus glacialis	0.37	0.65	0.75	0.82

*Morisita Overlap Index (Horn 1966).

[†] n = range in number of stomachs compared.

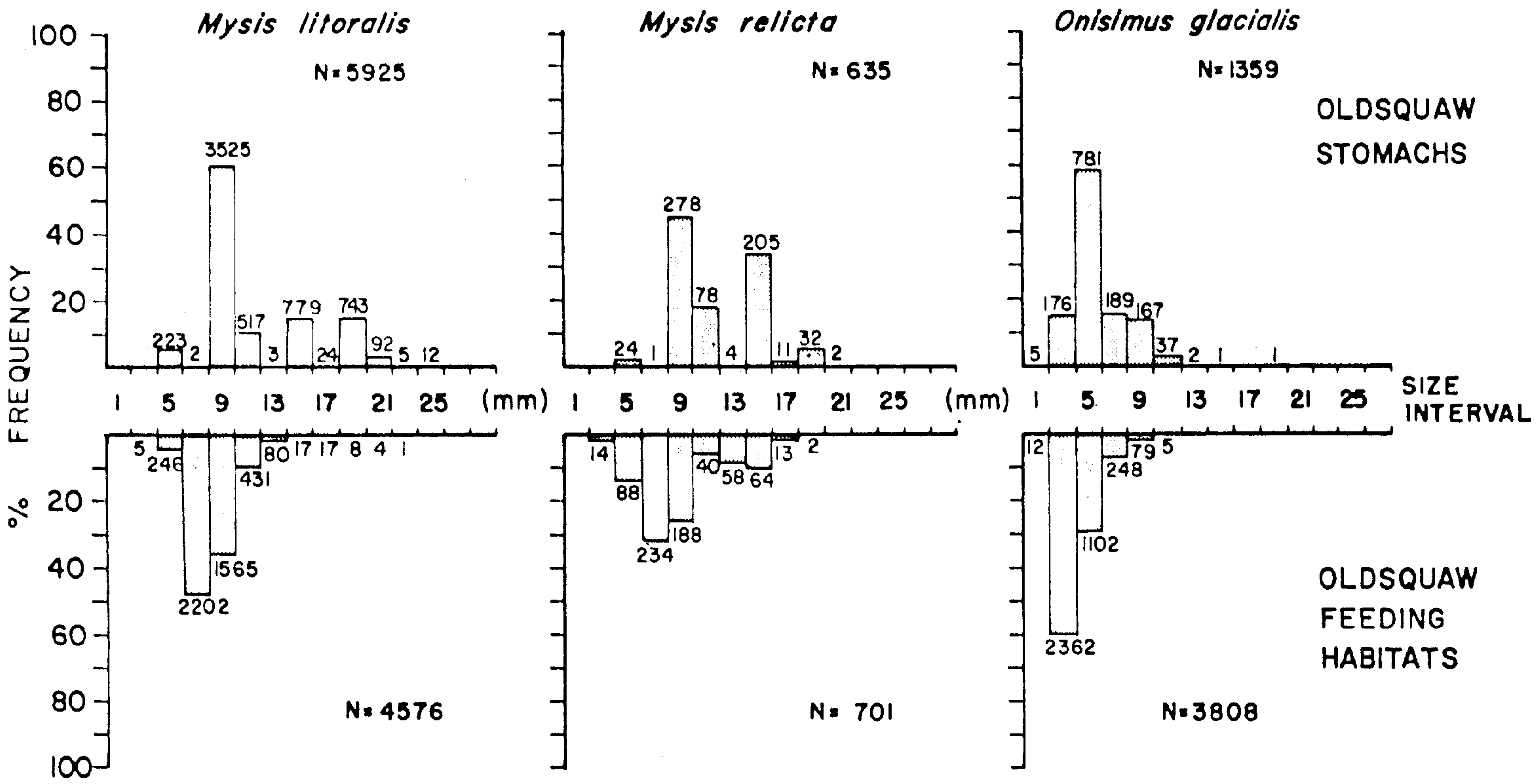

Figure 5. Distributions of sizes of prey in the stomachs of feeding Oldsquaws and in the epibenthos where feeding Oldsquaws were collected.

locally abundant minnows in Lake Michigan. Cottam (1939), Pehrsson (1974) and Bengtson (1971) showed that the abundant crustaceans comprise a major proportion of the diet of Oldsquaws in freshwater habitats. Lagler and Wienert (1948) reported crustaceans and molluscs to be important prey of Oldsquaws in Lake Michigan. In northern Sweden, Pehrsson (1973) found that both female oldsquaws with broods and other post-breeding Oldsquaws selected and were concentrated on lakes that supported high densities of euphyllopod crustaceans.

Gjosaeter and Saetre (1974) reported Oldsquaws and eiders feeding extensively on the eggs of capelin (Mallotus villosus) during the spawning season of this fish in the Barents Sea. Madsen (1954) found that bivalves comprised the major portion of the diet of Oldsquaws collected off the coast of Denmark, where those molluscs were very abundant in the marine waters.

The diets of Oldsquaws in coastal wintering areas in North America (Stott and Olson 1973, Vermeer and Levings 1977; Sanger and Jones 1981), as in Europe (Bagge et al. 1973; Nilsson 1972), show that Oldsquaws feed extensively on those organisms that are most abundant, primarily epibenthic crustaceans and molluscs.

In Simpson Lagoon, the principal prey of oldsquaws consisted of two species of mysids, six amphipods, two bivalves, several copepods, several isopods, and various fish. The two mysids and Onisimus glacialis are epibenthic-dwelling crustaceans. In Simpson Lagoon and many other lagoons along the Beaufort Sea coast these crustaceans are associated with a detrital suspension several centimetres thick on the lagoon bottom (Griffiths and Dillinger 1981). In Lake Michigan, Peterson and Ellarson (1977) found the primary prey to be a single species of epibenthic amphipod (*Pontoporeia affinis*; 82% of winter diet). Furthermore, they found that Oldsquaws concentrated to feed in the same areas where *Pontoporeia affinis* reached maximum density.

Data from Schell (1980) indicate that the detritus on lagoon bottoms is derived from several sources, primarily coastal erosion and river runoff, and that it directly provides only a small portion of the energy (carbon) necessary to support the marine benthic community. The majority of the primary production supporting coastal lagoon ecosystems is of marine origin (Schell 1980).

The relationship between Oldsquaws and their benthic prey in portions of Lake Michigan is remarkably similar to that in Simpson Lagoon. Field experiments in Lake Michigan by Marzolf (1962, in Peterson and Ellarson 1977) indicated that a thin detrital film (less than 5 mm) was generally present on the bottom of the lake, and his laboratory experiments suggested that *Pontoporeia* densities were positively correlated with the density of bacteria in this organic matter. Although Schell (1980) found no such relationship between the common invertebrates (e.g., mysids and *Onisimus*) living in Simpson Lagoon and peat-associated bacteria, further study of other types of detritus and bacteria may show a relationship in Simpson Lagoon similar to that described by Marzolf (1962) in Lake Michigan.

The standing stock of benthic infauna (bivalves, polychaetes, cumaceans, tunicates and other organisms) in Simpson Lagoon substrates is at least as high as that of the mobile epibenthos (2.2 g versus 0.1-2.5 g ash-free dry wt/m^2; Griffiths and Dillinger 1981). Nevertheless, only 10% of the diet of Oldsquaws in Simpson Lagoon was composed of bivalves (primarily *Cyrtodaria kurriana* and, to a lesser extent, *Portlandia arctica*), cumaceans and polychaetes (Table 3). Some of these organisms may have been available in the epibenthos (H. Feder, Univ. of Alaska, pers. comm. 1981), so the percentages of the diet represented by infaunal organisms may have been even lower than 10%.

Similarly in Milwaukee Harbor infaunal organisms (Tubificidae) were also very abundant (up to 335,000/m^2; Rofritz 1972:56) but during some months were absent from the diet of Oldsquaws. These organisms may have been in burrows in the sand and silt substrates and therefore may have been largely inaccessible to the ducks. In contrast, Rofritz (1977) found that during winter in Milwaukee Harbor, Oldsquaws fed almost exclusively on oligochaetes, even though molluscs and crustaceans were also present in the benthos where Oldsquaws were feeding. He suggested that Oldsquaws in Milwaukee Harbor may have selected oligochaetes as food during winter because of their significantly higher caloric value per gram of body weight than other benthic fauna present.

Our results suggest that oldsquaws select the larger mysids and amphipods, and prey most effectively in areas where the density and biomass of food is high (Figures 4 and 5). Griffiths and Dillinger (1981) in systematic samples at shallow and deep stations in Simpson Lagoon that were established independently of the presence or absence of Oldsquaws, showed that the density of invertebrates was not homogeneous.

They found that densities of both mysids and amphipods were significantly greater than elsewhere at their deep ($\bar{x}$ = 2.5 m) lagoon sampling stations in the central trough near the middle of Simpson Lagoon. Average depths where Oldsquaws were feeding and were collected in Simpson Lagoon during both 1977 and 1978 ranged from 2 to 3 m, i.e., in the area where densities of lagoon invertebrates were highest.

We have not investigated rates of predation by Oldsquaws. This aspect of the functional feeding response is an important one because it no doubt would be affected by changes in the density of invertebrates. If dramatic reductions in invertebrate density should occur (see Cabioch 1980; Berne et al. 1980), Oldsquaws and other organisms dependent on invertebrates for food may be forced to: (1) move to a more suitable area; or (2) increase their searching time, thus becoming less efficient. We know little of the local movements of flocks of Oldsquaws. Turnover rates of individuals within flocks or of flocks within a lagoon system are not well understood.

Nilsson (1970) indicated that oldsquaws he observed wintering along the coast of South Sweden during 1964-1967 spent approximately 79% of daylight hours diving and that the rate of feeding increased as the ambient temperatures along the coast decreased. Thus, Oldsquaws are capable of functional changes in their feeding behaviour in response to some types of natural perturbations. It remains to be seen, however, whether these seaducks can adapt to the increased disturbance and development-related alterations of their lagoon habitats along the Beaufort Sea coast of Alaska.

6. ACKNOWLEDGEMENTS

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CONTINUING INVESTIGATIONS OF OLDSQUAWS (CLANGULA HYEMALIS L.) DURING THE MOLT PERIOD IN THE ALASKAN BEAUFORT SEA

by

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Final Report
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INTRODUCTION

Tundra regions along the central Beaufort Sea coast of Alaska have been rapidly developed for oil and gas over the past decade; exploration and drilling in adjacent nearshore waters have recently begun and no doubt will follow a similar pattern of rapid development. Scientific investigations of broad scale biological and physical processes have also been carried out along this portion of the coast of Alaska, and much new information has been reported (OCSEAP 1978, 1979, SAI 1980, Norton and Sackinger 1981). Several reports have documented the importance of Beaufort Sea barrier island-lagoon systems to large numbers of fishes and birds and their invertebrate prey resources (Craig and Haldorson 1981, Johnson and Richardson 1981, Griffiths and Dillinger 1981).

This report presents the results of research conducted in 1980 and 1981; these results supplement information presented by Johnson and Richardson (1981) concerning the oldsquaw duck (*Clangula hyemalis*), one of the dominant and most visible vertebrate species using barrier island-lagoon habitats along the Beaufort coast during the open water period. Some attention also has been given in this report to several other species of marine birds. Prior to the initiation of our 1980 field program, emphasis was placed on studies in and near the Beaufort Lease Sale 71 area, including the area near Harrison Bay. Consequently, investigations that we had proposed to conduct in the Flaxman Island-Leffingwell lagoon region were redirected to Harrison Bay, near the Lease Sale 71 area. Thetis Island was chosen as the focal point for our investigations in 1980 because (1) an all-weather shelter (small cabin) was available on the island, (2) it was in Harrison Bay and close to Lease Sale 71, (3) it was known (Johnson and Richardson 1981) to support several thousand oldsquaws during the molt period, and (4) because of its presumed isolation from man-made disturbances. This last characteristic was important because of our need to make detailed observations of normal oldsquaw behavior, distribution and movements in a relatively undisturbed barrier island environment.

The major objectives of our field programs were the following:

1) Conduct the fourth (1980) and fifth (1981) annual aerial surveys of molting oldsquaw habitat along 22 coastal transects from the Colville Delta eastward toward the Alaska-Canada border during the peak of the oldsquaw molt period (early August). These surveys provide useful comparative information on the numbers of oldsquaws and other birds using specific coastal locations and habitats over a broad area of the Alaskan Beaufort.
2) Conduct a census of the birds nesting on Thetis Island. On the basis of limited data (Divoky 1978, Johnson and Richardson 1981), Thetis Island has been classified as one of the three or four most productive bird nesting islands along the Alaskan Beaufort coast. Since this island lies close to the Lease Sale 71 area, it was important to conduct another census of the island during 1980.
3) Collect and prepare a series of reference specimens of male oldsquaws during the peak of their molt period. Few museums in North America have specimens of oldsquaws during summer molt plumage. This material provides important documentation of the timing of flightlessness and condition of the birds during the molt period in this part of Alaska.

4) Initiate a study of habitat use and behavior of oldsquaws during their molt period. Several important questions concerning oldsquaws remained unanswered throughout our work with this species in Simpson Lagoon (Johnson and Richardson 1981). Of particular concern were questions relating to the normal patterns of distribution and abundance during the period of molt when they are flightless and therefore thought to be most vulnerable to disturbance and to water borne contaminants. Until presently, it has been unknown whether the large concentrations of flightless male oldsquaws, documented to occur in the barrier island-lagoon complexes (Spindler 1979, Johnson and Richardson 1981), move from one lagoon to the next during the molt period (i.e., whether there is a turnover of birds within a concentration or flock at a particular location) or whether the birds are relatively sedentary and do not make use of adjacent lagoons for feeding, resting, etc. during the molt period. An understanding of the patterns of oldsquaw behavior and habitat use is important to ensure their proper management. These important questions relate directly to the fate of oldsquaws as various barrier island-lagoon habitats are altered during industrial development.

STUDY AREA

Thetis Island (70°33'N, 150°10'W; Figure 1) is the most westerly of the Jones Island group and is the only barrier island in Harrison Bay. It lies about 14 km N of the Colville River delta, and about 7 km W of Simpson Lagoon. The island is approximately 5 km long by 0.5 km wide and is comprised almost exclusively of sand and gravel, however, there are patches of *Puccinellia* sp., and sparse clumps of *Arenaria* sp. and *Mertensia* sp. at several locations on the islands. It lies downstream of the E to W nearshore flow of marine and brackish water that moves through Simpson Lagoon; it is oriented in a SE to NW direction, perpendicular to prevailing northeasterly winds.

Driftwood from both the Mackenzie River in Canada and from the nearby Colville River is littered across much of the approximately 3 km^2 surface of the island. One particularly large accumulation of driftwood at the center of the island supports a dense concentration of nesting common eiders (*Somateria mollissima v-nigra*). About 4-8 pairs of brant (*Branta bernicla nigricans*) nest and rear their broods in association with the sparse growth of *Puccinellia* sp., and 8-10 pairs of glaucous gulls (*Larus hyperboreus*) and 3-6 pairs of arctic terns (*Sterna paradisaea*) nest along the length of the island. Thetis Island supports several hundred pre-migratory staging juvenile red and northern phalaropes (*Phalaropus fulicarius* and *Lobipes lobatus*, respectively) during August and also provides shelter for thousands of oldsquaws during mid-July to mid-August, the male molt period.

Flocks of oldsquaws are normally distributed along the leeward (SW) side of the island; most birds are concentrated in the embayments

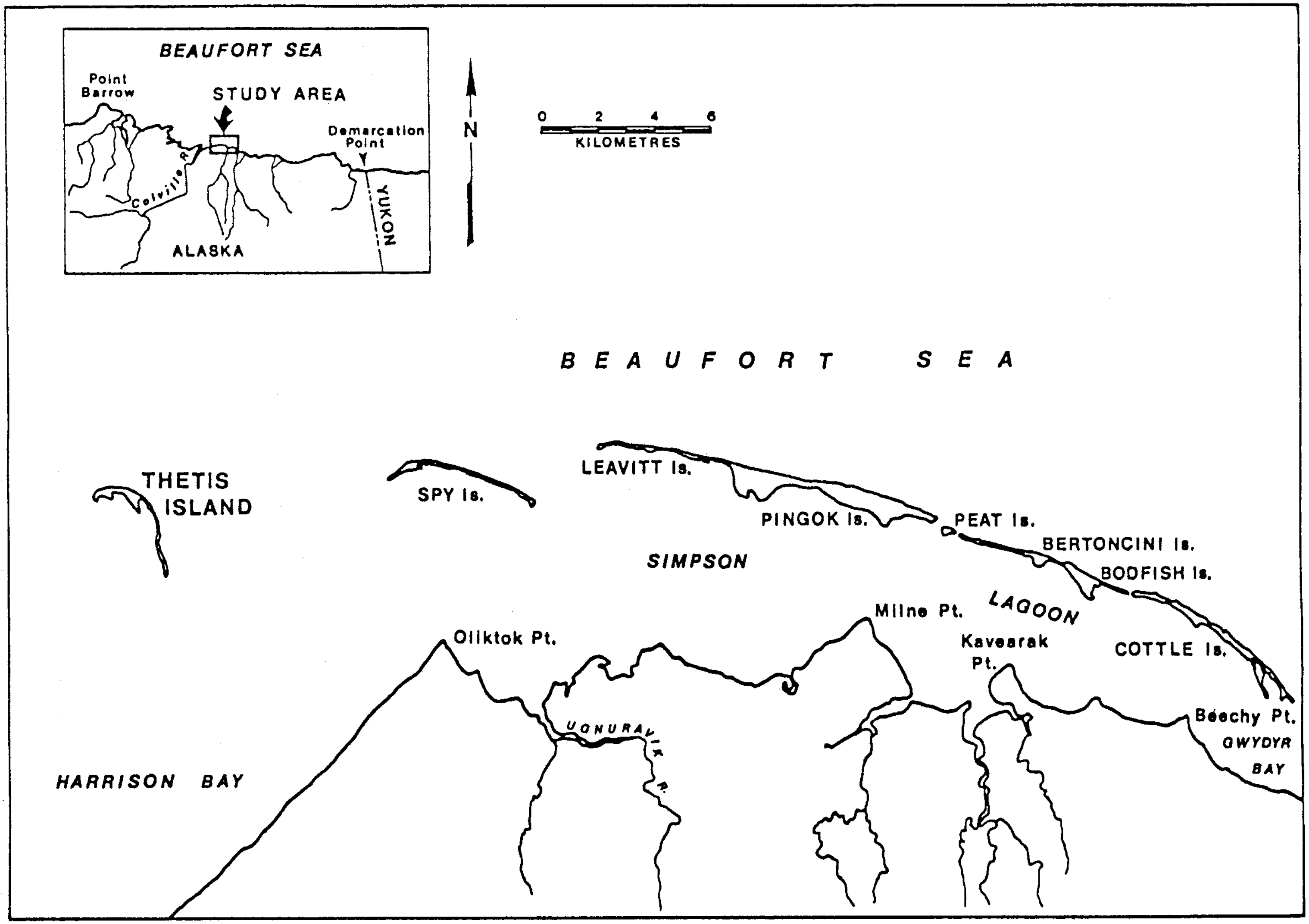

Figure 1. Location of Thetis Island, Alaska.

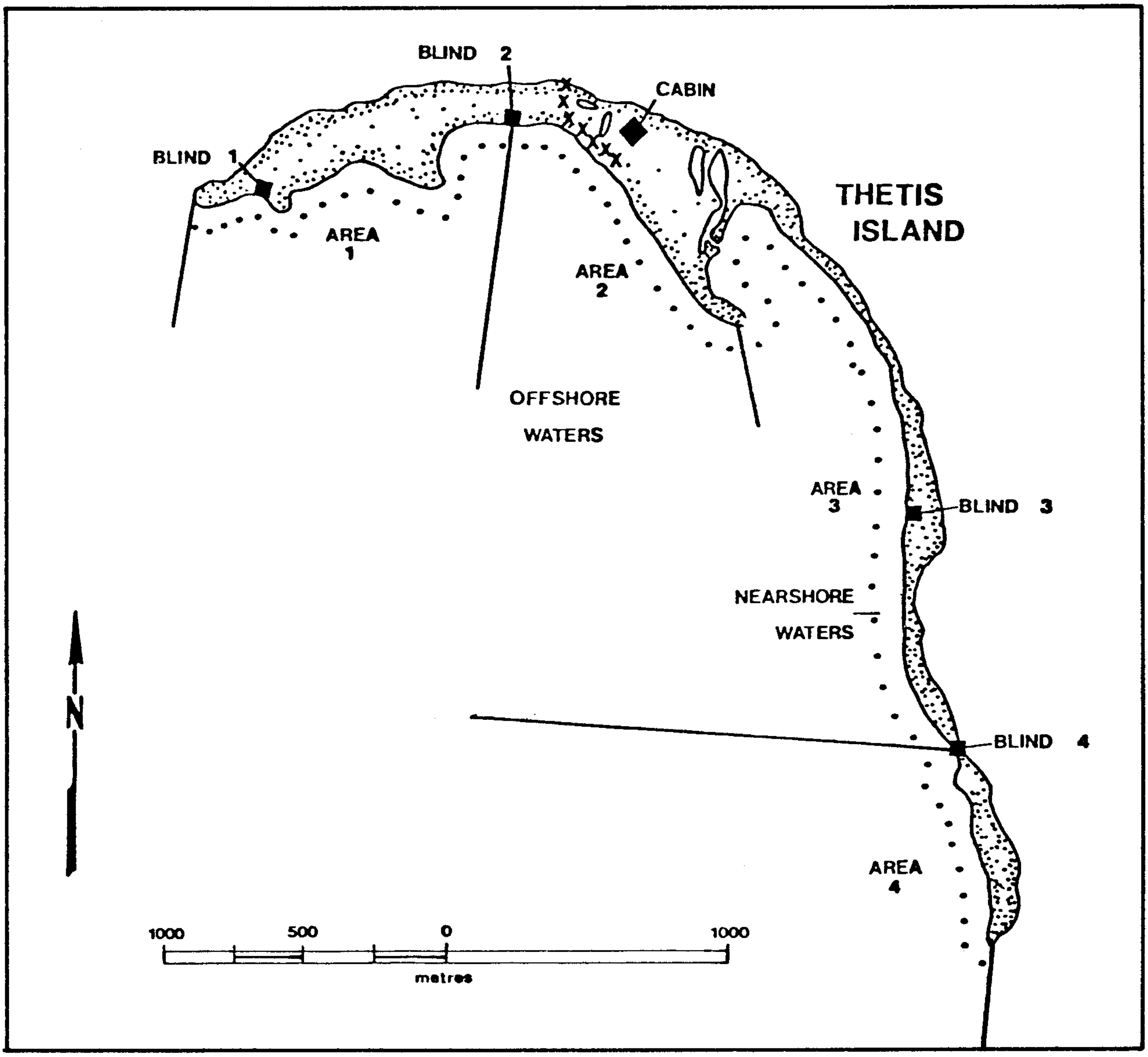

Figure 2. Thetis Island, Alaska, with locations of observation blinds and subdivision of the leeward waters. Nearshore waters were <100 m from the shoreline. X's denote an area of driftwood very important to nesting birds.

at the NW end (Area 2) and along the southern end of the island in Area 4. Figure 2 shows our subdivisions of the leeward waters and the locations of our four observation blinds used in 1980.

METHODS

Aerial Surveys

Aerial surveys were conducted on 2 August 1980 and 1981, using identical procedures and along identical routes described by Johnson and Richardson (1981) for aerial surveys conducted in 1978 and 1979. During 1980, transects 15 and 16 and small portions of transects 14 and 17 were not surveyed because of dense fog and poor visibility encountered near the west end of Arey Island. The area east of Arey Island, as far as the Alaska-Canada border was surveyed by USFWS personnel on 1-3 August 1980 (Spindler 1981). The 1981 aerial surveys included the Beaufort coast from Atigaru Pt. in the west to Brownlow Pt. in the east.

Nesting Bird Census

The census of birds nesting on Thetis Island generally followed procedures used by us in 1978 (see Johnson and Richardson 1981). On 21 July 1980, four individuals slowly walked from NW to SE along the island, recording all potentially nesting birds, all nest scrapes, all active (eggs present) nests and all apparently destroyed nests. Clutch sizes were recorded only if the nest was unattended. The approximate location of each nest or concentration of nests was sketched on a map and obvious habitat relationships were recorded (nest near driftwood, old oil drums, etc.). Special care was taken not to flush female common eiders from their nests.

Oldsquaw Collections

Oldsquaws were collected near Thetis Island between 27 July and 9 August 1980. One bird was salvaged from a gill net set about 600 m SE of the cabin on Thetis Island, and a small sample were collected while feeding among ice chunks (brash) 75 m N of the cabin and the rest were collected from flocks of molting males concentrated along the south end of the island. Birds collected along the south end were approached from a speeding boat and were shot as they moved from loafing areas on and near the leeward beach. Aside from the birds collected while feeding among brash N of the island, no attempt was made to determine if birds were feeding prior to their collection. However, stomachs (and gonads) of all birds were inspected and preserved for later analysis.

Oldsquaw Behavior

Four burlap observation blinds were erected at locations (see Figure 2) where major concentrations of oldsquaws were observed during the nesting bird census on 21 July. Each blind was 4-sided with no roof and was slit on each side for placement of a variable power (20-45x) spotting scope. Blinds of this type were not weatherproof and were used until 27 July when below freezing and wet weather forced us to use a weather-proof tent. The tent limited our visibility to 180° (leeward direction only) and was used continuously until our intensive observations terminated on 5 August.

Continuous but preliminary observations of flocks of oldsquaws were initiated at 2200 ADT on 21 July 1980 at Blind 4, near the south end of Thetis Island. These preliminary observations were discontinued after

48 h in order for the three observers to discuss problems and to standardize observation and recording procedures. Continuous observations were reinitiated at Blind 4 at 2200 ADT on 24 July and continued there for another 48 h after which all observations were made from Blind 2 (see Figure 2).

The four prescribed areas of observation are shown on Figure 2. Some important initial observations of oldsquaw movements were made from Blind 4, but the majority of all the intensive observations were of Areas 2 and 1 from Blind 2. The largest concentration of oldsquaws near the north end of the island was in Area 2 and that portion of Area 1 in the bay adjacent to Blind 2. Most of our observations and almost all of our results relate to our intensive observations made in these two areas from 2200 h on 26 July (hour 120 of the study) to 2200 h on 5 August (hour 360 of the study).

Each of the 4 areas were further subdivided into 4 habitats: beach, interface, nearshore and offshore. Beach habitat included the area above waterline to the limits of the area washed by storm surfs. The beach slope extended about 10 m from the water line at high tide and about 12 m from the water line at low tide.

Interface habitat consisted of an area that extended approximately 0.15 m (6") either side of the waterline. This habitat initially was thought to be important because birds often stopped at the interface when leaving or entering the water. We later pooled birds in interface habitat with those in beach habitat; all analyses of birds using beach habitat include those in interface habitat.

Nearshore habitat includes the area from waterline out to 100 m. The limits of this area were standardized by using local landmarks, but along portions of the area it was necessary to estimate the 100 m distance.

Offshore habitats were those greater than 100 m from shore. Birds often moved beyond the limits of visibility in this habitat, depending on the presence of fog, rough water, disturbances or other factors.

A typical day of observations involved three individuals, each conducting hourly counts and classifications during one of the following three periods: 2201-0600, 0601-1400, 1401-2200. At the beginning of each hour, a census was conducted of all birds within each habitat in a prescribed area. The behavior of oldsquaws was recorded in each habitat. If the total number of birds present in beach or nearshore habitats did not exceed approximately 150 birds, the behavior of each bird was recorded; if the total number exceeded 150 birds, the behavior of 5 subsamples of 25-30 birds each was recorded. In offshore habitats, behavior was based on observations of 25-30 individual oldsquaws. We seldom observed birds longer than 30 seconds before assigning a behavior code. Birds that were diving were considered to be feeding. Those floating idly on the water, those sitting or standing on the beach or those apparently sleeping were considered to be resting. Birds making deliberate directional movements either in the water or on the beach were considered to be travelling or moving and birds manipulating or cleaning their plumage or bathing were considered to be preening. All disturbances that were natural (predators, autopanics) and man-caused (aircraft, boat, human presence) were recorded when they occurred; the reactions of oldsquaws to these disturbances were also recorded.

Aside from habitat and behavioral classifications, the distance from the observation blind to the closest bird in a particular habitat was recorded; we used this measurement as a subjective index of the possible effects on the birds of the blind and movements of the observer and spotting scope. As often as possible, observers recorded the total number of females or the proportion of females in each subsample in each habitat.

The total number of oldsquaws present seaward (N) of Thetis Island were counted when it was possible (from Blind 4 only). However, other than during the observations from 21 through 26 July, no systematic information was recorded concerning oldsquaw behavior seaward (N) of Thetis Island.

For seven of the total 19 days of observations on Thetis Island, total counts of oldsquaws visible both seaward and leeward of the island were recorded after morning and evening watch periods (after 0600 h and after 2200 h ADT, respectively). On 10 additional days, only the morning (∿0600 h) or the evening (∿2200 h) count was conducted.

Prior to their watch, or in the event of a noticeable change in the weather, each observer recorded the ambient temperature, wind direction and speed, percent cloud cover, wave height, precipitation (fog, rain or snow), visibility and percent ice cover seaward (N) and leeward (S) of the island.

On an opportunistic basis throughout the study period, individual feeding oldsquaws were watched and the duration of dives and recovery periods on the surface were recorded in various habitats. Also, in order to more closely examine the relationship between wind direction and speed, wave height and oldsquaw distribution, wind speeds and directions at 22 locations along both the N and S sides of the island were measured under varying weather conditions. Wind direction was measured with a compass, wind speed (mi/hr) was measured at 2 m and 0.2 m heights above the beach/water interface with a Dwyer hand-held wind meter; wave height (ft) at the waterline was estimated.

Analysis Procedures

Throughout this report, analysis procedures involved simple parametric and nonparametric statistical comparisons (Siegel 1956, Sokal and Rohlf 1969). Methods and descriptions of the autocorrelation procedures that were used in the analysis of the oldsquaw behavior time series are described in Davis (1973), Kendall (1973), and Miller and Kahn (1962); Sokal and Oden (1978a, b) also give a good discussion of autocorrelation procedures.

RESULTS AND DISCUSSION

Aerial Surveys of Molting Oldsquaws

A total of 42,195 oldsquaws were recorded along 314.4 km^2 of coastal habitat between Atigaru Pt. and Arey Island on 2 August 1980. On 2 August 1981, a total of 16,493 oldsquaws were seen along 256.5 km^2 of coastal habitat between Atigaru Pt. and Brownlow Pt. Areas where major concentrations of oldsquaws were recorded are given in Table 1 and Appendix 1. Appendix 2 gives the total numbers of oldsquaws seen on- and off-transect during the 2 August 1980 and 2 August 1981 aerial surveys.

A summary of results of aerial surveys during the peak of the old-squaw molt in 1978, 1979, 1980 and 1981 is given in Table 2. During all four years, but especially in 1980 and 1981, the density of oldsquaws in Harrison Bay was one order of magnitude less than in either Simpson Lagoon or in areas east of Simpson Lagoon, and in each year the density of oldsquaws in Simpson Lagoon was higher than in areas east or west of there. Simpson Lagoon, Gwydyr Bay and Leffingwell Lagoon continue to support the largest numbers of molting oldsquaws along the central Alaskan Beaufort coast. Detailed information on the distribution of oldsquaws in Simpson Lagoon on 2 August 1980 and 1981 is given in Appendices 3 and 4. Results of aerial surveys in Simpson Lagoon in 1980 and 1981 were similar to those given by Johnson and Richardson (1981) for the three preceding years (Appendix 3).

The number of birds recorded on- and off-transect on all transects was markedly lower in 1981 than during the preceding years, especially

Table 1. Locations of major oldsquaw concentrations recorded in 1980 and 1981 during the period of summer molt in areas west* and east** of Simpson Lagoon, Alaska.

2 August 1980	# of Oldsquaws
Barrier Island Locations	
S Thetis Island	3883
S of W end of Long Island	4343
S of E end of Long Island	2505
S of Challenge Island	1500
S of W end Flaxman Island	1800
S of E end Flaxman Island	1882
Mid Lagoon Locations	
Canning Lagoon	1070
Prudhoe Bay	997
N Tigvariak Island	1610
Camden Bay	2145
Mainland Shoreline Locations	
W of Anderson Point	2603
E of Konganevik Point	1120
2 August 1981†	
Barrier Island Locations	
S Thetis Island	1482
SE Spy Island	1811
SE Pingok Island	1031
S Jeanette Island	1050
S Flaxman Island	3203

*Surveys W of Simpson Lagoon in 1980 and 1981 extended to Atigaru Pt., on the west side of Harrison Bay.

**Surveys E of Simpson Lagoon in 1980 extended to Arey Island, approximately 30 km W of Kaktovik.

†Surveys E of Simpson Lagoon in 1981 extended beyond the U.S. Canada border, but data in this table are only for coastal habitats as far E as Brownlow Pt.

Table 2. Densities of oldsquaws recorded during the peak of the summer molt in Harrison Bay compared with Simpson Lagoon and areas east of Simpson Lagoon, 1978-1981.

	5-6 August 1978	28 July 1979	2 August 1980	2 August 1981	All Years ($\bar{x}$ ± 1 s.d.)*
Harrison Bay					
km^2 surveyed	65.5	65.5	65.5	65.5	65.5 ± 0
oldsquaws/km^2	27.7	45.1	36.4	12.7	30.5 ± 13.8
Simpson Lagoon					
km^2 surveyed	39.9	39.9	39.9	39.9	39.9 ± 0
oldsquaws/km^2	142.6	247.8	355.3	155.8	225.4 ± 98.5
E of Simpson Lagoon					
km^2 surveyed	315.1	222.3	197.1	151.1	221.4 ± 69.1
oldsquaws/km^2	103.7	219.2	142.4	57.2	130.6 ± 68.5

*Unweighted mean for all four years.

in the area E and W of Simpson Lagoon. However, even in Simpson Lagoon the number of birds recorded during 1981 was lower than the preceding two years (1979 and 1980) and only slightly higher than in 1978.

Thetis Island Nest Census

A total of 52 active nests, 181 inactive nests or scrapes and 5 destroyed nests were recorded on Thetis Island during the nest census in 1980 (Table 3). The majority of all nests or scrapes found were of common eiders, with far fewer black brant, glaucous gulls and arctic terns. Thirty-six of the 52 active nests and 124 of the 176 scrapes or inactive nests of common eiders were found on the west half of the island (N of the cabin), and a significant proportion of the 41 active common eider nests (13 nests; 31%) were found in the dense pile of driftwood immediately W of the cabin (Figure 2).

Very few nests (5) were positively recorded as having been destroyed and the majority (4) of those were nests of common eiders abandoned by incubating females because of disturbance by humans.

The total number of active nests and the number of common eider nests on Thetis Island has remained relatively constant during 1976, 1978 and 1980 (Table 4) and is relatively high compared with the total number nesting on other barrier islands in the Alaskan Beaufort Sea (see OCSEAP 1978). In fact, after Cross and Pole islands, Thetis Island supports the third largest number of nesting common eiders along the Alaskan Beaufort coast.

Table 3. Total number of nests found on Thetis Island, Beaufort Sea, Alaska, during 1980.

	# Active Nests	# Nest Scrapes or Inactive Nests	# Destroyed Nests
Common Eider	41	176	4
Arctic Tern	1	0	0
Glaucous Gull	5	5	1
Black Brant	5	0	0
Total	52	181	5

Table 4. A comparison of the numbers of nests found on Thetis Island, Alaska, in 1976, 1978 and 1980. (Data for 1976 provided by James W. Helmericks.)

	# Active Nests	# Inactive Nests or Nest Scrapes*	# Destroyed Nests
Common Eider			
1976	38	-	-
1978	34	198	0
1980	41	176	4
Arctic Tern			
1976	1	-	-
1978	2	8	-
1980	1	0	-
Glaucous Gull			
1976	4	-	-
1978	5	4	0
1980	5	5	1
Black Brant			
1976	3	-	-
1978	9	1	0
1980	5	0	0
Total			
1976	46	-	-
1978	50	211	0
1980	52	181	5

*Nest scrapes are depressions in the sand or gravel and designate an early stage of nest establishment.

Oldsquaw Collections

We collected 26 oldsquaws near Thetis Island between 27 July and 9 August 1980. Nine (8 males; 1 female) were collected on 27 July, 8 (3 males; 5 females) during 3-5 August and 9 (5 males; 4 females) during 7-9 August. Although the main objective in making this collection was to provide documentation of molt classification, other information was recorded also. Whole body weights, length of the right wing and right tarsus, subcutaneous fat thickness and gonad size for the three collection periods are given in Table 5; Appendix 5 gives details for each bird. Even though body weights of males tended to be greatest during the 3-5 August period, they were not significantly different from those during the other two periods. Female oldsquaw body weights remained about the same during the latter two collection periods; only one very light-weight bird was collected during the first period. Lengths of right wings of male oldsquaws tended to increase (regrowth of primaries) throughout the 27 July to 9 August collection period while those of females tended to decrease (loss of primaries); none of these differences were statistically significant ($p > 0.05$). Subcutaneous fat thickness in male oldsquaws tended to be greatest during the mid (3-5 August) period but this tendency was not significantly different from the early or late collection period ($p > 0.05$). In general, too few birds were collected over too short a time period to provide detailed information for comparison of this sample of oldsquaws with much larger samples collected in earlier years (see Johnson and Richardson 1981).

Table 5. Summary of weights and measurements of oldsquaws collected during the peak of the male molt period at Thetis Island, Alaska, 1980.*

	27 July ($\bar{x}$ ± s.d.)	N	3-5 August ($\bar{x}$ ± s.d.)	N	7-9 August ($\bar{x}$ ± s.d.)	N
Weight (gms)						
M	832.9 ± 65.9	8	883.3 ± 60.1	3	843.0 ± 70.9	5
F	590	1	711.0 ± 46.0	5	716.8 ± 60.5	4
Rt. Wing (mm)						
M	127.8 ± 20.5	8	134.7 ± 15.2	3	166.4 ± 34.2	5
F	192	1	181.6 ± 45.5	5	157.5 ± 63.7	4
Rt. Tarsus (mm)						
M	45.3 ± 1.3	7	46, 46	2	42.4 ± 0.5	5
F	43	1	42.4 ± 1.3	5	40.7 ± 1.6	3
Sub Q Fat Thickness (mm)						
M	4.3 ± 1.8	7	4.9 ± 1.3	3	3.6 ± 1.3	5
F	3.5	1	3.5 ± 1.3	5	2.7 ± 1.2	4
Gonads (mm)**						
M Rt.	9.9 ± 1.9 x 4.7 ± 1	7	11.3 ± 1.5 x 5.3 ± 0.6	3	10.2 ± 1.9 x 3.8 ± 0.8	5
L.	10.1 ± 2.0 x 4.6 ± 1.1	7	13.0 ± 0 x 5.7 ± 0.6	3	10.8 ± 0.4 4.6 ± 2.2	5
F	1.5	1	1.9 ± 0.6	5	2.0 ± 0.1	4

*Appendix Table gives individual weights and measurement of all oldsquaws collected.

**Measurements of testes are length x width; measurements of ova are largest dimension of largest ovum.

Because little time was available to determine if birds were feeding prior to their collection, they were collected arbitrarily and few had significant amounts of food in their stomachs (Appendix 6). The 2 birds observed to be feeding N of Thetis Island prior to their collection on 7 August 1980, had stomachs of fullness 8 and 9 (about half full, see Johnson and Richardson 1981 for procedures). These birds were both males and had consumed relatively large amounts of the amphipod *Apherusa* sp. Another bird with a relatively full stomach was a male collected on 5 August 1980 whose stomach was about half full of a mixture of *Mysis* sp. and *Onisimus* sp.

Mysis relicta and *M. littoralis* and *Onisimus glacialis* were the most common prey consumed by oldsquaws farther east, in Simpson Lagoon (Johnson 1982), similarly *Apherusa* was taken from the stomachs of a small sample of oldsquaws collected while feeding among ice flows north of Pingok Island (~12 km NE of Thetis Island) during August 1978 (Johnson 1978, Griffiths and Craig 1978:53).

Oldsquaw Behavior

Movements

One of the major objectives of this program of near continuous oldsquaw observations was to determine if molting birds move between major molting locations (e.g., move between barrier islands). On two occasions when exceptionally calm weather prevailed (on 23 and 24 July; see Figure 3 and Appendix 7) two groups of oldsquaws were watched with a telescope as they swam eastward from the SE tip of Thetis Island (Area 4) at least 5 km toward Oliktok Pt. (Figure 1). They were

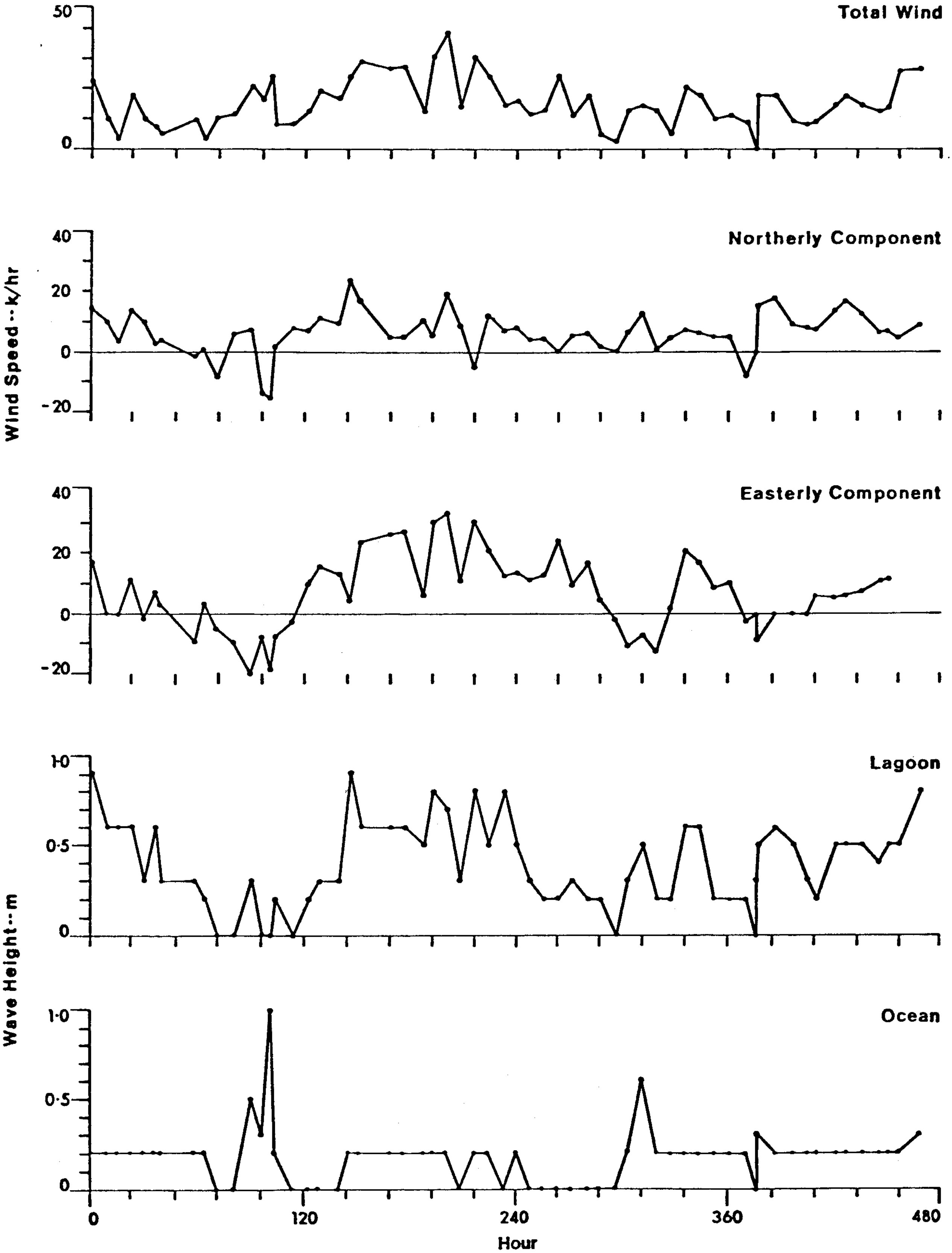

Figure 3. Relationship between wind speed and direction (component) and wave height adjacent to oceanside beaches (generally windward) and lagoonside beaches (generally leeward) along Thetis Island, Alaska.

eventually lost in the surface haze and myriad of other oldsquaws. Oliktok Pt. is also a major molting area for several thousand oldsquaws (Johnson and Richardson 1981:250). In total, about 800 birds (one group of about 300 and another of about 500) left Thetis Island in these two movements. It is not known whether these birds eventually returned to Area 4 after winds from the NE began again on 25 July.

We recorded no other movements of oldsquaws to other potential molting areas away from Thetis Island. Although Area 2 was monitored nearly continuously from hour 120 of the study through hour 360, dense fog on some occasions made it impossible to watch birds as they moved from beach or nearshore habitats to offshore habitats. Furthermore, without a large sample of marked birds it was uncertain whether the same individuals or the same flocks were under observation in an area from one hour to the next, especially after some birds disappeared into the fog for periods of time.

Daily censuses of birds around Thetis Island at locations away from the area under continuous observation were thought to provide further indication of immigration to or emigration from the general Thetis Island area by oldsquaws, or of major movements of birds from one end of the island to the other. However, because of inconsistencies in our count procedures, the island censuses provided little additional information. On the seven days when evening counts were conducted between 1930 h and 2230 h ADT, total numbers away from the Blind 2 area fluctuated between 3905 and 1066 birds ($\bar{x}$ ± s.d.=2450 ± 1002.2, n=7 days between 29 July and 5 August; see Appendix 8). The evening counts fluctuated much less radically than those conducted in morning (0900 to 1300 h ADT; range= 3083 birds on 28 July to 442 birds on 2 August; $\bar{x}$ ± s.d.=1489 ± 1323.6; n=5 days between 28 July and 2 August).

Influences of Weather

As indicated in Figure 3 and Appendix 7, winds from the northeast prevailed throughout most of our study on Thetis Island. We showed earlier (Johnson and Richardson 1981:275) that during the molt, oldsquaws appear to seek shelter on the leeward sides of barrier islands and spits, away from wind and rough water. We conducted more detailed investigations of surface winds in this study and found that even the relatively low profile of Thetis Island (1.2 ± 0.29 m above waterline; n=13 locations along the islands total length) had a highly significant influence on wave height. On the morning of 9 August, measurements of wind speed and wave height were taken at 11 windward and 11 leeward locations along the length of Thetis Island and at a location at the W and E tip of the island. Winds during the several hour period when the measurements were taken averaged from 66.9° ± 14.20° magnetic (range=45° to 90°; n=24). Average wave height at the 11 windward locations was 0.32 ± 0.072 m, which was significantly higher than at the 11 immediately adjacent leeward locations (0.05 ± 0.048 m, $p < 0.005$, n=11 pairs of comparisons). However, one remarkable result of these morning measurements was that windspeed (as measured with the relatively crude Dwyer wind guage) was little affected by island relief at either the 0.2 or 2.0 m height above water level at the shoreline. Wind speeds 0.2 m (∿6 in) above the water line on the windward side of the island averaged 9.1 ± 0.52 km/hr compared with 8.3 ± 1.21 km/hr on the leeward side where oldsquaws commonly concentrated ($p > 0.05$; n=11 pairs of comparisons).

Similarly, measurements at the 2.0 m (∿6 ft) level were not significantly different (windward=13.4 ± 1.58 km/hr; leeward=12.4 ± 1.21 km/hr; $p > 0.05$; n=11 pairs of comparisons).

Similar measurements taken under a slightly different wind regime (mean direction=78.8° ± 11.35°) on the evening of 9 August, gave different results than those taken earlier in the morning. Wind speeds at the same 11 windward locations 0.2 m above the water line averaged 13.6 ± 1.27 km/hr, which was almost double the average 8.2 ± 2.97 km/hr at the 11 immediately adjacent leeward locations ($p < 0.05$; n=11 pairs of comparisons). However, at the 2.0 m level differences in windspeed at windward *vs.* adjacent leeward locations (24.1 ± 2.23 km/hr *vs.* 20.7 ± 4.91 km/hr, respectively) were not significant ($p > 0.05$; n=11 pairs of comparisons). As one might expect, in all comparisons both for the morning and evening measurements, wind speeds at the 2.0 m level were significantly greater than those at the 0.2 m level (9.8 ± 3.40 km/hr at 0.2 m *vs.* 17.7 ± 5.66 at 2.0 m; n=44 comparisons; $p < 0.05$).

Thus, even though oldsquaws apparently favor the leeward sides of barrier islands during their molt period, windspeeds may or may not be profoundly different there from adjacent windward sides. Wind fetch and wave height may be more of a factor influencing oldsquaw distribution than windspeed; certainly, oldsquaws seeking roosting locations would find it easier to leave the water on a leeward beach with no waves.

In general, throughout the first 120 h of observations in Area 4 (where oldsquaws had easy access to the seaward side of Thetis Island) there was a significant negative correlation ($r=0.384$; $p < 0.01$; df=94) between the numbers of birds on the windward *vs.* the leeward side of the island, further indicating an apparent preference for sheltered waters. Only during a rare period of calm and/or very slight southwesterly winds around hour 96 of this study, did oldsquaws move around the SE tip of Thetis Island from Area 4 to the seaward and (at that time) the leeward side of the island (Figure 4). Figures 5 and 6 show a similar remarkable movement of oldsquaws from the area SE of Blind 2 (Area 2) to the leeward beach SW of Blind 2 (Area 1). This movement occurred shortly after a major shift in the wind direction and a significant increase in the wave height along the beach east of Blind 2 (Area 2) around hour 288 of this study (Figure 3). As discussed later, a significant increase in the level of human disturbance occurred almost simultaneous to the change in weather in the area near Blind 2; these disturbances also may have influenced the distribution and movement patterns of the oldsquaws under observation.

Periodicity of Habitat Use

Oldsquaw use of barrier island-lagoon habitats followed a regular cycle of abundance and activity with a period of about 24 h (Figures 5 and 6). Results of the autocorrelation analyses (Figure 7A) give the most clear picture of the cyclic nature of oldsquaw behavior. Peak numbers of birds counted in all habitats were during the late evening (∿2100 h) through early morning (∿0300 h) hours (Figures 5 and 6). This result does not agree with that given by Gollop *et al.* (1974) for molting oldsquaws at Herschel Island, Y.T. They found peak abundance of birds on beach and nearshore habitats between 1300 and 1500 h YDT, during the warmest part of the day. However, their counts were not over a 24 h period, but only over the 7 h period 1100 to 1800 h ADT. Ward and Sharp (1974) watched oldsquaws at Herschel Island, Y.T., over a longer portion of the day

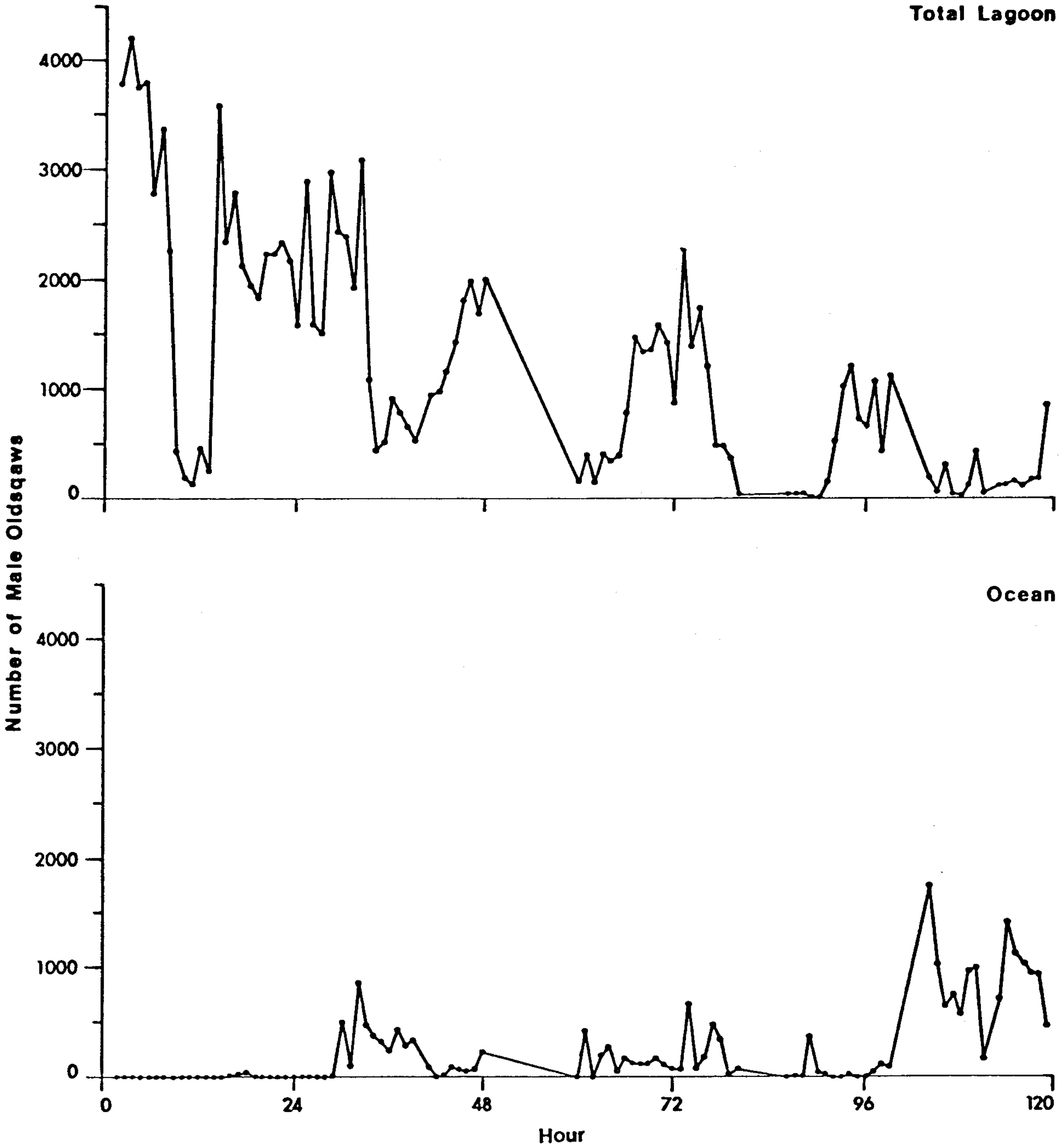

Figure 4. Numbers of molting male oldsquaws near the SE tip (Area 4) of Thetis Island, Alaska, 21 to 26 July 1980.

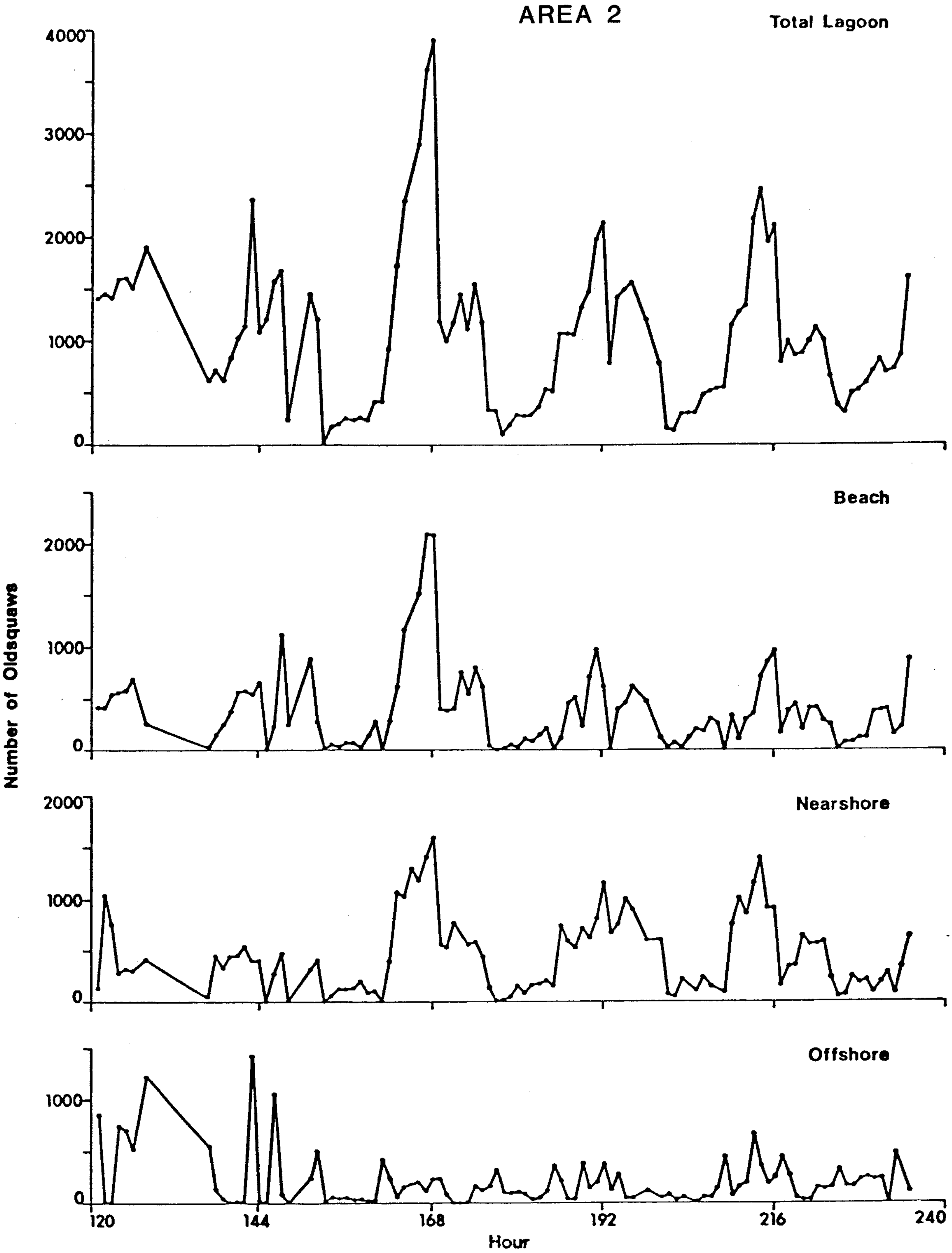

Figure 5. Numbers of oldsquaws in barrier island-lagoon habitats in Area 2 (see Figure 2) during the 240 h period of intensive observations from Thetis Island, Alaska. (See next page for hours 240 to 360.)

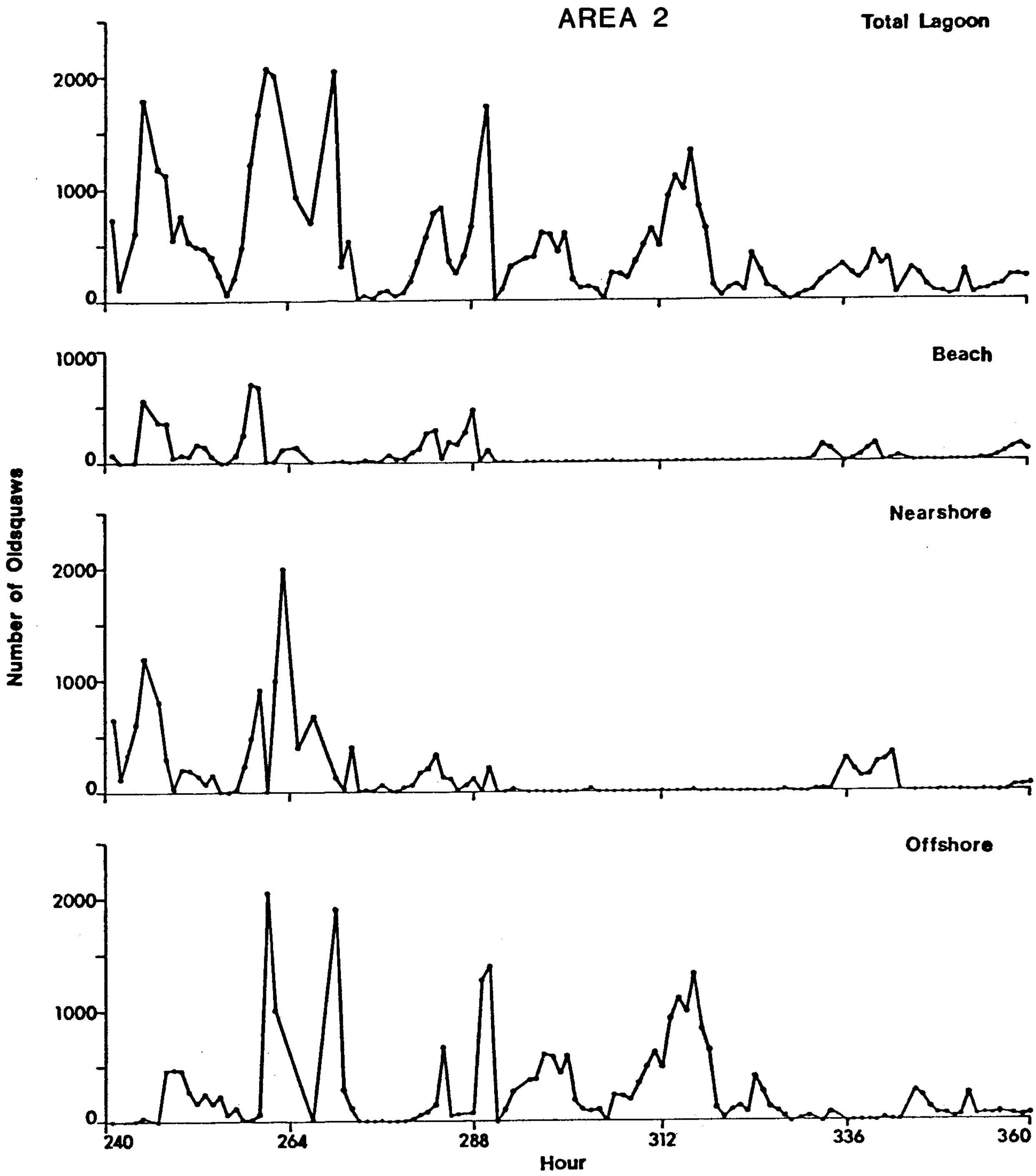

Figure 5. Continued.

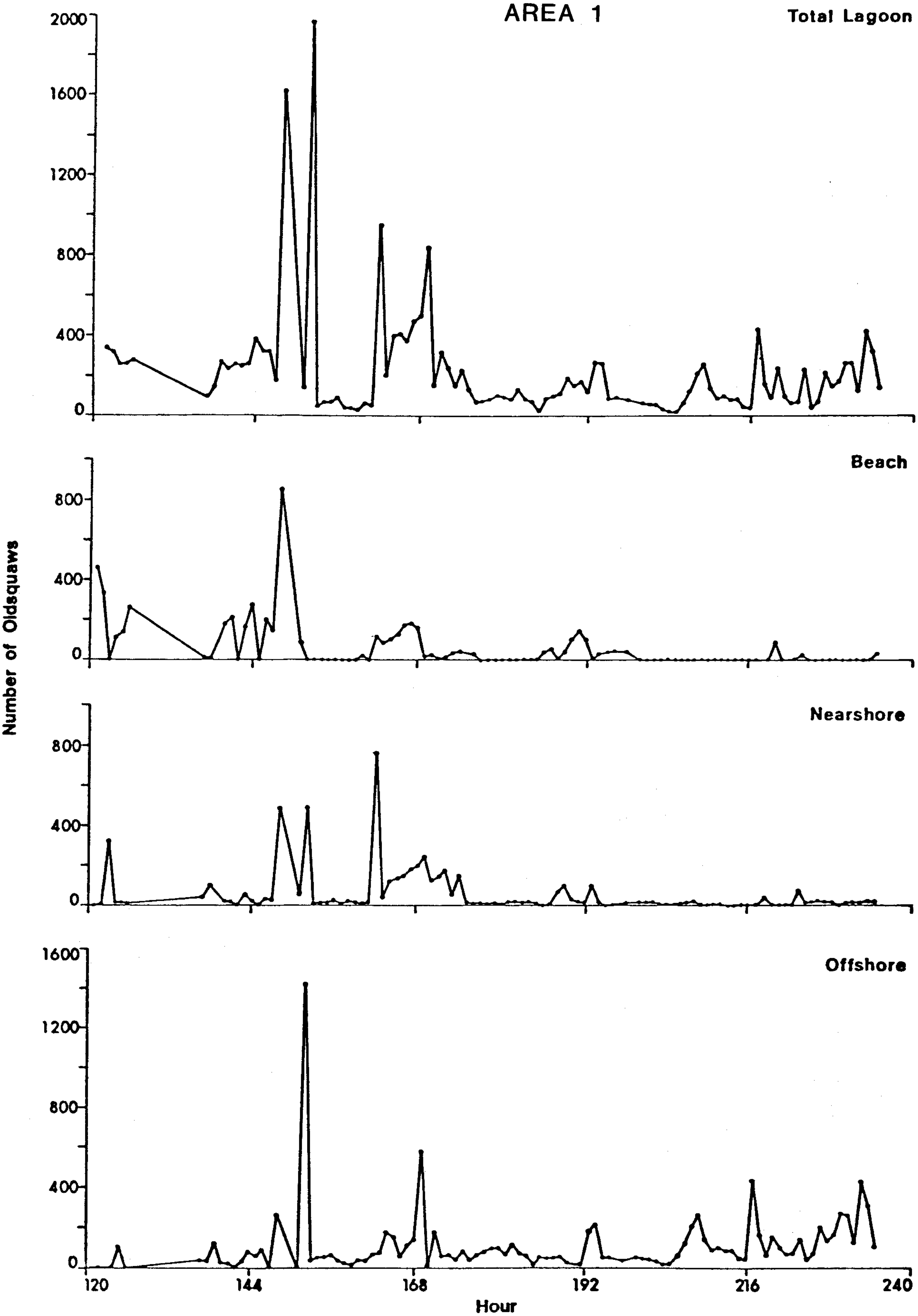

Figure 6. Numbers of oldsquaws in barrier island-lagoon habitats in Area 1 (see Figure 2) during the 240 h period of intensive observations from Thetis Island, Alaska. (See next page for hours 240 to 360.)

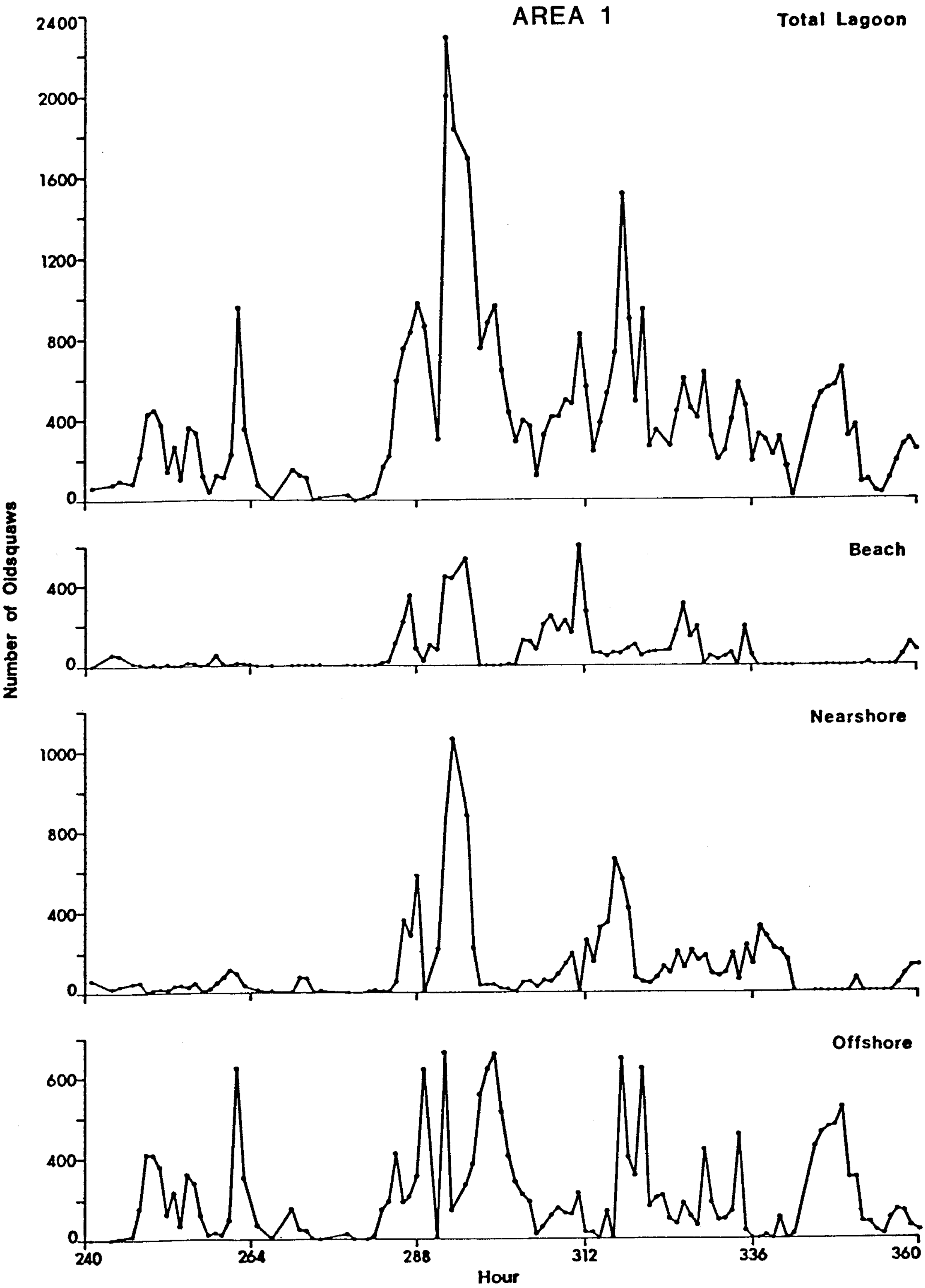

Figure 6. Continued.

Figure 7A. Results of autocorrelation analyses of numbers of birds in various barrier island-lagoon habitats in Area 2 during four 30-h cycles (120 hrs) of activity when oldsquaws were relatively undisturbed and when waters were calm. Peak to peak or 0 to 0 lag correlation of numbers in beach, nearshore and total lagoon habitats showed a 24-h period; numbers in offshore habitats showed little periodicity.

Figure 7B. Results of autocorrelation analyses of numbers of birds in various barrier island-lagoon habitats in Area 2 during four 30-h cycles (120 hrs) of activity when oldsquaws were subjected to disturbance and rough water. Peak to peak or 0 to 0 lag correlation of numbers in beach, nearshore and total lagoon habitats showed a 24-h period; use of offshore habitats showed little periodicity.

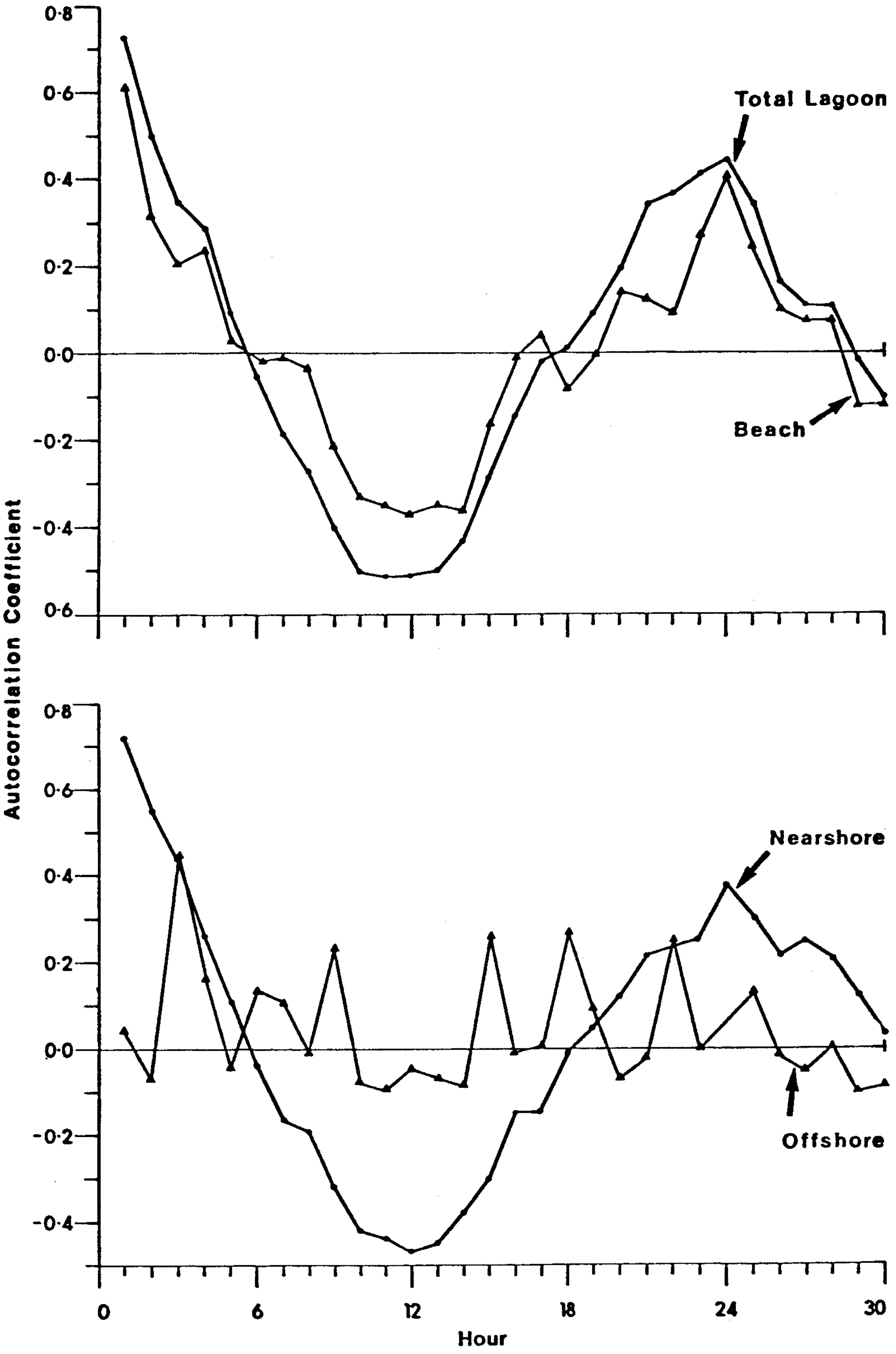
0·8
0·6
0·4
0·2
0·0
-0·2
-0·4
-0·6
Total Lagoon
Beach
Autocorrelation Coefficient
0·8
0·6
0·4
0·2
0·0
-0·2
-0·4
Nearshore
Offshore
0
6
12
18
24
30
Hour

Figure 7A.

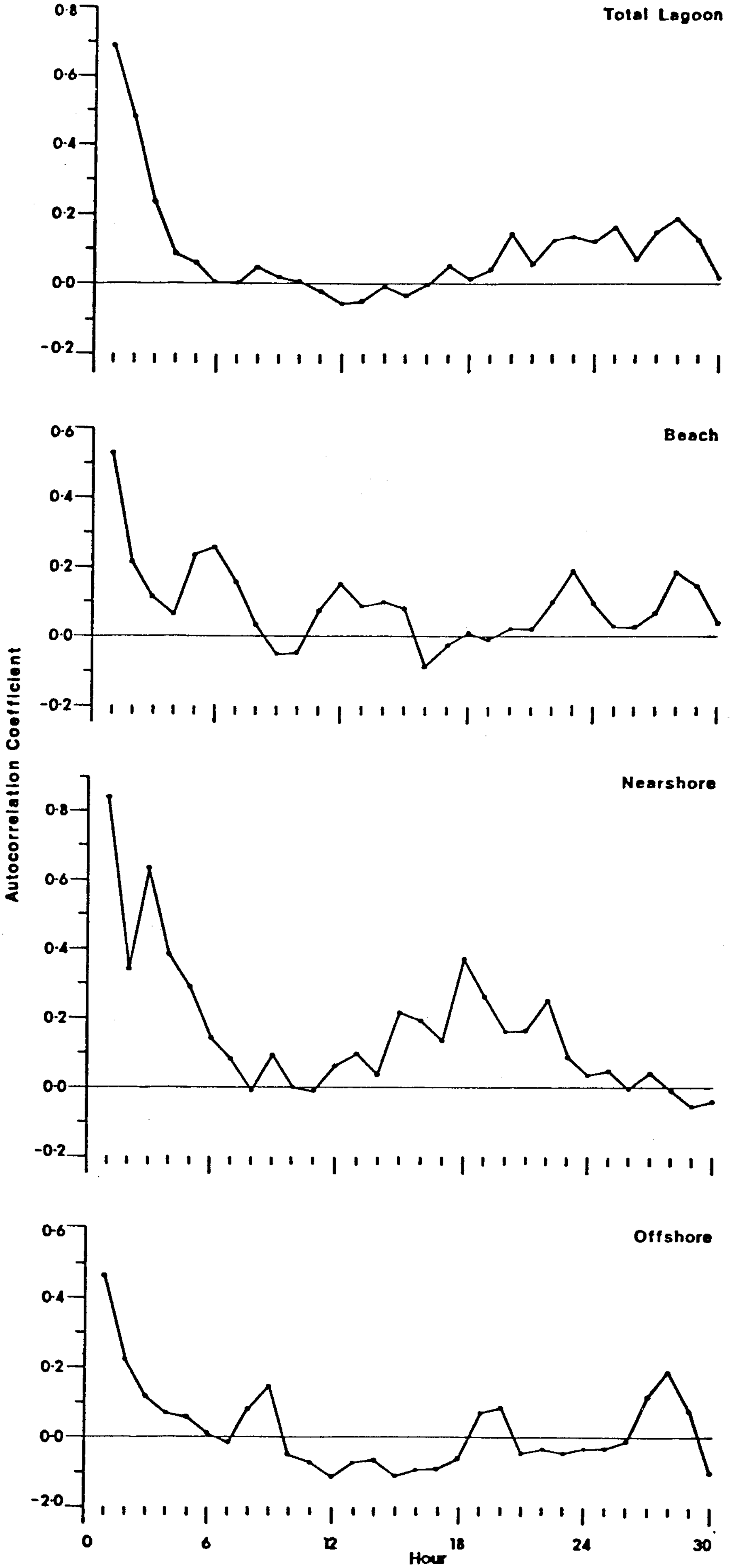
Total Lagoon
Beach
Nearshore
Offshore
Autocorrelation Coefficient
0·8
0·6
0·4
0·2
0·0
-0·2
-2·0
0
6
12
18
24
30
Hour

Figure 7B.

(0600 through 2000 h YDT) during the following year (1973), however, and found a significant increase in the number of birds moving toward land from offshore waters during the evening. Our results indicate that peak numbers of birds occur on and near roosting sites during the two to three hour period either side of midnight.

The most notable cyclic rhythms of habitat use and changes in bird numbers were on the beaches and in adjacent nearshore habitats in Area 2 during hours 120 to 240 (Figure 7A) and in Area 1 during hours 288 to 336 (Figures 6 and 7B). However, there were indications of cyclic behavior by oldsquaws early in the study in Area 4 (Figure 8).

The southern limits of offshore habitat near Thetis Island were not defined, i.e., we did not place an outer limit on this habitat. No doubt for this reason, the recorded increases in numbers of birds on beach and nearshore habitats did not correspond to decreases in numbers in offshore habitats, and *visa versa*. Birds normally moved beyond our limits of clear vision (not countable) when they moved offshore. Also, movements by birds to offshore habitats were often rapid; on many occasions (see Figure 5) a large proportion of the total number of birds on the beach or in nearshore waters had moved out of sight to offshore waters within one count period (1 h). Similarly, often times birds clearly visible in offshore habitats disappeared farther offshore from one count period to the next (Figure 5).

As mentioned in the preceding section, the cyclic use by oldsquaws of Area 2 was abruptly discontinued around h 288 when rough weather (Figure 3) and the level of disturbance (Figure 9) coincidentally increased markedly. As the number and rhythmicity of birds using habitats in Area 2 became less marked, a corresponding increase in rhythmicity

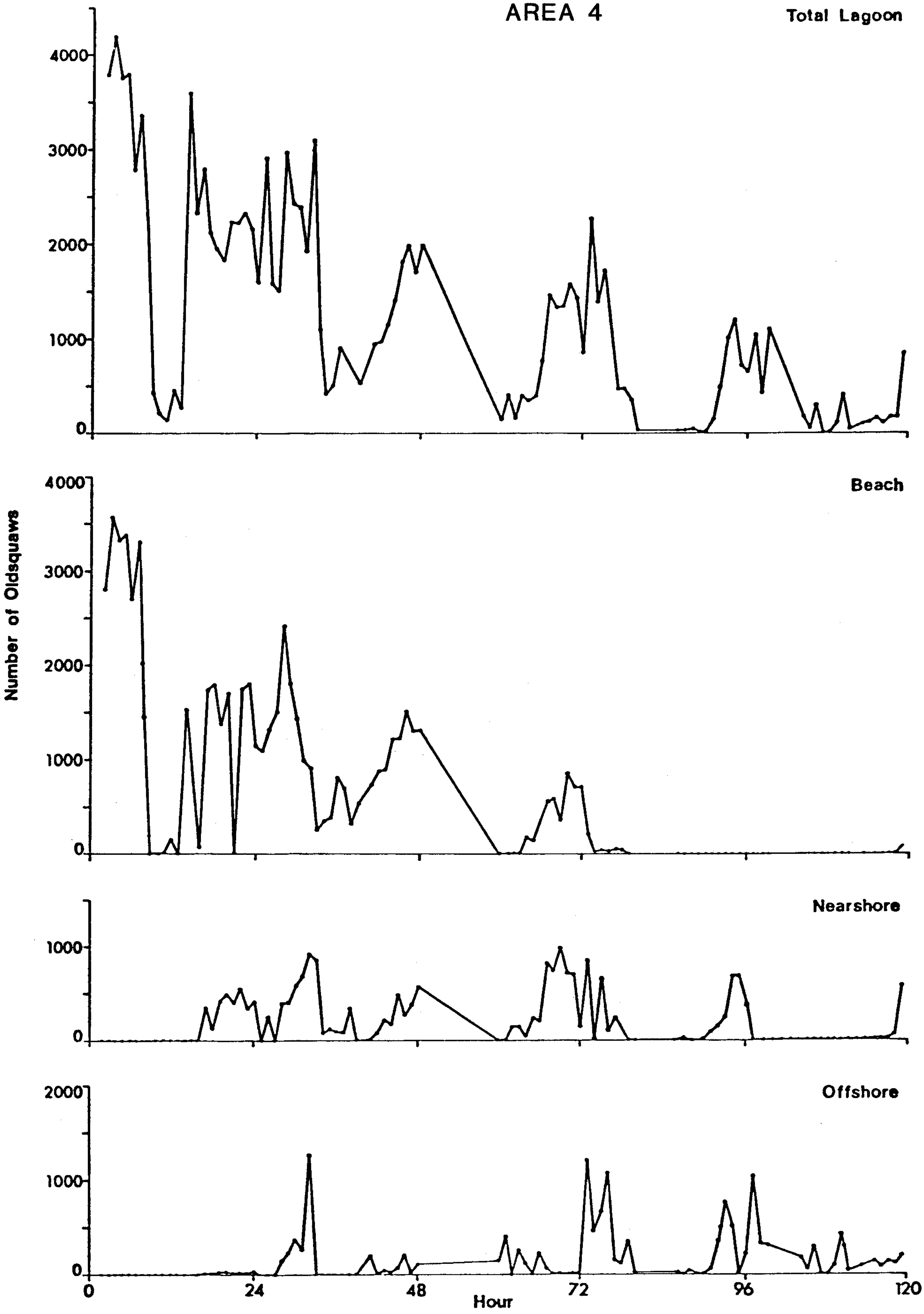

Figure 8. Numbers of oldsquaws in barrier island-lagoon habitats in Area 4 (see Figure 2) during the initial 120 h period of intensive observations from Thetis Island, Alaska.

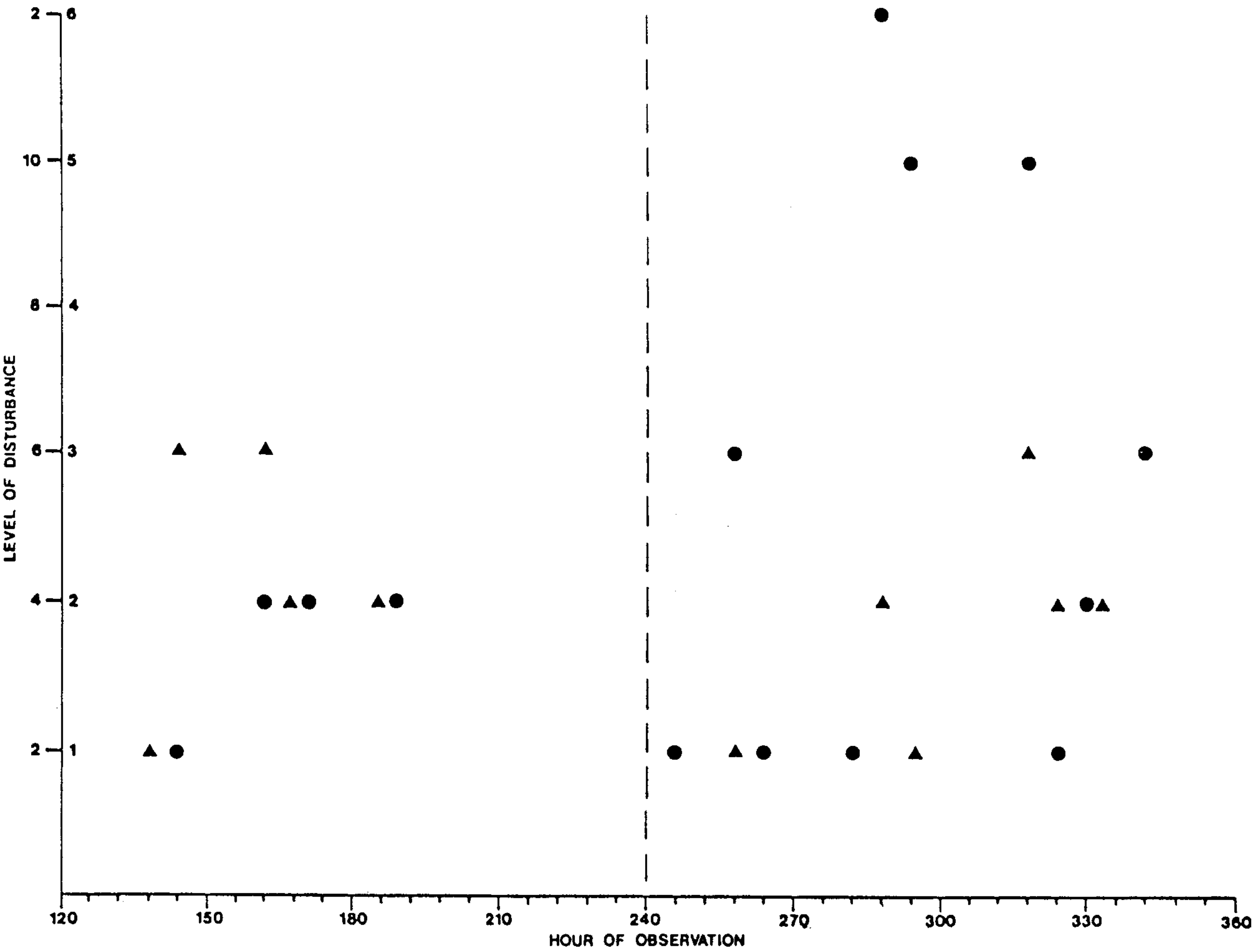

Figure 9. Level of disturbance to oldsquaws throughout the 240-h period of intensive observations. (▲ represent data from Area 1; ● represent data from Area 2.)

and use occurred on the opposite side of the bay in Area 1, which under the new wind regime (Figure 3) was the leeward side of the bay.

Influences of Disturbance

Although there was clear documentation on numerous occasions of oldsquaws fleeing from one habitat to another in response to observed aircraft, boat and human disturbances, as well as natural disturbances, the fact that they did not abandon the bay adjacent to Blind 2, suggests some level of tolerance by oldsquaws to these perturbations. However, the gradual decline (from near 4000 to near 2000, see Figures 5 and 6) in the total number of oldsquaws in Areas 2 and 1 from hour 120 to 360 may in fact indicate that some birds did abandon this part of Thetis Island. Only a few male oldsquaws normally have regrown their wing feathers sufficient for flight by 5 August (see Johnson and Richardson 1981), thus, although some birds may have flown away from Thetis Island during the latter half of the study, the number doing so would have been small compared to the number still flightless (far too few to account for a loss of nearly 2000 birds). Furthermore, the total counts of birds in the Thetis Island area (see Appendix 8), although incomplete, indicated no overall decline in numbers of birds. The decline in percent males in Area 2 (Figures 5 and 10 to 12 and Appendices 9 to 11) after hour 288 can be explained in part by their movement to Area 1 (Figure 6 and Appendices 12 to 14). Female oldsquaws are still flying during early August, the peak of their molt and flightless period is later in the month (Johnson and Richardson 1981); those few birds present in the large flocks of males near barrier islands were therefore able to fly the short distance to the beach in Area 2 after hour 288 (Figures 10 to 12).

Another indication of the possible effects of bad weather and disturbance on oldsquaws was the markedly greater proportions of birds occupying offshore habitats from Area 2 between hours 288 to 300 and 301 to 324 (Figures 5 and 6 and Tables 6 and 7); prior to this time, the combined number of birds occupying nearshore and beach habitats

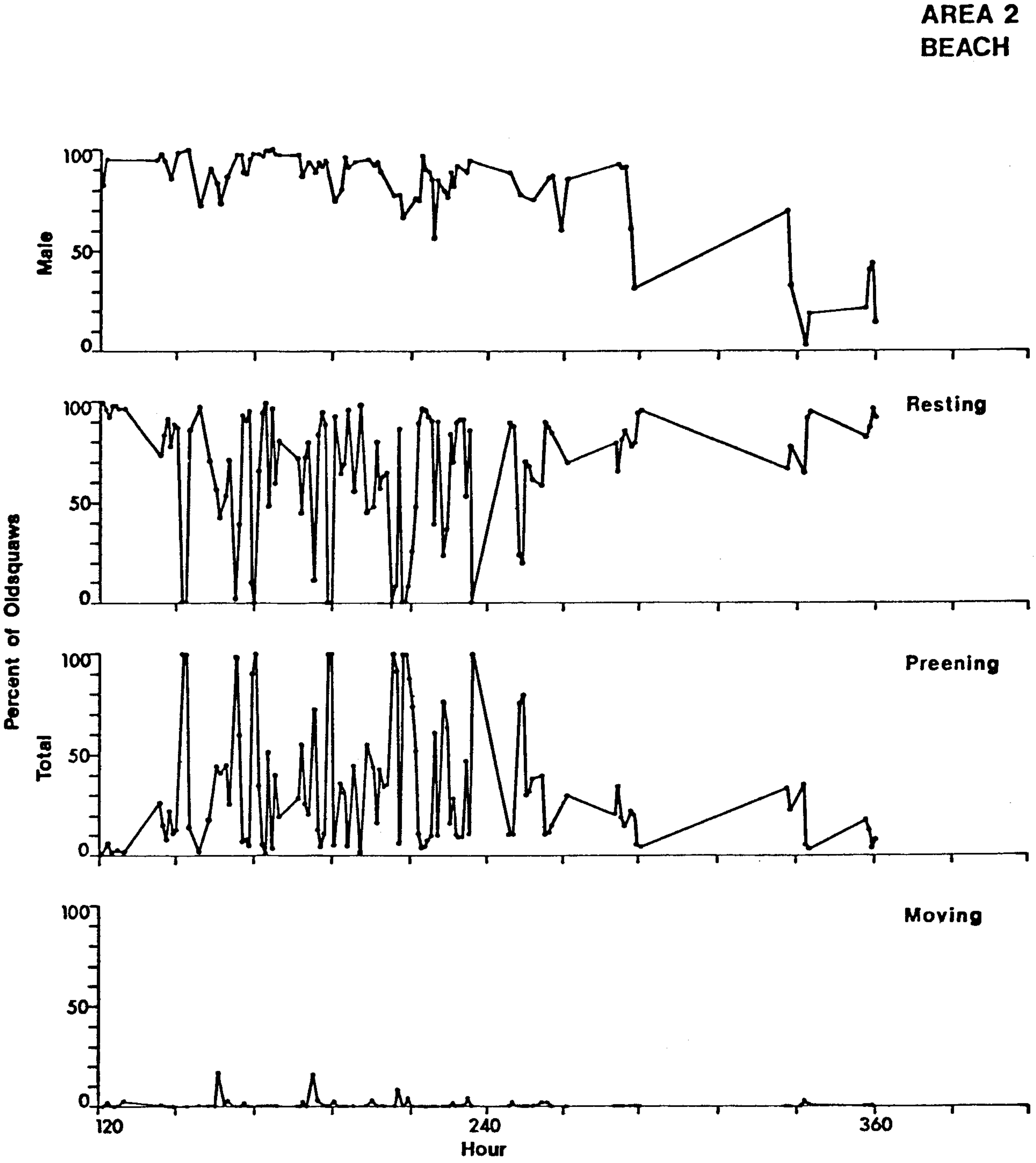

Figure 10. Percent male oldsquaws and their observed behavior on beach habitats during hours 120 to 360 in Area 2 (see Figure 2), Thetis Island, Alaska.

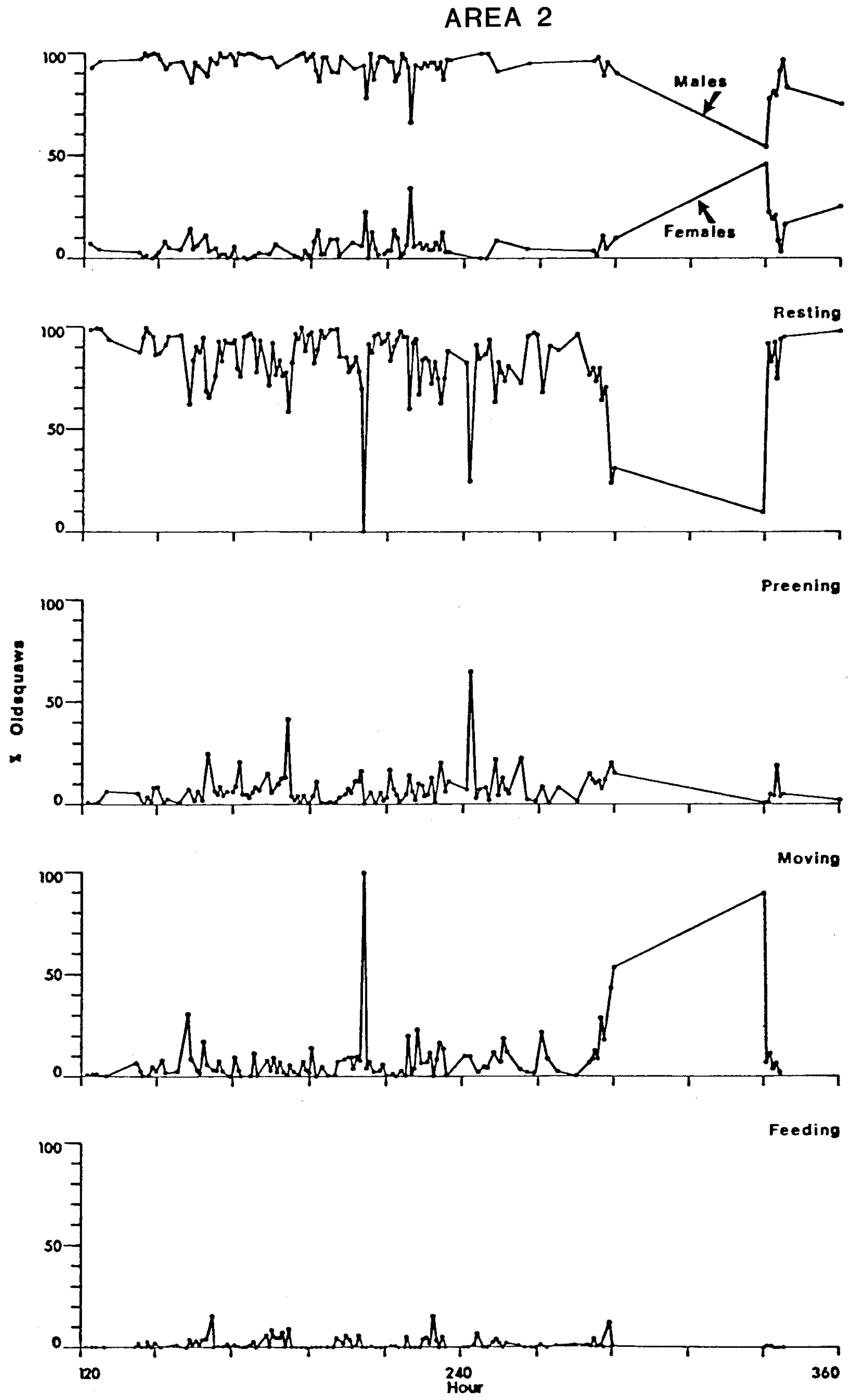

Figure 11. Percent male oldsquaws and their observed behavior in nearshore habitats during hour 120 to 360 in Area 2 (see Figure 2), Thetis Island, Alaska.

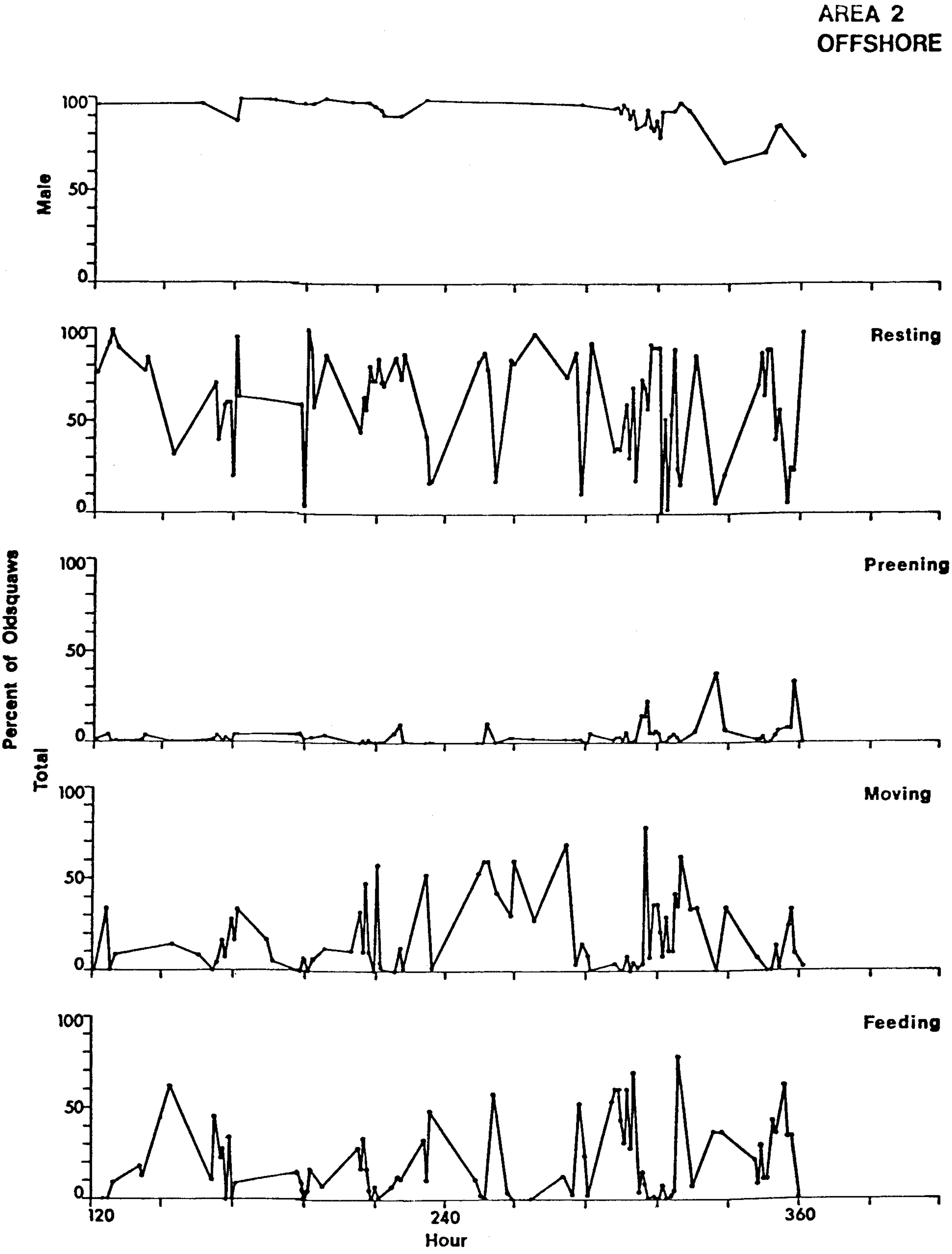

Figure 12. Percent male oldsquaws and their observed behavior in offshore habitats during hours 120 to 360 in Area 2 (see Figure 2), Thetis Island, Alaska.

was much greater than those occupying offshore habitats (Tables 6 and 7). In fact, the 24-cycle when the largest proportion of oldsquaws were recorded in offshore habitats (99.3%; Table 6B), was during hours 301 to 324, simultaneous with the peaks of disturbance and rough water in Area 2 (Figure 3). Similarly, Gollop *et al.* (1974) found that molting seaducks spent more time away from shore in open water on days when they were disturbed by aircraft than on days when they were not. They also found that swimming and feeding activities and population levels of seaducks appeared to be unaffected by aircraft disturbance. Furthermore, Ward and Sharp (1974) found that disturbance during one molting season (year), had little effect on the numbers and behavior of molting seaducks using the same location the next year.

Although wind regimes at Thetis Island returned to normal by hour 336, few oldsquaws returned to the beach at Area 2; most remained in beach, nearshore and offshore habitats in Area 1 until hour 360, the end of intensive observations (see Appendices 12 to 14).

Oldsquaw Behavior in Area 2

In beach habitats - The average proportion of oldsquaws on beach habitats in Area 2 that were resting was well over 70% (see Figure 10 and Appendix 9). Preening behavior on the beaches averaged about 25%; many birds preened their feathers while pausing at the beach/water interface during movements from nearshore to beach habitats. Very little time was spent moving once birds reached the beach (<2% average) and virtually no birds were recorded feeding on the beaches.

Table 6A. Summaries of 1-cycle* subtotals, subtotal percentages, means, standard deviations and sample sizes of all birds classified in Area 2 during hours 121 through 240.

Hours	Beach	Nearshore	Offshore	Total
121 to 132				
subtotals	3456	3281	4059	10906
%	32.0	30.4	37.6	100.0
$\bar{x}$	439.7	468.7	577.9	1558.0
s.d.	143.6	370.4	450.6	175.25
n	7	7	7	7
133 to 156				
subtotals	5998	4884	4282	16364*
%	39.6	32.2	28.2	100.0
$\bar{x}$	333.2	271.3	237.9	909.1
s.d.	324.1	192.7	406.9	624.4
n	18	18	18	18
157 to 180				
subtotals	12196	12975	3050	26778
%	43.2	46.0	10.8	100.0
$\bar{x}$	530.3	540.6	127.1	1164.2
s.d.	628.4	490.1	108.0	1092.7
n	23	24	24	23
181 to 204				
subtotals	6315	10995	2831	20141
%	31.4	54.6	14.1	100.1
$\bar{x}$	287.0	499.8	128.7	915.5
s.d.	271.8	333.4	119.8	601.7
n	22	22	22	22
205 to 228				
subtotals	7158	11777	4719	23654
%	30.3	49.8	20.0	100.1
$\bar{x}$	298.3	490.7	196.6	985.6
s.d.	243.8	386.3	160.8	619.5
n	24	24	24	24

...continued

Table 6A. Continued.

Hours	Beach	Nearshore	Offshore	Total
229 to 240				
subtotals	2472	1861	1589	5922
%	41.7	31.4	26.8	99.9
$\bar{x}$	353.1	265.9	227.0	846.0
s.d.	253.6	191.8	153.9	343.5
n	7	7	7	7
121 to 240				
subtotals	37595	45778	20530	103765
%	36.1	44.1	19.8	100.0
$\bar{x}$	372.2	448.8	201.3	1027.4
s.d.	386.0	370.5	256.0	730.9
n	101	102	102	101

*1-cycle=24 hours; see Figure 7.

Table 6B. Summaries of 1-cycle* subtotals, subtotal percentages, means, standard deviations and sample sizes of all birds classified in Area 2 during hour 241 through 360.

Hours	Beach	Nearshore	Offshore	Total
241 to 252				
subtotals	1045	4267	1890	7802
%	21.1	54.7	24.2	100.0
$\bar{x}$	164.5	426.7	189.0	780.2
s.d.	190.5	373.3	214.2	469.1
n	10	10	10	10
253 to 276				
subtotals	2161	6590	6678	13304
%	14.0	42.7	43.3	100.0
$\bar{x}$	108.1	329.5	351.5	700.2
s.d.	207.6	501.7	620.2	728.5
n	20	20	19	19
277 to 300				
subtotals	2084	1508	7280	10872
%	19.2	13.9	67.0	100.1
$\bar{x}$	90.6	65.6	316.5	472.7
s.d.	125.3	91.9	392.7	405.4
n	23	23	23	23
301 to 324				
subtotals	4	61	9695	9760
%	0.0	0.6	99.3	99.9
$\bar{x}$	0.2	2.5	404.0	406.7
s.d.	0.6	6.6	376.6	377.0
n	24	24	24	24
325 to 348				
subtotals	678	1793	1939	3864
%	17.5	46.4	36.1	100.0
$\bar{x}$	30.8	81.5	63.3	175.6
s.d.	50.1	119.7	86.7	118.2
n	22	22	22	22

...continued

Table 6B. Continued.

Hours	Beach	Nearshore	Offshore	Total
349 to 360				
subtotals	467	195	836	1498
%	31.1	13.0	55.8	
$\bar{x}$	38.9	16.3	69.7	124.8
s.d.	52.2	21.3	58.8	77.2
n	12	12	12	12
241 to 360				
subtotals	7039	14414	27772	47110
%	14.3	29.3	56.4	100
$\bar{x}$	63.4	129.9	252.5	428.3
s.d.	130.0	284.4	386.1	469.1
n	111	111	111	111

*1-cycle=24 hours; see Figure 7.

Table 7A. Summaries of 1-cycle* subtotals, subtotal percentages, means, standard deviations and sample sizes of all birds classified in Area 1 during hours 121 through 240.

Hours	Beach	Nearshore	Offshore	Total
121 to 132				
subtotals	1314	368	105	1912
%	73.5	20.6	5.9	100.0
$\bar{x}$	219.0	61.3	17.5	318.7
s.d.	165.7	126.8	42.9	76.5
n	6	6	6	6
133 to 156				
subtotals	2256	1493	2351	6658
%	37.0	24.5	38.5	100.0
$\bar{x}$	125.3	82.9	130.6	369.9
s.d.	206.6	151.9	327.0	529.2
n	18	18	18	18
157 to 180				
subtotals	1177	2615	2173	5965
%	19.7	43.8	36.4	99.9
$\bar{x}$	49.0	109.0	90.5	248.5
s.d.	62.1	160.1	113.8	247.2
n	24	24	24	24
181 to 204				
subtotals	645	523	1131	2299
%	28.1	22.7	49.2	100.0
$\bar{x}$	29.3	27.8	51.4	104.5
s.d.	40.5	23.8	51.1	68.2
n	22	22	22	22
205 to 228				
subtotals	120	256	2638	3014
%	4.0	8.5	87.5	100.0
$\bar{x}$	5.0	10.7	109.9	125.6
s.d.	18.8	15.4	89.6	94.8
n	24	24	24	24

...continued

Table 7A. Continued.

Hours	Beach	Nearshore	Offshore	Total
229 to 240				
subtotals	34	93	1563	1690
%	2.0	5.5	92.4	
$\bar{x}$	4.9	13.3	223.3	241.4
s.d.	12.0	5.7	114.4	107.9
n	7	7	7	7
121 to 240				
subtotals	5546	5348	9961	21538
%	26.6	25.6	47.8	100.0
$\bar{x}$	54.9	53.0	98.6	213.2
s.d.	115.7	111.7	163.2	274.9
n	101	101	101	101

*1-cycle=24 hours; see Figure 7.

Table 7B. Summaries of 1-cycle* subtotals, subtotal percentages, means, standard deviations and sample sizes of all birds classified in Area 1 during hours 241 through 360.

Hours	Beach	Nearshore	Offshore	Total
241 to 252				
subtotals	164	282	1479	1925
%	8.5	14.6	76.8	99.9
$\bar{x}$	18.2	31.3	164.3	213.9
s.d.	22.9	20.6	183.1	158.9
n	9	9	9	9
253 to 276				
subtotals	127	722	2612	3461
%	3.7	20.9	75.5	100.1
$\bar{x}$	7.1	40.1	145.1	192.3
s.d.	12.7	34.2	206.3	223.3
n	18	18	18	18
277 to 300				
subtotals	2409	4901	7131	13749
%	16.7	33.9	49.4	100.0
$\bar{x}$	114.7	245.1	339.6	723.6
s.d.	173.0	367.2	333.8	641.0
n	21	20	21	19
301 to 324				
subtotals	2937	3842	5224	11663
%	24.5	32.0	43.5	100.0
$\bar{x}$	127.7	160.1	217.7	507.1
s.d.	126.1	177.7	230.4	303.7
n	23	24	24	23
325 to 348				
subtotals	1234	2917	4143	8294
%	14.9	35.2	50.0	100.1
$\bar{x}$	56.1	132.6	188.3	377.0
s.d.	85.9	95.4	207.4	164.3
n	22	22	22	22

...continued

Table 7B. Continued.

Hours	Beach	Nearshore	Offshore	Total
349 to 360				
subtotals	258	458	1943	2659
%	9.7	17.2	73.1	100.0
$\bar{x}$	21.5	38.2	161.9	221.6
s.d.	36.4	50.3	179.7	176.3
n	12	12	12	12
241 to 360				
subtotals	7129	13122	22532	41751
%	16.7	30.7	52.7	100.1
$\bar{x}$	67.9	125.0	212.6	405.3
s.d.	114.8	199.7	242.7	385.0
n	105	105	106	103

*1-cycle=24 hours; see Figure 7.

The proportion of male oldsquaws in beach habitats averaged well above 80% until after hour 288. After that period most of the males (most of the birds) moved offshore and to the leeward nearshore waters on the opposite side of the bay (see Figures 5 and 6). There was, however, a general declining trend in the proportion of males from over 90% early in the study to about 35% in the final stages (Figure 10 and Appendix 9).

In nearshore habitats - The average proportion of oldsquaws that were resting in nearshore waters in Area 2 was near 85% during hours 120 to 288 (Figure 11 and Appendix 10). After that period, the number of birds counted in the nearshore in Area 2 decreased markedly and a much higher proportion of the birds remaining were females and were birds that were moving, especially during hours 287 and 288 and hour 336. After hour 336, the average proportion of birds resting on the nearshore waters of Area 2 increased, as did the proportion of males. Although a significant proportion of feeding and preening oldsquaws were recorded in this habitat, the average proportion that were moving was greater. Appendix 15) provides a summary of information on diving (feeding) behavior of oldsquaws in nearshore habitat.

The general trend in the proportion of males on this habitat declined from over 90% early in the study, to about 77% in the final stages (Figure 11 and Appendix 10).

In offshore habitats - The average proportion of birds recorded resting and moving fluctuated much more markedly in offshore habitats than was recorded on either beach or nearshore habitats (Figure 12 and Appendix 11). Although a relatively high proportion of birds in offshore habitats were classified as resting, the proportion feeding was notably greater than in either of the previous two habitats considered. The cyclic trend of oldsquaws feeding in offshore habitats is also evident from Figure 12. It was often difficult to isolate a diving oldsquaw in offshore habitats therefore it was not possible to record information on diving behavior. The summary of diving (feeding) behavior in Appendix 15 constitutes our only information on this subject, and this was collected only in nearshore habitats.

The proportion of birds moving in offshore habitats was quite variable, especially during hours 216 to 288 and from hour 312 through the end of the study. A very small proportion of the birds classified in offshore habitats in Area 2 were recorded preening. In part, this may have been because of the greater distances over which birds were observed in offshore habitats and the difficulty in discerning this more subtle behavior; birds that were diving and moving were much more easily classified in offshore habitats.

As on the beaches and in the nearshore habitats, the average proportion of male oldsquaws that were classified in offshore habitats in Area 2 gradually declined from over 90% in the early stages of this study, to around 75% during the final stages (Figure 12 and Appendix 11).

Oldsquaw Behavior in Area 1

Few birds were present in the portion of Area 1 adjacent to Blind 2 prior to hour 288 of the study, therefore little can be said about their behavior. However, as mentioned earlier, after hour 288 the number of birds in this area increased markedly (Figure 6). Their behavior patterns in Area 1 were essentially identical to those recorded and discussed for Area 2 (see Appendices 12 through 14).

SUMMARY AND CONCLUSIONS

Aerial Surveys

Aerial surveys along the entire central Alaskan Beaufort coast have been conducted during the peak of the oldsquaw molt (late July to early August) for the past four years (1978-1981). Certain locations such as Simpson Lagoon, Gwydyr Bay and Leffingwell Lagoon (S of Flaxman Island) have consistently supported very large numbers of molting oldsquaws, and the highest densities consistently have occurred along transects immediately south of barrier island shorelines. This habitat appears to be particularly important to the flightless males that comprise over 90% of the birds in these molting concentrations. The barrier islands provide protection from wind and rough water, they afford easy access to roosting areas along leeward beaches and are close to the very abundant prey resources in the nearby lagoons.

Thetis Island

Thetis Island lies about 12 km N of the Colville River delta and about 7 km W of Simpson Lagoon. There is about 5 acres of private land on this small (∿2.5 km²) barrier island in Harrison Bay. Thetis Island supports one of the largest colonies of common eiders in the Alaskan Beaufort Sea (∿50 nests). The rows of driftwood along the top of the island appear to be particularly attractive to nesting eiders; these areas should be avoided during the nesting season (mid-June to late July).

The leeward waters and beaches of Thetis Island support the only significant molting concentrations of oldsquaws (∿4000 birds) in Harrison Bay.

Oldsquaw Collections

The 26 oldsquaws collected during the period 27 July to 9 August were primarily males (65%; 17 birds). Because we wanted to document that females were not flightless near Thetis Island at this time, we selectively collected a relatively higher proportion of females that were present in the area. All but 2 of the 17 males were flightless; the two that were barely able to fly were taken late in the collection period. All of the seven females were able to fly, although one bird had dropped an outer primary (one wing feather) from each wing and was obviously in the early stages of her wing molt.

Twenty-five specimens of oldsquaws were deposited in the vertebrate collection at the University of Alaska Museum, Fairbanks. The one specimen taken from a gill net was too badly decomposed to prepare as a study skin.

Oldsquaw Behavior

During the molt period (mid-July to mid-August) male oldsquaws shed their wing feathers and are unable to fly for about two weeks. Birds collected at Thetis Island during this period in 1980 conformed to this pattern of molt and flightlessness. Molting oldsquaws typically cycled through a 24-h period of activity, with peak numbers of birds resting and preening in the leeward nearshore and beach habitats during late evening and early morning (∿2100 to 0300 h ADT*). During mid-day they typically moved farther offshore to feed.

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*Alaska Daylight Time.

On two occasions when the waters around Thetis Island became very calm, oldsquaws moved 5 km toward an adjacent molting location at Oliktok Pt. (∿7 km E of Thetis Island), thus suggesting that under some conditions, flightless oldsquaws do make long-distance movements from one molting location to another.

On one occasion during our 360 h period of intensive observations of oldsquaws, the level of man-made disturbance doubled from the background of natural and biologist-induced disturbances. This period of disturbance coincidentally occurred during a period when the normal patterns of wind and waves changed. Although it was impossible to distinguish between the effects of these two perturbations, oldsquaws responded by moving to another location which provided better protection from wind and waves, thus suggesting a more significant functional response to weather, rather than disturbance.

However, the fact that the total number of male oldsquaws in the bay adjacent to Blind 2 declined from near 4000 birds early in the study to near 2000 birds later in the study may indicate a general movement by oldsquaws away from the sources of disturbance near Area 2. It is unlikely that the general attrition of birds throughout the study was the result of some males regrowing flight feathers and leaving the Thetis Island area; it is more likely that they moved to another sheltered bay on the west end of the island.

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Appendix 1. Locations of major oldsquaw concentrations recorded during the period of summer molt in Simpson Lagoon, Alaska, 1980 and 1981.

2 August 1980	# of oldsquaws
Barrier Island Shoreline Locations	
SW of Spy Island	2455
SW of Leavitt Island	3957
SW of Bertoncini Island	1163
SE Shore Cottle Island	980
Mid Lagoon Locations	
NW of Milne Point	3459
S of Leavitt Island	2617
Mainland Shoreline Locations	
NE of Kavearak Point	1891
2 August 1981	
Barrier Island Shoreline Locations	
SE Spy Island	1811
SE Pingok Island	1031

Appendix 2. Total numbers and densities of oldsquaws on all transects and during the 2 August 1980 and 2 August 1981 aerial surveys along the Alaskan Beaufort Sea coast.*

Transect Number	Density #/km²		# on-transect		# off-transect	
	1980	1981	1980	1981	1980	1981
1	0.0	0.0	0	0	0	0
2	645.8	284.7	9,558	4,214	160	184
3	168.3	128.9	2,010	1,578	5,294	74
4	197.9	38.2	2,557	421	2,179	43
5	0.0	0.6	0	8	8	30
6	327.9	113.0	1,810	629	0	1,109
7	44.1	0.9	319	6	1,175	0
8	7.7	5.7	175	128	0	88
9	0.0	1.4	0	17	15	0
10	0.1	0.0	2	0	0	0
11	0.8	10.3	4	50	1,220	40
12	568.6	86.1	7,915	1,204	30	174
13-1	7.8	0.0	51	0	0	0
13-2	168.8	143.7	8,364	6,883	95	1,640
14	54.3	-	1,916	-	0	-
17	216.5	-	7,500	-	280	-
18	2.8	9.4	92	298	1,635	50
19	0.0	2.5	0	17	0	0
20	0.0	6.2	0	16	0	0
21	150.1	56.8	2,222	1,026	35	0
overall/total	128.1	49.1	42,195	16,495	12,095	3,432

*See Johnson and Richardson (1981) for transect locations and descriptions.

Appendix 3. Densities of oldsquaws during the peak of the male molt period in Simpson Lagoon, Alaska, 1977-1981.

Survey Date	Oldsquaws/km^2		
	Transect 2	Transect 3	Transect 4
28/29 July 1977	401.7	501.1	516.4
25 July 1978	284.7	73.0	19.1
28 July 1979	520.5	123.6	31.2
2 August 1980	645.8	168.3	197.9
2 August 1981	284.7	128.9	33.2
Unweighted mean density ± 1 s.d.	427.5 ± 156.3	198.9 ± 172.3	159.6 ± 212.7

Appendix 4. Estimates of the total number of oldsquaws present in Simpson Lagoon, Alaska, during the peak of the molt period on 2 August 1980 and 2 August 1981.

Transect Number	Location	Approximate Lagoon Area Represented (km²)	Lagoon Area Surveyed (km²)	Estimated Number of Oldsquaw	
				1980	1981
2	North Lagoon (<1.82 m deep)	22	14.80	10,223 (9,558)	4,400 (4,214)
3	Mid Lagoon (>1.82 m deep)	102	12.24	17,080 (2,060)	13,084 (1,578)
4	South Lagoon (<1.82 m deep)	36	12.88	4,233 (2,557)	1,928 (421)
Total		160	39.92	31,536 (14,175)	19,412 (6,213)

Mean 1980 Density (weighted) = 197.1 oldsquaws/km²
Mean 1981 Density (weighted) = 121.3 oldsquaws/km²

Appendix 5. Weights and measurements of 26 oldsquaws collected* during the peak of the male molt period (27 July to 9 August) in the vicinity of Thetis Island, Alaska, 1980.

							Gonads (mm)				
							Male				
							Rt.		L.		Female
Date	Sex	Wt. (g)	Rt. Wing (mm)	Longest Primary on Rt. Wing (mm)	Rt. Tarsus (mm)	Sub Q Fat Thickness (mm)	L	W	L	W	Largest Ovum
27 July	M	825	140	0	46	2.5	11	5	11	6	
	M	950	145	49	44	4.0	12	6	12	5	
	M	870	103	15	45	4.5	9	5	9	5	
	M	830	113	17	44	7.9	12	5	13	5	
	M	-	99	7	44	-	-	-	-	-	
	M	785	140	51	47	2.5	9	4	8	3	
	M	740	154	57	45	4.0	7	3	8	3	
	M	830	128	32	47	4.7	9	5	10	5	
	F	590	192	127	43	3.5					1.5
3 Aug.	M	880	132	39	46	5.5	11	5	13	6	
	F	749	219	139	43	4.8					2.5
5 Aug.	F	765	218	140	43	3.0					1.5
	M	945	151	56	46	5.8	10	6	13	6	
	M	825	121	34	-	3.5	13	5	13	5	
	F	695	132	0	40	4.0					1.0
	F	700	132	0	43	4.0					2.0
	F	650	207	127	43	1.5					2.3
7 Aug.	M	910	121	28	43	4.1	9	4	11	8	
	M	790	216	131	42	1.0					2.0
	F	720	209	136	40	3.0					2.0
	M	725	143	64	42	1.7	8	3	10	2	

...continued

Appendix 5. Continued.

							Gonads (mm)				
							Male				
							Rt.		L.		Female
Date	Sex	Wt. (g)	Rt. Wing (mm)	Longest Primary on Rt. Wing (mm)	Rt. Tarsus (mm)	Sub Q Fat Thickness (mm)	L	W	L	W	Largest Ovum
7 Aug.	M	880	177	88	42	4.0	11	5	13	5	
	M	860	184	96	43	5.0	11	4	11	4	
9 Aug.	F	715	108	22	-	4.0					1.8
	F	642	97	8	40	2.8					2.0
	M	840	207	133**	42	3.0	10	3	11	4	

*All 26 specimens have been deposited in the vertebrate collection of the University of Alaska Museum, Fairbanks, Alaska.

**Longest primary on this bird was #9; on all other birds was #10.

Appendix 6. Fullness of 25 oldsquaw stomachs collected in the vicinity of Thetis Island, Alaska, during 27 July to 9 August 1980.

Bird #	Hynes Point Fullness Classification	Stomach Contents*
1	2	-
2	2	-
3	1	-
4	1	-
5	1	-
6	1	-
7	1	-
8	1	-
9	1	-
10	1	-
11	1	-
12	1	-
13	12	*Mysis* sp. and *Onisimus* sp.
15	1	-
16	2	-
17	3	-
18	9	*Apherusa* sp.
19	10	*Apherusa* sp.
20	2	-
21	2	-
22	3	-
23	2	-
24	1	-
25	-	-
26	-	-
27	3	-

*See Griffiths *et al.* 1975 for a description of the Hynes Pt. method of assessing stomach fullness. See Johnson and Richardson 1981 for descriptions of modification of this technique as we have applied it to oldsquaw stomachs.

Appendix 7. Thetis Island weather, 2200 h ADT 21 July 1980 to 1000 h ADT 9 August 1980.

1*	2	3	4	5	6	7	8	9	10	11
1	0.9	0.2	-0.6	1.0	22.5	14.5	17.3	50.	10	Fog
10	0.6	0.2	-1.1	0.8	9.7	9.7	-0.0	360.	10	Fog
16	0.6	0.2	2.2	21.0	3.2	3.2	-0.0	360.	00	Clear
24	0.6	0.2	0.3	21.0	17.7	13.6	11.4	40.	08	Clear
37	0.6	0.2	1.1	21.0	7.2	2.5	6.8	70.	09	From SW
40	0.3	0.2	3.3	21.0	4.8	3.7	3.1	40.	08	
31	0.3	0.2	0.6	21.0	9.7	9.5	-1.7	350.	10	Ovrcst
59	0.3	0.2	4.4	0.2	9.7	-1.7	-9.5	260.	10	Fog
64	0.2	0.2	5.6	11.2	3.2	0.0	3.2	90.	04	Pt Cldy
71	0.	0.	11.7	21.0	10.1	-8.8	-5.1	210.	10	Ovrcst
80	0.	0.	5.6	0.1	11.3	5.6	-9.8	300.	10	Fog
90	0.3	0.5	3.4	21.0	20.9	7.2	-19.7	290.	00	Clear
96	0.	0.3	4.4	1.6	16.1	-13.9	-8.0	210.	10	Fog
101	0.	1.1	2.8	1.0	24.1	-15.5	-18.5	230.	10	Ovrcst
103	0.2	0.2	1.7	21.0	8.0	1.4	-7.9	280.	10	Ovrcst
113	0.	0.	5.0	21.0	8.0	7.6	-2.8	340.	10	Ovrcst
122	0.2	0.	2.8	11.2	12.1	6.9	9.9	55.	10	Ovrcst
128	0.3	0.	1.7	14.4	19.3	11.1	15.8	55.	10	Ovrcst
139	0.3	0.	0.6	21.0	16.1	9.2	13.2	55.	999	Cld Lat
145	0.9	0.2	0.0	21.0	24.1	23.8	4.2	10.	999	
151	0.6	0.2	-0.6	14.4	29.0	16.6	23.7	55.	09	
168	0.6	0.2	-0.6	21.0	26.6	4.6	26.2	80.	10	Ovrcst
176	0.6	0.2	-1.1	14.4	27.4	4.8	26.9	80.	10	Ovrcst
187	0.5	0.2	1.1	11.2	12.1	10.5	6.0	30.	10	
192	0.8	0.2	0.6	16.0	30.6	5.3	30.1	80.	10	Lt Prcip
200	0.7	0.2	0.6	3.2	38.6	19.3	33.4	60.	10	Fog
208	0.3	0.	2.2	11.2	13.7	8.8	10.5	50.	999	
216	0.8	0.2	1.6	8.0	30.6	-5.3	30.1	100.	10	
224	0.5	0.2	1.1	11.2	24.1	12.1	20.9	60.	999	
240	0.5	0.2	-0.6	0.8	16.1	8.0	13.9	60.	10	Fog
233	0.8	0.	-0.6	3.2	14.5	7.2	12.5	60.	10	Ovrcst
248	0.3	0.	-0.6	11.2	11.3	3.9	10.6	70.	10	Ovrcst
256	0.2	0.	1.1	1.6	12.9	4.4	12.1	70.	07	Fog
264	0.2	0.	1.1	1.6	24.1	0.0	24.1	90.	10	Fog
272	0.3	0.	1.1	0.4	10.5	5.2	9.1	60.	10	Fog
281	0.2	0.	2.2	1.6	17.7	6.1	16.6	70.	10	Fog

...continued

Appendix 7. Continued.

1*	2	3	4	5	6	7	8	9	10	11
288	0.2	0.	2.2	21.0	4.8	1.7	4.5	70.	07	
297	0.	0.	3.3	21.0	2.4	-0.4	-2.4	260.	10	Ovrcst
304	0.3	0.2	4.4	2.2	12.9	6.4	-11.1	300.	999	Fog
312	0.5	0.6	1.7	999	14.5	12.5	-7.2	330.	10	Fog
320	0.2	0.2	0.6	1.6	12.9	-0.0	-12.9	270.	10	Mist
328	0.2	0.2	2.8	21.0	4.8	4.5	1.7	20.	09	
336	0.6	0.2	2.2	11.2	20.9	7.2	19.7	70.	08	
344	0.6	0.2	3.99	999	17.7	6.1	16.6	70.	08	
352	0.2	0.2	8.3	999	9.7	4.8	8.4	60.	09	
361	0.2	0.2	7.8	999	11.3	4.8	10.2	65.	06	Endwatch
370	0.2	0.2	10.0	999	8.9	-8.3	-3.0	200.	10	
376	0.	0.	7.8	21.0	0.	0.	0.	0.	10	Calm
376	0.5	0.3	5.6	0.2	17.7	15.3	-8.9	330.	10	Fog
386	0.6	0.2	4.4	16.0	17.7	17.7	-0.0	360.	10	Fog/Rain
396	0.5	0.2	3.9	0.2	8.9	8.9	-0.0	360.	10	Fog/Mist
404	0.3	0.2	3.3	21.0	8.0	8.0	-0.0	360.	999	
409	0.2	0.2	2.2	16.0	8.9	6.8	5.7	40.	10	Lt Rain
420	0.5	0.2	2.2	1.6	14.5	13.6	5.0	20.	999	
426	0.5	0.2	2.8	0.4	17.7	16.6	6.1	20.	10	Fog
435	0.5	0.2	1.7	0.8	14.5	12.5	7.2	30.	10	
445	0.4	0.2	3.9	21.0	12.6	6.3	10.9	60.	999	
450	0.5	0.2	3.3	21.0	13.7	6.8	11.8	60.	999	
456	0.5	0.2	2.8	0.1	25.7	4.5	25.4	80.	10	Fog
468	0.8	0.3	3.7	1.0	26.6	9.1	25.0	70.	10	Fog

*1=hour of study; 2=wave ht (m) on seaward side of Thetis Island; 3=wave ht (m) on leeward side of Thetis Island; 4=Temp (°C); 5=visibility (miles); 6=wind speed (km/hr); 7=N component of wind; 8=E component of wind; 9=wind direction (° origin); 10=cloud cover or opacity (%); 11=comments; 999=not recorded or unknown.

Appendix 8. Total counts of oldsquaws around Thetis Island, Alaska, 22 July to 9 August 1980.

	Total Number of Birds					
	Morning*			Evening**		
Date	E[†]	W	Total	E	W	Total
July 22	2916	475	3391	-	-	-
23	1958	1630	3588	-	-	-
24	-	-	-	-	-	-
25	1748	870	2618	-	-	-
26	1903	1911	3814	-	-	-
27	1106	-	-	-	-	-
28	1033	2050	3083	-	-	-
29	633	-	-	2530	1080	3610
30	275	215	490	2560	1345	3905
31	577	75	652	601	1130	1731
August 1	1982	800	2782	1023	1668	2691
2	310	132	442	-	1100	-
3	-	1270	-	706	360	1066
4	-	-	-	1700	941	2641
5	-	460	-	872	1270	2142
6	2945	2775	5720	1245	1600	2845
7	2301	724	3025	1675	2975	4650
8	669	510	1179	1941	2172	4113
9	575	385	980	626	1212	1838
$\bar{x}$	1397	952	2443	1407	1404	2839
±s.d.	911.7	804.6	1593.9	724.2	660.7	1120.4

*0530 h ADT to 1300 h ADT.

**1930 h ADT to 2330 h ADT.

[†] E=east half of island, W=west half.

Appendix 9. Relative proportion of male and female oldsquaws and those birds classified as resting, preening, moving and feeding in beach habitat in Area 2.

1*	2	3	4	5	6	7
121	100.0	0.0	0.0	0.0	82.4	17.6
122	96.6	2.3	1.1	0.0	94.9	5.1
123	92.8	5.6	1.6	0.0	-	-
124	98.4	0.8	0.8	0.0	-	-
125	98.4	1.6	0.0	0.0	-	-
126	96.8	2.4	0.8	0.0	-	-
128	96.8	0.8	2.4	0.0	-	-
138	-	-	-	-	94.5	5.5
139	73.3	26.0	0.8	0.0	97.7	2.3
140	83.8	14.9	1.4	0.0	94.4	5.6
141	91.9	8.1	0.0	0.0	-	-
142	77.9	22.1	0.0	0.0	85.7	14.3
143	88.7	10.7	0.7	0.0	-	-
144	87.5	12.0	0.5	0.0	98.2	1.8
146	0.0	100.0	0.0	0.0	-	-
147	0.0	100.0	0.0	0.0	100.0	0.0
148	86.1	13.9	0.0	0.0	-	-
151	97.6	1.6	0.8	0.0	72.0	28.0
154	70.5	18.0	0.0	11.5	90.2	9.8
156	56.3	43.7	0.0	0.0	83.1	16.9
157	42.3	40.8	16.9	0.0	73.2	26.8
159	53.4	45.1	1.5	0.0	86.5	13.5
160	70.8	25.3	2.6	1.3	-	-
162	1.8	98.2	0.0	0.0	97.4	2.6
163	39.2	60.0	0.8	0.0	97.6	2.4
164	93.3	6.7	0.0	0.0	89.0	11.0
165	90.9	7.6	1.5	0.0	88.0	12.0
166	95.3	4.3	0.3	0.0	95.2	4.8
167	10.0	90.0	0.0	0.0	98.1	1.9
168	0.0	100.0	0.0	0.0	-	-
169	65.6	34.4	0.0	0.0	97.7	2.3
170	94.7	5.3	0.0	0.0	96.7	3.3
171	99.3	0.7	0.0	0.0	99.3	0.7
172	48.3	51.7	0.0	0.0	99.3	0.7
173	96.7	3.3	0.0	0.0	100.0	0.0
174	59.8	39.7	0.0	0.4	97.5	2.5
175	80.6	18.9	0.6	0.0	97.3	2.7

...continued

Appendix 9. Continued.

1*	2	3	4	5	6	7
181	71.7	28.3	0.0	0.0	97.2	2.8
182	45.1	54.9	0.0	0.0	86.6	13.4
183	72.3	25.5	2.1	0.0	-	-
184	79.7	20.3	0.0	0.0	93.7	6.3
186	11.3	72.6	16.0	0.0	88.7	11.3
187	84.0	12.8	3.2	0.0	93.6	6.4
188	94.7	4.0	1.3	0.0	91.3	8.7
189	88.8	10.4	0.8	0.0	94.4	5.6
190	0.0	100.0	0.0	0.0	-	-
191	0.0	100.0	0.0	0.0	-	-
192	92.7	4.7	2.7	0.0	74.4	25.6
194	64.1	35.9	0.0	0.0	80.0	20.0
195	68.9	31.1	0.0	0.0	95.8	4.2
196	95.8	4.2	0.0	0.0	91.1	8.9
198	55.4	44.6	0.0	0.0	93.8	6.3
200	98.5	1.5	0.0	0.0	-	-
202	45.0	55.0	0.0	0.0	95.0	5.0
204	48.2	43.9	3.5	4.4	91.9	8.1
205	80.0	15.9	0.5	3.6	93.8	6.2
206	57.0	43.0	0.0	0.0	89.0	11.0
207	63.3	34.0	0.0	2.7	-	-
208	64.7	34.7	0.0	0.7	-	-
210	0.0	100.0	0.0	0.0	76.9	23.1
211	8.4	91.6	0.0	0.0	-	-
212	86.4	5.6	8.0	0.0	77.6	22.4
213	0.0	100.0	0.0	0.0	66.5	33.5
214	0.0	100.0	0.0	0.0	-	-
215	8.1	88.1	3.8	0.0	-	-
216	25.9	74.1	0.0	0.0	-	-
217	48.0	52.0	0.0	0.0	75.7	24.3
218	89.3	10.7	0.0	0.0	74.4	25.6
219	96.7	3.3	0.0	0.0	96.7	3.3
220	96.0	4.0	0.0	0.0	90.0	10.0
221	92.7	7.3	0.0	0.0	88.9	11.1
222	90.7	9.3	0.0	0.0	85.0	15.0
223	39.3	60.7	0.0	0.0	56.3	43.7
224	90.0	10.0	0.0	0.0	84.4	15.6
226	23.8	76.2	0.0	0.0	79.4	20.6
227	36.6	63.4	0.0	0.0	76.1	23.9

...continued

Appendix 9. Continued.

1*	2	3	4	5	6	7
228	84.0	16.0	0.0	0.0	88.7	11.3
229	69.9	28.3	1.8	0.0	81.4	18.6
230	89.7	10.3	0.0	0.0	91.9	8.1
231	91.3	8.7	0.0	0.0	-	-
232	91.3	8.7	0.0	0.0	-	-
233	53.1	46.9	0.0	0.0	88.8	11.3
234	85.6	10.4	4.0	0.0	94.4	5.6
235	0.0	100.0	0.0	0.0	-	-
247	89.8	10.2	0.0	0.0	88.3	11.7
248	88.3	10.0	1.7	0.0	-	-
250	23.9	76.1	0.0	0.0	77.5	22.5
251	20.0	80.0	0.0	0.0	-	-
252	70.3	29.7	0.0	0.0	-	-
253	68.3	31.7	0.0	0.0	-	-
254	61.7	38.3	0.0	0.0	75.0	25.0
257	58.6	39.7	1.7	0.0	-	-
258	90.0	10.0	0.0	0.0	-	-
259	87.5	10.8	1.7	0.0	85.6	14.4
260	85.3	14.7	0.0	0.0	86.7	13.3
263	-	-	-	-	60.0	40.0
265	70.1	29.9	0.0	0.0	85.2	14.8
280	79.5	20.5	0.0	0.0	-	-
281	65.6	34.4	0.0	0.0	92.6	7.4
282	81.4	18.6	0.0	0.0	90.5	9.5
283	85.8	14.2	0.0	0.0	91.0	9.0
285	77.9	22.1	0.0	0.0	60.8	39.2
286	79.7	20.3	0.0	0.0	31.2	68.8
287	94.7	5.3	0.0	0.0	-	-
288	96.0	4.0	0.0	0.0	-	-
333	66.4	33.6	0.0	0.0	69.2	30.8
334	77.5	22.5	0.0	0.0	32.6	67.4
338	64.7	35.3	0.0	0.0	-	-
339	91.9	5.1	3.0	0.0	3.0	97.0
340	95.5	3.2	1.3	0.0	18.7	81.3
357	82.5	17.5	0.0	0.0	21.3	78.7
358	87.4	12.6	0.0	0.0	40.5	59.5
359	96.6	3.4	0.0	0.0	43.8	56.2
360	92.5	7.5	0.0	0.0	14.0	86.0

*1=hour of study; 2=percent resting; 3=percent preening; 4=percent moving or traveling; 5=percent feeding; 6=percent males; 7=percent females.

Appendix 10. Relative proportion of male and female oldsquaws and those birds classified as resting, preening, moving and feeding in nearshore habitat in Area 2.

1*	2	3	4	5	6	7
122	98.4	0.8	0.8	0.0	92.8	7.2
124	99.2	0.0	0.8	0.0	-	-
125	99.0	0.0	1.0	0.0	96.0	4.0
128	93.6	6.4	0.0	0.0	-	-
138	87.5	5.7	6.8	0.0	97.0	3.0
139	94.9	2.1	2.4	0.6	99.5	0.5
140	99.3	0.4	0.2	0.0	98.5	1.5
141	96.4	3.3	0.2	0.0	99.3	0.7
142	95.3	0.7	1.3	2.7	100.0	0.0
143	86.1	8.2	5.2	0.4	99.1	0.9
144	86.7	8.7	2.7	2.0	97.3	2.7
146	91.0	1.0	8.0	0.0	92.0	8.0
147	95.2	2.4	1.6	0.8	95.0	5.0
151	96.0	0.8	2.4	0.8	96.0	4.0
154	61.8	7.3	30.9	0.0	85.5	14.5
155	83.5	3.9	8.7	3.9	95.3	4.7
156	90.3	1.6	6.5	1.6	94.4	5.6
157	87.1	6.8	3.0	3.0	-	-
158	94.7	2.7	1.3	1.3	-	-
159	68.2	11.4	17.0	3.4	88.6	11.4
160	65.4	25.0	5.8	3.8	97.1	2.9
162	75.6	6.4	2.6	15.4	94.9	5.1
163	92.7	4.7	2.5	0.0	99.6	0.4
164	82.9	8.7	7.6	0.7	97.8	2.2
165	93.5	4.0	2.2	0.4	97.8	2.2
166	92.0	5.8	1.5	0.7	99.6	0.4
167	92.0	6.2	0.4	1.5	98.4	1.6
168	93.5	6.1	0.4	0.0	94.3	5.7
169	79.9	9.0	9.7	1.4	100.0	0.0
170	75.7	20.8	2.8	0.7	99.3	0.7
171	95.3	4.7	0.0	0.0	99.2	0.8
172	95.3	4.7	0.0	0.0	100.0	0.0
173	96.7	3.3	0.0	0.0	100.0	0.0
174	94.0	5.3	0.0	0.7	98.7	1.3
175	77.2	8.7	11.4	2.7	98.0	2.0
176	93.3	6.7	0.0	0.0	97.3	2.7
179	71.2	15.4	7.7	5.8	98.1	1.9

...continued

Appendix 10. Continued.

1*	2	3	4	5	6	7
180	92.0	5.3	2.7	0.0	-	-
181	75.9	6.9	9.2	8.0	93.1	6.9
182	83.6	9.9	2.0	4.6	-	-
183	76.0	12.7	6.7	4.7	-	-
184	77.3	13.3	2.0	7.3	-	-
185	58.6	41.4	0.0	0.0	-	-
186	82.5	3.6	5.1	8.8	-	-
187	96.8	1.6	1.6	0.0	98.7	1.3
188	94.4	4.0	1.6	0.0	99.2	0.8
189	100.0	0.0	0.0	0.0	100.0	0.0
190	88.0	4.8	7.2	0.0	96.0	4.0
191	96.0	0.8	3.2	0.0	98.4	1.6
192	97.3	0.0	1.3	1.3	100.0	0.0
193	82.0	4.0	14.0	0.0	91.3	8.7
194	88.7	11.3	0.0	0.0	86.1	13.9
195	98.7	1.3	0.0	0.0	98.0	2.0
196	94.7	0.7	4.7	0.0	98.0	2.0
198	98.7	1.3	0.0	0.0	90.7	9.3
200	99.3	0.7	0.0	0.0	90.5	9.5
201	85.3	2.9	7.4	4.4	98.5	1.5
203	85.3	4.7	8.0	2.0	-	-
204	78.0	7.3	9.3	5.3	-	-
205	80.6	5.8	9.7	3.9	92.2	7.8
206	85.3	11.3	3.3	0.0	-	-
207	78.5	11.4	9.5	0.6	-	-
208	69.6	16.3	8.1	5.9	94.1	5.9
209	0.0	0.0	100.0	0.0	77.7	22.3
210	92.0	4.0	4.0	0.0	100.0	0.0
211	87.2	5.6	6.8	0.4	86.8	13.2
212	96.0	1.6	1.6	0.8	95.2	4.8
213	96.8	1.6	1.6	0.0	98.4	1.6
214	92.0	5.6	2.4	0.0	98.4	1.6
215	92.8	1.6	5.6	0.0	97.6	2.4
216	96.8	3.2	0.0	0.0	96.0	4.0
217	83.3	16.7	0.0	0.0	96.0	4.0
218	90.7	7.3	1.3	0.7	86.0	14.0
219	94.0	4.7	0.7	0.7	90.0	10.0
220	98.7	1.3	0.0	0.0	100.0	0.0
221	95.3	2.0	2.7	0.0	97.8	2.2

...continued

Appendix 10. Continued.

1*	2	3	4	5	6	7
222	95.3	4.7	0.0	0.0	93.3	6.7
223	60.0	14.7	20.0	5.3	65.8	34.2
224	92.7	6.7	0.7	0.0	94.7	5.3
225	94.3	1.9	3.8	0.0	-	-
226	67.1	10.1	22.8	0.0	92.4	7.6
227	84.3	9.4	5.9	0.4	95.6	4.4
228	85.0	3.9	6.7	4.4	93.3	6.7
229	84.0	4.1	6.8	5.0	95.9	4.1
230	72.5	13.2	12.1	2.2	95.6	4.4
231	83.5	0.5	0.5	15.5	92.0	8.0
232	75.4	12.8	8.3	3.5	95.5	4.5
233	62.8	20.5	16.7	0.0	87.2	12.8
234	75.2	6.4	13.6	4.8	96.8	3.2
235	88.8	11.2	0.0	0.0	96.8	3.2
241	82.8	6.9	10.3	0.0	-	-
242	25.0	64.8	10.2	0.0	-	-
244	91.8	2.7	4.5	0.9	-	-
245	84.5	6.9	1.7	6.9	100.0	0.0
247	87.1	8.1	4.8	0.0	100.0	0.0
248	94.2	1.7	4.2	0.0	-	-
250	63.3	22.4	11.9	2.4	91.0	9.0
251	83.4	4.0	8.5	4.0	-	-
252	78.0	13.2	6.9	1.9	-	-
253	73.9	7.2	18.8	0.0	-	-
254	81.1	4.9	11.6	2.4	-	-
258	72.6	22.6	3.6	1.2	-	-
260	96.0	2.0	2.0	0.0	95.3	4.7
262	97.5	0.8	1.7	0.0	-	-
263	96.7	2.0	1.3	0.0	-	-
265	68.2	9.0	21.4	1.5	-	-
267	91.5	0.0	8.5	0.0	-	-
270	88.7	8.1	2.4	0.8	-	-
276	96.9	1.6	0.0	1.6	-	-
280	76.9	15.4	6.2	1.5	-	-
281	80.1	11.4	7.8	0.6	96.4	3.6
282	73.5	9.5	12.8	4.3	98.1	1.9
283	80.3	11.3	8.4	0.0	-	-
284	64.3	6.3	28.6	0.8	88.9	11.1
285	70.9	11.8	17.3	0.0	95.5	4.5

...continued

Appendix 10. Continued.

1*	2	3	4	5	6	7
287	24.1	20.7	43.1	12.1	-	-
288	31.3	14.8	53.0	0.9	90.4	9.6
336	9.7	0.6	89.6	0.0	54.0	46.0
337	92.3	0.5	6.7	0.5	77.7	22.3
338	82.8	4.9	11.5	0.8	81.1	18.9
339	92.6	4.0	3.4	0.0	79.2	20.8
340	74.9	19.0	6.1	0.0	91.3	8.7
341	94.3	3.9	1.8	0.0	96.8	3.2
342	95.4	4.6	0.0	0.0	83.4	16.6
360	98.2	1.8	0.0	0.0	75.0	25.0

*1=hour of study; 2=percent resting; 3=percent preening, 4=percent moving or traveling; 5=percent feeding; 6=percent males; 7=percent females.

Appendix 11. Relative proportion of male and female oldsquaws and those birds classified as resting, preening, moving and feeding in offshore habitat in Area 2.

1*	2	3	4	5	6	7
121	76.0	1.7	22.3	0.0	96.0	4.0
125	92.0	4.0	4.0	0.0	-	-
126	99.2	0.0	0.8	0.0	-	-
128	89.6	0.8	0.8	8.8	-	-
137	76.8	1.1	4.2	17.9	-	-
138	84.1	3.4	0.0	12.5	-	-
147	31.7	0.0	6.7	61.7	-	-
156	-	-	-	-	96.4	3.6
161	70.3	1.3	18.2	10.2	-	-
162	39.6	3.8	11.3	45.3	-	-
163	-	-	-	-	0.0	100.0
164	58.4	0.0	19.5	22.1	-	-
165	59.9	2.0	10.5	27.6	-	-
166	0.0	100.0	0.0	0.0	-	-
166	60.0	0.0	40.0	0.0	-	-
167	20.0	0.0	46.2	33.8	-	-
168	95.2	4.0	0.8	0.0	87.2	12.8
169	63.2	3.7	24.3	8.8	99.1	0.9
179	-	-	-	-	98.9	1.1
181	-	-	-	-	98.8	1.3
190	59.1	4.4	21.9	14.6	-	-
191	4.2	1.4	85.9	8.5	97.1	2.9
192	99.1	0.9	0.0	0.0	-	-
193	90.2	2.5	3.3	4.1	-	-
194	58.2	2.7	22.7	16.4	97.1	2.9
198	85.8	4.2	2.5	7.5	100.0	0.0
207	-	-	-	-	98.1	1.9
210	45.0	0.0	26.7	28.3	-	-
211	63.8	1.3	18.1	16.9	-	-
212	57.1	0.0	9.2	33.7	-	-
213	80.2	1.6	1.6	16.7	98.4	1.6
214	72.6	1.1	21.3	5.0	-	-
215	72.2	0.0	27.8	0.0	96.1	3.9
216	84.1	0.0	9.0	6.9	-	-
217	71.7	1.7	26.7	0.0	94.2	5.8
218	69.7	0.0	28.7	1.6	91.0	9.0
222	84.7	5.3	3.3	6.7	-	-

...continued

Appendix 11. Continued.

1*	2	3	4	5	6	7
224	73.6	9.9	4.1	12.4	90.8	9.2
225	86.7	1.1	1.1	11.1	-	-
233	42.7	0.0	24.5	32.7	100.0	0.0
234	17.0	0.0	72.3	10.6	-	-
235	17.9	0.0	33.7	48.4	-	-
251	82.8	0.0	6.5	10.8	-	-
253	87.7	0.0	10.5	1.8	-	-
254	78.9	10.6	9.9	0.7	-	-
257	18.0	0.0	24.0	58.0	-	-
262	83.9	2.8	10.0	3.3	-	-
263	81.7	2.5	15.0	0.8	-	-
270	98.0	2.0	0.0	0.0	-	-
281	74.2	1.6	11.3	12.9	-	-
284	87.4	1.9	8.9	1.7	-	-
286	11.1	1.4	34.7	52.8	97.2	2.8
288	66.7	0.0	9.8	23.5	-	-
289	92.7	4.9	0.7	1.6	-	-
297	34.4	1.6	10.4	53.6	95.2	4.8
298	36.0	3.0	1.0	60.0	96.0	4.0
299	35.2	3.2	1.6	60.0	92.8	7.2
300	48.0	1.6	7.2	43.2	97.6	2.4
301	60.0	5.6	4.0	30.4	95.2	4.8
302	30.6	0.0	9.3	60.2	89.8	10.2
303	68.9	0.0	3.3	27.8	94.4	5.6
304	18.3	1.0	11.5	69.2	84.6	15.4
306	73.2	14.8	8.6	3.3	-	-
307	68.8	14.6	1.5	15.1	87.0	13.0
308	57.5	22.8	11.4	8.4	94.8	5.2
309	92.2	5.2	2.1	0.5	85.2	14.8
310	90.7	5.3	0.0	4.0	83.3	16.7
311	90.4	6.3	1.9	1.4	88.8	11.2
312	90.6	5.0	3.9	0.6	79.6	20.4
313	0.0	0.0	100.0	0.0	93.6	6.4
314	51.6	0.0	40.5	7.9	-	-
315	2.4	3.2	94.4	0.0	-	-
316	54.4	2.4	38.4	4.8	-	-
317	89.6	4.8	4.0	1.6	93.6	6.4
318	24.8	3.2	68.0	4.0	-	-
319	16.1	0.8	5.1	78.0	98.3	1.7

...continued

Appendix 11. Continued.

1*	2	3	4	5	6	7
322	-	-	-	-	94.1	5.9
324	86.0	5.8	1.2	7.0	-	-
331	5.8	38.5	19.2	36.5	-	-
334	21.6	6.8	35.2	36.4	65.7	34.3
345	69.8	1.6	7.1	21.4	-	-
346	87.3	1.6	3.2	7.9	-	-
347	64.3	3.5	2.6	29.6	71.0	29.0
348	89.2	0.0	0.0	10.8	-	-
349	89.1	0.0	0.0	10.9	-	-
351	40.4	3.8	13.5	42.3	84.6	15.4
352	56.4	6.4	1.6	35.6	85.2	14.8
355	5.7	7.5	24.5	62.3	-	-
356	24.6	7.7	33.8	33.8	-	-
357	23.4	32.8	9.4	34.4	-	-
360	98.3	0.0	1.7	0.0	69.0	31.0
408	89.3	0.0	7.9	2.9	-	-

*1=hour of study; 2=percent resting; 3=percent preening; 4=percent moving or traveling; 5=percent feeding; 6=percent males; 7=percent females.

Appendix 12. Relative proportion of male and female oldsquaws and those birds classified as resting, preening, moving and feeding in beach habitat in Area 1.

1*	2	3	4	5	6	7
121	80.0	9.0	11.0	0.0	44.3	55.7
122	98.3	0.6	1.2	0.0	66.3	33.7
124	97.4	2.6	0.0	0.0	-	-
125	95.6	1.5	2.9	0.0	-	-
126	87.9	7.9	4.3	0.0	-	-
139	83.7	16.3	0.0	0.0	78.7	21.3
140	92.3	7.7	0.0	0.0	-	-
141	96.3	3.7	0.0	0.0	-	-
143	93.0	7.0	0.0	0.0	-	-
144	72.5	27.5	0.0	0.0	86.8	13.2
147	87.1	8.6	4.3	0.0	50.7	49.3
148	94.4	2.4	3.2	0.0	-	-
163	79.1	19.8	1.2	0.0	89.7	10.3
165	88.3	10.2	1.6	0.0	-	-
166	88.2	11.8	0.0	0.0	-	-
167	95.6	4.4	0.0	0.0	87.8	12.2
168	-	-	-	-	87.5	12.5
187	92.5	5.7	1.9	0.0	88.7	11.3
190	90.0	8.8	1.3	0.0	57.5	42.5
191	96.6	2.8	0.7	0.0	49.0	51.0
192	98.1	1.9	0.0	0.0	46.6	53.4
220	61.1	38.9	0.0	0.0	-	-
245	53.6	46.4	0.0	0.0	64.3	35.7
259	73.1	26.9	0.0	0.0	-	-
285	89.9	10.1	0.0	0.0	-	-
286	65.7	34.3	0.0	0.0	65.7	34.3
287	97.3	2.7	0.0	0.0	-	-
288	27.9	72.1	0.0	0.0	64.0	36.0
290	81.0	19.0	0.0	0.0	10.8	89.2
291	16.5	81.0	1.3	1.3	-	-
292	92.6	7.4	0.0	0.0	40.4	59.6
293	0.0	100.0	0.0	0.0	-	-
295	89.2	5.8	5.0	0.0	67.5	32.5
296	88.7	11.3	0.0	0.0	74.0	26.0
303	68.0	31.2	0.8	0.0	78.4	21.6
304	63.6	36.4	0.0	0.0	-	-
306	96.8	3.2	0.0	0.0	-	-

...continued

Appendix 12. Continued.

1*	2	3	4	5	6	7
307	94.9	4.5	0.6	0.0	88.1	11.9
308	92.5	7.5	0.0	0.0	94.3	5.7
309	100.0	0.0	0.0	0.0	90.1	9.9
310	79.6	20.4	0.0	0.0	74.5	25.5
311	90.0	8.6	1.5	0.0	75.8	24.2
312	94.4	5.6	0.0	0.0	67.8	32.2
313	56.9	41.4	1.7	0.0	-	-
314	61.9	38.1	0.0	0.0	-	-
318	56.6	43.4	0.0	0.0	-	-
319	54.4	43.7	1.9	0.0	77.7	22.3
321	70.1	29.9	0.0	0.0	83.6	16.4
322	57.1	42.9	0.0	0.0	74.3	25.7
325	61.4	38.0	0.6	0.0	81.5	18.5
326	88.8	11.2	0.0	0.0	88.5	11.5
327	68.3	30.2	1.4	0.0	65.4	34.6
328	93.7	5.8	0.5	0.0	54.8	45.2
333	66.7	33.3	0.0	0.0	56.1	43.9
335	85.9	14.1	0.0	0.0	44.5	55.5
336	96.0	4.0	0.0	0.0	26.0	74.0
358	50.9	49.1	0.0	0.0	35.8	64.2
359	71.2	28.8	0.0	0.0	53.2	46.8
360	98.6	1.4	0.0	0.0	33.3	66.7
407	61.7	36.7	1.7	0.0	38.3	61.7
408	78.5	15.1	6.5	0.0	69.9	30.1

*1=hour of study; 2=percent resting; 3=percent preening, 4=percent moving or traveling; 5=percent feeding; 6=percent males; 7=percent females.

Appendix 13. Relative proportion of male and female oldsquaws and those birds classified as resting, preening, moving and feeding in nearshore habitat in Area 1.

1*	2	3	4	5	6	7
123	96.0	0.0	4.0	0.0	-	-
138	85.4	2.4	0.0	12.2	-	-
139	83.6	13.1	3.3	0.0	-	-
143	34.0	13.2	22.6	30.2	-	-
148	94.7	0.0	4.0	1.3	92.8	7.2
151	94.2	0.0	3.8	1.9	-	-
162	84.1	7.2	5.1	3.6	-	-
164	95.8	0.8	0.0	3.3	70.2	29.8
165	78.4	1.1	15.9	4.5	-	-
166	89.3	5.4	1.3	4.0	-	-
167	92.6	2.0	0.0	5.4	-	-
169	0.0	2.3	96.6	1.1	-	-
171	86.9	6.2	6.2	0.7	98.6	1.4
172	93.3	5.0	0.8	0.8	98.3	1.7
174	94.0	1.3	4.7	0.0	96.0	4.0
189	97.0	0.0	3.0	0.0	97.0	3.0
193	97.0	0.0	2.0	1.0	35.6	64.4
241	86.2	1.5	4.6	7.7	-	-
248	44.0	20.0	34.0	2.0	58.2	41.8
261	91.5	5.1	1.7	1.7	-	-
271	84.0	8.0	2.7	5.3	-	-
272	81.4	2.9	7.1	8.6	-	-
285	26.7	0.0	68.3	5.0	-	-
286	82.0	6.0	6.0	6.0	-	-
287	82.7	4.0	6.7	6.7	100.0	0.0
288	57.6	1.5	40.9	0.0	-	-
290	88.9	3.3	7.8	0.0	62.0	38.0
292	94.7	3.3	2.0	0.0	78.0	22.0
296	65.0	3.3	30.0	1.7	78.3	21.7
303	13.7	3.9	3.9	78.4	-	-
304	31.6	3.5	7.0	57.9	-	-
306	43.3	21.7	30.0	5.0	-	-
308	87.5	4.5	2.3	5.7	95.5	4.5
309	82.3	6.4	4.3	7.1	95.7	4.3
310	87.3	5.6	2.0	5.1	91.8	8.2
312	98.3	0.8	0.0	0.8	99.2	0.8
313	7.9	7.2	84.9	0.0	-	-

...continued

Appendix 13. Continued.

1*	2	3	4	5	6	7
314	74.7	0.6	14.4	10.3	-	-
315	24.0	1.6	71.2	3.2	-	-
316	84.9	0.8	12.7	1.6	-	-
317	96.7	0.0	0.0	3.3	96.0	4.0
318	82.4	8.8	4.8	4.0	94.4	5.6
319	93.2	4.1	2.7	0.0	97.3	2.7
320	69.2	0.0	23.1	7.7	57.7	42.3
322	72.2	19.4	5.6	2.8	86.1	13.9
323	92.9	0.0	3.1	3.9	95.3	4.7
324	93.3	5.6	1.1	0.0	95.6	4.4
325	71.9	14.3	1.5	12.2	94.2	5.8
326	67.8	1.7	0.9	29.6	90.9	9.1
327	87.9	6.9	1.1	4.0	89.7	10.3
328	80.1	9.9	3.3	6.6	-	-
329	74.0	17.3	0.7	8.0	-	-
330	56.2	20.2	4.5	19.1	-	-
331	50.0	15.4	15.4	19.2	-	-
332	28.6	21.4	23.5	26.5	-	-
333	80.9	3.7	2.7	12.8	89.4	10.6
334	83.6	13.1	3.3	0.0	47.5	52.5
335	90.9	5.6	0.4	3.0	68.5	31.5
336	85.0	13.6	1.4	0.0	76.4	23.6
337	91.9	8.1	0.0	0.0	72.7	27.3
338	94.2	3.3	0.0	2.6	56.7	43.3
339	93.5	4.6	0.0	1.9	67.1	32.9
340	93.1	5.4	1.0	0.5	80.8	19.2
341	92.5	6.8	0.0	0.6	81.4	18.6
351	83.1	7.7	0.0	9.2	86.2	13.8
358	71.1	16.9	3.6	8.4	-	-
359	92.1	3.9	3.1	0.8	90.7	9.3
360	95.6	3.8	0.0	0.6	81.8	18.2

*1=hour of study; 2=percent resting; 3=percent preening; 4=percent moving or traveling; 5=percent feeding; 6=percent males; 7=percent females.

Appendix 14. Relative proportion of male and female oldsquaws and those birds classified as resting, preening, moving and feeding in offshore habitat in Area 1.

1*	2	3	4	5	6	7
125	-	-	-	-	52.4	47.6
146	78.2	0.0	17.2	4.6	-	-
152	82.3	12.0	5.6	0.0	64.2	35.8
164	46.9	3.8	26.3	23.1	-	-
165	24.3	0.0	41.2	34.6	-	-
166	12.0	0.0	38.0	50.0	-	-
167	77.9	1.0	4.8	16.3	93.4	6.6
168	9.2	0.0	18.5	72.3	-	-
169	82.6	3.4	8.1	6.0	98.7	1.3
175	0.0	0.0	96.8	3.2	-	-
180	-	-	-	-	96.7	3.3
181	-	-	-	-	98.3	1.7
193	91.7	2.5	0.8	5.0	90.0	10.0
194	97.3	2.0	0.0	0.7	100.0	0.0
206	-	-	-	-	92.2	7.8
210	55.8	0.0	19.4	24.8	-	-
211	30.7	1.3	2.7	65.3	-	-
212	27.2	2.2	4.3	66.3	-	-
213	78.4	1.4	5.4	14.9	-	-
214	88.4	2.9	5.8	2.9	-	-
217	94.0	2.0	0.0	4.0	96.7	3.3
222	80.0	0.0	0.0	20.0	-	-
223	87.7	4.6	0.0	7.7	-	-
226	-	-	-	-	93.1	6.9
227	22.0	6.0	4.0	68.0	-	-
233	19.0	0.0	17.6	63.4	-	-
234	52.8	1.9	26.4	18.9	-	-
235	23.9	3.4	55.7	17.0	-	-
249	36.8	10.3	2.9	50.0	-	-
256	83.8	4.1	0.0	12.2	-	-
257	79.1	4.5	4.5	11.8	-	-
261	58.6	5.7	25.7	10.0	-	-
285	54.2	0.0	45.8	0.0	-	-
289	94.2	3.7	0.4	1.8	-	-
290	78.3	6.7	14.2	0.8	75.8	24.2
297	32.8	4.8	8.0	54.4	94.4	5.6
298	29.6	3.2	12.8	54.4	94.4	5.6

...continued

Appendix 14. Continued.

1*	2	3	4	5	6	7
299	34.9	8.7	5.6	50.8	-	-
300	52.8	4.0	7.2	36.0	-	-
301	45.7	4.7	6.3	43.3	94.4	5.6
302	33.6	4.8	3.2	58.4	96.8	3.2
303	8.7	0.0	5.5	85.8	-	-
304	17.3	0.0	8.1	74.6	-	-
306	16.4	0.0	72.7	10.9	-	-
307	0.0	2.6	91.3	6.1	-	-
308	43.2	11.6	27.1	18.1	85.6	14.4
309	20.3	7.0	63.9	8.9	94.1	5.9
310	63.3	2.2	21.1	13.3	98.1	1.9
311	52.2	5.4	26.1	16.3	94.6	5.4
315	11.6	5.1	80.4	2.9	-	-
317	91.2	5.6	3.2	0.0	95.2	4.8
319	41.3	5.2	34.8	18.7	-	-
320	16.7	3.1	9.4	70.8	-	-
321	55.2	3.4	2.3	39.1	-	-
323	56.9	3.9	13.7	25.5	-	-
326	72.7	7.1	9.1	11.1	-	-
327	50.5	18.7	1.9	29.0	-	-
328	71.2	5.8	0.0	23.1	-	-
329	19.5	1.3	55.7	23.5	-	-
330	49.5	5.7	26.7	18.1	-	-
331	67.9	11.5	3.8	16.7	-	-
332	75.8	5.5	9.4	9.4	-	-
333	60.6	2.1	14.1	23.2	-	-
334	67.9	2.5	11.9	17.6	78.0	22.0
340	98.1	1.9	0.0	0.0	-	-
345	71.2	1.6	9.6	17.6	-	-
346	74.4	1.6	9.6	14.4	-	-
347	50.4	1.6	12.8	35.2	56.0	44.0
348	58.5	0.0	4.4	37.0	-	-
349	73.9	2.5	16.8	6.7	88.0	12.0
350	56.3	5.3	6.0	32.3	90.7	9.3
351	78.7	6.7	0.7	14.0	87.3	12.7
352	60.0	5.0	0.0	35.0	-	-
353	46.9	18.5	6.2	28.4	-	-
357	59.1	4.3	11.8	24.7	-	-
358	25.4	15.7	52.2	6.7	72.4	27.6
359	76.3	20.3	1.7	1.7	87.5	12.5
407	68.4	2.7	6.6	22.3	70.9	29.1
408	39.2	0.0	8.1	52.8	-	-

*1=hour of study; 2=percent resting; 3=percent preening; 4=percent moving or traveling; 5=percent feeding; 6=percent males; 7=percent females.

Appendix 15. Summary of information concerning diving (feeding) behavior of oldsquaws in nearshore habitats at Thetis Island, Alaska.

Sex	Number of Dives Recorded	Water Depth (m)	Time Submerged (Feeding) (s)	Time at Surface (s)
-	1	-	19.6	
-	5	-	27.7 ± 2.1	13.1 ± 2.6
-	4	-	28.2 ± 2.0	14.6 ± 2.8
-	1	-	28.7	8.4
-	1	-	28.6	10.5
-	1	-	28.4	11.2
-	1	-	31.0	10.9
-	1	-	29.1	14.7
-	1	-	29.8	8.3
-	1	-	28.8	8.3
-	1	-	28.7	8.9
-	6	-	28.3 ± 1.3	9.3 ± 1.2
F	8	∿1	21.0 ± 2.1	7.9 ± 1.1
M	4	∿4	25.6 ± 2.1	8.6 ± 1.1
F	1	∿4	23.5	8.2
M	5	∿4	26.8 ± 1.2	8.5 ± 0.9
M	1	∿4	23.6	9.1
-	5	-	23.2 ± 4.1	10 14
-	1	-	26.9	7
-	1	-	24.4	14
-	1	-	31.4	8
-	1	-	30.2	7
-	1	-	20.8	10
-	1	-	25.9	7
-	1	-	23.2	6
-	1	-	25.2	20
M	3	shallow	27.5 ± 3.0	7.7 ± 1.2
M	6*	deep	29.7 ± 1.0	8.9 ± 1.5
-	6	-	27.6 ± 0.8	10.5 ± 0.8
-	1	-	29	8
-	1	-	31	10
F	1	-	19	21
F	5*	-	17.7 ± 3.9	9.8 ± 6.4
F	1	-	31	7

...continued

Appendix 15. Continued.

Sex	Number of Dives Recorded	Water Depth (m)	Time Submerged (Feeding) (s)	Time at Surface (s)
F	1	-	25	10
F	1	-	34	-
F	1	-	30	8
				10
F	3	-	26.7 ± 7.5	11.0 ± 7.9
M	1	-	39	25
M	5	-	23.8 ± 3.6	5.8 ± 1.6
Total M=6	25		27.4 ± 4.6	6.7 ± 3.1
Total F=8	22		21.3 ± 4.8	9.1 ± 3.7
Total=40	90		24.8 ± 3.8	10.1 ± 3.9

*Same bird as in preceding row.

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