OUTER CONTINENTAL SHELF ENVIRONMENTAL ASSESSMENT PROGRAM

The Environment and Resources of the Southeastern Chukchi Sea

A Review of Scientific Literature

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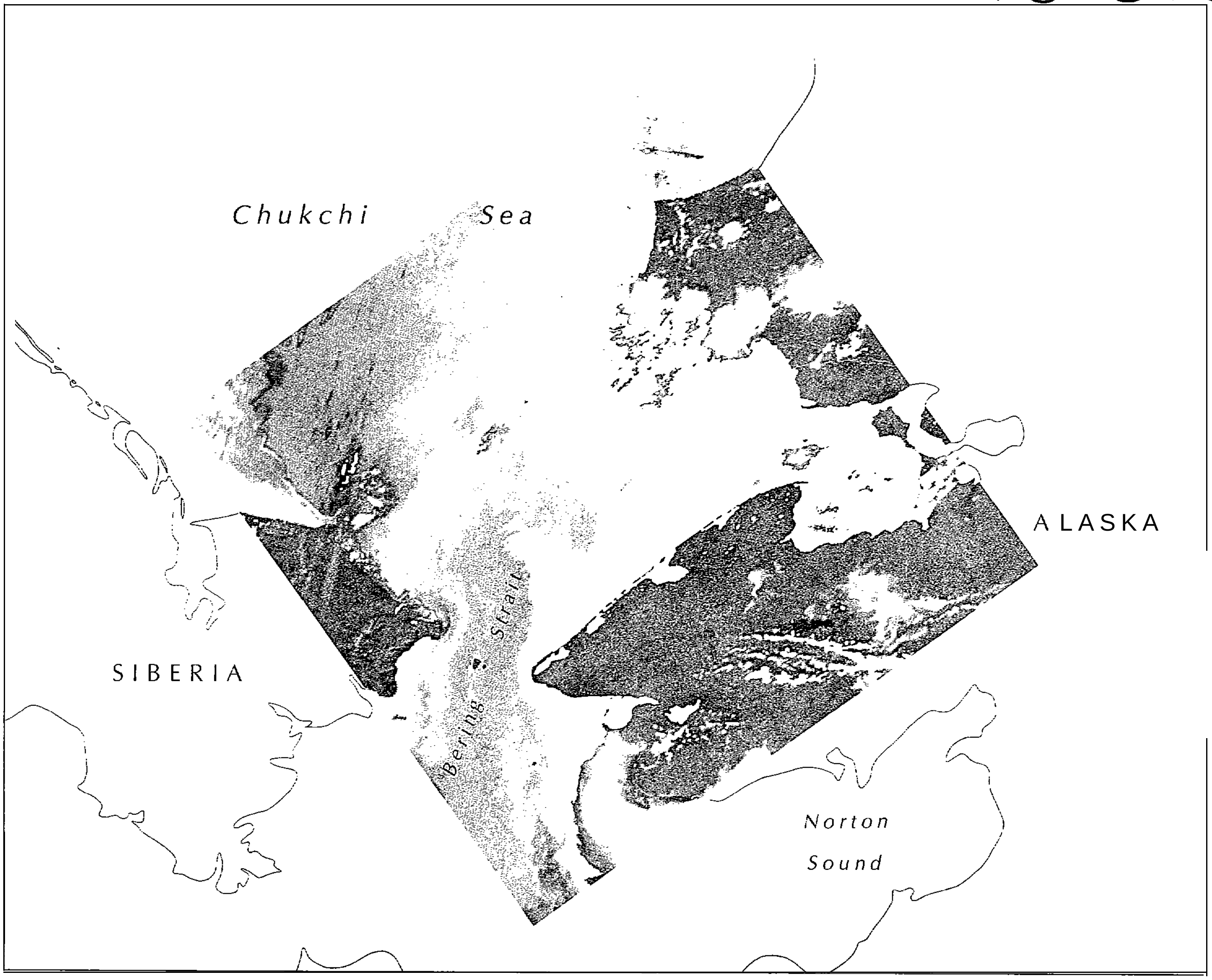

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Cover Illustration—*The satellite image reproduced on the cover depicts surface-water thermal gradients as shades of gray (darker shades represent cooler water). Cloud cover, mostly in the vicinity of land, appears light gray. From a false-color original courtesy of Dr. W. Stringer, University of Alaska.*

The Environment and Resources of the Southeastern Chukchi Sea

A Review of Scientific Literature

Edited by

M.J. Hameedi and A.S. Naidu

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National Oceanic and Atmospheric Administration,
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Preface

The Kotzebue Sound-Chukchi Bight (Hope Basin) region can be classified as one of the "turbid coastal environments" that have been the subject of increased research in recent years and were the focus of three international symposia during this decade (for a review, see the Canadian Journal of Fisheries and Aquatic Sciences Vol. 40 Supplement 1, 1983). These environments are known to be extremely complex; they are more difficult to study than the oceanic environments because of the larger and more frequent variabilities of the environmental characteristics and a more profound influence of the marine, terrestrial, and atmospheric factors. Most of these environments have experienced population growth and industrialization and also, as a result, a suite of environmental problems and resource-use conflicts.

The year-round availability and the variety of biological resources in Kotzebue Sound and on the adj scent tundra, high brush, and forests have nurtured a more stable (non-transient) society and a unique cultural heritage among the people of the region. The subsistence dependencies on the marine resources, the dearth of previous oceanographic and ecological data, and the nascent state of industrial activities in the region have all exacerbated the need for intensive and focused research in view of planned offshore oil and gas development. The current (July 1987) plarming schedule calls for a "frontier exploration" lease sale (Sale 133) in the region (Hope Basin) in May 1992.

The preparation of this document represents the first phase of a study on the physiochemical, geological, and biological features and processes extant in the region. The study is part of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), which is established through an interagency agreement between the Minerals Management Service (MMS), U.S. Department of the Interior, and the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce. OCSEAP is a comprehensive, multidisciplinary environmental studies program providing MMS and other pertinent agencies with environmental data and results of original research, as well as data synthesis reports, to help them formulate leasing decisions and to develop management strategies to obviate or mitigate undesirable effects of outer continental shelf oil and gas development. This study is being funded as a cooperative effort between NOAA and the Univeristy of Alaska in order to share the cost and resources for the successful accomplishment of the study objectives, to maintain flexibility in the study protocol, to accommodate unanticipated data requirements, and to foster government-academia partnership in areas of mutual benefit.

The review of literature, as summarized in this document, was a prerequisite for the formulation of testable scientific hypotheses leading to the observational and experimental research protocols. The chapters are authored by the principal participants of the study. Field work for the study has recently been concluded. It is anticipated that the results of the study will provide an improved understanding of the hydrodynamical, sedimentological, and ecological aspects of the region and, perhaps, some quantitative data (or simulation models) for use in resource management decisions.

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1

Introduction

M.). Hameedi

1.1 REGIONAL SETTING

The Arctic Circle bisects Kotzebue Sound and the adjoining Chukchi Bight (the word "bight" is used herein to describe a rather large bay situated between Lisburne and Seward peninsulas) in the southeastern Chukchi Sea. The city of Kotzebue is located 42 km inside the circle, at the northern tip of the Baldwin Peninsula, which is bound on the west by the sound and on the east by Hotham Inlet (locally known as Kobuk Lake). The sound was named after Otto von Kotzebue, a German serving the Russian Navy, who described the sound following the voyage of the *Rurik* in 1816. It is possible that Russians might have known about the sound's existence nearly 100 years earlier by way of maps of the region prepared by Mikhail Gvozdev and Ivan Fedorov (Alaska Geographic 1981).

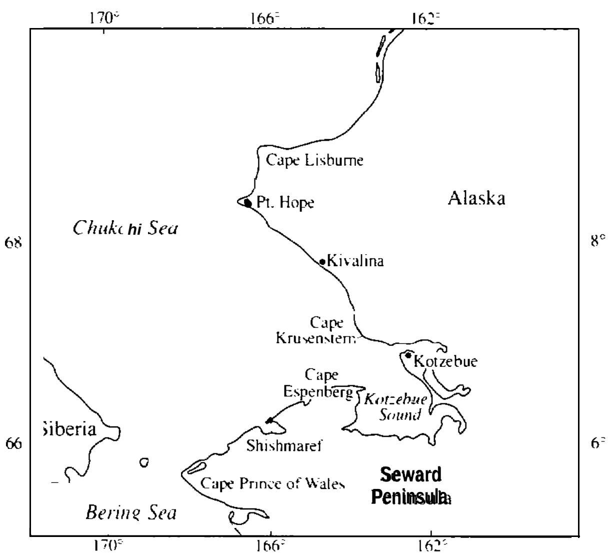

Figure 1.1 The northern Bering and Chukchi seas.

The coastal geomorphology of the region is highly varied, consisting of sand and gravel beaches, isolated coastal bluffs, large deltas, and estuaries. Coastal mountain ranges (DeLong, Baird, and Schwatke mountains) are extensive; one of these also has a 750 km^2 desert area of shifting sands and 30-m-high sand dunes. The runoff of the two large rivers-the Noatak and the Kobuk—and the smaller Selawik River enters Kotzebue Sound via Hotham Inlet and a narrow channel between the Baldwin Peninsula and the mainland near the Noatak River delta (Fig. 1.1).

1.2 CLIMATE

Kotzebue Sound's nearshore region has a maritime climate when the water is ice-free, late May to October. The climate changes to a continental type when sea ice is formed.

The occurrence of cyclonic storms, which are frequent from October to April, produces average winter temperatures that are not as low as one might expect at this latitude. Most storms cause blizzard conditions during the winter. The absence of prominent shelter-terrain usually results in unimpeded air movement over the region, although mountains on the Seward Peninsula probably deflect the path of some of the storms.

During the open-water period, skies are cloudy, westerly winds predominate, daily temperatures are fairly uniform, relative humidity exceeds 85%, and fog occurs frequently. Such normal conditions are altered only by the passage of cyclonic storms or by pressure systems strong enough to overcome local climatic tendencies. During the winter, winds are predominantly from the east, humidity is lower but still exceeds 70%, and skies are less cloudy. Uneven heat radiation from adjoining land and water areas maintains persistent windy conditions throughout the year (Table 1,1).

Total precipitation for a normal year is -low, less than 22 cm, but is distributed over 107 days. Snowfall occurs 9 to 10 months during the year.

Table 1.1 Monthly mean air-temperature (“C), precipitation (cm), and wind speed (m/s) and direction for a normal year for Kotzebue Sound. Extreme recorded values are given in parentheses for each parameter; low values for precipitation and wind speed are less than L The data are based on a record of 43 years for temperature and precipitation and 39 years for wind speed and direction (NOAA/NCDC 1985).

	TEMP.	PRECIP.	WIND
January	–19 (-44 to 04)	0.89 (4.57)	6.53 E (32.1 8 E)
February	21 (–47 to 04)	0.76 (2.79)	5.63 E (25.93 E)
March	–18 (-44 to 04)	0.79 (3.05)	5.50 E (29.50 E)
April	-11 (-42 to 09)	0.79 (3.30)	5.59 ESE (21 .01 SE)
May	0 (-28 to 23)	0.79 (2.54)	4.92 W (21.46 SE)
June	7 (-07 to 28)	1.35 (3.56)	5.50 w (20.56 SE)
July	12 (–01 to 29)	3.71 (8.89)	5.77 w (20.1 2 SE)
August	11 (-01 to 26)	5.16 (13.21)	5.86 W (1 7.43 NW)
September	5 (-09 to 21)	3.81 (1 0.92)	5.90 E (20.56 E)
October	 (–09-: 11)	1.55 (6.1 O)	6.12 ENE (24.58 E)
November	–13 (-38 to 03)	1.19 (4.57)	6.61 E (27.27 E)
December	–15 (-44 to 03)	0.89 (2.03)	5.81 NE (28.1 6 E)

1.3 MARINE ENVIRONMENT

The marine environment of interest, including the Chukchi Bight and Kotzebue Sound, lies within the continental shelf in waters less than 60 m deep. The sea bottom is generally flat, with depth gradients ranging from immeasurably low to 0.8m/km. Two topographic features predominate the otherwise featureless plain: the Cape Prince of Wales Shoal, which is a large shoal extending northward from Cape Prince of Wales, and the Hope Sea Valley, situated south and west of Pt. Hope. The shoal extends more than 120 km northward from the Seward Peninsula, and has an east–west width of 30 to 50 km (Creager and McManus 1966). The shoal is much steeper on its western side and is oriented nearly parallel to the axis of the predominantly northward-flowing current from the Bering Strait. The shoal was probably formed and is presently maintained by sediment brought in from the northern Bering Sea by ocean currents and storms (McManus and Creager 1963). In turn, the shoal effectively shields the nearshore areas to its east from this sediment source.

The configuration of the Hope Sea Valley is not well-defined, particularly to the west. Its maximum relief is only about 9 m, with gradients ranging from 0.2 to 1.0 m/km (Creager and McManus 1966).

Kotzebue Sound is generally 10 to 18 m deep west of the Baldwin Peninsula; the sound's entrance to the southeastern Chukchi Sea has a maximum depth of 24 m. A well-defined sill is not evident, although Creager and McManus (1966) speculated that a southwest-northeast-trending feature in the central portion of the sound with a relief of 2 m is a sill. East of the Baldwin Peninsula, in Hotham Inlet, water depth is less than 6 m.

The presence of sea ice is the most dominant physical feature in the marine environment. The seasonal formation, movement, and melting of sea ice play a dominant role not only in determining the pattern of water circulation but also in biological productivity and habitat use. Within Kotzebue Sound the duration of the maximum ice-free period is estimated as 126 days, and about 150 days in the middle of the Chukchi Bight (Stringer and Groves 1986).

Tides in the region are the mixed, semidiurnal type. Tidal elevations are low (mean tidal range at Kiwalik in Kotzebue Sound is 0.6 to 0.8 m); only when accompanied by strong winds does the tide inundate the coastline with storm surges. Storm surges and coastal flooding in Kotzebue Sound are usually caused by storms generating persistent westerly winds of 20 m/s or more. The presence of sea ice impedes the transfer of momentum from the atmosphere to the sea, thereby affecting the spatial and temporal distribution of storm waves and surges. Water currents are primarily tidal, particularly within Kotzebue Sound, where current speeds are of the order of 10 cm/s. The swift, northward current through the Bering Strait flows around the Cape Prince of Wales Shoal, where its speed decreases. A large eddy is usually formed east of the distal end of the shoal, and intensifies the northwesterly movement of water between Kivalina and Pt. Hope when combined with the deflection of the current by land along the north side of the bight and locally-formed currents.

1.4 COASTLINE

The nearly 2,500-km-long coastline extending from Cape Prince of Wales to Pt. Hope is predominantly erosional. The coastline consists of barrier islands backed with lagoons, gravel beaches, tundra scarps, rocky headlands, and deltas (Hayes and Ruby 1979). Sand barrier-islands and spits characterize the southern shoreline between Cape Prince of Wales and Goodhope Bay. The shoreline is convex toward the Chukchi Sea; sediment transport is generally in a northeast direction toward Kotzebue Sound. Cape Espenberg is an example of this trend in sediment transport, although a number of recurved spits built into the lagoons document local reversals in transport direction. There is no major source of sediment to the Chukchi Sea from the northern side of the Seward Peninsula or the adjacent hinterland, as evident in the nearly continuous barrier-island chain, poorly drained coastal plain, and presence of large coastal lagoons that are nearly filled with sediment. However, considerable volumes of fine-grained sediments are supplied to the central Chukchi Sea from the Yukon River outflow via the Bering Strait (Naidu and Mowatt 1983),

The northern side of the bight area is characterized by continuous barrier islands and spits, both of which are made of sand and gravel. The shoreline is concave toward the Chukchi Sea. Unlike other parts of the study area, the stretch of the coastline between Pt. Thomson and Kivalina is relatively well-studied, both in terms of the geology and the archeology of the beach-ridge plain. The human use of the area can be traced back over 4,000 years (Hopkins 1977). Much of the coastline consists of barrier islands backed by lagoons. As in many microtidal coastal areas, the barrier bars show washover channels and storm-surge deltas as well as the grooves and ridges that result from ice push (Hayes 1978). The direction of the coastal sediment transport between Cape

Thompson and Shesualek is southeastward. The primary sediment source is bedrock cliffs at Cape Thompson that provide large quantities of sandstone, chert, and limestone. Gravel sources probably also include onshore alluvial fans, Quaternary glacial outwash deposits, and deltas. Some of the gravel deposits on the beach are presumably lag deposits following redistribution of finer particles from eroded coastal bluffs. Storm waves have been observed to erode large amounts of pebble-sized particles from the nearshore area and deposit them on the shore (Hopkins 1977).

The Hotham Inlet area is dominated by deltas formed by the Selawik, Kobuk, and Noatak rivers, the Kobuk River delta being the most active and largest. Since the sedimentary sources are blocked off, no real beach is formed. Marsh is established almost to the water line. Deltas outside the inlet, e.g., the Buckland River delta in Eschscholtz Bay, show a typical estuarine environment with surrounding fluvial bars, marsh area, and a low, sandy beach.

Tundra scarps are widespread within Kotzebue Sound, mostly on the Baldwin Peninsula and in Eschscholtz Bay. Rocky headlands are few, but Cape Thompson is a prominent example, having a vertical drop of 300 m with little or no beach at the base. The height and vegetative cover on coastal bluffs and tundra scarps are highly varied, reflecting relative wave energies and local sources of sediment (Hayes and Ruby 1979).

Coastal vegetation has been fairly well described for the Cape Espenberg coast and the inland region of the Seward Peninsula as a result of studies on vegetation in the Chukchi-Imuruk area (Racine 1974), interpretation of Earth Resources Technology Satellite (ERTS) imagery (Anderson et al. 1974), and studies of bird nesting habitats (Mickelson 1978). Coastal vegetation in this area is quite diverse, and is categorized as "Coastal Meadows-Dwarf Shrub Tundra Mosaic" (Anderson et al. 1974). Meadows of the sedge *Carex aquatilis* abound locally on the coast and on lower back shores. Extensive saltwater meadows have developed near the coast and along the estuaries at Deering and Cape Espenberg. They are recognized as light-green lawn-like areas with short prostrate sedges and grasses, e.g., *Puccinellia* spp. (a low grass with scaberulous herbage) and *Carex* spp. Coastal vegetation data from other parts of the study area are rare.

1.5 BIOTIC RESOURCES

Eleven species of marine mammals are known to occur in the southeastern Chukchi Sea, including Kotzebue Sound. Three among these, killer whales (*Orcinus orca*), harbor porpoises (*Phocoena phocoena*), and minke whales (*Balaenoptera acutorostrata*), are generally not common. Polar bears (*Ursus maritimus*), bowhead whales (*Balaena mysticetus*), gray whales (*Eschrichtius robustus*), bearded seals (*Erignathus barbatus*), and Pacific walruses (*Odobenus rosmerus*) do not move into nearshore and estuarine areas; their usual migratory path is northward from the Bering Strait. Belukha whales (*Delphinapterus leucas*), ringed seals (*Phoca hispida*), and spotted seals (*Phoca largha*) are seasonally abundant in Kotzebue Sound.

Belukha whales are abundant in coastal waters, particularly Kotzebue Sound, during spring and early summer. As many as 2,000 animals are seen in Kotzebue Sound during this period. Their life history is well known, but data on the population size and dynamics in Kotzebue Sound remain lacking (Seaman and Burns 1981). They feed at the mouths of such salmon streams as the Noatak and Buckland rivers, although their food consists of a variety of fishes and shellfishes, e.g., saffron cod, Pacific herring (*Clupea harengus pallasi*), arctic char (*Salvelinus alpinus*), flounders, smelts, squids, and shrimps. Calving takes place in Eschscholtz Bay, and perhaps also near Shesualek.

Ringed seals are present in large numbers during winter, with a population of between 6,000 and 9,000 animals. They are widely distributed, but utilize shorefast ice for breeding. Ringed seals are born in lairs excavated under thick snow or in natural cavities in ice in order to provide protection for the young. The principal food of ringed seals during winter consists of sculpins, arctic cod (*Boreogadus saida*), saffron cod (*Eleginus gracilis*), and shrimps and other crustaceans that are evidently plentiful in coastal waters throughout the year. Ringed seals move northward with the advent of summer, and by July they are usually not seen in Kotzebue Sound.

Spotted seals are common in bays and river mouths during the open-water period, and haul out on barrier islands and promontories on the coastline. Major haulout areas in the study area include Shishmaref, Cape Espenberg, Elephant Point, Eschscholtz Bay, and Shesualek, with as many as 1,000 seals hauling out at some locations in summer (Frost et al. 1983). They feed on salmon (*Onchorynchus* spp.), arctic cod, smelts, and other fishes characteristic of the nearshore and estuarine waters.

Connors and Connors (1982) recorded 113 bird species from the southeastern Chukchi Sea and Kotzebue Sound during surveys conducted in 1977-78. Among these, the shorebird fauna (sandpipers, plovers, and similar birds), comprising 28 regularly occurring species, was most prominent and characteristic of the region's extensive lagoon and saltmarsh habitats. Seabird densities ranged from 47 nests/km^2 at Cape Krusenstern to 62 to 336 nests/km^2 at Cape Espenberg to 129 nests/km^2 near Shishmaref (Connors 1984). The western sandpiper (*Calidris mauri*) was the most abundant species throughout the region, with population densities as high as 5 birds/ha (Connors and Connors 1982).

All of the marine birds are seasonal migrants to the region, some from as far south as the Southern Hemisphere. They are present from late May to early October, but are most abundant during August. Two of their most important habitats are the Noatak River delta-Shesualek area, and the barrier island-lagoon system on the north side of the Seward Peninsula, particularly areas east and west of Shishmaref. Although they nest on the tundra, shorebirds frequently forage on the beaches, in salt marshes, and on mud flats. Their food consists of small fishes, pelagic and benthic crustaceans, worms, plant matter, and chironomid fly adults and larvae; chironomids frequently constitute the single most important food source.

Connors and Connors (1982) noted similarities in the composition of shorebird fauna between the southern Chukchi Sea and Beaufort Sea regions, but also observed marked differences between the two regions in the abundance and breeding status of many species. Several species seldom seen on the Arctic Coastal Plain are regular migrants or breeders in the southern Chukchi Sea-Kotzebue Sound region, e.g., sharp-tailed sandpipers (*Erdia acuminata*), common snipe (Capella *gallinago*), rock sandpipers (*Calidris ptilocnemis*), Hudson godwits (*Limosa haemastica*), and black turnstones (*Arenaria melanocephala*).

The largest of the seabird colonies in the region, with over 500,000 birds, is located near Cape Thompson. Murres, black-legged kittiwakes (*Rissa tridactyla*), and puffins are very abundant, with smaller numbers of glaucous gulls (*Laurus hyperboreus*), pelagic cormorants (*Phalacrocorax pelagicus*), and black guillemots (*Cepphus grylle*). Eighteen smaller colonies have been mapped in southern Kotzebue Sound, with Chamisso and Puffin islands supporting 60% of the nearly 46,000 birds in the area. These islands are part of the Alaska Maritime National Wildlife Refuge and represent one of the very few sites for which historic records of bird abundance and habitat use exist. Horned puffins (*Fratercula corniculata*), common murres (*Uris aalge*), and black-legged kittiwakes predominate in terms of numerical abundance, with glaucous gulls, pelagic cormorants, thick-billed murres (*U. lomvia*), and arctic terns (*Sterna paradisaea*) present in small numbers. The horned puffin population at Chamisso Island declined 35 to 60% between 1976 and 1981. It is not clear whether this decline represented a long-term trend or a reflection of poor reproductive success in 1981 (Nelson and Sowls 1985).

Migratory jaegers (*Stercorarius* spp.) concentrate in very large numbers to feed near Kotzebue in late May and early June, soon after the breakup of the Noatak River.

There are no seabird colonies on the north shore of the Seward Peninsula because of the lack of nesting cliffs and rocky headlands there, but terns and gulls may be present in wetlands.

Numerous estuarine habitats, including lagoons and deltas, particularly those of the Kobuk, Noatak, Kiwalik, and Buckland rivers, are important habitats for a variet y of seaducks during summer. Geese, black brant (*Branta bernicula nigricans*), and whistling swans (*Cygnus columbianus*) congregate in Eschscholtz Bay, Hotham Inlet, and Selawik Lake prior to the fall migration. Coastal lagoons in the vicinity of Capes Espenberg and Krusenstern are nesting areas for several species of ducks, as well as for Canada geese (*Branta canadensis*), sandhill cranes (*Grus canadensis*) and whistling swans.

Kotzebue Sound supports the northernmost commercial fishery for Pacific salmon in Alaska. This fishery, targeted on chum salmon (*Onchorynchus keta*) returning to the Noatak River, dates as far back as 1914, when a small cannery was built in the area. In recent years fish have been caught in gill nets operated from small skiffs with outboard motors in a very small area extending northeast and northwest of the Baldwin Peninsula. The 1986 commercial catch consisted of 261,000 chum salmon (average weight 4 kg) and 101 chinook salmon (O. *tshawytscha*) (average weight 7 kg), with 187 fishermen reporting catches. This catch was considerably smaller than the average catch for the 1980-86 period, 392,000 fish (ADF&G 1986). Ex-vessel price fluctuated considerably during the 1986 season, but the average price was $0.90/kg for chum salmon and $2.76/kg for chinook salmon. The total catch was valued at $931,000. The arctic char catch was over 2,000 fish, but this species is usually not sold on the commercial market. It is harvested in mid-August, usually after the chum salmon season.

The 1986 salmon catch for subsistence was nearly 19,000 fish, nearly equal to the average catch during the 1980-86 period. Other fish caught for subsistence use, some in the winter, included whitefishes and sheefish (*Stenodus leucichthys*).

Many other species of fish and invertebrates occur in the estuarine and marine environments; prominent among these are smelts, sticklebacks, ciscos, starry flounder (*Platichthys stellatus*), Pacific herring, and the shrimp *Crangon septemspinosus* (Raymond et al. 1984).

1.6 PEOPLE

The Eskimos of Kotzebue Sound called themselves "Kikitarmiut"-the people who live on a place that is almost an island. Unlike Eskimos living elsewhere on the coast who migrated seasonally, these people were permanent residents of the region because they subsisted on a variety of resources on land, in the rivers, and in the sound. In a typical year, seal hunting ceased in June or early July with the disappearance of ice. Most families then moved to Shesualek (hunting place for "sheshak" or belukha whale) for the summer, residing in lodges that resembled tipis of the inland Indians.

The archeological remains found in many parts of this region show remarkable similarities in the material culture of the people of Kotzebue Sound with those of the deeper, interior parts of Alaska. Giddings (ea. 1956), who noted such cultural similarity, has argued that the material culture of the Kotzebue-Kobuk people could not be considered intermediate between that of the Athabascans and the Eskimos. In Kotzebue-Kobuk culture, he observed, there was a remarkable adaptation to a diverse environment consisting of clear streams, rugged mountains, forests, and a bay with plenty of food resources. The historic dependence of the people of this culture on the variety of fish and game is reflected in artifacts for fishing and hunting in the forest, rivers, and bay. There is also substantial evidence that to enrich their lives they used and traded furs, tree bark, root fibers, and hard minerals without having to move continually from one region to another, which was a prevalent life-style of coastal Eskimos elsewhere (Giddings 1967). The bone count from one of the archeological sites—a house-on the Choris Peninsula consisted of remains of caribou *(Rangifer arcticus)*, belukha whales, seals, white [arctic] foxes (*Alopex lagopus*), ducks and other seabirds, ground squirrels (*Citellus parryi*), and "black whale" (Giddings ca. 1956). Other findings pointed out that in summer, caribou and bird hunting prevailed on land, and seal and belukha whale hunting in the sound, presumably from kayaks and umiaks. Berries and bird eggs were also gathered in summer. Fishing in winter focused on pike (family Esocidae, most probably northern pike [*Esox lucius*]), sheefish, and whitefishes, usually through ice-holes.

The Kotzebue culture was further defined by Van Stone (1965) as a coastal manifestation of the Arctic Woodland Culture with the addition of some specialized fishing techniques (i.e., ice fishing) and a heavier emphasis on hunting seals. Unlike arctic coast dwellers elsewhere along the Alaska and Siberia shores, the Eskimos of Kotzebue Sound failed to develop a culture based on whaling and walrus hunting. These large animals are almost never seen in the brackish waters of Kotzebue Sound. Only belukha whales, ringed seals, and spotted seals are present on a regular basis and in large enough numbers for subsistence use. The number of animals harvested each year varies considerably, e.g., 129 belukha whales were taken at Eschscholtz Bay in 1982, only 5 in 1979, and none in 1984 (Burns and Seaman 1986).

1.7 LITERATURE CITED

ADF&G
1986. Kotzebue District salmon, 1986: a report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Nome, AI&20 pp.

Alaska Geographic
1981. The Kotzebue Basin. Alaska Geographic 8(3), 184 pp.

Anderson, J.H., **C.H. Racine,** and **H.R. Melchior**
1974. Preliminary vegetation map of the Espenberg Peninsula, Alaska based on an earth resource technology satellite image, pp. 290-310. In: Chukchi-Imuruk biological survey, Final report, Vol. 2, (H.R. Melchior, cd.), Cooperative Park Studies Unit, University of Alaska, Fairbanks, AK.

Burns, J.J., and **G.A.** Seaman
1986. Investigation of belukha whales in coastal waters of western and northern Alaska. II. Biology and ecology. OCSEAP Final Report (Research Unit 612), U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK, 129 pp.

Connors, **P.G.**
1984. 'Regional patterns in coastal shorebird communities of Arctic and sub-arctic Alaska, pp. 59-95. In: Final Reports of Principal Investigators, Vol. 35, U.S. Department of Commerce, National Oceanic andAtmosphericAdministration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK

Connors, P.G., and **C.S.** Connors
1982. Shorebird littoral zone ecology of the southern Chukchi coast of Alaska, pp. 1-57. In: Final Reports of Principal Investigators, Vol. 35, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage; AK.

Creager, J.S., and **D.A. McManus**
1966. Geology of the southeastern Chukchi Sea, pp. 755-786. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.), U.S. Atomic Energy Commission, Washington, D.C.

Frost, **K.J., L.F.** Lowry, and **J.J. Burns**
1983. Distribution of marine mammals in the coastal zone of the eastern Chukchi Sea during summer and autumn, pp. 563-650. In: Final Reports of Principal Investigators, Vol. 20, U.S. Department of Commerce, National 'Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Juneau, AK.

Giddings, **J.L.**
ca. 1956. The results of a field trip to Eschscholtz Bay, Alaska. Unpublished and undated manuscript. Alaska Resources Library, Anchorage, AK, 31 pp.

Giddings, **J.L.**
1967. Ancient men of the Arctic. Knopf, New York, NY, 391 pp.

Hayes, IWO.
'1978. Barrier island morphology as a function of tidal and wave energy, pp. 1-27. In: Barrier Islands: from the Gulf of St. Lawrence to the Gulf of Mexico (S.P. Weatherman, cd.), Academic Press, New York, NY.

Hayes, **M.O.,** and **C.H.** Ruby
1979. Oil spill vulnerability, coastal morphology and sedimentation of Kotzebue Sound, pp. 115–170. In: Annual Reports of Principal Investigators, Vol. 7, U.S. Department of Commerce, National Oceanic andAtmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Hopkins, **D.M.**
1977, Coastal processes and coastal erosional hazard to the Cape Krusenstern archaeological site. Open-File Report 77-32, U.S. Geological Survey, Menlo Park, CA, 15 pp.

McManus, D.A., and **J.S.** Creager
1963. Physical and sedimentary environments on a large spot-like shoal. Journal of Geology 71:498-512.

Mickelson, P.G. (with D. **Schamel,** D. **Tracy,** and **A. Seguin)**
1978. Avian community ecology at two sites on Espenberg Peninsula in Kotzebue Sound, Alaska, pp. 289-608. In: Final Reports of Principal Investigators, Vol. 5 (Biological Studies), U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Naidu, AS., and **T.C. Mowatt**
1983. Sources and dispersal patterns of clay minerals in surface sediments from the continental shelf area off Alaska. Geological Society of America Bulletin 94:841-854.

Nelson, J.W., and A.L. Sowls
1985. Breeding bird survey of Chamisso Island and southern Kotzebue Sound, 8-20 August, 1981. U.S. Fish and Wildlife Service, Anchorage, AK, 38 pp.

NOAA/NCDC
1985. Local climatological data: Kotzebue, Alaska. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, 8 pp.

Racine, C.H.
1974. Vegetation of the Chukchi-Imuruk area, pp. 239–289. In: Chukchi-Imuruk biological survey, Final report, Vol. 2 (H.R. Melchior, cd.), Cooperative Park Studies Unit, University of Alaska, Fairbanks, AK.

Raymond, J.A., M. Merritt, and C. Skaugstad
1984. Nearshore fishes of Kotzebue Sound in summer. FRED Report No. 37, Alaska Department of Fish and Game, Juneau, AK, 31 pp.

Seaman, G.A., and J.J. Burns
1981. Preliminary results of recent studies on belukhas in Alaskan waters. Report of the International Whaling Commission 31:567-574.

Stringer, W.J., and J.E. Groves
1986. Statistical description of the summertime ice edge in the Chukchi Sea (Report prepared under contract DE-AC21-83MC20037 with the U.S. Department of Energy). Geophysical Institute, University of Alaska, Fairbanks, AK, 27 pp. plus appendices.

Van Stone, J.W.
1965. Archaeological excavations at Kotzebue, Alaska. Ph.D. dissertation, University of Pennsylvania, Philadelphia, PA, 116 pp.

2

Marine Geology

A. S. Naidu
G. Gardner

2.1 INTRODUCTION

The Chukchi Sea is a shallow, wide epicontinental sea on the continental shelf of arctic Alaska and eastern Siberia. Its boundaries are defined by the Bering Strait to the south, the longitude of Wrangel Island to the west, the latitude of Pt. Barrow to the north, and the coast of Alaska to the east. The average depth of the Chukchi Sea is about 50 m. Kotzebue Sound is an embayment in the southeastern Chukchi Sea. The sound is very shallow, with depths ranging from 1 to 25 m.

2.2 BATHYMETRY

Early bathymetric surveys of the southeastern Chukchi Sea (the Chukchi Bight) and Kotzebue Sound revealed an almost featureless plain with an average depth of about 50 m and gradients ranging from 0.9 m/km down to immeasurably gentle slopes (Creager and McManus 1965). Subsequent studies revealed a number of bathymetric features, the most notable of which are the Hope Sea Valley and the Cape Prince of Wales Shoal (Fig. 2.1).

The Hope Sea Valley is a relict geomorphic feature, the result of ancient streams and rivers that drained this area during periods of lowered sea level (Selkregg 1975). Kotzebue Sound is strongly influenced by the prodeltation of the Kobuk and Noatak rivers.

A well-developed shoal, known as the Cape Prince of Wales Shoal (Creager 1963), extending northward from Cape Prince of Wales for about 144 km, is 36 to 54 km wide, and less than 10 m below sea level (Fig. 2.2). A strong current flowing northward through the Bering Strait passes along the western slope of the shoal. The Bering Strait itself has very irregular and hummocky bathymetry, probably the result of current scouring on an ancient river valley. A narrow depression beginning near the strait and widening northward lies just west of the Cape Prince of Wales Shoal. Many small irregularities lie along its margin, having relief of up to 7 m (Selkregg 1975). The gradient of the western slope is 0.7 m/km (Creager 1963).

The Hope Sea Valley trends west-northwest in a broad S-shaped course that begins between Kivalina and Cape Thompson (Fig. 2.3). Relief at the head of the valley varies between 5.8 and 7.4 m. Southwest of Pt. Hope, relief greater than 9.1 m was noted. Down-valley gradients vary from 0.16 m/km at the landward end to 1.1 m/km at the seaward extremity. The valley is approximately 810 km long and ranges from 7.2 to 9.0 km wide. It has several tributary valleys, but only the Ogotoruk Sea Valley has been studied in some detail (Scholl and Sainsbury 1961a). This valley is a flat-

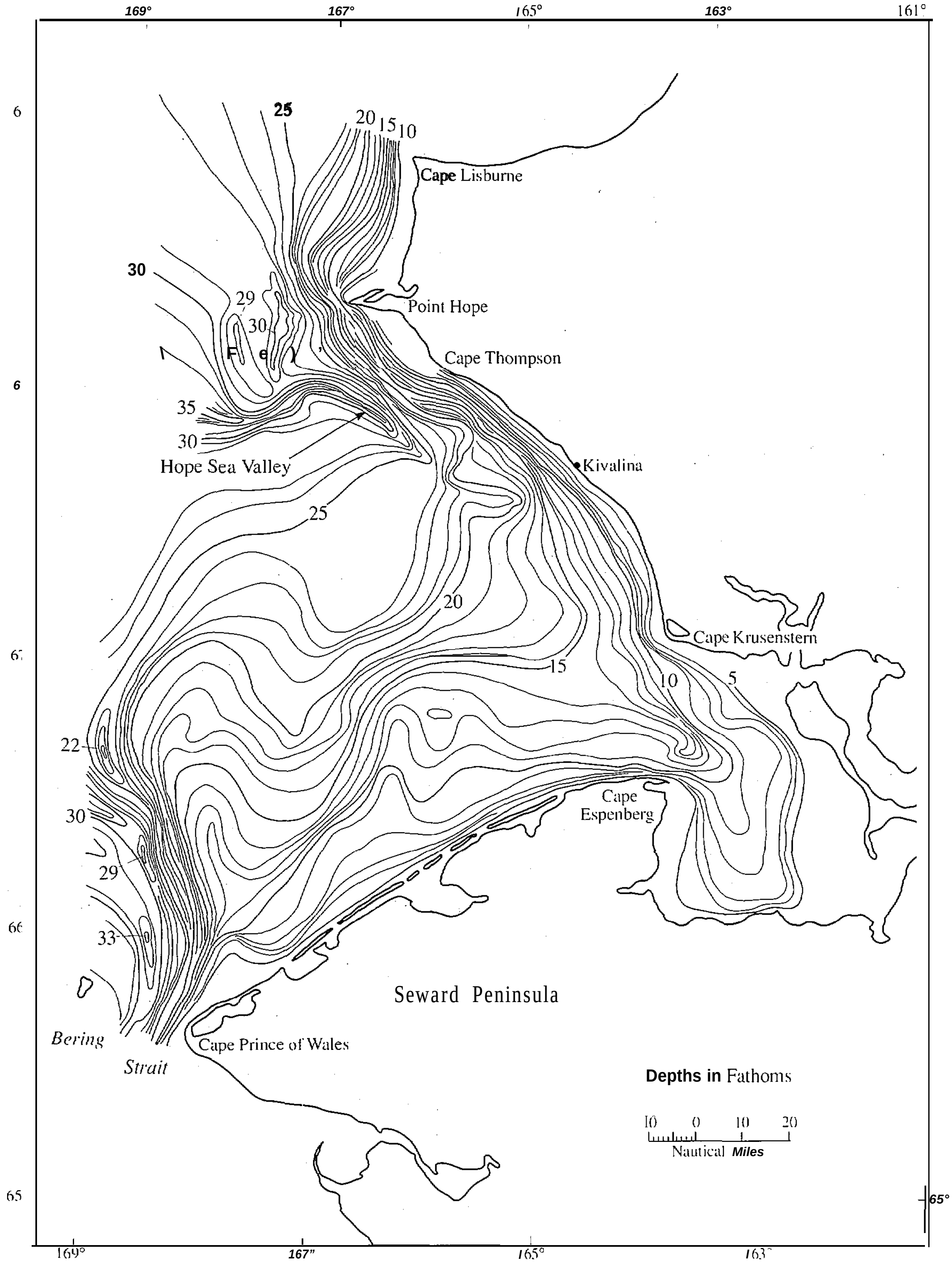

Figure 2.1 Bathymetric chart of the southeastern Chukchi Sea (from Creager 1963).

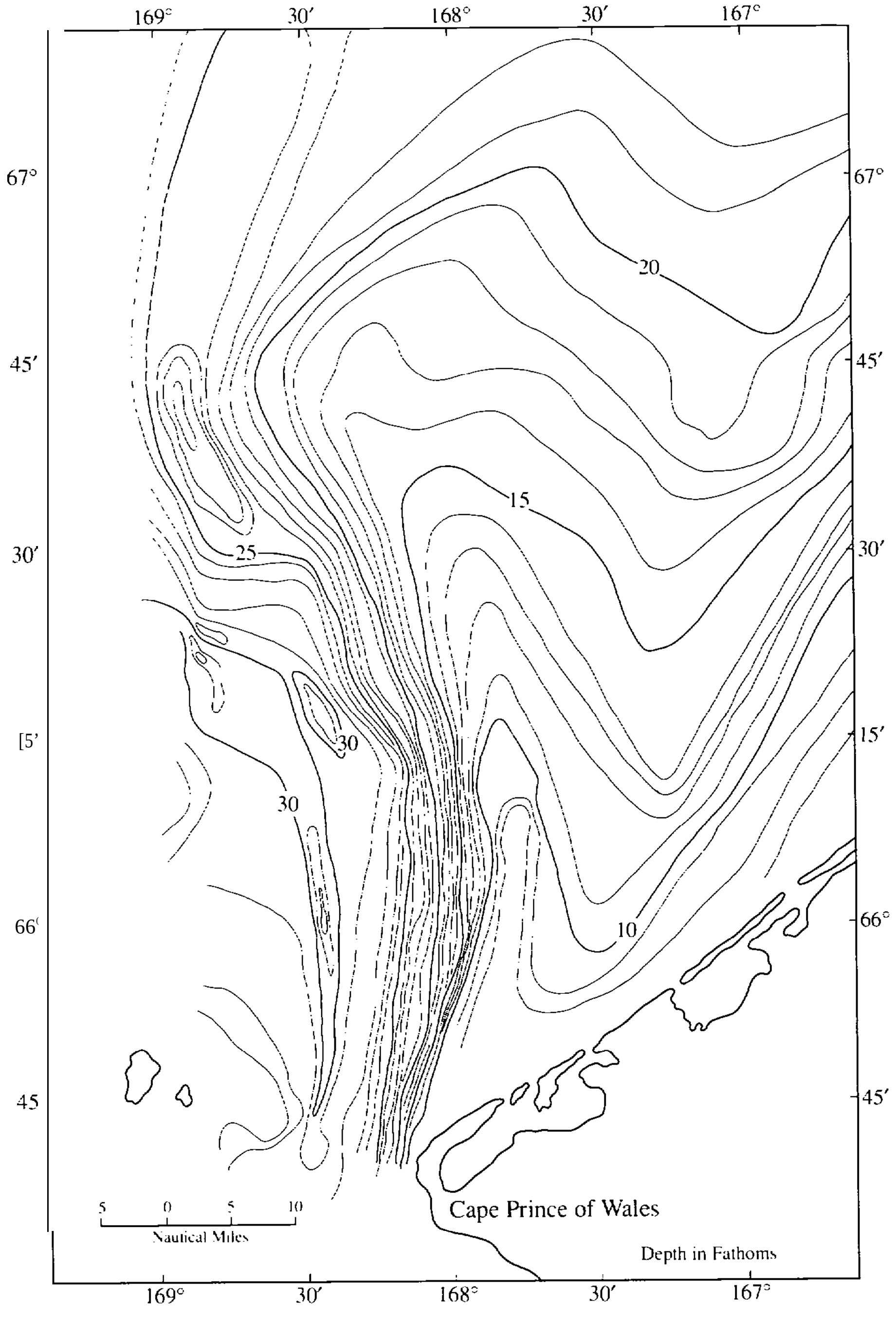

Figure 2.2 Bathymetry and sedimentary environments of Cape Prince of Wales Shoal (from Creager 1963).

bottomed trough cut into bedrock, extending 24 km seaward of the mouth of Ogotoruk Creek to a depth of 45 m (Fig. 2.4). The alignment of a channel between Cape Krusenstern and Cape Espenberg suggests that the valley may have extended into Kotzebue Sound during past sea level regressions (Creager and McManus 1965). Such an extension is supported by sonoprobe records showing a valley and an interfluvial drainage pattern in the central portion of the Chukchi Bight (see Fig. 2.3 for sonoprobe location), indicating that the Hope Sea Valley is continuous through the area south of

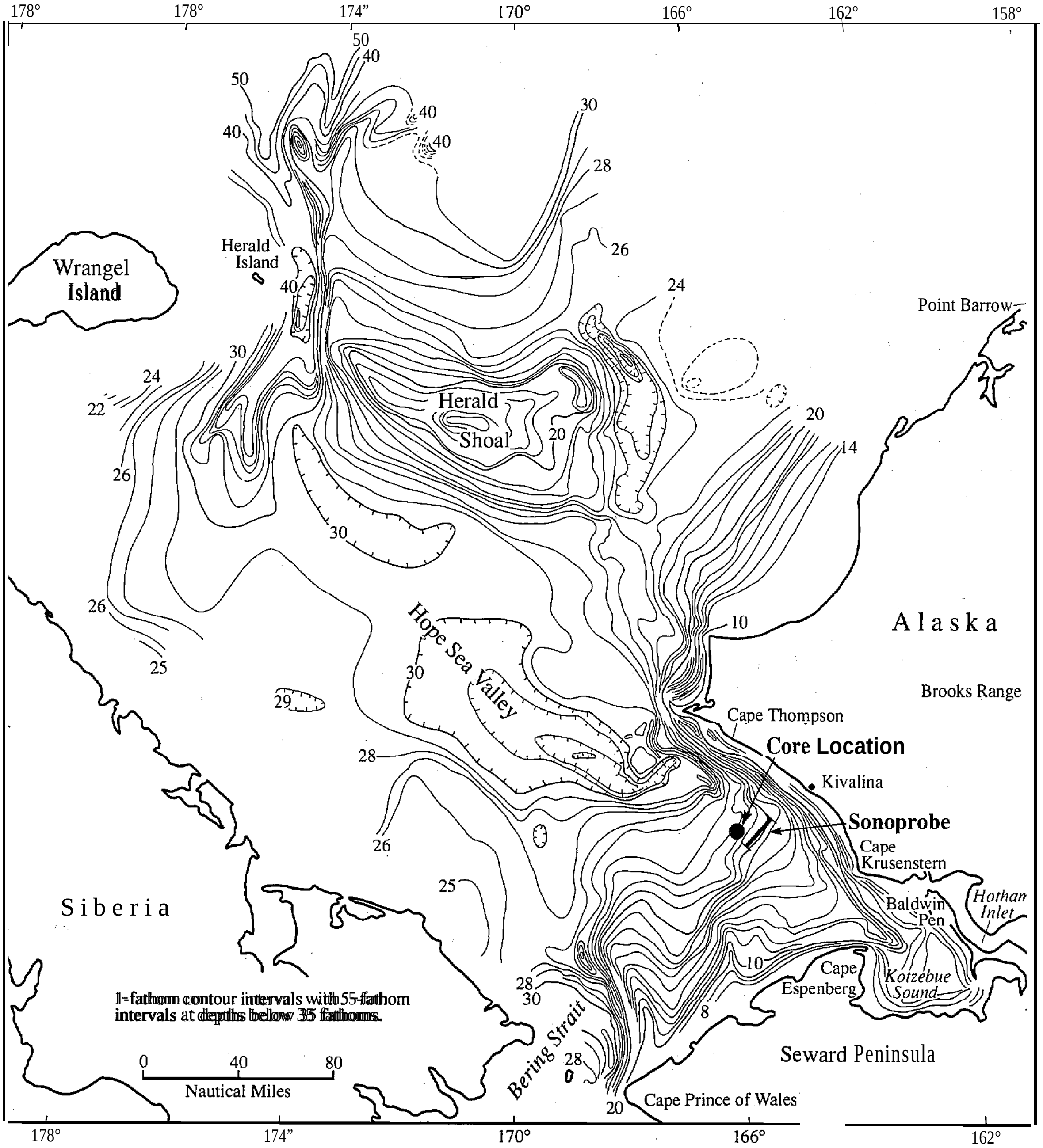

Figure 2.3 Bathymetry of the Chukchi Sea (from Creager and McManus 1965).

Cape Thompson, but is buried by 6.5 to 11.5 m of sediment (Creager and McManus 1965). The Kobuk and Noatak rivers are not continuous with the Hope Sea Valley at present. The area between Cape Krusenstern and the Baldwin Peninsula, where the river outflow enters Kotzebue Sound, is shallow and featureless. The Hope Sea Valley is presently not a transportation route for sediments (Creager 1963). It is believed that the Hope Sea Valley was the major drainage route across the continental shelf during the Pleistocene epoch (Creager and McManus 1965; McManus et al. 1983). The interrupted grade

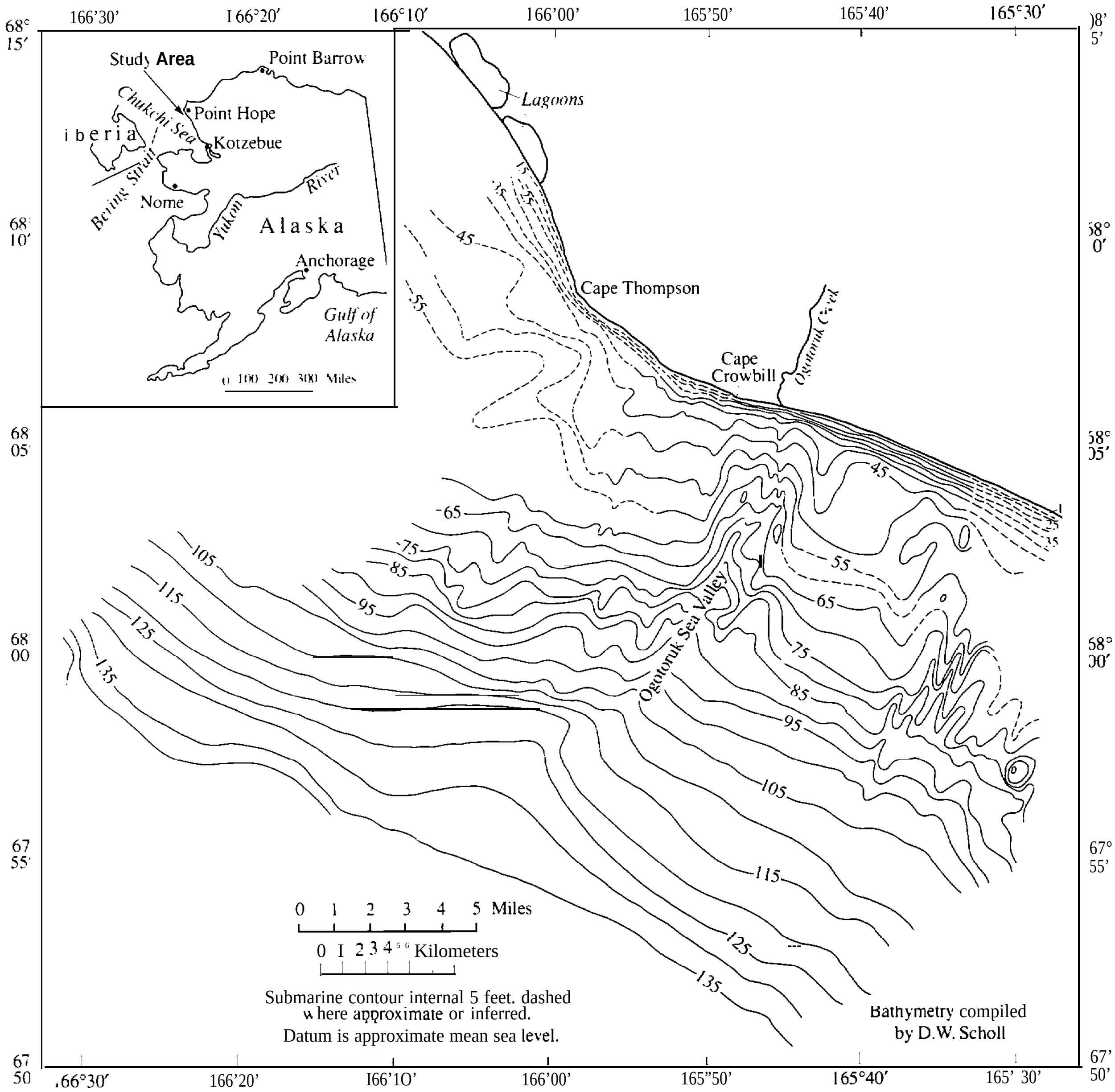

Figure **2.4 Bathymetry** off **Ogotoruk** Creek area, Chukchi Sea, northwestern Alaska (from Scholl and **Sainsbury 1961b**).

of the valley, which is evident in its present bathymetric expression, is probably the result of **deltaic** deposition during sea level **stillstands** or periods of gradual sea level rise. Three periods of sea level stillstands have been recognized: (1) present sea **level**–3,000 to 6,000 years ago; (2)36 to 48 m below the present sea level–12,000 years ago; and (3) 58 m below the present sea level-13,000 **to 17,000** years ago. Wave action may have redistributed these **deltaic** sediments and caused the flatness of the continental shelf under the **Chukchi** Sea (**Creager** and **McManus** 1965).

Kotzebue Sound is extremely flat, with an average depth of 14 to 16 m. The entrance to the sound is more than 24 m deep with no apparent sill. The area between Cape

Krusenstern and the Baldwin Peninsula has an average depth of only 4 m. A 2-m-deep sill may exist, trending northeast–southwest through the center of the sound (Creager and McManus 1965). Recently obtained data on bottom-water properties also support its existence (Johnson and Naidu[a]).

2.3 SEDIMENTOLOGY

2.3.1 *Sources.* The main source of sediment to the southeastern Chukchi Sea is believed to be the steady northward-setting current moving through the Bering Strait (Creager 1963). The evidence for this lies in the extensive shoaling and the pattern of changes in sediment grain-size parallel to the current, north of Cape Prince of Wales. Sediment supplied by the Seward Peninsula is impounded in extensive, low-lying flood plains and a barrier-island system that is not breached by river outflows. Within Kotzebue Sound, the Noatak and Kobuk river systems supply large amounts of sediment. Wave erosion of the cliffs in the region between Cape Thompson and Kivalina supplies coarse sediment to the beaches and immediate nearshore of this area. Net transport of this gravel is to the southwest (Creager and McManus 1966). Coarse sediment is also found in the Bering Strait, representing a lag deposit produced by swift currents (Creager 1963). Ice rafting is probably only a minor source of sediment in Kotzebue Sound, and only a slightly greater source in the southeastern Chukchi Sea.

2.3.2 ***Grain Size*** *Distribution.* In general, the sediment grain size decreases away from the shore (McManus et al. 1969; Naidu 1988). Gravel and coarse sand occur in the Bering Strait, adjacent to rocky cliffs between Cape Lisburne and Kivalina, and near Muffs of Pleistocene sediments on the Baldwin Peninsula (Hunter and Reiss 1985). Clayey silt occurs in Kotzebue Sound and in the central region of the Chukchi Bight. The remainder of the region is dominated by sand and silt (Fig. 2.5). However, the mean sizes of samples range from pebbles to granules, sand, and silt (Fig. 2.6). The overall pattern of grain size distributions is regional gradation rather than patchwork distribution (Fig. 2.5). Deviations from this pattern are caused by localized sediment sources and increases in current velocity. Four principal factors contribute to this pattern of mean sizes and sorting: currents, bottom topography, proximity to sediment sources, and transportation processes. The regions of poorest sorting reflect a continuous supply of sediment. Generally, sorting increases downcurrent as grain size decreases. Sediment grain size in Kotzebue Sound also decreases in a southeast direction, away from the mouth of the sound. The barrier-island systems are characterized by well-sorted sand, indicating a low sediment output and intense reworking by waves. Since the entrance of Kotzebue Sound is a tidal inlet, the tide enters near Cape Espenberg, creating a finger of well-sorted sand extending from the cape. The tide exits near Cape Krusenstern, creating a band of silt there. Within the sound, sediments are poorly to very poorly sorted, indicating a low-energy depositional environment (Fig. 2.7).

2.3.3 ***Calcium*** **Carbonate.** High values of calcium carbonate are generally correlated with coarse sediment, rock fragments, and shell material. Between Cape Lisburne and Kivalina, coarse detrital carbonates are derived from adjacent coastal limestone cliffs. Sand and silts offshore contain less than 5% calcium carbonate (Fig. 2.8).

2.3.4 *Organic Carbon.* The organic carbon content of sediment in this area is highly variable, from O to 1.9% on a dry-weight basis (Creager and McManus 1966). The highest values were found in Kotzebue Sound and in the central region of the Chukchi Bight in association with the finest sedi-

[a]W.R. Johnson and A.S. Naidu, Institute of Marine Science, University of Alaska, Fairbanks, AK 99775-1080, unpublished data.

ment grain sizes and poorest sorting (see Fig. 2.9). This organic matter is probably terrestrial, originating in the runoff from the Kobuk and Noatak rivers and smaller streams.

2.3.5 ***Foraminifera.*** Benthic foraminifera in the bottom sediments of the Chukchi Sea/Kotzebue Sound region are grouped into three distinct assemblages, all dominated by three species: *Eggerella advena*, *Bucella frigida*, and *Elphidium clavatum*. The major factor controlling their distribution appears to be the sediment grain size, since temperature, salinity, and depth change only little in this region.

Group I consists of the three dominant species plus a wide variety of other species. This group is limited to the Bering Strait and a nearshore band between Cape Lisburne and Kivalina, preferring stronger currents and coarse sediment (M_z = 1.50 phi). Group II contains a greater proportion of the dominant species, which occur in constant proportion to one another. This group is intermediate between groups I and III and separates them spatially (M_z = 3.00 phi). *Eggerella advena* composes 50 to 90% of Group 111 fauna, and recurs in silty areas of Kotzebue Sound and in the central Chukchi Bight (Fig. 2.10).

2.3.6 *Suspended Sediments.* The suspended load associated with currents flowing northward through the Bering Strait could be the major source of sediment coming into the Chukchi Sea. McManus and Smyth (1970) reported measurements of the suspended load across the strait. Bottom water had the highest concentration at each of the stations sampled. These authors found moderately sorted silt-sized particles (mode at 20 μm); 85% were angular mineral grains. Most samples contained at least 2-ppm particle concentrations (approximately 5 mg/L). Within a few kilometers of shore, concentrations rose to more than 4 ppm. McManus and Smyth (1970) also noted that their sampling was done during calm seas, and that, given the shallowness of the study area, storms could resuspend sediment and play a large role in sediment transport.

Burbank (1974) and Sharma (1979) studied suspended sediment distributions using Earth Technology Resources Satellite (ERTS) imagery (Fig. 2.11). Images of Kotzebue Sound show that the sediment plume of the Kobuk River settles out in Hotham Inlet, located east of the Baldwin Peninsula. The Noatak River plume flows in three directions: eastward into Hotham Inlet, westward along the northern shore of Kotzebue Sound toward the Chukchi Bight, and southward into central Kotzebue Sound, carried by a counterclockwise gyre. A small amount of sediment is seen entering the nearshore area around Cape Espenberg but is confined to the southwest coast of the sound. The erosional sea cliffs at Deering, Cape Thompson, and Cape Seepings contribute coarse sediment to the sea floor, but they do not appear to contribute much suspended-sediment load to the surface waters. It is generally believed that sediment from the Yukon River passes northward through the Bering Strait, bypassing the southeastern Chukchi Sea (Naidu and Mowatt 1983).

2.3.7 ***Clay** Mineralogy.* Distribution of clay minerals in bottom sediments of the northern Bering and Chukchi sea (Fig. 2.12) and of the major rivers draining into the area have been useful in elucidating the sources, transport pathways, and depositional sites of the clay-sized particles (Naidu et al. 1981; Naidu and Mowatt 1983). The primary source of the predominantly illitic clay in Kotzebue Sound is from the Kobuk and Noatak rivers. A small proportion of the clays discharged into Kotzebue Sound is further dispersed in a northwestward direction, presumably by the littoral currents. The southcentral Chukchi Sea appears to be the major repository of the expandable clays from the Yukon River, channelized through the Bering Strait by currents flowing northward.

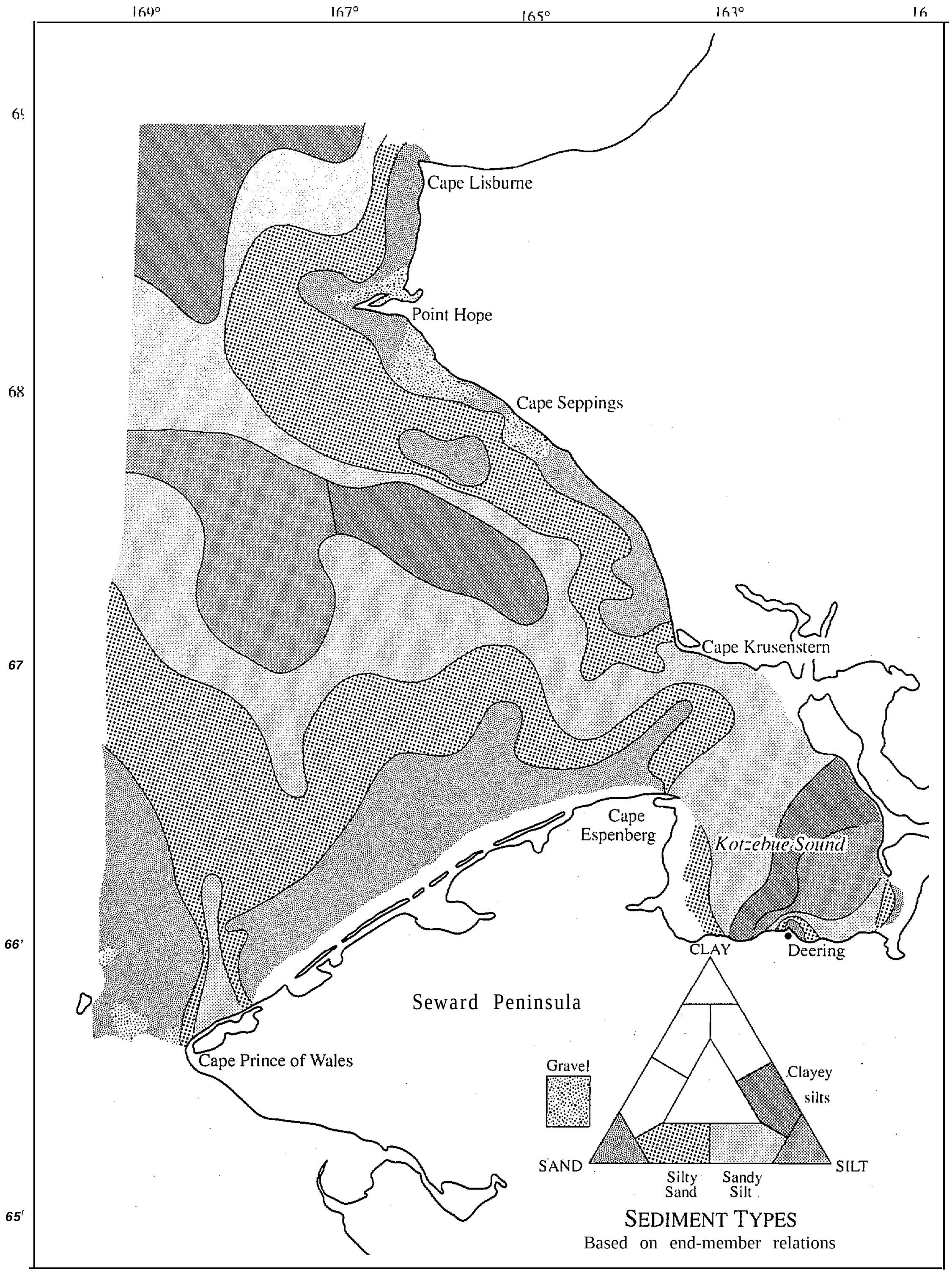

Figure **2.5** Distributions of sediment types in the Chukchi Bight and Kotzebue Sound, based on end-member relations (from Creager and McManus 1966).

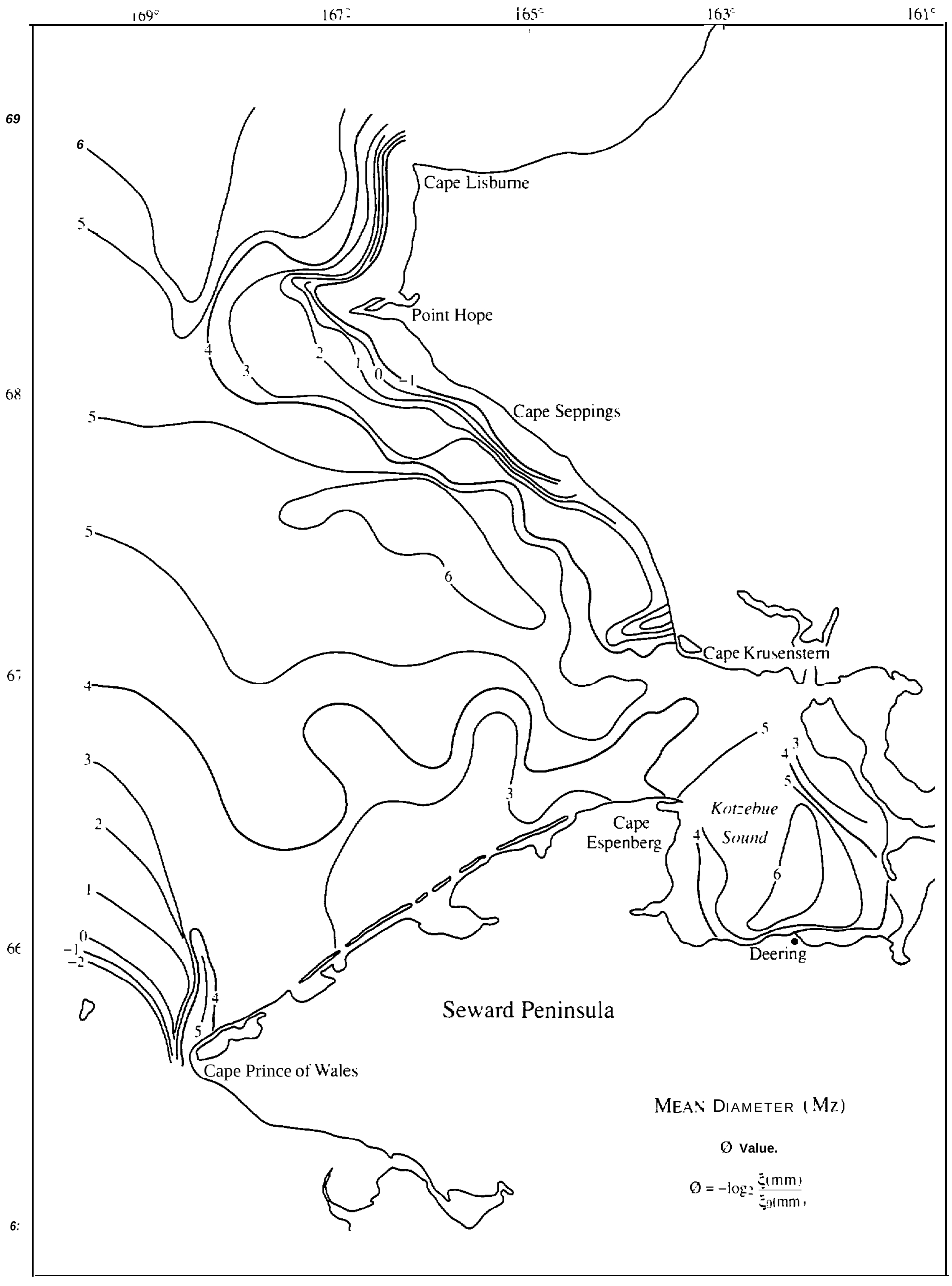

Figure **2.6** Distribution of sediment mean sizes in the **Chukchi** Bight and Kotzebue Sound (from **Creager** and **McManus** 1966).

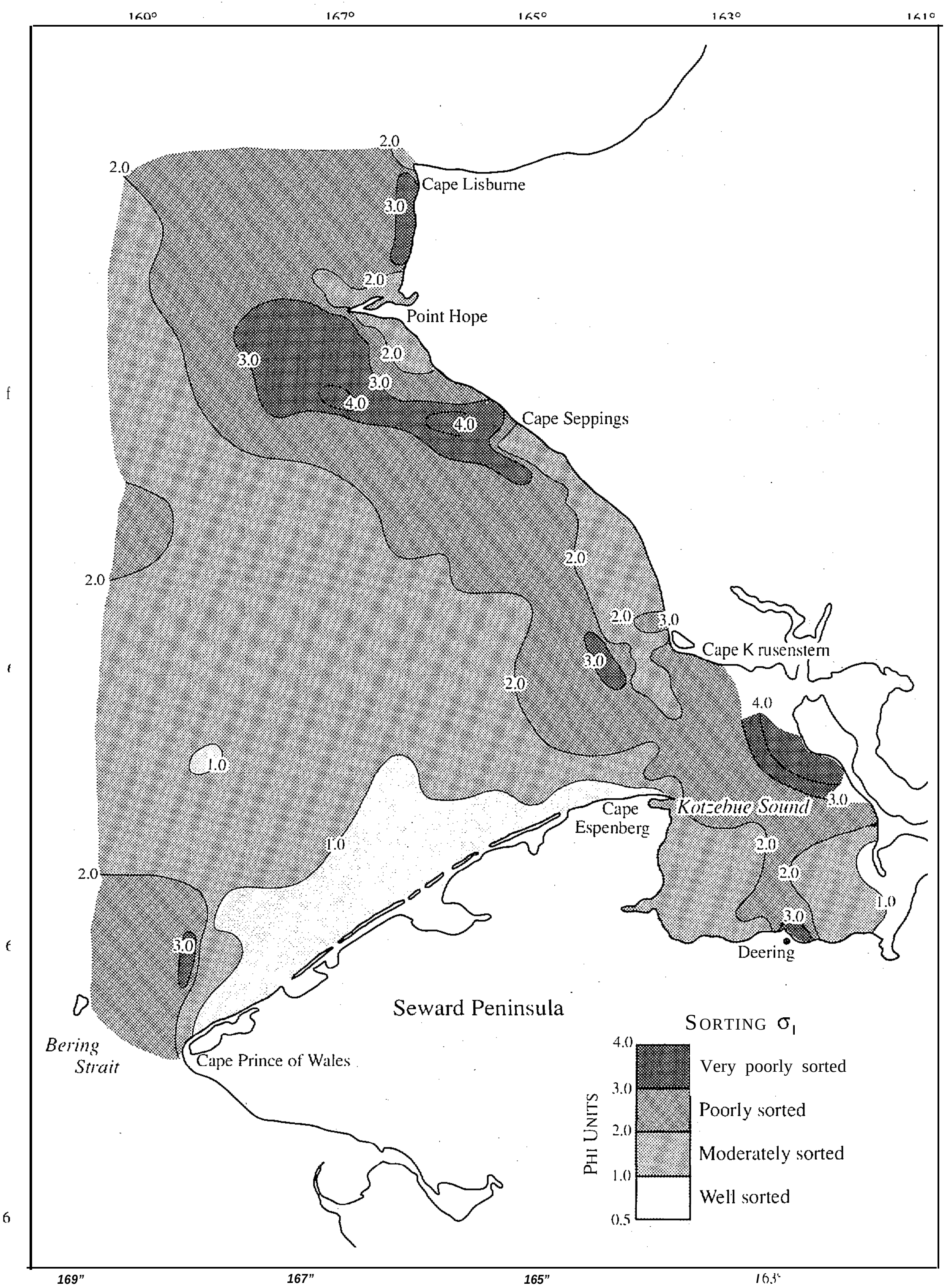

Figure 2.7 Standard deviation of sediment size distribution in the Chukchi Bight and Kotzebue Sound (from Creager and McManus 1966).

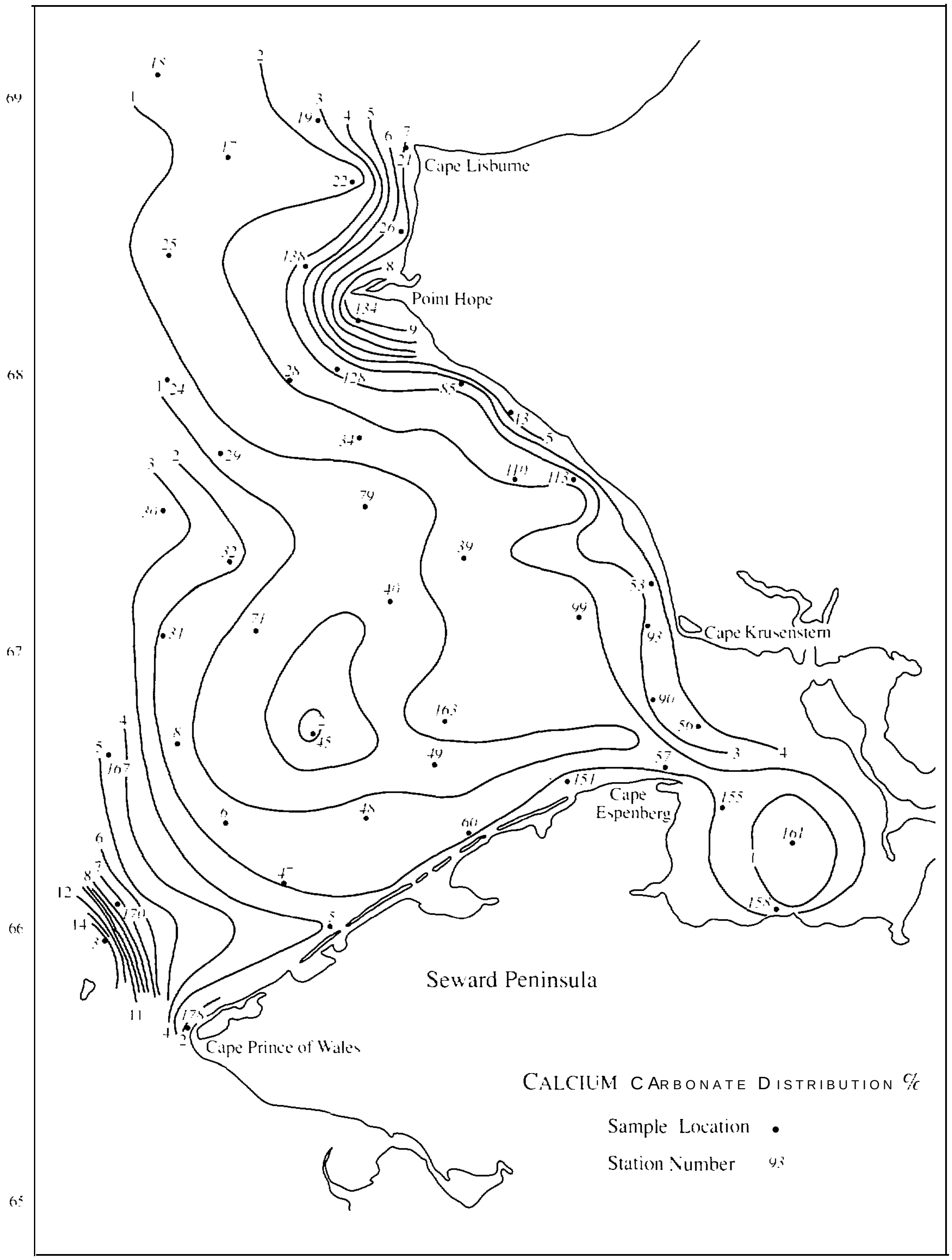

Figure 2.8 Calcium carbonate distribution in the Chukchi Bight and Kotzebue Sound (from Creager and McManus 1966).

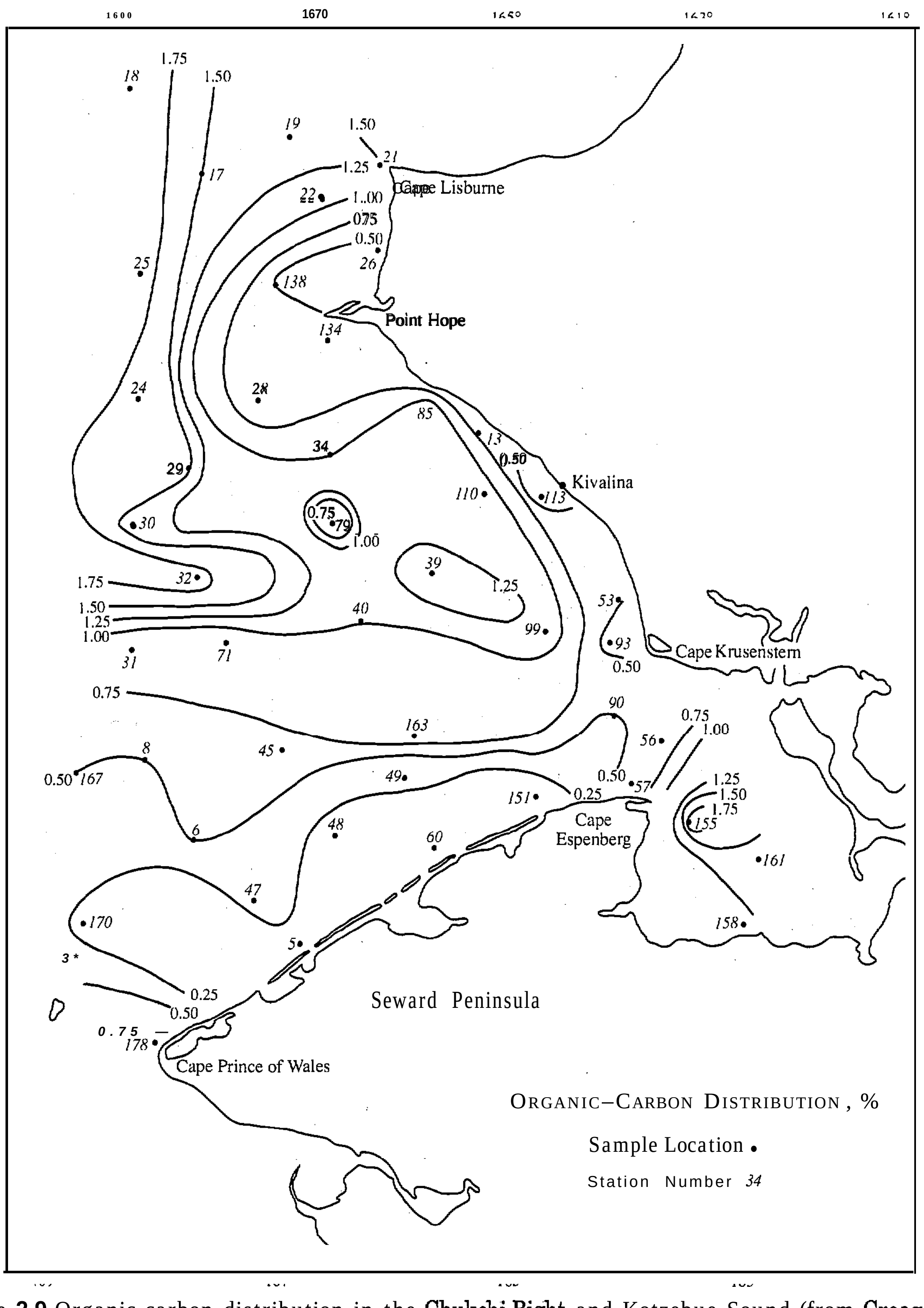

Figure **2.9** Organic carbon distribution in the **Chukchi Bight** and Kotzebue Sound (from **Creager** and **McManus** 1966).

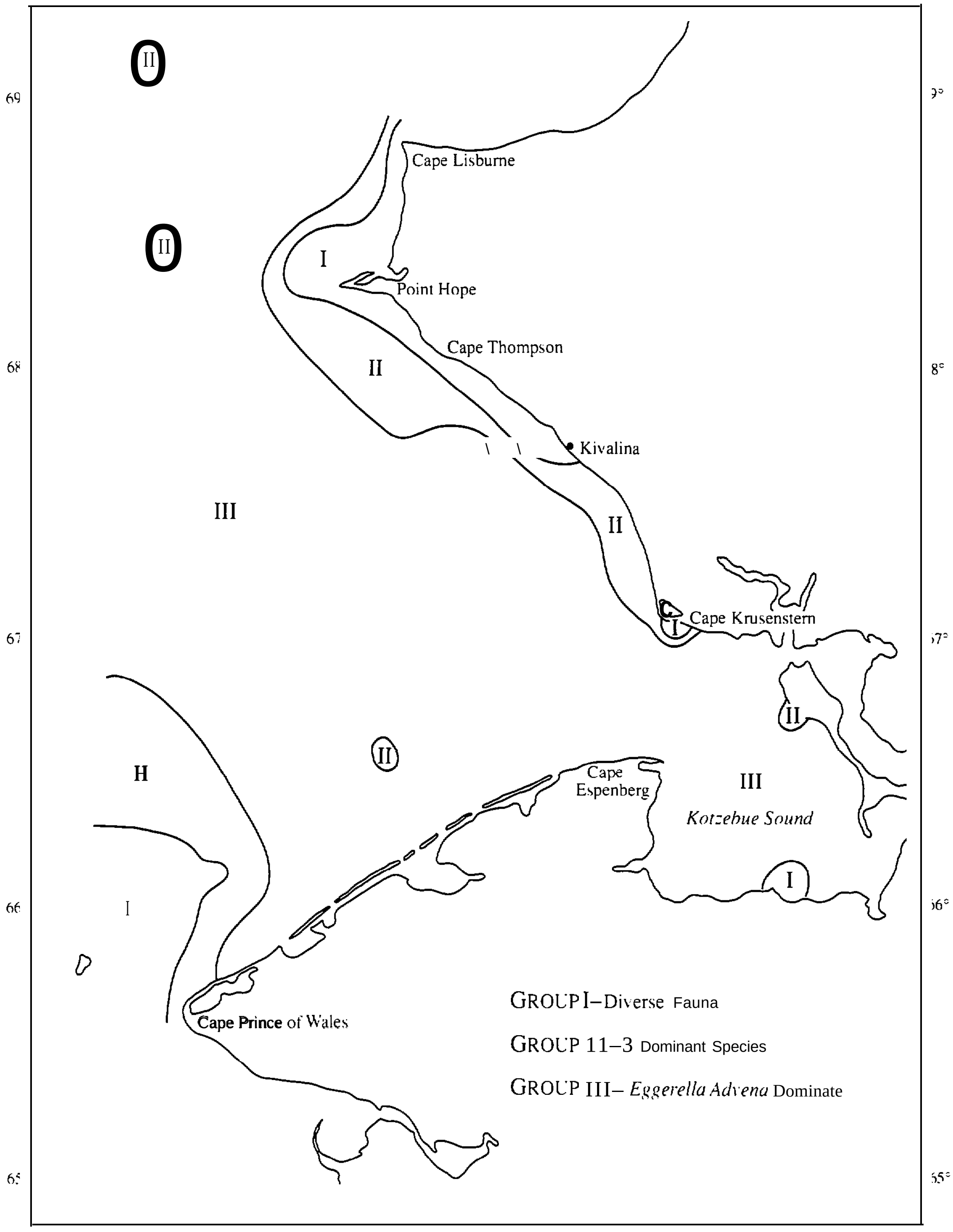

Figure **2.10** Distribution of **foraminiferal** assemblages in the Chukchi Bight and Kotzebue Sound (from **Creager** and **McManus** 1966).

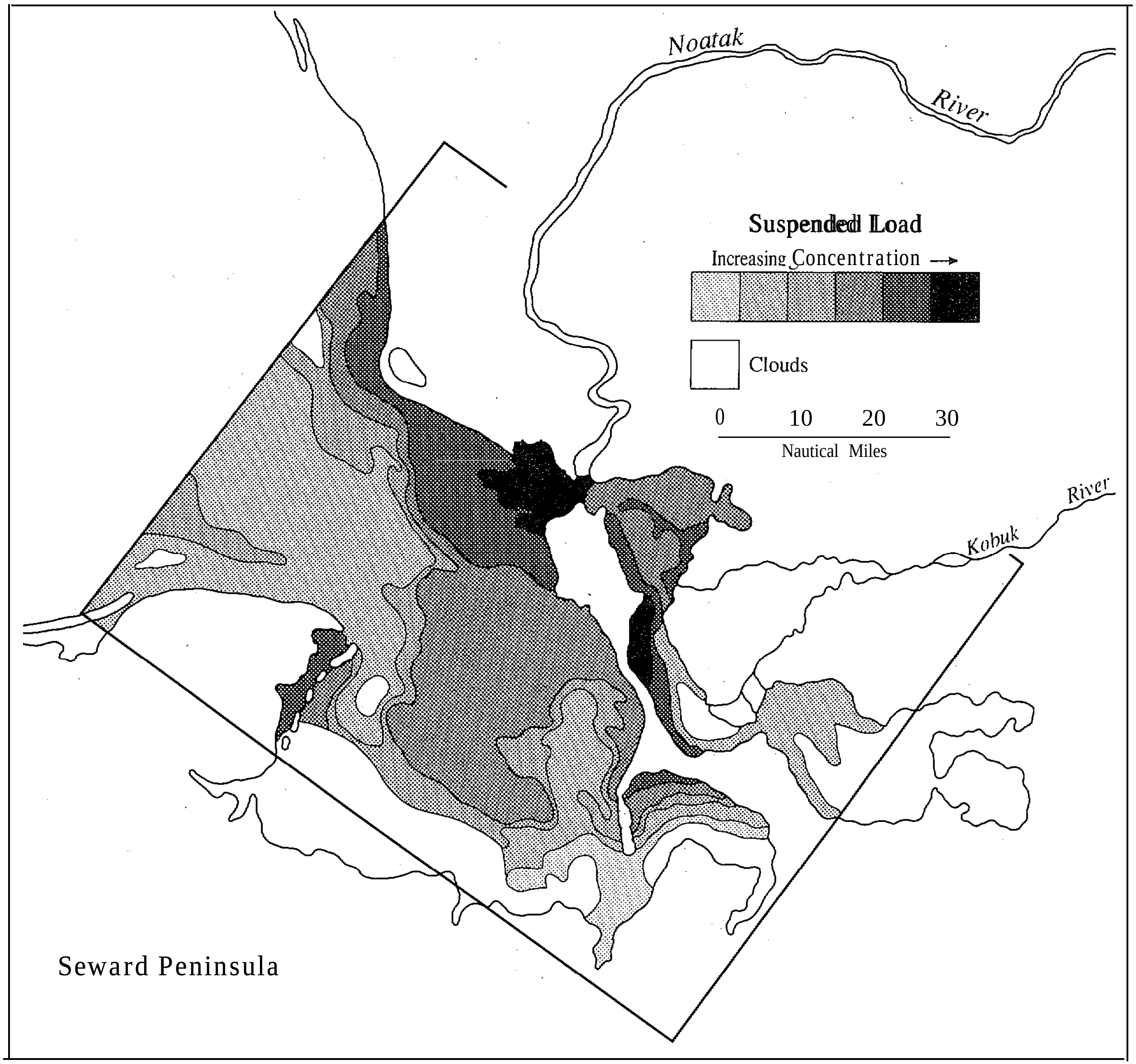

Figure 2.11 Relative suspended-load distribution in Kotzebue Sound on 5 October 1973. based on color density-slice of ERTS image No. 1439-215655-5 (from Burbank 1974).

2.3.8 *Ice Gouging.* The Chukchi Bight and Kotzebue Sound are less affected by ice gouging than the relatively more open waters of the Chukchi Sea, and much less than the Beaufort Sea. The barrier-island system between Cape Prince of Wales and Cape Espenberg is subject to drifting ice and large waves. Kotzebue Sound is somewhat more protected from waves and drifting ice. Side-scan monographs have shown that ice gouging is moderate to intense near Cape Krusenstern, decreasing to the southeast (Hunter and Reiss 1985). The deepest gouge found was 0.5 m. The gouges trend northwest ward-southeastward. Ice gouges were also found on the western margin of the shoal near Kotzebue. In southern Kotzebue Sound, ice gouging is rare. Throughout Kotzebue Sound there are furrows that resemble ice gouges but are most likely the

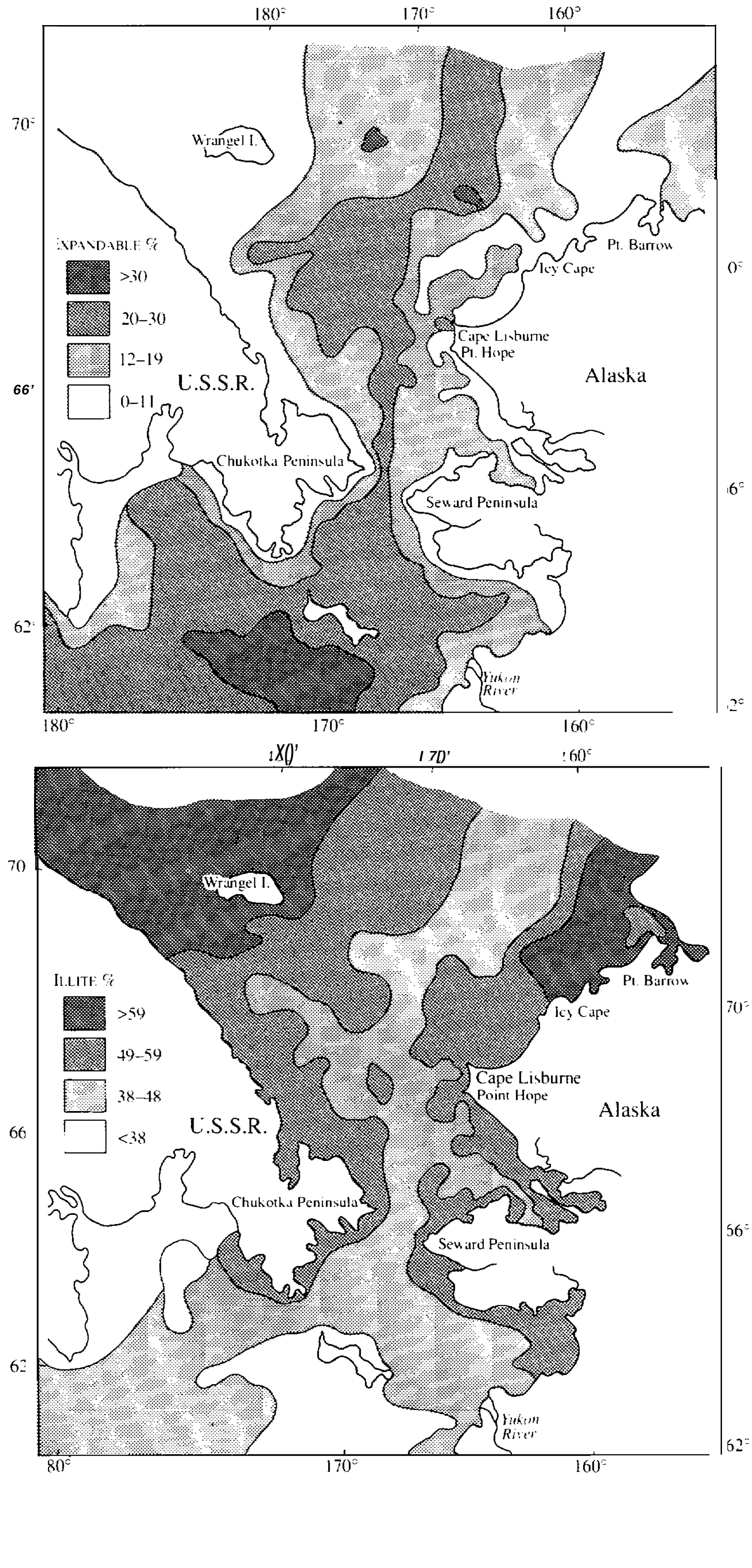

Figure **2.12** Distributional pattern of the weighted, peak-area percentages of the expandable group and the illite group of clay-mineral phases in the north Bering and Chukchi seas (from Naidu et al. 1981).

result of strong currents acting on cohesive muds (Hunter and Reiss 1985). Ice gouges in sand are more easily reworked than those in mud, and this may have an effect on the record of gouges preserved in the Chukchi Bight.

2.4 LITERATURE CITED

Burbank, D.D.
1974. Suspended sediment transport and deposition in Alaskan coastal waters, M.S. thesis, University of Alaska, Fairbanks, AK, 222 pp.

Creager, J.S.
1963. Sedimentation in a high energy embayed continental shelf environment. Journal of Sedimentary Petrology 33(4):815-830.

Creager, J.S., and D.A. McManus
1965. Pleistocene drainage patterns on the floor of the Chukchi Sea. Marine Geology 3:279-290.

Creager, J.S., and D.A. McManus
1966. Geology of the southeastern Chukchi Sea, pp. 755-786. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.), U.S. Atomic Energy Commission, Washington, D.C.

Hunter, R.E., and T.E. Reiss
1985, Inner-shelf geology of southeastern Chukchi Sea. Journal of Geology 71:498-512.

McManus, D.A., and C.S. Smyth
1970. Turbid bottom water on the continental shelf of the northern Bering Sea. Journal of Sedimentary Petrology 40(3):869-873.

McManus, D.A., and J.S. Creager
1963. Physical and sedimentary environments on a large spitlike shoal. Journal of Geology 71:498-512.

McManus, D.A., J.C. Kelley, and J.S. Creager
1969. Continental shelf sedimentation in an arctic environment. Geological Society of America Bulletin 80:1961-1984.

McManus, D.A., J.S. Creager, R.J. EchoIs, and M.J. Holmes
1983. The Holocene transgression on the Arctic flank of Beringia: Chukchi Valley-to Chukchi Estuary to Chukchi Sea, pp. 365-388, In: Quaternary. coastline, Academic Press, New York, NY.

Naidu, AS.
1988. Marine surficial sediments, Section 1.2. In: Bering, Chukchi and Beaufort seas, Strategic assessment data atlas, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Ocean Assessment Division, Washington, D.C. (in press).

Naidu, AS., and T.C. Mowatt
1983. Sources and dispersal patterns of clay minerals in surface sediments from the continental shelf areas off Alaska, Geological Society of America Bulletin 94:841-854.

Naidu, A.S., J.S. Creager, and T.C. Mowatt
1981. Clay mineral dispersal patterns in the North Bering and Chukchi seas. Marine Geology 47:1-15.

Selkregg, L.S.
1975. Alaska regional profiles: Vol. V, Northwest region, Arctic Environmental Information and Data Center, University of Alaska, Anchorage, AK, 265 pp.

Scholl, D.W., and C.L. Sainsbury
1961a. Marine geology and bathymetry of the Chukchi shelf off the Ogotoruk Creek area, northwest Alaska, pp. 718–732. In: Geology of the Arctic, Proceedings of the First International Symposium on Arctic Geology, Vol. 1, University of Toronto Press, Toronto, ON, Canada.

Scholl, D.W., and C.L. Sainsbury
196 lb. Subaerially carved arctic seavalley under a modern epicontinental sea. Geological Society of America Bulletin 72:1433-1436.

Sharma, G.D.
1979. The Alaskan shelf hydrographic, sedimentary and geochemical environment. Springer-Verlag, New York, NY, 498 pp.

3

Physical oceanography

W. R. Johnson

3.1 GENERAL

The Chukchi Sea is a shallow sea extending from the Bering Strait on the southern boundary to the Arctic Ocean on the northern boundary (Fig. 3.1). It is bounded on the east by the northern half of Alaska and on the west by Siberia and Wrangel Island. Ocean circulation in the southeastern Chukchi Sea is controlled by the northward flow through the Bering Strait, atmospheric forcing, and land runoff. Water transport through the Bering Strait is caused by the sea surface sloping downward towards the north to the order of 10^{-6} (Fleming and Heggarty 1966; Coachman and Aagaard 1966), which is due to the mean density differences between the North Pacific and Arctic oceans (Coachman et al. 1975; Stigebrant 1984). These influences have been inferred from the distribution of water-mass properties and direct measurements of the currents. The first comprehensive analysis of the circulation in this region was made by Fleming and Heggarty (1966). A significant review of the oceanography of this region was written by Coachman et al. (1975). Additional field work has been performed in the region in the intervening years, but these two references remain important source documents to describe regional oceanography of the southeastern Chukchi Sea.

A sub-region of the domain is Kotzebue Sound. The circulation within Kotzebue Sound is linked to that on the neighboring continental shelf. In addition, the sound receives significant amounts of freshwater runoff in summer and ice production in winter, which greatly modify the water properties within the sound. The influence of these modifications can be observed in the coastal flow as far north as Cape Lisburne, where the coastline changes direction.

3.2 HYDROGRAPHY

The water masses are determined by both advection and local modifications. The Bering Strait contributes the largest quantity of water advected into the region. The water masses of the Bering Strait are (1) Bering Shelf water, (2) Anadyr water, and (3) Alaska Coastal water (ACW) (Saur et al. 1954; Aagaard 1964; Coachman et al. 1975) (Fig. 3.2). Within a short distance north of the strait, the Bering Shelf and Anadyr water masses mix laterally, and the salinity difference between them is lost (Coachman et al. 1975). Within the Chukchi Sea, this newly formed water mass is termed Bering Sea water. Siberian Coastal water and Resident Chukchi water (RCW) are the other water masses that contribute significantly to the hydrographic structure in the Chukchi

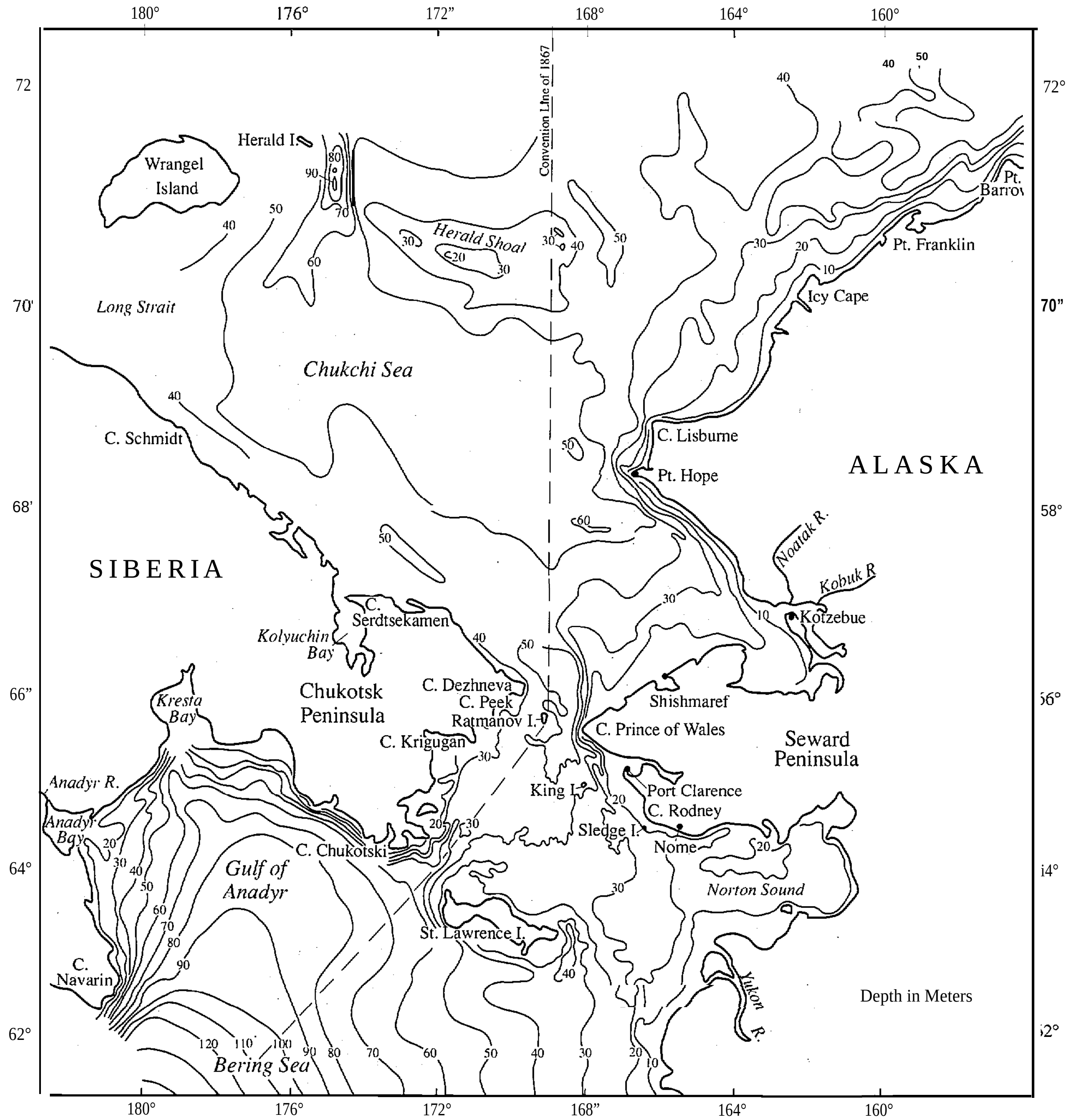

Figure **3.1** The northern Bering and Chukchi seas, including the Bering Strait (from Coachman et al. 1975).

Sea. These water masses allowed Coachman et al. (1975) to describe the northward flow through the Bering Strait as transiting the southeastern Chukchi Sea, bypassing Kotzebue Sound, and splitting into two major branches northwest of Point Hope. There, the western branch flows southward and westward of Herald Shoal and then northward into the Arctic Ocean. The eastern branch remains near the Alaskan coast to Point Barrow, although near the coast, eddies and coastal current structures are

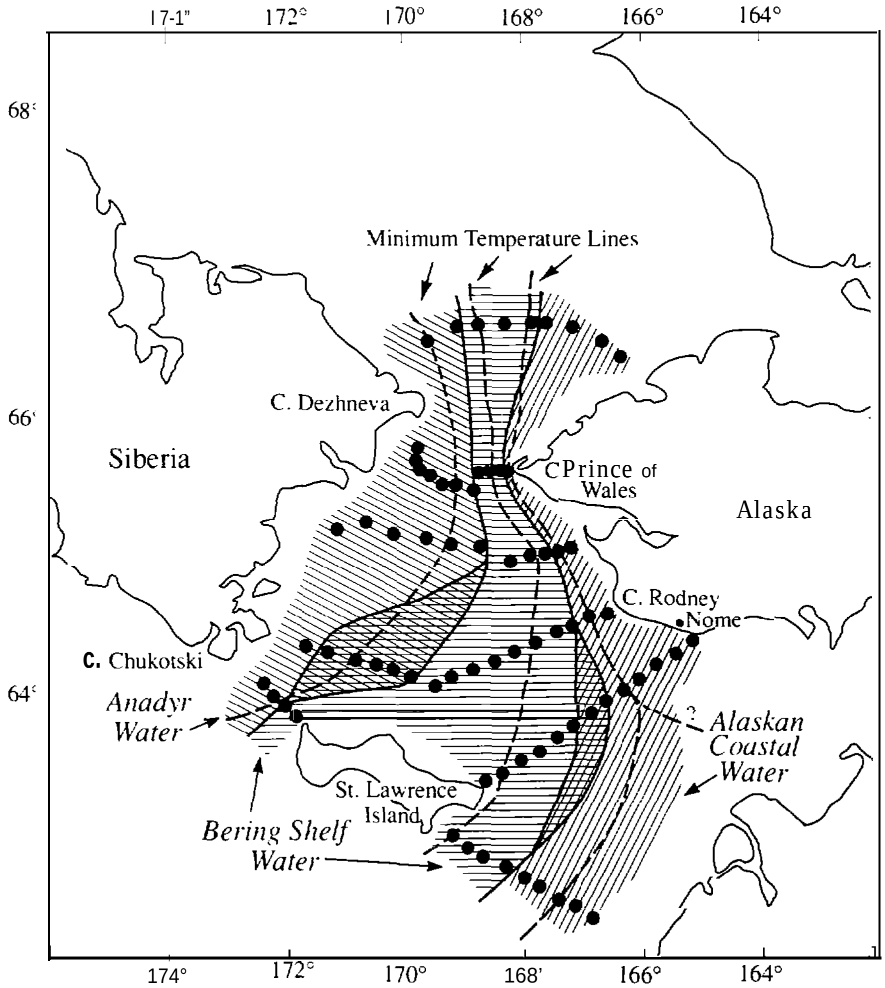

Figure 3.2 Spatial distribution of water masses for the 1968 cruise of the USCGC *Staten Island.* Dashed lines connect stations that showed minimum temperature in each water mass (modified from Coachman et al. 1975).

found. The ACW water was not observed between Cape Lisburne and Point Barrow in the summer of 1981 (Aagaard 1984). The observed temperatures were colder than those accepted for ACW, and were ascribed to RCW. In 1982, the more typical ACW as well as the RCW were present (Aagaard 1984). Aagaard (1984) explained the absence of the ACW along the coast in 1981 as attributable to all of the northward-flowing water branching toward Herald Shoal.

The ACW has distinct features; it is relatively warm (2 to 6°C) and has a wide range of salinity. The maximum salinity is normally between 32.1 and 32.50/.., but it has large interannual variability. The lack of exact correspondence between the sets of observed values and previously "defined" water masses are the result of the interannual variations of the atmospheric forcing and the Bering Sea water influx. The ACW is generally found directly adjacent to the Alaskan coast, at least as far north as Shishmaref on the Seward Peninsula. Near this location, the northward-flowing current from the Bering Strait appears to separate partially from the coast, with much of the transported water bypassing Kotzebue Sound. Kotzebue Sound contributes additional fresh water near the surface, which serves to reinforce the ACW. This influence is primarily observed north of Kotzebue Sound (Fleming and Heggarty 1966), although some effect has been suggested southwest of the sound, near the location of the separation of the northward flow from the coast (Coachman et al. 1975). Lower near-bottom temperatures and higher near-bottom salinities have been observed associated with outflow of bottom water from Kotzebue Sound (Coachman et al. 1975; Kinder et al. 1977). This bottom water is formed during ice formation in the fall and winter, and within the Sound it has a temperature of approximately −1.5 to −1.7°C and a salinity between 33.5 and 35.0‰ During early summer, this bottom water has high oxygen concentrations and high productivity (McRoy[a]). These very high salinities are mixed rapidly as the water emerges from the entrance to Kotzebue Sound, but its remnants have been observed on the adjacent shelf (Kinder et al. 1977; Aagaard 1984). In addition, horizontal and vertical diffusive mixing occurs in place within the Sound, resulting in warming and salinity reduction of the interior bottom water. On the western side of the basin, Siberian Coastal water penetrates southward near the Bering Strait. The predominantly northward transport of water through the Bering Strait and the presence of the RCW prevents the Siberian Coastal water from reaching as far south as the Bering Strait (Ratmanov 1937a,b, as interpreted by Coachman et al. 1975). In the central basin of the Chukchi Sea, resident near-bottom water is formed during ice formation and has high salinity and low temperature. The temperature and salinity are relatively close to the Bering Sea water, which flows adjacent to it, and in some cases overlies it (Coachman et al. 1975). This resident water is distinguished by its low oxygen concentration (Aagaard 1964). This implies reduced advection in the center of the gyre, and some level of near-bottom oxygen consumption, since this bottom water should be formed in the fall and early winter with relatively well-oxygenated water. The reduction of oxygen concentration from summer to early fall was observed (Aagaard 1964). Coachman et al. (1975) described this as "extraordinarily high" oxygen consumption.

The RCW has been described as "draining" from the Chukchi Sea along the Barrow submarine canyon, forming an intermediate layer (50 to 200 m) in the Arctic Ocean (Coachman et al. 1975; Garrison and Becker 1976).

3.3 CURRENTS

Direct current measurements in the southeastern Chukchi Sea are relatively few. Some moored instruments have been deployed, and ship-lowered current meters have been used. Most of these data have been obtained in waters north and south of the Chukchi Bight (see Chapter 1), particularly in the Bering Strait (Fig. 3.3). The emphasis on direct determination of the transport in the Bering Strait is understandable, since it represents the major "external" input to the Chukchi Sea and a significant input to the Arctic Ocean as well. The area of Point Hope, Cape Thompson, and Cape Lisburne has also been the site of a considerable number of current measurements (Coachman and Aagaard 1981).

Water currents in and north-northeast of the Bering Strait during summers and winters have been obtained by Coachman and Aagaard (1966) and Coachman and Tripp (1970). Early estimates of the average current in the Bering Strait varied from 15 to 50 cm/s (Ozturgut 1960; Creager 1963; Fleming and Heggarty 1966), and the currents were fairly uniform throughout the water column (barotropic flow). The current meter records revealed a generally northward flow through the Bering Strait, which approximately paralleled the coast. These studies concluded that the flow closely followed the bottom topography, since it is constrained to conserve potential vorticity. More recent estimates showed a maximum in the baroclinic coastal current of over 100 cm/s

[a]C.P. McRoy, University of Alaska, Fairbanks, AK 99775-1080, personal communication at the ISHTAR Annual Workshop 1987.

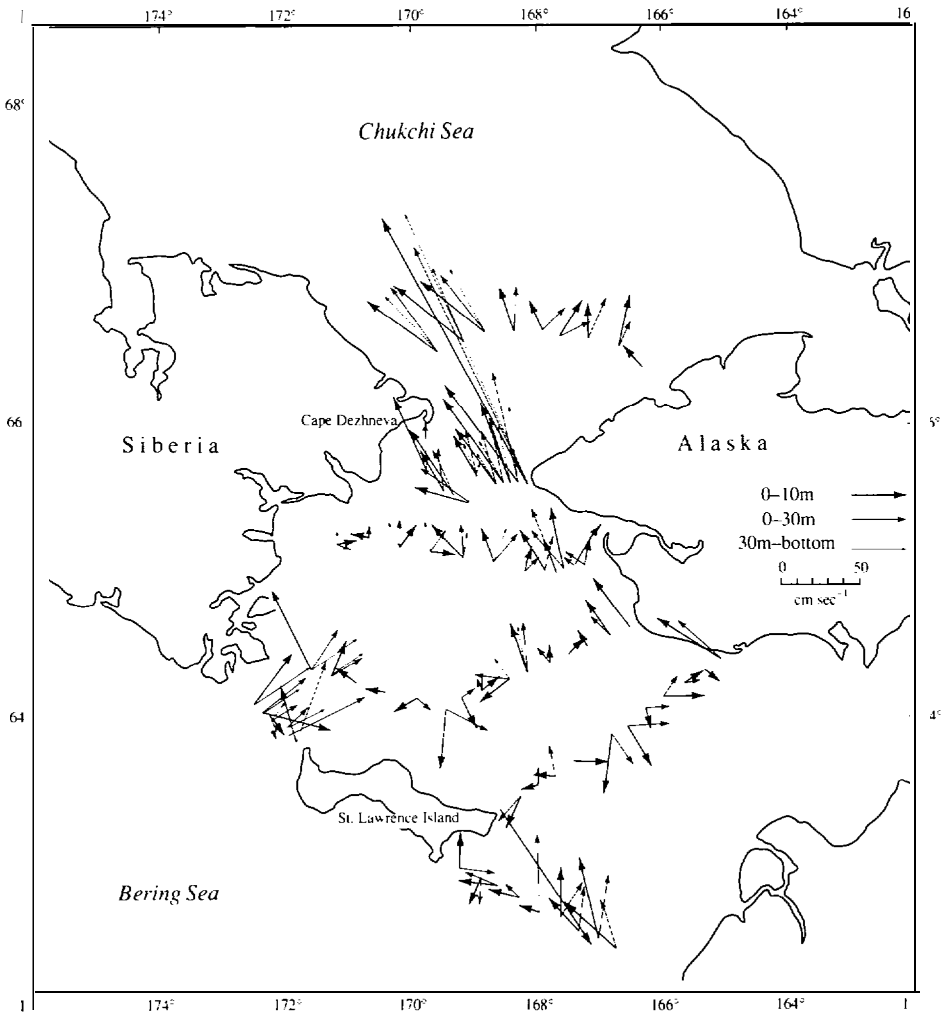

Figure 3.3 Currents averaged over three layers measured from the USC GC *Staten Island*, 9-19 July 1968 (from Coachman et al. 1975).

(Coachman et al. 1975). Once past the Bering Strait, the current flows toward the north and northeast (Fig. 3.4). The northeastward flow proceeds along the northern coast of the Seward Peninsula and, upon arriving near Kotzebue Sound, is deflected toward Point Hope. Near Point Hope, the flow gains speed (to 50 cm/s) and merges with the northward-flowing component. A branch of the northward flow continues on the west side of Herald Shoal, while the main coastal branch flows northward and eastward along the Alaskan coast, and enters the Arctic Ocean near Point Barrow. Coachman et al. (1975) reported that during July 1972 the northward transport through the Cape Lisburne section was 1.3 x 10^6 m^3/s with approximately one-third moving northwestward toward Herald Shoal and two-thirds northeastward toward Point Barrow. As stated earlier, Aagaard (1984) implied that all of the northward-transported water flowed northwestward toward Herald Shoal in the summer of 1981.

The flow through Bering Strait is fundamental to the circulation in the Chukchi Sea. This flow is generally northward, with occasional southward events (Coachman et al. 1975). The northward transport was thought to be 1 to 1.5 x 10^6 m^3/s. Recent results from longer-term mooring data and analysis of historic records have reduced this estimate to a long-term mean northerly transport of approximately 0.6 x 10^6 m^3/s

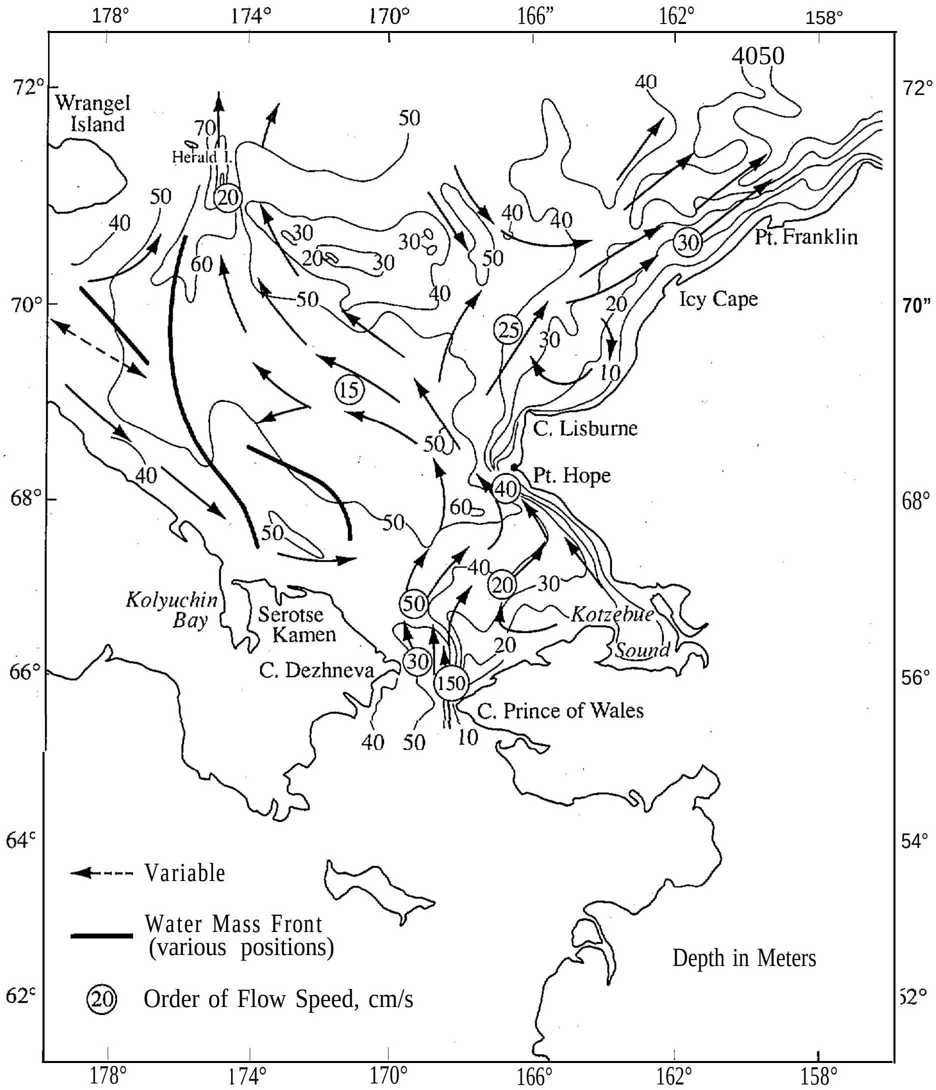

Figure 3.4 Schematic of upper-layer flow in the **Chukchi** Sea. Dotted arrows indicate variable currents. Various positions of water mass fronts are indicated, and circled numbers are estimated flow **speeds** in cm/s (from Coachman et al. 1975).

(**Aagaard** et al. 1985), The present theory on the southward-flow events is that they are the result of wind forcing over the entire northern Bering Sea (Coachman and Aagaard 1981; **Aagaard** et al. 1985). Southward winds produced by intense low-pressure systems in the Gulf of Alaska and high-pressure systems in Siberia drive the water southwestward in the northern Bering Sea. This water must be compensated for by southward flow through the strait. **Geostrophic** wind derived from barometric pressure maps correlated well with the winter transport in Bering Strait (**Aagaard** et al. 1985). Other predictive (regression) results have been derived for the southward transport as a function of pressure differences (e.g., Coachman et al. 1975), but the wind-stress mechanism is now considered most appropriate. Research on the sea ice movement to refine the ocean current effects has been performed by Kozo and Torgerson (1986). Barometric pressure estimates from U.S. and Soviet meteorological stations were used to calculate **geostrophic** winds and then correlate the wind with the ocean-current transport in the Bering Strait. Their results indicated that a wind speed of 8 **m/s** would produce a current reversal under open-water conditions (**Kozo** and **Torgerson** 1986).

Off the Lisburne Peninsula, the currents have been studied across the Cape Lisburne section, which proceeds west from Cape Lisburne and then angles southward to the Siberian coast. The current meter data indicated somewhat lower than expected mean currents (Coachman and Aagaard 1981), primarily due to vector-averaging of the fluctuations. The station nearest the Alaskan coast (NC7) showed significantly more southward flow in the winter months than had been expected. The mean vector currents were also lower in the deeper part of the Chukchi basin, averaging only 5 cm/s (Coachman and Aagaard 1981). The NC7 station had more low-frequency (0.08 to 0.2 cycles/d) energy than the station (NC1) in the western part of the basin (Coachman and Aagaard 1981). Water-transport values calculated for the Cape Lisburne section correlated strongly with the Bering Strait transports ($r^2 = 0.81$). This indicates that the southern Chukchi Sea responds coherently to the wind-forcing on the several-day time scale (Coachman and Aagaard 1981). The fundamental northward flow through the Bering Strait and subsequently through the Cape Lisburne section is generally still correct, but the value of the mean transport is lower and the significance of the fluctuations is larger than previously thought.

The influence of Kotzebue Sound on the currents is still somewhat unknown. The input of water from runoff is small compared to the transport of the Bering Strait (10^4 compared to 10^6 m^3/s). The runoff does result in a reinforcement of the Alaska Coastal Current, and thus may be very important in the coastal zone. The bottom water formation in Kotzebue Sound may also be significant, again perhaps not to the transport of water, but to the modification of water mass properties. In summer the outer portion of the sound appears to be a three-layered system (Kinder et al. 1977). Both the near-surface and near-bottom waters flow out of the sound, and replacement water flows in at intermediate depths. The inner part of the sound is nearly a two-layered system, with a very sharp pycnocline supported by both temperature and salinity.

A system of coastal currents occurs along the Alaskan coast. These currents appear to be, at least in part, connected. The Alaska Coastal Current, flowing along the eastern side of the Bering Strait, has been described as a continuous flow to Point Barrow (Hufford 1973). The ACW features help define the current at this point. North of the strait, the coastal current is not well-organized along the Seward Peninsula to Shishmaref and across the mouth of Kotzebue Sound. North of Kotzebue Sound, the additional fresh water contributed from the sound makes the coastal current more identifiable. Further north, the coastal current has been studied more thoroughly (Paquette and Bourke 1974; Paquette and Bourke 1981; Wiseman and Rouse 1980; Wilson et al. 1982; Ahlnas and Garrison 1984). North of Cape Lisburne, the ACW is as much as 40 to 80 km offshore (Aagaard 1984). The coastal current is maintained by local heating and freshwater runoff. The work by Ahlnas and Garrison (1984) is important because it attempts to link the presence of polynyas and eddies in satellite images to the coastal current. While this gives a more complete geographical picture of the coastal currents, it does not describe in much detail the time-variability of the coastal flow.

3.4 SEA ICE

Most of the year the waters of the Chukchi Sea are covered by winter ice and polar pack-ice. Ice begins to form in early October, and its southward growth proceeds rapidly. By late October or early November, moving pack-ice is found in the Bering Strait. Breakup occurs about mid-June in the southern Chukchi Sea, and ice begins to recede northward. The coastal regions are covered by shorefast ice for about 8 months. Generally, August and September are months with the least sea-ice coverage. The extent of open water along the Alaskan coast varies seasonally and depends on the wind field and winter ice-cover. Easterly and southerly winds keep the ice at some distance from the coast.

The formation of yearly ice and the extension of polar pack-ice into the Chukchi Sea modifies the water masses. The ice cover keeps the water temperature of the near-surface layers close to the freezing point because of salinity: during ice formation, salt is extruded from ice to the underlying waters. During melting, the ice becomes a source of low-salinity water, which provides density stratification in the water column early in the spring, coincident with a significant increase in insolation. These conditions are favorable for a spring bloom in primary production. Since the melting of the ice often begins near the coast, the increased buoyancy can result in a coastal current.

The effect of wind forcing is also modified by the presence of ice. When the wind blows over the ice the stress is generally larger than over open water (Macklin 1983; Walter and Overland 1984), The ice, in turn, couples more strongly with the water, resulting in an overall increase in effective wind stress by a factor of about two (Overland et al. 1984). However, in the case of fast ice, the effect of wind stress is greatly reduced.

3.5 TIDES

Tides are small in the Chukchi Sea, and the tidal range along the eastern coast, on an average, is less than 30 cm. The tides are of the semi-diurnal type (Creager 1963; Wiseman et al. 1974; Kowalik 1981; Kowalik and Matthews 1982). Wind-driven currents cause variations in sea level far in excess of those produced by the tides, up to 3 m (Matthews 1970). These sea level changes strongly influence the water mass properties in the nearshore areas and can subject beaches to wave action.

3.6 LITERATURE CITED

Aagaard, K.
1964. Features of the physical oceanography of the Chukchi Sea in the autumn. M.S. thesis, Department of Oceanography, University of Washington, Seattle, WA, 41 pp.

Aagaard, K.
1984. Current, CTD, and pressure measurements in possible dispersal regions of the Chukchi Sea. Research Unit 91 Final Report, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK, 77 pp.

Aagaard, K., A.T. Roach, and J.D. Schumacher
1985. On the wind-driven variability of the flow through Bering Strait. Journal of Geophysical Research 90:7213-7222.

Ahlnas, K., and G.R. Garrison
1984. Satellite and oceanographic observations of the warm coastal current in the Chukchi Sea. Arctic 34:224-254.

Coachman, L.K., and K. Aagaard
1966. On the exchange through Bering Strait. Limnology and Oceanography 11:44-59.

Coachman, L.K., and K. Aagaard
1981. Reevaluation of water transports in the vicinity of Bering Strait, pp. 95–110. In: The Eastern Bering Sea shelf: oceanography and resources, Vol. 1 (D.W. Hood and J.A. Calder, eds.), U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Juneau, AK,

Coachman, L.K., and R.B. Tripp
1970. Currents north of Bering Strait in winter. Limnology and Oceanography 15:625-632.

Coachman, L.K., K. Aagaard, and R.B. Tripp
1975. Bering Strait: the regional physical oceanography. University of Washington Press, Seattle, WA, 172 pp.

Creager, J.S.
1963. Sedimentation in a high-energy, embayed, continental shelf environment. Journal of Sedimentary Petrology 33:815-830.

Fleming, R.H., and D. Heggarty
1966. Oceanography of the southeastern Chukchi Sea, pp. 697–754. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.), U.S. Atomic Energy Commission, Washington, D.C.

Garrison, G.R., and P. Becker
1976. The Barrow submarine canyon: a drain for the Chukchi Sea. Journal of Geophysical Research 81:4445-4453.

Hufford, G.L.
1973. Warm water advection in the southern Beaufort Sea, August–September 1971. Journal of Geophysical Research 78:2702-2707.

Kinder, T.H., J.D. Schumacher, R.B. Tripp, and D. Pashinski
1977. The physical oceanography of Kotzebue Sound, Alaska, during late summer, 1976. Technical Report M77-99, Department of Oceanography, University of Washington, Seattle, WA, 84 pp.

Kowalik, Z.
1981. A study of the M2 tide in the ice-covered Arctic Ocean. Modeling, Identification and Control 2:201-223.

Kowalik, K., and JJ3. Matthews
1982. The M2 tide in the Beaufort and Chukchi seas. Journal of Physical Oceanography 12:743-746.

Kozo, T.L., and L.J. Torgerson
1986. Geostrophic wind velocity thresholds for Bering Strait current reversals under open water and ice covered conditions EOS 67:1015 (Abstract only).

Macklin, S.A.
1983. Wind drag coefficient over first-year sea ice in the Bering Sea. Journal of Geophysical Research 88:2845-2852.

Matthews, J.B.
1970. Tides at Pt. Barrow. Northern Engineer 2:12-13.

Overland, J.E., H.O. Mofjeld, and C.H. Pease
1984. Wind-driven ice motion in a shallow sea. Journal of Geophysical Research 89:6525-6531.

Ozturgut, E.
1960. Currents and related water properties in the Eastern Chukchi Sea. M.S. thesis, University of Washington, Seattle, WA, 66 pp.

Paquette, R.G., and R.H. Bourke
1974. Observations on the coastal current of arctic Alaska. Journal of Marine Research 32:195-207.

Paquette, R.G., and R.H. Bourke
1981. Ocean circulation and fronts as related to ice melt-back in the Chukchi Sea. Journal of Geophysical Research 86:4215-4230.

Ratmanov, E.G.
1937a. K gidrologii beringova i chukotskogo morei. Issledovaniya Morie SSSR 25:10-118.

Ratmanov, E.G.
1937b. K voprosu o vodoobmene cherez beringov proliv. Issledovaniya Morie SSSR 25:119-135.

Saur, J.F.T., **J.P. Tully,** and **E.C. LaFond**
1954. Oceanographic cruise to the Bering and **Chukchi** seas, summer 1949. Part **IV:** Physical oceanographic studies: Vol. 1. Descriptive Report 416, Vol. 1, U.S. Navy Electronic Laboratory, San Diego, CA, 31 pp.

Stigebrant, A.
1984. The North Pacific: a global-scale estuary. Journal of Physical Oceanography **14:464-470.**

Walter, **B.A.,** and **J.E.** Overland
1984. Air-ice drag coefficient for first-year ice derived from aircraft measurements. Journal of Geophysical Research 89:3550-3560.

Wilson, **D.E, S.D.** Pace, **P.D.** Carpenter, H. **Teas,** T. Goddard, P. Wilde, and P. Kinney
1982. Nearshore coastal currents in the **Chukchi** Sea, summer 1981. Research Unit531 Final Report, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, **Juneau, AK,** 289 pp.

Wiseman, W. J., Jr., and **L.J. Rouse,** Jr.
1980. A coastal jet in the **Chukchi** Sea, Arctic **33:21-29.**

Wiseman, W.J., Jr., **J.N. Suhayda,** and **S.A.** Hsu
1974. Characteristics of nearshore oceanographic environment of arctic Alaska, pp. 49-64. In: The coast and shelf of the Beaufort Sea (**J.C.** Reed and **J.E. Sater, eds.),** The Arctic Institute of North America, Alexandria, VA,

4

primary Productivity and Nutrient Dynamics

D. M. Schell
S. Saupe
R. Johnson-McNichols

4.1 BACKGROUND

Primary productivity in the southeastern Chukchi Sea and Kotzebue Sound arises from two principal sources-an ice-associated flora during spring, and phytoplankton in the water column during open water. Since the melting of the ice cover is controlled by several factors that also affect primary productivity, such as currents, input of river run-off and suspended sediments, presence and persistence of leads in sea ice, and water flow through the Bering Strait, the onset of spring primary productivity is highly variable from location to location. Although very little information on primary productivity is available for Kotzebue Sound, sufficient sampling has been performed in the Bering Sea and in the coastal areas of the Chukchi and Beaufort seas to allow reasonable approximation of the annual cycle.

4.2 ICE ALGAE

In the Arctic there are two separate ice-associated microalgal communities: one consists of algae that grow in surface-melt ponds on the ice cover and are found only in perennial ice; the other, which is more dominant, consists of under-ice (or "epontic") algae that bloom in late spring. The epontic algae grow in the lower few centimeters of the sea ice; these algae and their associated fauna have been deemed an "epontic community" by Bunt and Wood (1963) and an "inverted benthic community" by Homer (1977). Pennate diatoms compose 90% or more of the total ice-associated flora near Barrow (Alexander et al. 1974) and are dominant in the Canadian Arctic (Apollonio 1965) and the Antarctic (Bunt and Wood 1963). In the high Arctic, epontic algae occurs in clumps and streamers, with the species *Melosira arctica* predominating (Melnikov 1980).

The epontic algae evidently are extremely shade-adapted. Photo-inhibition of photosynthesis was observed in antarctic phytoplankton at 230 $\mu E/m^2 \cdot s$, and photosaturation occurred at 21 $\mu E/m^2 \cdot s$ (Bunt 1964, 1968). Ice algae begins growing in the area of the Chukchi Sea off Barrow at light intensities of only 2.3 to 9.3 $\mu E/m^2 \cdot s$ (Alexander et al. 1974). Algal biomass reaches maxima in late May and begins to diminish rapidly with the first melting of sea ice in early June. The dark color of the algae is believed to hasten melting in situ by absorbing the light penetrating the ice and thereby fostering localized melting. *Nitzschia* spp. were the most common observed component of the ice-algal bloom at Barrow during the two years of study (Alexander et al. 1974). The total estimated annual primary production of the ice-algal bloom at Barrow is 5 g C/m^2.

Parrish (1987) synthesized data on ice-algal productivity y acquired during spring 1981 in the eastern Chukchi Sea, and calculated a yearly estimate of 13 g C/m^2. This value represents an increase over previous estimates for the area of the Chukchi Sea near Barrow and for the coastal Beaufort Sea (Alexander 1974). In comparison, annual production by ice algae in the Bering Sea was estimated at 24 g C/m^2 (McRoy and Goering 1976).

4.3 PHYTOPLANKTON PRODUCTION

Very little new data have been acquired on the primary productivity and nutrient dynamics in the Chukchi Sea region since the original NOAA-sponsored work in 1976. The major additions, therefore, are derived from reworking and refining the existing data into a broader context and by attempting to integrate new information from the Bering Strait. We prepared a map showing contours of annual primary production for the Beaufort and Chukchi seas (Fig, 4.1) and related this map "to secondary production as inferred from historical distribution of bowhead whales (Schell 1987).

Further insight into the sources of energy supporting the southern Chukchi Sea is evident from the work of Sambrotto et al. (1984), which describes apparent mechanisms for high primary productivity in the western portion of the Bering Strait. Upwelled, nutrient-rich water from the Gulf of Anadyr flows northward across the shelf and supports very high concentrations of phytoplankton as it moves through the Bering Strait. This production is reflected in a large zooplankton crop and the high benthic biomass of the region. Although Sambrotto et al. (1984) estimated annual production as high as 324 g C/m^2 for this region, their data set was very limited. Actual values may only be in that order of magnitude. Sambrotto et al. (1984) did not consider the consequences of the winter season. If the upwelling and northerly current prevail throughout the winter season, this mechanism may provide a supply of nutrient-rich waters to the southern Chukchi Sea. In spring, the formation of a stable surface-layer coupled with the onset of ice-melt and the increase in solar radiation would result in a phytoplankton bloom of the same magnitude as found further south in the Bering Sea. Regeneration of a fraction of this nutrient pool over the summer would serve to keep production at an elevated level. There are no data to support or deny this hypothesis,

Models of primary production do not exist for Kotzebue Sound, but Parrish (1987) attempted to describe the seasonal production in the northern Chukchi Sea. He used the instantaneous-rate measurements from Alexander et al. (1975), Dawson (1965), Hameedi (1978), Saito and Taniguchi (1978), Horner (1981), and his own data to construct a synthesis of primary production estimates for the Alaskan Arctic. He segregated ^{14}C uptake data by month and region to calculate mean rates of monthly productivity. The average rates of under-ice productivity y were based on data from ice islands, such as T-3, and applied to all regions. Nutrient-depletion data were used to approximate euphotic zone depths in the open water. Under-ice photic depths were estimated from an average light-extinction coefficient calculated from data in Maykut and Grenfell (1975), from under-ice measurements taken by Alexander et al. (1974), and from data provided by Schell et al. (1984). He then estimated the light-energy penetrating the ice each month and calculated the average monthly under-ice euphotic zone.

Satellite imagery (Defense Meteorological Satellite Program) and the Navy/NOAA biweekly sea-ice projection maps were used by Parrish (1987) to obtain the average sea-ice retreat for the summers of 1977-83. From these projections, he obtained the ice-free days per year for calculation of seasonal productivity along three arbitrary transects in the Chukchi Sea. After projecting the primary productivity at points along the transects, he contoured the estimates to prepare the map shown in Figure 4.1. Although observational data were very few, the inferred annual primary production for the southeastern Chukchi Sea and Kotzebue Sound was 75 to 100 g C/m^2. This estimate is considerably lower than the value provided by Sambrotto et al. (1984). The difference could be due to the nature and spatial extent of data used in these two estimates.

In the northern Chukchi Sea and regions with perennial ice-cover, the estimates of primary production are much more tenuous. Subba Rao and Platt (1984) reviewed the primary-productivity data and applied their estimates of euphotic zone depths and deep productivity rates. They calculated annual production values that were up to 16 times the values reported in the literature. Nonetheless, even the revised estimates of annual primary production for the arctic waters are very small compared to values in the temperate seas. Since many of the assumptions made by Subba Rao and Platt (1984) were also used by Schell et al. (1984) in calculating the productivity of waters in the southern Beaufort Sea, the contours shown in Figure 4.1 are still believed to be valid within the precision of the estimates.

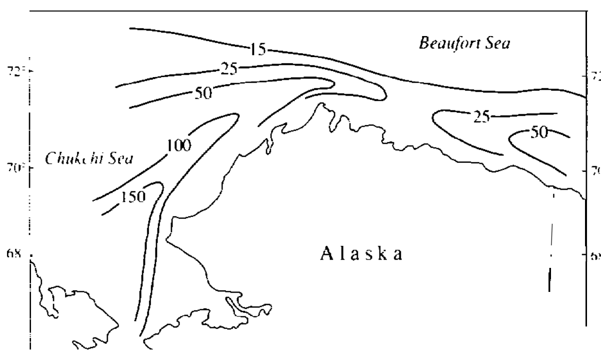

Figure 4.1 Projected annual primary production (g C/m^2·yr) in the Chukchi and Bering seas.

4.4 LITERATURE CITED

Alexander, V., R. Homer, and R.C. Clasby
1974. Metabolism of arctic sea ice organisms. Institute of Marine Science, Report R74-4, University of Alaska, Fairbanks, AK, 120 pp.

Alexander, V., C. Coulon, and J. Chang
1975. Studies of primary productivity and phytoplankton organisms in the Colville River system, pp. 299-427. In: Environmental studies of an arctic estuarine system, Final report (EPA-660/3-75-026), U.S. Environmental Protection Agency, Corvallis, OR.

Alexander, V.
1974. Primary productivity regimes of the nearshore Beaufort Sea, with reference to the potential roles of ice biota. In: The coast and shelf of the Beaufort Sea, (J.C. Reed and J.E. Sater, eds.) Arctic Institute of North America, Arlington, VA, pp. 609–632.

Apollonio, S.
1965. Chlorophyll in arctic sea-ice. Arctic 18:118-122.

Bunt, J.S.
1964. Diatoms of antarctic sea ice as agents of primary production. Nature 199:1255-1257.

Bunt, J.S.
1968. Microalgae of the Antarctic pack ice zone, pp. 198-218. In: Symposium on antarctic oceanography (R.I. Currie, cd.), Scott Polar Research Institute, Cambridge, England.

Bunt, J.S., and E.J.F. Wood
1963. Microalgae in sea ice. Nature 199:1254-1255.

Dawson, W.A.
1965. Phytoplankton data from the Chukchi Sea. Technical Report No. 117, Department of Oceanography, University of Washington, Seattle, WA, 123 pp.

Hameedi, M.J.
1978. Aspects of water column primary productivity in the Chukchi Sea during summer. Marine Biology 48:37-46.

Homer, R.
1977. History and recent advances in the study of ice biota, pp. 285-299. In: Polar oceans (M.J. Dunbar, cd.), The Arctic Institute of North America, Calgary, AB, Canada.

Homer, R.
1981. Beaufort Sea plankton studies, pp. 65–314. In: Final Reports of Principal Investigators, Vol. 13, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Maykut, **G.A.,** and **T.A. Grenfell**
1975. The spectral distribution of light beneath first year sea ice in the Arctic Ocean. Limnology and Oceanography 20:554-563.

McRoy, C.P., and **J.J. Goering**
1976. Annual budget of primary production in the Bering Sea, Marine Science Communications 2:255-267.

Melnikov, I.A.
1980. Ecosystems of arctic drift ice, pp. 61-97. In: Biology of the central Arctic Basin (M.E. Vinogradov and I.A. Melnikov, eds.), Izdatelstvo Nauk, Moscow.

Parrish, **D.M.**
1987. An estimate of annual primary production in the Alaska Arctic Ocean. M.S. thesis, Department of Marine Science and Oceanography, University ofAlaska, Fairbanks, AK, 166 pp.

Saito, K., and **A. Taniguchi**
1978. Phytoplankton communities in the Bering Sea and adjacent seas, 2: Spring and summer communities in seasonally ice-covered areas. Astarte 11:27-35.

Sambrotto, R.N., **J.J. Goering,** and **C.P. McRoy**
1984. Large yearly production of phytoplankton in the western Bering Strait. Science 225:1147-1150.

Schell, D.M.
1987. Primary production and nutrient dynamics in the Chukchi Sea, pp. 43-47. In: Chukchi Sea information update (P.R. Becker, cd.), U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK.

Schell, D.M., **P.J.** Ziemann, **D.M.** Parrish, **K.H.** Dunton, and **E.J.** Brown
1984. Food web and nutrient dynamics in nearshore Alaska Beaufort Sea waters, pp. 327499. In: Final Reports of Principal Investigators, Vol. 25, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK.

Subba Rae, D.V., and T. **Platt**
1984. Primary production of arctic waters. Polar Biology 3:191-201.

5

Zooplankton

M.J. Hameedi

5.1 INTRODUCTION

Although very few zooplankton studies have been conducted in the southern Chukchi Sea, the significance of this region to transitional zooplankton from the Bering Sea has long been recognized (Stepanova 1937). The presence of *Calanus tonsus* and *Metridia lucens* at 72°N, 170°W was used as biological evidence of the extensive northward flow of water from the Bering Sea (LaFond and Pritchard 1952). The absence of *Acartia longiremis* in the Beaufort Sea—this species is widespread and sometimes numerically abundant in the Chukchi Sea—was accounted for by a flow of surface water from the Polar Basin, which apparently was not suitable for its existence (Johnson 1956). The distributions of *Calanus tonsus*, *Centropages mcmurchii*, *Epilabidocera amphitrite*, *Eucalanus bungii*, *Metridia lucens*, and *Tortanus discaudatus* in the northern Bering and southern Chukchi seas were related to surface isotherms and the northward flow of water through the Bering Strait (Johnson 1956).

Saur, Tully, and LaFond (1954) obtained evidence of a flow of water from the northeastern Siberian coast to a point directly north of the Bering Strait, at the latitude of Kotzebue Sound. This flow was also expected to bring plankton populations from the Siberian coast into a region noted for the northward transport of Bering Sea zooplankton. Siberian coastal zooplankton contribution to the central and eastern portions of the Chukchi Sea, if any, remains unknown.

Only two studies, those of English (1966) and Cooney (1977), have been carried out in the Chukchi Bight and Kotzebue Sound with sufficient resolution in field sampling to describe spatial features of zooplankton distribution and abundance. Neimark (1979), in a study of zooplankton distribution and community structure and of its importance as food for coastal fishes in Norton Sound, also included comparisons of the distribution of the numerically dominant zooplankton species and zooplankton biomass between Norton Sound and the southeastern Chukchi Sea.

5.2 ZOOPLANKTON BIOMASS

English (1966) described zooplankton biomass in the Chukchi Bight and Kotzebue Sound as settled volume after removal of salps, ctenophores, and medusae. His data, obtained in 1959 from 81 stations, afforded a nearly complete spatial coverage of the area under consideration in this review. The geometric mean of the settled-volume data was 1.4 mL/m^3. Low values, less than the mean, were generally found in Kotzebue Sound and in the eastern portion of the bight. High values, between 2 and 5 mL/m^3, were found in the western portion of the bight and within the Bering Strait (Fig. 5.1). Higher values of settled volume seemed to coincide with the higher salinity water flowing northward from the Bering Sea.

English's (1966) data obtained in 1960 were from a fewer number of stations (64) that were more widely distributed, from Shpanberg Strait to locations west of Pt. Barrow. Further, no samples were collected in 1960 in either Kotzebue Sound or the eastern part of the Chukchi Bight. A comparison between the 1959 and 1960 data sets to infer interannual variability is not meaningful, although English (1966) reported that the mean settled volume in 1960, 2.2 mL/m^3, was significantly greater than in 1959.

Settled volume as an estimator of zooplankton biomass is imprecise: the confidence limits for the geometric mean for the 1959 and 1960 data were between 58 and 172% (English 1966). The conversion of settled volume to dry weight values (or carbon equivalents) is even more tenuous. Jawed (1970), using both the original and logarithmically transformed data, described the relationship between settled volume and dry weight of zooplankton collected from Puget Sound, Washington, and off the Washington-Oregon coast, in the northeast Pacific Ocean. The relationship using logarithmically transformed data is

$$Y_i = 0.7216 + 1.1995\ Xi$$

where Xi is settled volume, in log mL/m^3, and Y_i is dry weight, in log mg/m^3. According to this relationship, the zooplankton settled-volume of between 2 and 5 mL/m^3 in Figure 5.1 corresponds to between 12 and 36 mg dry weight/ins, respectively. However, the relationship is quite imprecise: for a predicted mean dry-weight value of 44 mg, 95%-confidence limits were between 15 and 134 mg (Jawed 1970).

There are no other data with which to compare English's (1966) settled-volume (or derived dry-weight) data. The author[a] obtained zooplankton samples from 28 stations in the northeastern Chukchi Sea in 1974. The dry-weight values of those samples, as determined by the method of Lovegrove (1966), ranged from 1 to 64 mg/m^3 (the corresponding ash-free dry-weight values ranged from 1 to 38 mg/m^3). The higher range in the author's data for plankton dry weight is because of the smaller mesh size of the net used to collect zooplankton (0.75 -m-diameter Puget Sound-type closing net, mesh size 0.110 mm) in comparison with the net used by English (Clarke -Bumpus plankton sampler, mesh size 0.240 mm).

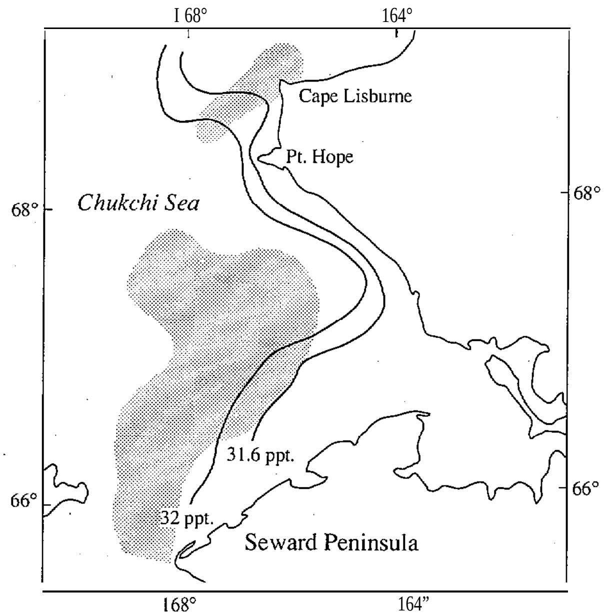

Figure **5.1** Settled volume of net zooplankton collected in 1959. Shaded areas encompass values between 2 and 5 mL/m^3; values in the remaining area are less than 2 mL/m^3. Salinity contours denote the extent of the northward-flowing water in the Bering Strait (modified from English 1966).

5.3 TAXONOMIC COMPOSITION

Data on zooplankton species composition and distribution are very scant. The vast majority of samples obtained during the two

[a]Unpublished data.

aforementioned surveys in the region (English 1966; Cooney 1977) was not analyzed for species composition, relative abundance, and geographic distribution.

Wing (1972, 1974) described 63 taxa of zooplankton collected during the WEBSEC-70 cruise in the northeastern Chukchi Sea, north of Pt. Hope. Among those taxa were 13 species of Copepoda, 4 species of Amphipoda, 3 species each of Scyphomedusa and Hydromedusa, and two species each of Euphausiacea, Cladocera, Mysidacea, Gastropoda, and Larvacea. Most other taxa were not identified to the species level. The number of species at each station varied between 5 and 29, with lower species-richness in coastal waters, particularly in Ledyard Bay. The region northwest of Cape Lisburne had a much larger number of species, between 15 and 29 per station. Among the most common species were *Aglantha digitale*, *Clione limacina*, *Sagitta elegans*, *Acartia longiremis*, *Calanus finmarchicus*, *Centropages abdominalis*, *Eucalanus bungii*, and *Pseudocalanus minutus*. As is typical of zooplankton in the Chukchi Sea during summer, the meroplankton fraction (notably balanoid nauplii and cyprids, polychaete larvae, pagurid and hippolytid zoeae, veliger, bipinnaria, and plutei larvae) in samples collected during the WEBSEC-70 (September-October 1970) and the USS *Nereus* (summer 1947) cruises was high (Johnson 1956; Wing 1974).

Cooney (1977) described taxonomic composition for only 4 of the 52 stations sampled in the Bering Strait, the Chukchi Bight, and Kotzebue Sound (Table 5.1). His data also showed fewer species in nearshore water, i.e., within the sound (Station 51) and off Pt. Hope (Station 103).

Taxonomic analysis of zooplankton samples collected in 1976 showed a marked difference between species assemblages in Norton Sound and the southeastern Chukchi Sea (Neimark 1979). Zooplankton in Norton Sound was dominated by *Acartia clausi* in the eastern portion and by *Pseudocalanus* sp. in the central and western portions of the sound. The numerically dominant zooplankton species in the southeastern Chukchi Sea were more varied and their distributions were spatially more restricted: *Aglantha digitale* was found in shallow water along the Seward Peninsula; *Oikopleura* sp. was abundant at the mouth and west of Kotzebue Sound; *Fritillaria borealis* and *Evadne* sp. were abundant within Kotzebue Sound; and *Pseudocalanus* sp. had a meridional distribution in the central part of the Chukchi Sea between the Bering Strait and Pt. Hope (Fig. 5.2).

Perhaps reflecting the high abundance of these taxa, zooplankton biomass, expressed as dry weight, was also higher at some locations in the southeastern Chukchi Sea, between 100 and 1,000 mg/m^3, when compared with data from Norton Sound, where biomass values did not exceed 100 mg/m^3 (Neimark 1979). The difference in zooplankton assemblage between Norton Sound and the southeastern Chukchi Sea could be due to a variety of physical factors, e.g., influx of fauna with water advected from the Bering Sea, or biological features of the resident fauna, e.g., the ability of *Acartia clausi* to form dormant eggs that hatch when temperature and salinity conditions are optimal. Presently available data have insufficient resolution and detail to correlate the reported zooplankton distributions to specific features of the environment in the southeastern Chukchi Sea, but some of the important factors include the large amount of freshwater drainage into Kotzebue Sound, the influence of the northward-flowing water from the Bering Sea, the delimited nature of the Alaska Coastal water mass, the contribution of fauna from coastal lagoons, and the trophic phenology in the pelagic zone as reflected in the prey-predator ratio of zooplankton species.

It can be surmised from the limited amount of available data that zooplankton in

TAXON	STATION 51	82	103	105
Hydrozoa				
Perigonimus yoldia-arcticae	-	x		
Obelia longissima		x		
Aglantha digitale	x	x	x	x
Actinula larvae	x			
Polypoid larvae		x		
Scyphozoa				
Cyanea capillata	X	x		
Ctenophora		x	x	
Polychaeta larvae				
Polynoidae		x	x	
Phyllodocidae			X	
Spionidae	x	x	x	
Megilonidae	x			
Capitellidae	x			
Unidentified	X		X	
Pelecypod juveniles	x			
Gastropod				
Limacina helicina	x		x	x
Clione limacina	x		x	x
Cladocera				
Evadne sp.	x	x		
Podon sp.		x		x
Copepoda				
Calanus cristatus	x			
Calanus glacialis	x	x	x	x
Calanus plumchrus	x			X
Eucalanus bungii bungii	x		x	x
Pseudocalanus spp.	x	x	x	x
Microcalanus sp.	X			
Eurytemora herdmani				x
Metridia lucens	x			x
Centropages abdominalis	x	x		x

TAXON	STATION 51	82	103	105
Copepoda (cont.)				
Acartia longiremis	x	x	x	x
Acartia clausi	x	x		x
Oithona similis	x	x		
Oncaea sp.	x			
Copepod nauplii			x	
Cirripedia				
Nauplii				x
Cypris larvae	x	x	x	x
Cumacea	x			x
Amphipoda				
Protomedia sp.				x
Bathymedon nanseni				x
Westwoodila coecula	x			
Parathemisto spp.	x		x	x
Euphausiid larvae	x		x	x
Decapoda larvae				
Pandalidae	x		x	x
Hippolytidae			x	x
Paguridae		x		x
Oregoniidae	x	x		x
Unidentified anomuran	x		x	x
Echinoderm larvae				
Ophiopluteus	x			
Chaetognatha				
Sagitta elegans	x	X	x	x
Eukrohnia sp.	x			
Unidentified juveniles	x	x	x	x
Urochordata				
Ascidian larvae	x			
Oikopleura sp.	X		x	
Fritillaria borealis	X	x	x	x

Figure **5.1** Zooplankton identified from representative samples from the Bering Strait, (Station 51, Kotzebue Sound (Station 82), off Pt. Hope (Station 103), and the middle of Chukchi Bight (Station 105) north of the Bering Strait.

this region consist of the numerically abundant arctic coastal and continental shelf species: *Pseudocalanus* sp., *Acartia longiremis*, *Calanus glacialis*, *Aglantha digitalis*, and *Sagitta elegans*. Coastal zooplankton also include cladocerans (*Evadne* sp. and *Podon* sp.) and small copepods (*Eurytemora* sp., *Centropages* sp., and *Oithona* sp.). Coastal lagoons, most of which have salinity less than 16°/00 in summer, contain some brack-

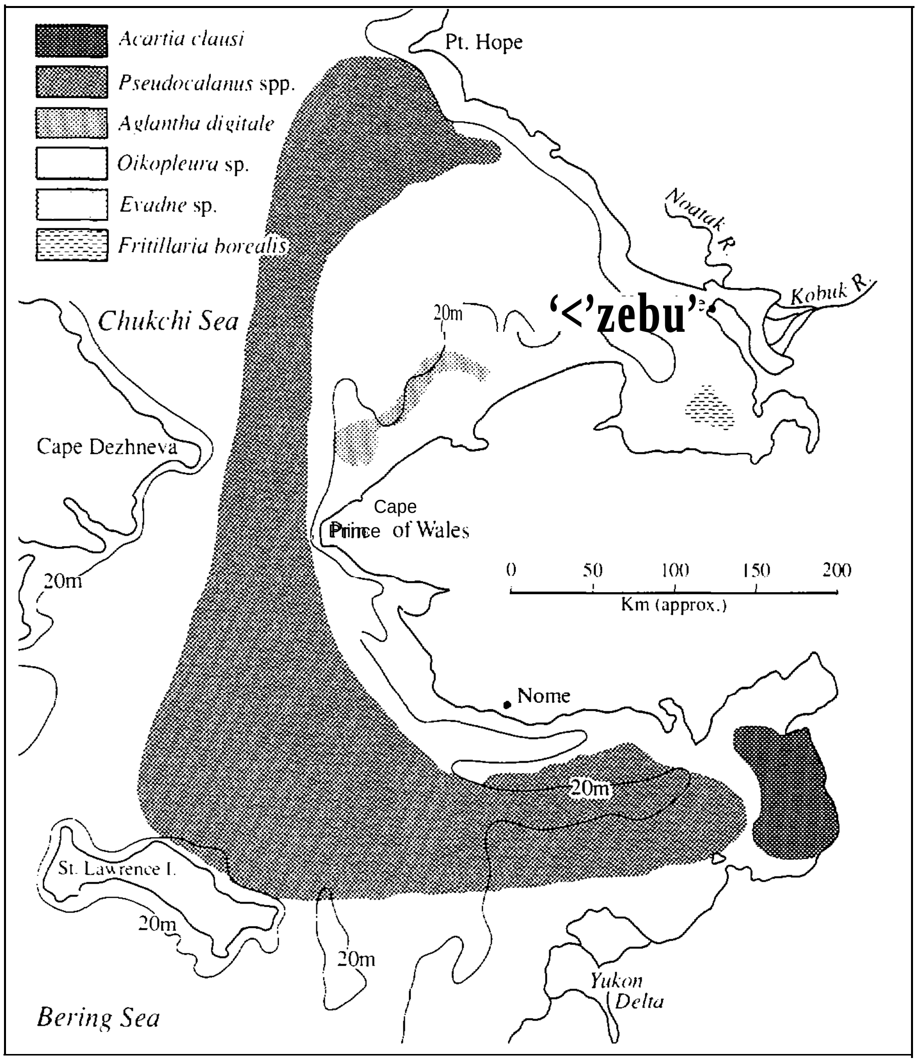

Figure 5.2 Distribution of the numerically dominant zooplankton species in regions of the Bering and Chukchi seas, summer 1976 (from Neimark 1979).

ish-water and freshwater species, notably *Limnocalanus johanseni* and *Eurytemora canadensis.* Zooplankton in one of the lagoons along the north coast of the Chukchi Bight, with a salinity of 0.16°/00, consisted nearly exclusively of *Daphnia* sp. (97 to 99% of all zooplankton). In a nearby lagoon with a salinity range of 14 to 16°/00 and which had a narrow above-sea-level outlet that was probably flooded with sea water during storms, zooplankton fauna consisted of *Acartia - bifilosa, Acartia clausi, Acartia longiremis, Centropages abdominalis, Eurytemora herdmani, Tortanus discaudatus,* and *Pseudocalanus* sp., among others (Johnson 1966).

Large copepods, such as *Neocalanus cristatus* and *Neocalanus plumchrus* (identified as *Calanus cristatus* and *Calanus plumchrus* in earlier literature) are found in the northward-flowing water originating in the Bering Sea. They are usually found in small numbers, and are present in late copepodite stages. Their early-life stages occur in the outer continental shelf and slope waters in the eastern Bering Sea. Their presence in the Chukchi Sea can only be considered transitional and short-lived, but is important for the food requirements of several bird species that feed on them.

5.4 NUMERICAL ABUNDANCE

Neither English (1966) nor Cooney (1977) described numerical abundance of zooplankton. Some data are available from the northeastern Chukchi Sea (Wing 1972, 1974; the author'). Wing's data outline areas of high abundance of calanoid copepods, with high concentrations (between 10 and 31 animals/m^3) off Cape Lisburne, and much fewer farther north (Fig. 5.3). Total zooplankton (averaged value for two samples collected at each station) varied between 191 and 27,386 animals/100 m^3. *Aglantha digitale,* a hydromedusan, was found at all locations sampled, often in large numbers (exceeding 26,000 animals/100 m^3).

Samples obtained by the author in August to September of 1974 in an area similar to that sampled by Wing (1972) showed a total zooplankton count of between 348 and 4,617 animals/m^3 in the water column. At stations where a significant concentration of zooplankton within a discernible layer in the water column was indicated by acoustic volume scattering strength (Shah 1975), much higher numbers, up to 6,000 animals/m^3 within a 10-m layer, were noted. Within the size range of 1 to 5 mm, which includes many adult copepods (Table 5.2), zooplankton concentration varied between 8 and 750 animals/m^3, with a mean value of 185 animals/m^3. Population density values for the 1- to 5-mm size range are roughly comparable with Wing's data, considering that the numerically abundant taxa other than calanoid copepods also contributed to zooplankton in the 1- to 5-mm size range. However, the large difference between Wing's and the author's data is most probably due to the mesh size of plankton samplers: 0.57 mm in Wing's (1972) study, and 0.110 mm in the author's study.

A principal feature of the author's zooplankton data is the large number and high proportion of small zooplankters, i.e., those with body size of 1 mm or less. On the average, zooplankton 0.5 mm in size accounted for 57% of all zooplankton, and those between 0.5 and 1 mm accounted for 32% of all zooplankton. In other words, small zooplankters, on the average, contributed 89% of all zooplankton. This small fraction

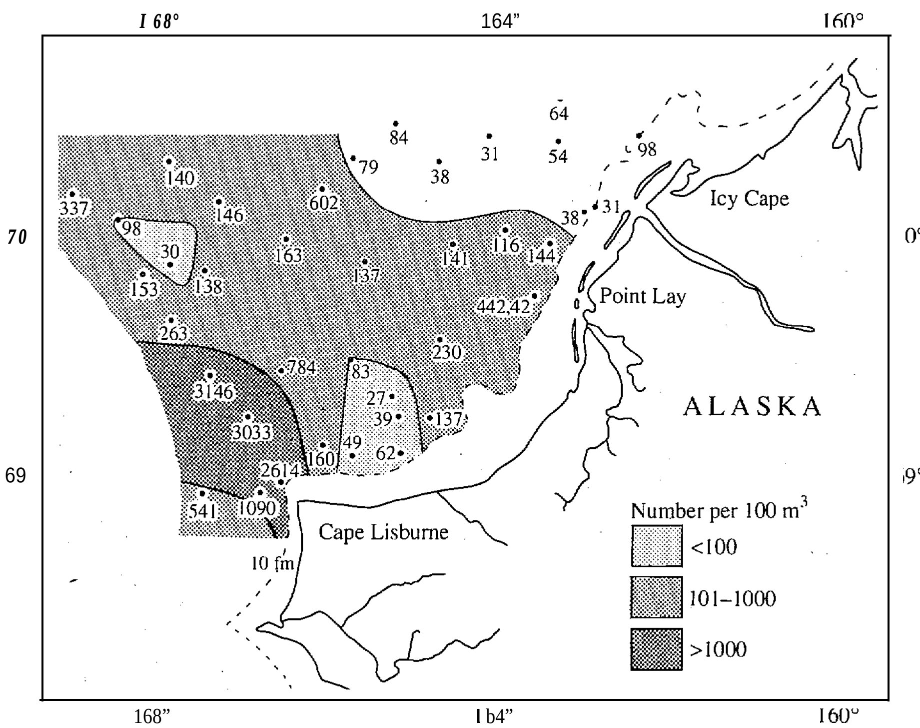

Figure **5.3** Concentration (individuals/100 m^3 of water) of calanoid copepods sampled by vertical net tows during WEBSEC-70 (from Wing 1972).

would not have been effectively sampled during the WEBSEC-70 cruise.

Although the data summarized above are not from the southeastern Chukchi Sea, they do underscore the numerical dominance and concomitant trophic significance of small zooplankton in the overall energetic of the regional ecosystem. Failure to account for this important ecological component would be a misrepresentation of the ecological dynamics of the study area.

Table 5.2 Numerically abundant zooplankton in the northeastern Chukchi Sea collected during AugustSeptember of 1974. Taxa are grouped according to size (the author[a]).

Less than 0.5 mm	1.1 to 5.0 mm
Copepod nauplii	Adult copepods
Copepodite stages	Small worms (found only at Station 49)
Gastropod larvae	Small shrimp (found only at Station 112)
Polychaete larvae	Juvenile snails (found only at Station 114)
Unidentified eggs	Chaetognaths
	Oikopleurans
0.5 to 1.0 mm	**5.1 to 10.0 mm**
Barnacle larvae (nauplii and cypris stages)	Chaetognaths
Copepodite stages	Oikopleurans
Cyclopoids	Ctenophores
Veligers	Copepods
Small oikopleurans	**Larger than 10 mm**
Polychaete larvae	Chaetognaths
Cladocerans	Oikopleurans
Echinoderm larvae	

5.5 LITERATURE CITED

Cooney, **R.T.**
1977. Zooplankton and micronekton studies in the Bering-Chukchi/Beaufort seas, pp. 275-363. In: Annual Reports of Principal Investigators, Vol. 10, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

English, **T.S.**
1966. Net plankton volumes in the Chukchi Sea, pp. 809-815. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.), U.S. Atomic Energy Commission, Washington, D.C.

Jawed, **M.**
1970. The distribution of zooplankton biomass in the northeastern Pacific Ocean. Research report for M.S. degree, Department of Oceanography, University of Washington, Seattle, WA, 36 pp.

Johnson, **M.W.**
1956. The plankton of the Beaufort and Chukchi sea areas of the Arctic and its relation to the hydrography. Technical Paper No. 1, The Arctic Institute of North America, Montreal, PQ, Canada, 32 pp.

Johnson, **M.W.**
1966. Zooplankton of some arctic coastal lagoons, pp. 679-693. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds). U.S. Atomic Energy Commission, Washington, D.C.

LaFond, E. C., and **D.W.** Pritchard
1952. Physical oceanographic investigations in the eastern Bering and Chukchi seas during summer of 1947. Journal of Marine Research 11:69-86.

Lovegrove, T.
1966. The determination of the dry weight of plankton and the effects of various factors on the values obtained, pp. 429-467. In: Some contemporary studies in marine sciences (H. Barnes, cd.), George Allen and Unwin, Ltd., London, England.

Neimark, L.M.
1979. Zooplankton ecology of Norton Sound, Alaska. M.S. thesis, University of Alaska, Fairbanks, AK, 93 pp.

Saur, J.F.T., **J.P. Tully,** and **E.C. LaFond**
1954. Oceanographic cruise to the Bering and **Chukchi** seas, summer 1949: Part IV. Physical oceanographic studies, Vol. I. Descriptive report. Report No. 416, U.S. Navy Electronics Laboratory, San Diego, **CA,** 31 pp.

Shah, **S.R.**
1975. Underwater acoustic studies of the **Chukchi** Sea, pp. 249-252. In: Ultrasonics International 1975: Conference proceedings, **IPC** Science and Technology Press, Ltd., **Guildford,** England.

Stepanova, V.
1937. **Biologische** zeichnungen der **stromungen** im **norlichen** teil des Bering und im **sundlichen** teil des Tschuktschen meeres. Publication of the Hydrological Institute of Leningrad 5:175-216.

Wing, **B.L.**
1972. Preliminary report on the zooplankton collected on WEBSEC-70, pp. 196-202. In: U.S. Coast Guard Oceanographic Report No. 50 (CG 373-50), Washington, **D.C.**

Wing, **B.L.**
1974. Kinds and abundance of zooplankton collected by the USCG icebreaker *Glacier* in the eastern Chukchi Sea, September-October 1970. Technical Report SSRF-679, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries **Service,** Seattle, WA, 18 pp.

6

Macrobenthos

H. M. Feder
S. C. Jewett

6.1 HISTORICAL INVESTIGATIONS

Investigations of the macrobenthic invertebrates north of the Bering Strait span nearly 30 years. An ecological study was carried out in the vicinity of Cape Thompson in 1959 under the auspices of the U.S. Atomic Energy Commission. The benthic component of that study provided a partial checklist and general discussion of the benthic biota, mostly epifauna (Sparks and Pereyra 1966; Abbott 1966). Benthic infauna collected at 16 stations as part of an ecological survey in the east-central Chukchi Sea were listed in the WEBSEC-70 cruise report (U.S. Coast Guard 1972). No quantitative data were given.

A trawl survey conducted in 1976 under OCSEAP sponsorship provided quantitative data on the benthic epifauna and demersal fishes in the area between the Bering Strait and Pt. Hope (Feder and Jewett 1978; Jewett and Feder 1981; Wolotira et al. 1977). Additional infaunal data obtained in 1979-80 from an area between the Bering Strait and Kotzebue Sound are presented by Feder et al. (1985).

Qualitative and quantitative infaunal, epifaunal, and fish sampling was conducted in shallow water, less than 15 m deep, near Kivalina in relation to the Red Dog Project (Blaylock and Erikson 1983; Blaylock and Houghton 1983).

The most comprehensive investigation of the infaunal benthos of the eastern Chukchi Sea is that of Stoker (1981), who studied the distribution, biomass, trophic relationships, and productivity of the fauna based on data collected during 1970-74.

The National Science Foundation-tided Inner Shelf Transfer and Recycling (ISHTAR) study is presently investigating various environmental parameters that influence benthic community structure and biomass on either side of the front between the Bering Shelf/Anadyr water and the Alaska Coastal water (Grebmeier 1987). Only a limited number of samples were obtained in the southeastern Chukchi Sea as part of this study.

6.2 DISTRIBUTION, ABUNDANCE, AND BIOMASS OF SELECTED SPECIES

Important factors affecting the distribution, abundance, and biomass of benthos are sediment properties, bottom water temperature, current regimes, and primary productivity (Mann 1977; Stoker 1978, 1981; Grebmeier 1987). Predation by marine mammals (mostly gray whales [*Eschrichtius robustus*], Pacific walruses [*Odobenus rosmerus*], and bearded seals [*Erignathus barbatus*]) in the southeastern Chukchi Sea is probably another important factor in this region (Johnson et al. 1966; Fay et al. 1977; Lowry et al. 1978; Nerini and Oliver 1983; and Fukuyama and Oliver 1985). Stoker (1981) did not find any strong and repeated interspecific affinities between infaunal invertebrates over the whole Chukchi-Bering region, although local interspecific affinities were occasionally strong. He concluded from this that biological interactions between species, including predation by invertebrates, were not very strong. The factors mentioned above, as well as other unspecified factors, are responsible for the distribution, abundance, and biomass of the benthos described in this chapter.

Benthic distributional studies north of the Bering Strait are divided into those using infaunal sampling gear, i.e., grabs and corers, and those using epifaunal sampling gear, i.e, trawls. The differences in sampling techniques make it difficult to compare results of the various investigations, but some generalizations can be made.

A relatively high-velocity current flows through the Bering Strait, carrying particulate and dissolved material from the northern Bering Sea, including riverine input from the Yukon River, into the southeastern Chukchi Sea (McManus et al. 1974). This current regime and its associated high concentration of inorganic nutrients and organic carbon make the Bering Strait area very productive. The average benthic biomass described for this region by Stoker (1978, 1981) was 903 (s.d. 1,416) g/m^2 wet weight, and the average faunal density was 325 (s.d. 237) individuals/m^2. The dominant invertebrates collected in grab samples were *Ophiura maculata* (brittle star), *Strongylocentrotus droebachiensis* (sea urchin), and *Pectinaria* (= *Cistenides*) *granulata* (polychaete worm). The variability between stations in the area was high. One station in the Bering Strait, which did not group with other stations in Stoker's analysis, was dominated by ampeliscid amphipods and had a density of 5,190 individuals/m^2 and a biomass of 935 g/m^2 wet weight. Feder et al. (1985) reported that a nearby station in the Bering Strait had 1,933 individuals/r^{n2}, a wet-weight biomass of 635 g/m^2, and was dominated by a small bivalve, *Hiatella arctica*. The Bering Strait substratum is composed mostly of rocks, gravel, and shell fragments. North of the strait, the current velocity decreases, and particulate matter is gradually deposited on the bottom. In the sandy substratum, just north and northeast of the strait, *Harpinia gurjanovae* (amphipod), *Echinarachnius parma* (sand dollar), and *Myriochele oculata* (polychaete worm) dominated the biomass and density. Wet-weight biomass in the latter areas ranged from <100 to >400 g/m^2, and population density ranged from 1,843 to 9,646 individuals/m^2 (Stoker 1978; Feder et al. 1985). As the sediment type changed from sand to silty sand to silt, the small clam *Macoma calcarea* became' more dominant (Mann 1977). *Macoma calcarea* was very abundant in the silty bottom between Pt. Hope and Cape Prince of Wales (Alverson and Wilimovsky 1966; Sparks and Pereyra 1966; Stoker 1978, 1981). Grebmeier[a] found 550 *Macoma calcarea*/m^2 with a total wet weight of 1,170 g/m^2 at a station in the latter region. Two shallow, muddy stations in outer Kotzebue Sound were dominated by *Nucula tenuis* (clam), *Nuculana fossa* (clam), *Serripes groenlandicus* (cockle), *Cucumaria* sp. (sea cucumber), and *Sternaspis scutata* (polychaete worm). The infaunal biomass ranged from 68 to 592 g/m^2 and the faunal abundance from 796 to 958 individuals/m^2 in outer Kotzebue Sound (Feder et al. 1985). North of Cape Krusenstern, along the eastern coastline as far north as Pt. Hope, the biomass and density values remained in this same range, but the dominant species were *Maldane sarsi* (polychaete worm), *Ophiura sarsi* (brittle star), *Golfingia margaritacea*

[a] J. Grebmeier, Marine Biology Research Section, Department of Biological Sciences, University of Southern California, Los Angeles, CA 90089, personal communication, 1987.

(sipunculid worm), and *Astarte borealis* (clam) (Stoker 1978, 1981). Shallow areas, less than 15 m deep, along the coastline between Cape Krusenstern and Pt. Hope had very reduced biomass, but a high density of small polychaete worms and ascidians (Blaylock and Erikson 1983; Blaylock and Houghton 1983).

The epifaunal biomass over the southeastern Chukchi Sea (Bering Strait to Pt. Hope, including Kotzebue Sound) averaged 3.3 g/m^2 (Feder and Jewett 1978). Echinoderms dominated the biomass, followed by molluscs and arthropods (Table 6.1). An additional group, the Tunicata, was occasionally present in large numbers (Jewett and Feder 1981). Nine species accounted for more than 70% of the wet-weight biomass. These species were the sea stars *Asterias amurensis*, *Leptasteria polaris acervata*, *Lethasterias nanimensis*, and *Evasterias echinosoma*, the basket star *Gorgonocephalus caryi*, the green sea urchin *Strongylocentrotus droebachiensis*, the snail *Neptunea heros*, and the crabs *Chionoecetes opilio* and *Hyas coarctatus alutaceus* (Feder and Jewett 1978; Jewett and Feder 1981). Other important species in this region, in terms of biomass, were the snails *Neptunea ventricosa* and *Beringius beringi* and the crustaceans *Pagurus trigonocheirus* and *P. capillatus* (hermit crabs), *Telmessus cheiragonus* (brachyuran crab), and *Argis lar* (crangonid shrimp).

Table 6.1 Percentage composition by weight and the feeding methods* of the leading invertebrate species collected in the Chukchi Sea–Kotzebue Sound area.

Phylum	% wt. of all phyla	Leading species	Feeding method†	Avg. wt. per individual	% wt. of phylum	% wt. of all phyla
Echinodermata	59.93	*Asterias amurensis*	P	202g.	35.54	21.21
		Leptasterias polaris acervata	P	96g.	20.90	12.47
		Strongylocentrotus droebachiensis	H-S-P	70g.	10.69	6.38
		Lethasterias nanimensis	P	299g.	9.67	5.77
		Evasterias echinosoma	P	656g	6.39	3.81
		Gorgonocephalus caryi	Sus-P	258g.	5.76	3.44
					88.95	53.08
Mollusca	12.79	*Neptunea heros*	P-s	101g.	79.98	10.19
		Neptunea ventricosa	P-s	71g.	10.80	1.38
		Beringius beringi	P-s	85g.	2.35	0.30
					93.13	11.87
Arthropoda (Crustacea)	12.52	*Chionoecetes opilio*	P-s	27g.	43.76	5.46
		Pagurus trigonocheirus	P-s?	17g.	15.77	1.97
		Hyas coarctatus alutaceus	P-5?	25g.	12.87	1.61
		Telmessus cheiragonus	P-s?	133g.	7.43	0.93
		Pagurus capillatus	P-s?	12g.	7.24	0.90
		Argis lar	S?	7g.	4.34	0.54
					91.41	11.41
	85.24					

*Based on Hatanaka and Kosaka (1958), Reese (1966), Pearce and ThorSon (1967), Feder and Jewett (1977a), and personal observation by the authors. Feeding methods for related species are included when no direct data are available for species included above. Feeding references are presented in Feder and Jewett (1978).

†Feeding methods: P=predator; P-S=predator-scavenger; S=scavenger; Sus=suspension feeder; Sus-P=suspension feeder-predator; H-S-P= herbivore-scavenger-predator.

The distribution and wet-weight biomass of the nine dominant epifaunal species collected by Feder and Jewett (1978) in the southeastern Chukchi Sea are presented in Figures 6.1–6.5. The sea star *Asterias amurensis* dominated in outer Kotzebue Sound and waters shallower than 40 m outside the sound (Fig. 6.1). This species also dominated in shallow areas, less than 15 m deep, near Kivalina (Blaylock and Erikson 1983). *Asterias is* a food generalist, but preferentially feeds on small bivalve molluscs when available (Feder and Jewett 1981; Fukuyama and Oliver 1985). Infaunal species that dominated the area occupied by this sea star were two small clams, *Nucula tenuis* and *Nuculana fossa* (Feder et al. 1985). The other three species of sea stars, *Leptasterias polaris acervata, Lethasterias nanimensis*, and *Evasterias echinosoma, are* apparently also food generalists (Feder and Jewett 1981), and have distributions that overlap that of *A. amurensis* (Figs. 6.1 and 6,2). However, differences in the distributions of the four species of sea stars suggest that there may be minor differences in feeding preferences of these echinoderms. The area of greatest biomass of *Leptasterias polaris acervata* is south of Pt. Hope at depths greater than 40 m, where tunicates, a preferred fbod of this sea star (Feder and Jewett 1981), may be more common (Fig. 6.1). Ascidians dominated where gravel or hard substratum provides good attachment. They were especially common in trawls taken near Cape Thompson (Abbott 1966).

The green sea urchin *Strongylocentrotus droebachiensis* mainly occurred from within Kotzebue Sound and along the coast to Pt. Hope (Fig. 6.3). The greatest biomass occurred off Pt. Hope. The diet of this urchin is variable (Hyman 1955). Throughout most of its range, it prefers plant material, but it will also graze on sessile epifauna attached to rocks. This urchin is distributed in areas identified as rock and gravel substratum and where sessile fauna is common (Sparks and Pereyra 1966).

The distribution of the basket star *Gorgonocephalus caryi* was somewhat similar to that of the green sea urchin. The main difference in distribution was that the basket star's biomass was greatest in waters off Pt. Hope (Fig. 6.3). *Gorgonocephalus* is generally considered an opportunistic feeder, ingesting whatever macroscopic plankton and small bottom-dwelling crustaceans it can capture (Patent 1970). The distribution of *Gorgonocephalus* in the southeastern Chukchi Sea generally coincides with the bottom described as sand, shell, gravel, and rock (Sparks and Pereyra 1966), regions influenced by strong bottom currents and turbulence.

The crabs *Chionoecetes* and *Hyas* occurred throughout the region between the Bering Strait and Pt. Hope, including Kotzebue Sound (Fig. 6.4). The biomass of *Chionoecetes* far exceeded that of *Hyas*. The area of greatest biomass of *Chionoecetes* was near the mouth of Kotzebue Sound. The area of greatest biomass of *Hyas* was primarily in waters outside the sound, extending to Pt. Hope. High biomass also occurred for the latter crab species in waters deeper than 40 m off Pt. Hope. Both of these species were found in all substrate types, probably reflecting the diverse nature of prey organisms consumed by them. *Chionoecetes* is the shellfish species in Kotzebue Sound with the most potential for economic exploitation (Wolotira et al. 1977),

The snail *Neptunea heros* was mainly distributed north of the Bering Strait, near the 40-m isobath and in northern Kotzebue Sound (Fig. 6,5). The diet of *Neptunea is* dominated by polychaete worms and small bivalve molluscs (Pearce and Thorson 1967). The areas of greatest biomass for this snail coincide with soft bottom substratum, regions usually characterized by populations of polychaetes and small bivalves. The region of high biomass dominance for this snail,

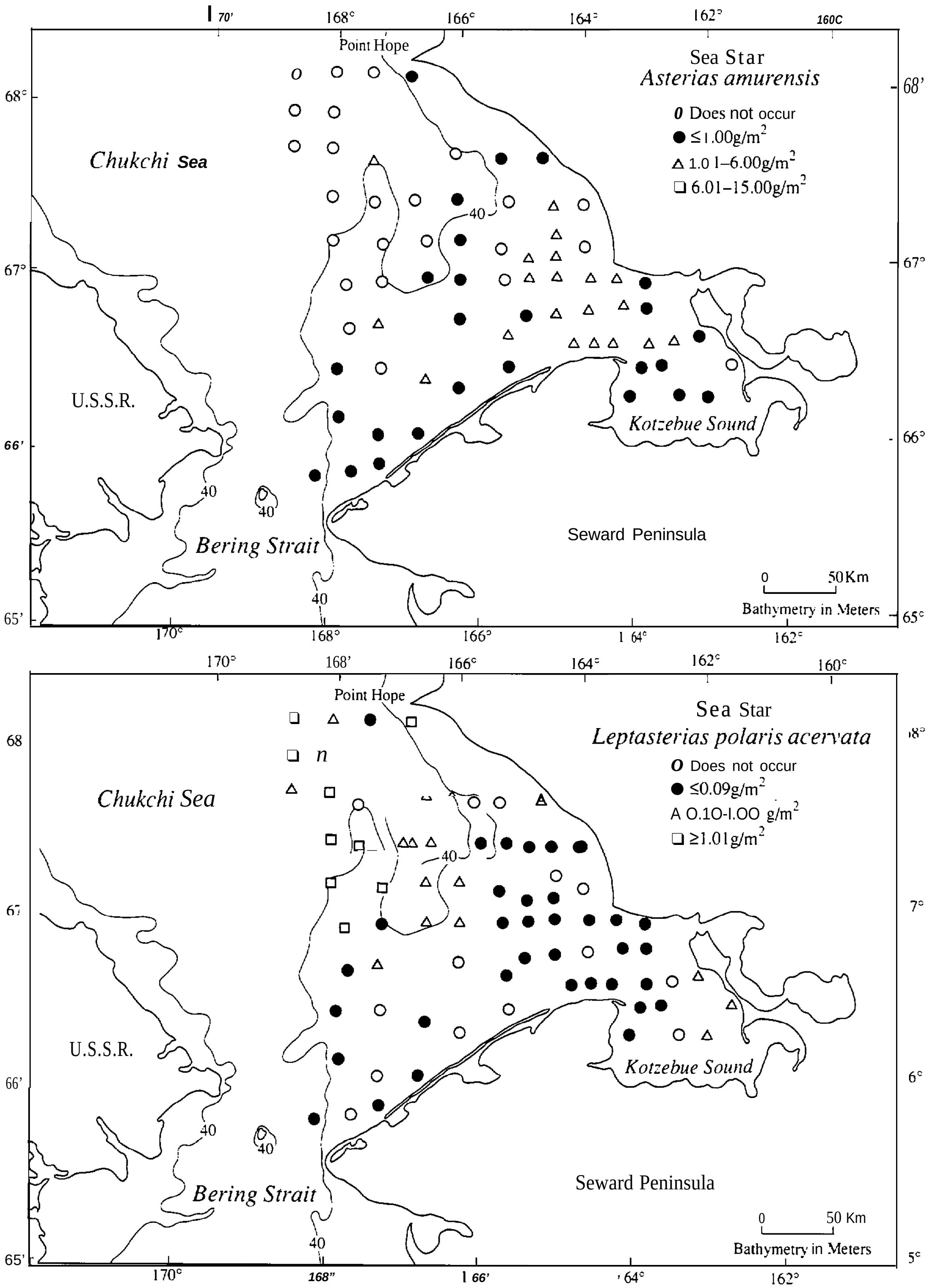

Figure **6.1** Distribution and wet-weight biomass of the sea stars *Asterias amurensis* and *Lepasterias polaris acervata* from the southeastern Chukchi Sea and Kotzebue Sound, September-October 1976 (from Feder and Jewett 1978).

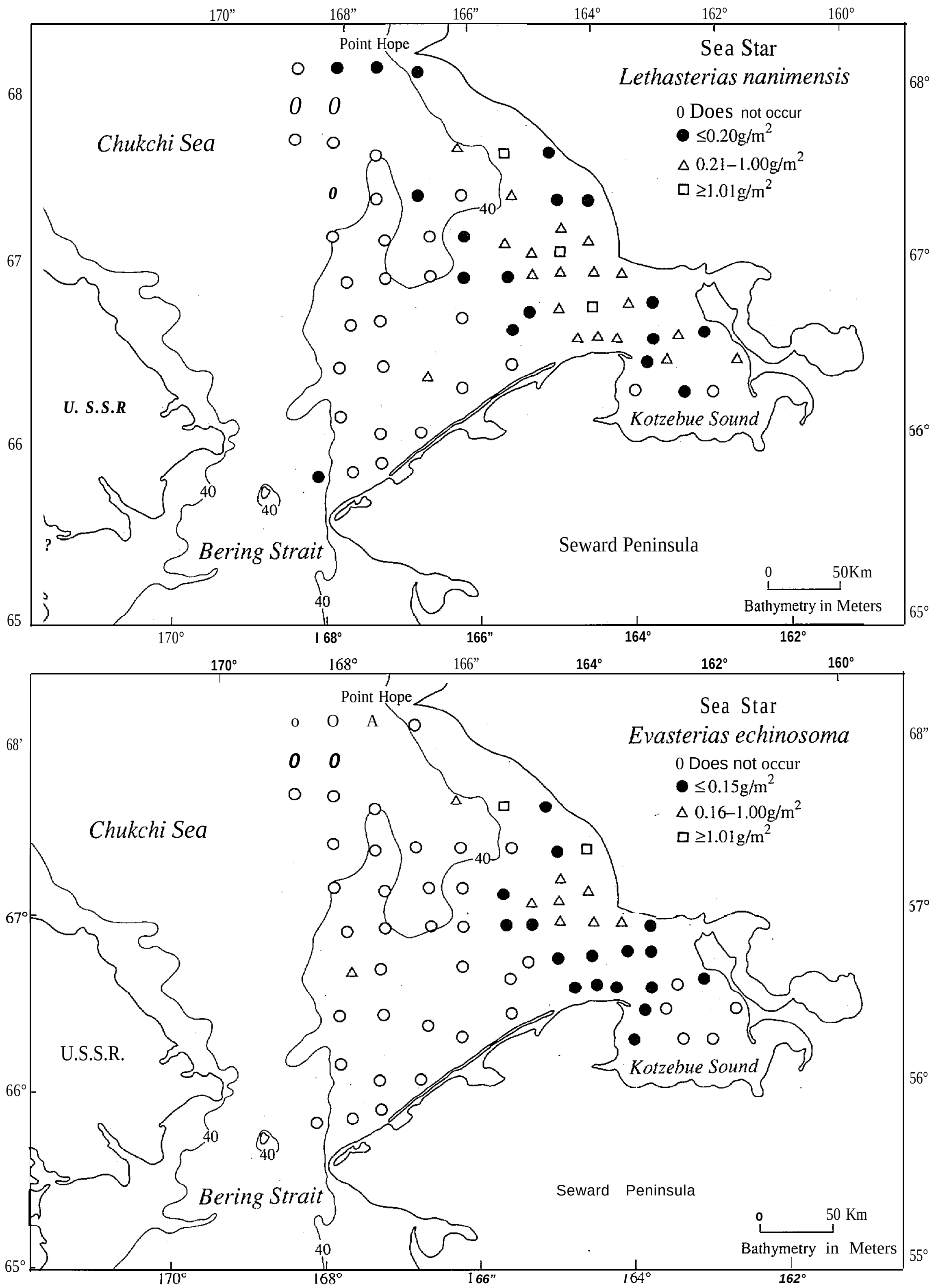

Figure **6.2** Distribution and wet-weight biomass of the sea stars *Lethasterias nanimensis* and *Evasterias echinosoma* from the southeastern Chukchi Sea and Kotzebue Sound, September-October 1976 (from Feder and Jewett 1978).

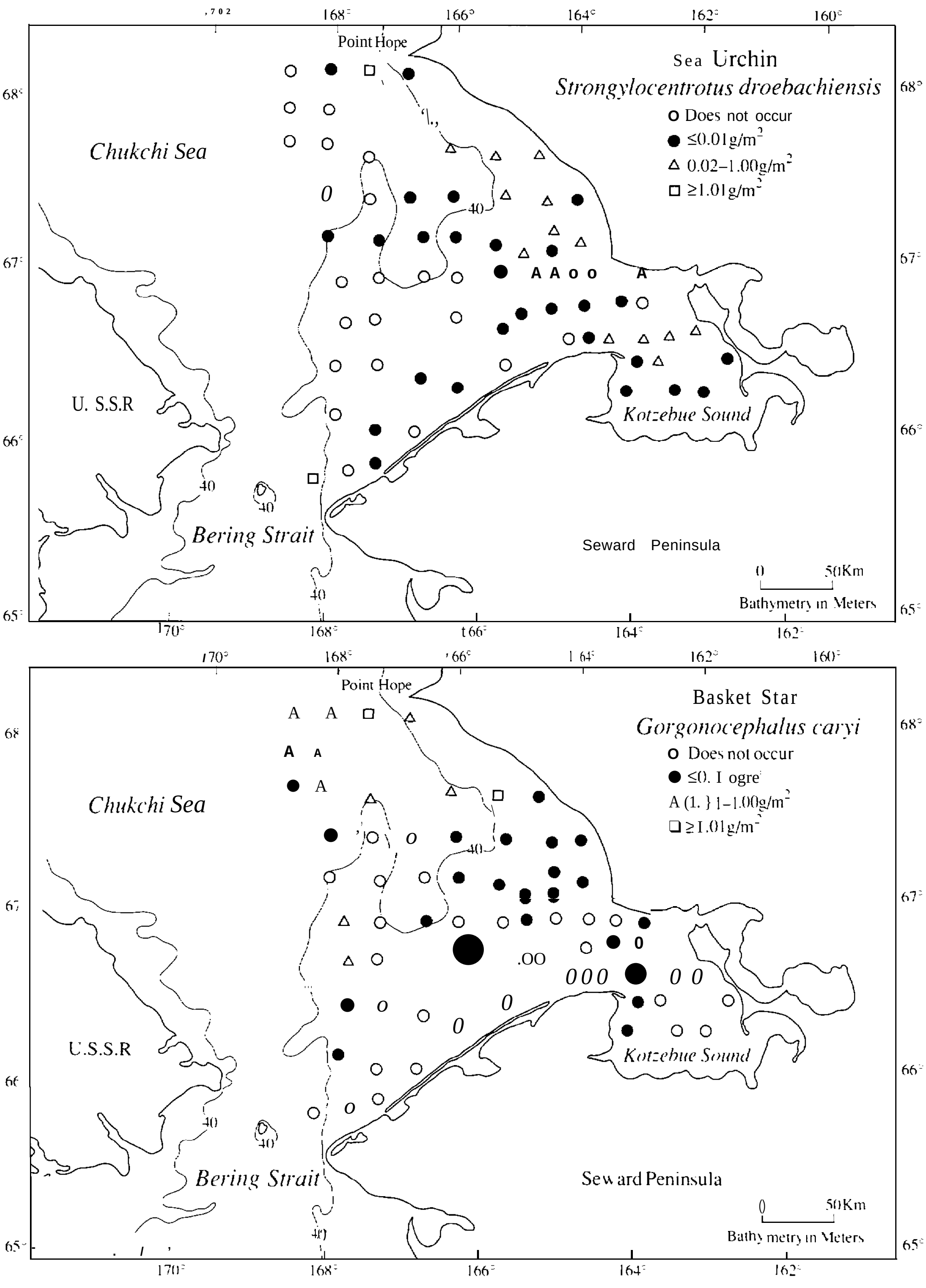

Figure 6.3 Distribution and wet-weight biomass of the sea urchin *Strongylocentrotus droebachiensis* and the basket star *Gorgonocephalus caryi* from the southeastern Chukchi Sea and Kotzebue Sound, September-October 1976 (from Feder and Jewett 1978).

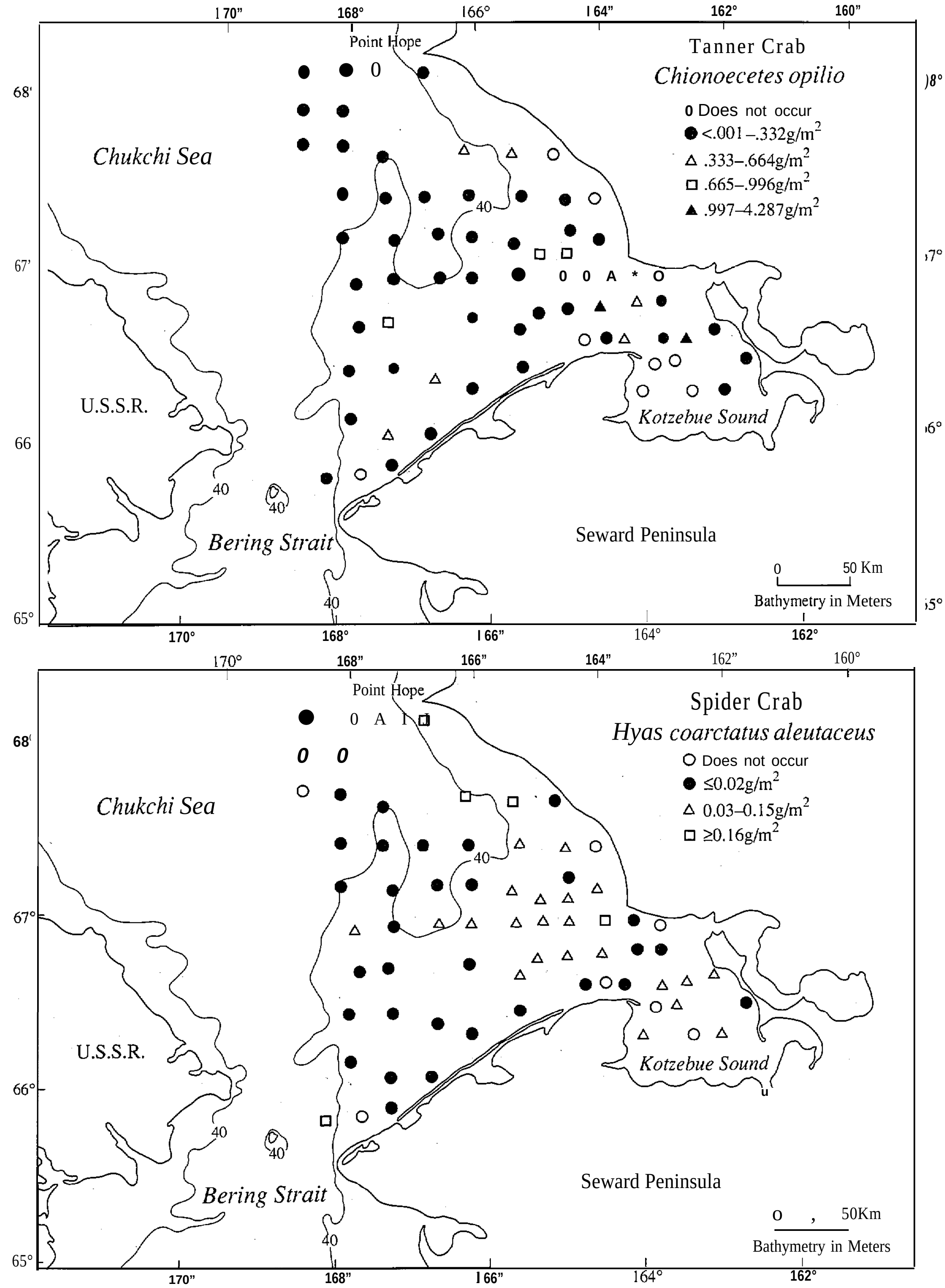

Figure *6.4* Distribution and wet-weight biomass of the crabs *Chionoecetes opilio* and *Hyas coarctatus aleutaceus* from the southeastern Chukchi Sea and Kotzebue Sound, September-October 1976 (from Feder and Jewett 1978).

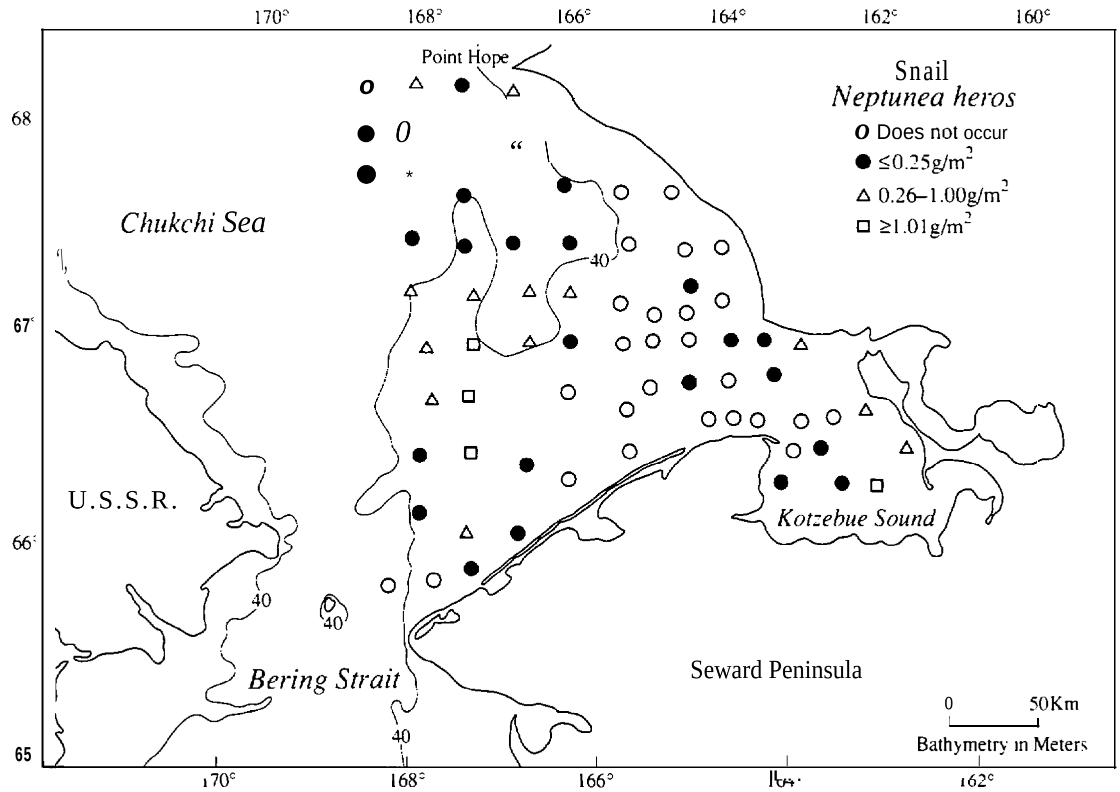

Figure *6.5* Distribution and wet-weight biomass of the snail *Neptunea heros* from the southeastern Chukchi Sea and Kotzebue Sound, September-October 1976 (from Feder and Jewett 1978).

north of the Bering Strait, is within the general area identified by Grebmeier (1987) as an organically enriched benthic environment. No data are presently available for the infauna within Kotzebue Sound, where the snail biomass is high.

6.3 TEMPERATURE EFFECTS ON SPECIES DOMINATION

The southeastern Chukchi Sea, in comparison with the southeastern Bering Sea, had a lower epifaunal biomass (Jewett and Feder 1981). As mentioned above, the echinoderms (mainly sea stars) dominated the demersal trawl catches in the southeastern Chukchi Sea, while demersal fishes dominated trawl samples in the southeastern Bering Sea (Wolotira et al. 1977). The lower temperatures of the northern Bering and Chukchi seas often exclude large populations of demersal fishes, thereby reducing predation on the food benthos (see review in Feder and Jewett 1981). However, in years when seawater temperature rises sufficiently above 6°C, flatfish populations invade the rich northern waters and actively compete with sea stars for food resources (Jewett and Feder 1980).

6.4 LITERATURE CITED

Abbott, D.P.
1966. The ascidians, pp. 839–841. In: Environment of the Cape Thomson Region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.), U.S. Atomic Energy Commission, Washington, D.C.

Alverson, D.L., and **N.J. Wilimovsky**
1966. Fishery investigations of the southeastern Chukchi Sea, pp. 843-860. In: Environment of the Cape Thomson Region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.) U.S. Atomic Energy Commission, Washington, D.C.

Blaylock, W.M., and **D.E. Erikson**
1983. **Chapter 4,** Marine biology, pp. 4-1-4-82. In: Environmental baseline studies, Red Dog Project, Report to **Cominco** Alaska prepared by Dames and Moore, Anchorage, **AK.**

Blaylock, W.M., and **J.P.** Houghton
1983. **Benthic** investigations, pp. 1–20 + appendices. In: Supplement to environmental baseline studies, Red Dog Project, Report to **Cominco** Alaska, Inc., by Dames and Moore, Anchorage, AK.

Fay, F.H., **H.M. Feder,** and **S.W.** Stoker
1977. An estimation of the impact of the Pacific walrus population **on** its food resources in the Bering Sea. Report to the Marine Mammal Commission, Washington, D. C., 38 pp. (NTIS **PB-273-505)**

Feder, H.M., and **S.C.** Jewett
1978. Survey of the **epifaunal** invertebrates of Norton Sound, southeastern Chukchi Sea, and Kotzebue Sound. Report No. **R78-1,** Institute of Marine Science, University of Alaska, Fairbanks, AK, 124 pp.

Feder, H.M., **R.H.** Day, **S.C.** Jewett, K. **McCumby,** S. McGee, and **S.V. Schonberg**
1985. **Infauna** of the southeastern Bering and southeastern **Chukchi** seas, pp. 1–20. In: Final Reports of Principal Investigators, Vol. 32, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK

Feder, **H.M.,** and **S.C.** Jewett
1981. Feeding interactions in the eastern **Chukchi** Sea with emphasis on the **benthos,** pp. 1229-1261. In: The Eastern Bering Sea **shelf:** oceanography and resources, Vol. 2 **(D.W.** Hood and **J.A. Calder, eds.),** U.S. Department of Commerce, National Oceanic and Atmospheric Administration, **Office** of Marine Pollution Assessment, Juneau, AK.

Fukuyama, **A.K.,** and **J.S.** Oliver
1985. Sea star and walrus predation on bivalves in Norton Sound, Bering Sea, Alaska. **Ophelia 24:17-36.**

Grebmeier, J.
1987. **Benthic** communities, pp. 241–271. In: **ISHTAR** Progress Report, Vol. 1, Component C, Institute of Marine Science, University of Alaska, Fairbanks, AK.

Hyman, L.H.
1955. The invertebrates: **Echinodermata,** The **coelomate bilateria,** Vol. IV. McGraw-Hill Book Company, Inc., New York, NY, 763 pp.

Jewett, S.C., and **H.M.** Feder
1980. Autumn food of adult starry flounders, ***Platichthys stellatus,*** from the northeastern Bering Sea and the southeastern **Chukchi** Sea. Journal du **Conseil** International pour **l'Exploration** de la Mer **39:7-14.**

Jewett, S. C., and **H.M.** Feder
1981. **Epifaunal** invertebrates of the continental shelf of the eastern Bering and **Chukchi** seas, pp. 1131–1153. In: The Eastern Bering Sea shelf oceanography and resources, Vol. 2 **(D.W.** Hood and **J.A. Calder, eds.),** Office of Marine Pollution Assessment, National Oceanic and Atmospheric Administration, Juneau, AK,

Johnson, **M.L., C.H.** Fiscus, **B.T.** Ostenson, and **M.L. Barbour**
1966. Marine mammals, pp. 877–924. In: Environment of the Cape Thompson region, Alaska **(N.J.** Wilimovsky and **J.N.** Wolfe, **eds.),** U.S. Atomic Energy Commission, Washington, **D.C.**

Lowry, L.F., **K.J.** Frost, and **J.J.** Burns
1978. **Trophic** relationships among ice **in**habiting **phocid** seals, pp. 161-372. In: Environmental Assessment of the Alaskan Continental Shelf, Annual Reports, Vol. 1, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Mann, **D.M.**
1977. Shelled benthic fauna of the eastern Chukchi Sea. Open-File Report 77-672, U.S. Geological Survey, 112 pp.

McManus, D.A., K **Venkatarathnam, D.M.** Hopkins, and **C.H.** Nelson
1974. Yukon River sediment on the northeastemmost Bering Sea shelf. Sedimentary Petrology 44:1052-1060.

Nerini, D.H., and **J.S.** Oliver
1983. Gray whales and the structure of the Bering Sea benthos. Oecologia 59:224-225.

Patent, **D.H.**
1970. Life history of the basket star *Gorgonocephalus eucnemis* (Muller and Troschel) (Echinodermata; Ophiuroidea). Ophelia 8:145-159.

Pearce, J.B., and G. **Thorson**
1967. The feeding and reproductive biology of the red whelk, *Neptunea antiqua* (L.) (Gastropod, Prosobranchia). Ophelia 4:277-314.

Sparks, **A.K.,** and **S.T. Pereyra**
1966. Benthic invertebrates of the southeastern Chukchi Sea, pp. 817-838. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.) U.S. Atomic Energy Commission, Washington, D.C.

Stoker, **S.W.**
1978. Benthic invertebrate macrofauna of the eastern continental shelf of the Bering and Chukchi seas. Ph.D. dissertation, University of Alaska, Fairbanks, AK, 259 pp.

Stoker, **S.W.**
1981. Benthic invertebrate macrofauna of the eastern Bering/Chukchi continental shelf, pp. 1069-1090. In: The Eastern Bering shelf: oceanography and resources, Vol. 2 (D.W. Hood and J.A. Calder, eds.), U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Juneau, AK

U.S. Coast Guard
1972. An ecological survey in the eastern Chukchi Sea, WEBSEC-70. Oceanographic Report No. 50 (CG 373-50), U.S. Coast Guard, Washington, D. C., 206 pp.

Wolotira, R.J., Jr., **T.M.** Sample, and **M. Morin,** Jr.
1977. Demersal fish and shellfish resources of Norton Sound, the southeastern Chukchi Sea, and adjacent waters in the baseline year 1976. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA, 292 pp.

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Fish Resources

J. A. Raymond

7.1 HISTORICAL INVESTIGATIONS

The first reports on fishes in the Chukchi Sea and Kotzebue Sound were made by 19th century explorers. Walters (1955), who summarized these reports, considered them mostly of historical interest. The first major scientific collections of fishes in the Chukchi Sea were those made by the Russians A.P. Andriyashev, K.I. Panin, and P.V. Ushakov in 1932 and 1933. The results of these and other studies through the early 1950's were presented by Andriyashev (1954). He listed 49 species caught in the Chukchi Sea, although the presence of 14 of these species, including Pacific herring (*Clupea harengus pallasi*), were in doubt.

In August 1959, Alverson and Wilimovsky (1966) sampled 74 stations in the eastern Chukchi Sea between Cape Lisburne and the Bering Strait and found up to a dozen additional species not found by the Russians. Alverson and Wilmovsky sampled with otter trawls, mid-water trawls, and gill nets. The most abundant species were arctic cod (*Boreogadus saida*), Bering flounder (*Hippoglossoides robustus*), and Pacific herring. Most of the herring were caught in a single set of the g-ill net. Additional data on the distribution, abundance, and age of flatfishes collected during the cruise were reported by Pruter and Alverson (1962).

Information on the salmon resources along the Alaskan coast between Point Hope and Kotzebue Sound was compiled by Smith et al. (1966). They observed native gill-net fisheries and collected samples of arctic char (*Salvelinus alpinus*) and adult salmon (*Oncorhynchus* spp.) with gill nets and a beach seine.

In 1966 Japanese scientists conducted test fishing operations for salmon over a wide portion of the Chukchi Sea between 66 and 68°N during the period 2 July to 21 August (Yonemori and Takahashi 1966). Approximately 25,000 chum salmon (O. *keta*) and small numbers of pink salmon (O. *gorbuscha*), chinook salmon (O. *tshawytscha*), and sockeye salmon (O. *nerka*) were caught. The age structure of the chum salmon was similar to that found in the Kotzebue fishery (Bigler 1985), so these fish were almost certainly in the Chukchi Sea as part of their spawning migration rather than for summer feeding and a subsequent southward migration. Neave et al. (1976) also attributed the chum salmon's presence in the Chukchi Sea to spawning migration and did not consider the area as part of the chum salmon's ocean distribution.

Quast (1972) conducted mid-water and bottom trawls in the northeastern Chukchi Sea in late September and mid-October. His collections consisted of 25 species of juvenile and post-larval fishes.

Wolotira et al. (1977) conducted extensive bottom trawling in the western Chukchi Sea south of Pt. Hope in September 1976. Arctic cod, arctic staghorn sculpin (*Gymnocanthus tricuspid),* and Bering flounder were the most frequently caught species. Data on the food of starry flounder (*Platichthys stellatus*), which were collected on the same survey, were reported by Jewett and Feder (1980). Frost and Lowry (1983) conducted bottom trawls at approximately 10 stations between Icy Cape and Pt. Barrow in early August 1977. The catches included 10 species, of which arctic cod was the most abundant.

7.2 DISTRIBUTION AND ABUNDANCE

The fish community in the Chukchi Sea, with its approximately 50 species (Andriyashev 1954; Alverson and Wilimovsky 1966), appears sparse compared to that in the Bering Sea, where approximately 300 species are found (Wilimovsky 1974). As shown by three of the flatfish species collected by Alverson and Wilimovsky (1966), maximum sizes and densities were also significantly smaller in the Chukchi Sea compared to the Bering Sea. The low densities were attributed to the harsh climate in the Arctic. Wolotira et al. (1977) found that the densities and growth of demersal fishes were, in general, lower in the southeastern Chukchi Sea than in the Bering Strait and Norton Sound: The catch per unit effort was 2.70 kg of fish per km trawled in the Chukchi Sea and 5.97 kg/km in the northern Bering Sea. Wolotira et al. (1977) concluded that none of the species found was present in sufficient numbers to support a commercial fishery.

Alverson and Wilimovsky (1966) speculated that warmer temperatures may have led to the occurrence of several species in their 1959 collections that were not reported in the Russian collections made during the *1930's.* Wolotira et al. (1977), whose sampling followed that of Alverson and Wilimovsky by 17 years, found no evidence of further changes in the fish community.

Fisheries research conducted by the Alaska Department of Fish and Game in coastal waters of Kotzebue Sound has focused on salmon and herring. This research included migration patterns of adult chum salmon (Yanagawa 1970; Bigler and Burwen 1984), early life history studies of chum salmon (Bird 1980; Merritt and Raymond 1981), distribution of herring (Barton 1978; Whitmore and Bergstrom 1983), and the distribution and abundance of nearshore fishes (Raymond et al. 1984). In the latter study, saffron cod (*Eleginus gracilis*), whitefishes (*Corengonus* spp.), and herring were found in the greatest biomass densities.

The only offshore fishery study in Kotzebue Sound was that of Wolotira et al. (1977). This study conducted bottom trawls at 11 stations within Kotzebue Sound during 8-10 September 1976. Herring, saffron cod, and rainbow smelt (*Osmerus mordax*) *were* found in the largest numbers. In general, fish population densities were lower in offshore waters than in inshore waters, as described by Raymond et al. (1984).

7.3 CHUM SALMON

The only significant commercial fishery in the Chukchi Sea-Kotzebue Sound region is the chum salmon fishery at Kotzebue, where about *300,000* chum salmon are caught each year as they approach the mouths of the Noatak and Kobuk rivers.

Juvenile chum salmon migrate into nearshore waters in June and early July (Bird 1980; Merritt and Raymond 1981) but their movements in offshore waters are largely unknown. Since salmon will freeze when water temperatures fall below –0.5°C, they must move into the southern Bering Sea or north Pacific Ocean to survive the winter, a migration that is consistent with limited tagged-salmon recoveries (French et al. 1975). The time that the juvenile chum salmon move through the Bering Strait is not known, but it must precede the onset of sea ice formation, which usually occurs in the latter half of October (NOAA 1974-78). Also, little is known about their migratory route. Although Kotzebue Sound water is thought to move generally northward in the Chukchi Sea, there is evidence that some of it moves south toward Shishmaref (Coachman et al. 1975). Similarly, currents through the Bering Strait are predominantly northward, but events suggesting southerly currents in the strait become more frequent in the fall and winter (Bloom 1964; Shapiro and Burns 1975; Burns et al. 1981; Coachman and Aagaard 1981). Thus, it may be possible for juvenile salmon to migrate into the Bering Sea without having to swim entirely against the currents.

Offshore sampling of the surface and mid-water regions, the regions most likely to have juvenile salmon, is summarized in Table 7.1 and Figure 7.1. Alverson and Wilimovsky (1966) made 11 mid-water trawls but caught only a few fish, none of which was a salmon. The absence of salmon may have been due to the location of the trawls, which was north of the expected path of Kotzebue Sound salmon bound for the Bering Strait. Gill nets set by the same authors caught a few chum salmon, but the size of the fish was not reported. Using a mid-water trawl with a 13-mm mesh, Quast (1972) caught many juvenile fish but no salmon. His sampling area was generally north of Cape Lisburne, where there are few salmon spawning areas. Barton (1978) caught five juvenile salmon with variable-mesh gill

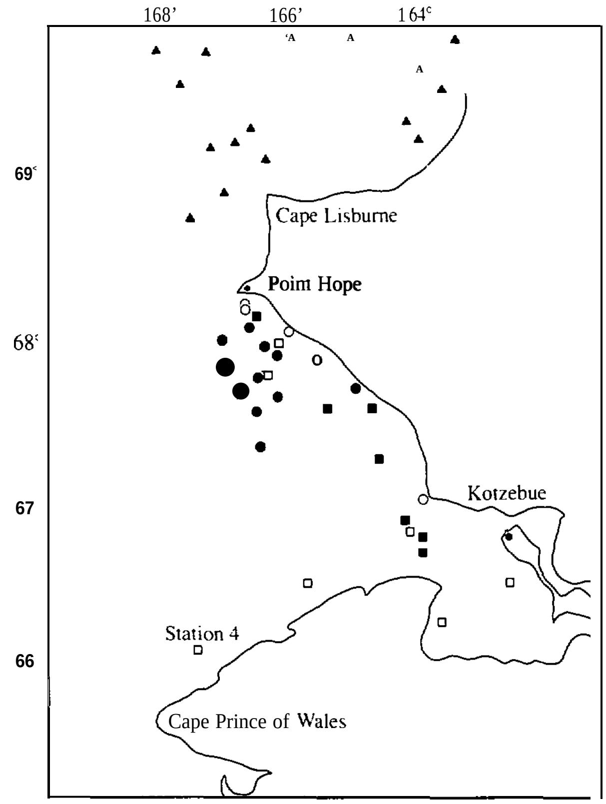

Figure 7.1 Locations of fish collections in surface and mid-water regions in offshore waters of the Chukchi Sea and Kotzebue Sound: ▲ Gill net stations of Alverson and Wilimovsky (1966); o mid-water trawl stations of Alverson and Wilimovsky (1966); • mid-water trawl stations of Quast (1972); ▪ gill net stations of Barton (1977); □ mid-water trawl stations of Wolotira et al. (1977).

Table 7.1 Offshore sampling of surface and mid-water regions in the Chukchi Sea and Kotzebue Sound.

Gear	No. stations	Mesh size (mm)	Dates	Reference
gill net	4	38 to 152	7-25 August 1959	Alverson and Wilimovsky (1966)
mid-water trawl	11	32	22-29 August 1959	Alverson and Wilimovsky (1966)
mid-water trawl	20	13	25 September to 17 October 1970	Quast (1972)
mid-water trawl	7	32	c. 10 September 1976	Wolotira et al. (1977)
gill net	9	21 to 133	6-15 September 1976	Barton (1977)

nets (Table 7.2) 50 km southeast of Shishmaref on 6 September 1976 (Fig. 7.1, Station 4). Nets set in eight other locations in Kotzebue Sound and the Chukchi Sea between 7 and 15 September 1976 caught no juvenile salmon (Barton 1978). Wolotira et al. (1977) made three mid-water trawls at the entrance to Kotzebue Sound but caught few fish. Their most successful trawl caught 13 fish, which included rainbow smelt, saffron cod, arctic char, and juvenile pink salmon.

The latter two studies suggest that by early September the northern limit of the distribution of juvenile salmon originating in Kotzebue Sound is between the mouth of Kotzebue Sound and the Bering Strait. The small number of juvenile salmon caught may be due to the lateness of the sampling or to the small number of stations sampled. The absence of surface trawling in these studies may have also contributed to the small catches of salmon.

Table 7.2 Catches ofjuvenile salmon at Station 4 on 6 September 1976 in the southeastern Chukchi Sea (from Barton 1977)*

Species	Length (mm)	Weight (g)	Mesh size (mm)
chum	188	72	42
pink	155	35	35
pink	195	77	35
pink	–	59	35
pink	203	80	42

*Station location is shown in Figure 7.1. Gill net consisted of seven 300-ft-long by 18-ft-deep sections with the following (stretched) mesh sizes: 21 mm, 35 mm, 42 mm, 64 mm, 83 mm, 114 mm, and 133 mm.

7.4 LITERATURE CITED

Alverson, ILL., and **N.J. Wilimovsky**
1966. Fishery investigations of the southeastern Chukchi Sea, pp. 843-860. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.), U.S. Atomic Energy Commission, Washington, D.C.

Andriyashev, A.P.
1954. Fishes of the northern seas of the USSR. (Translation from Russian by Israel Program for Scientific Translation, 617 pp.), Publication No. TT63-11160, U.S. Department of Commerce, National Technical Information Service, Springfield, VA.

Barton, **L.H.**
1977. Finfish resource surveys in Norton Sound and Kotzebue Sound, pp. 113-194. In: Environmental Assessment of the Alaskan Continental Shelf, Annual Reports, Vol. 7, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Barton, **L.H.**
1978. Finfish resource surveys in Norton Sound and Kotzebue Sound. Alaska Department of Fish and Game, Juneau, AK, 202 pp.

Bigler, B.
1985. Kotzebue Sound chum salmon escapement and return data, 1962–1984. Technical Data Report No. 149, Alaska Department of Fish and Game, Juneau, AK, 112 pp.

Bigler, B., and D. **Burwen**
1984. Migratory and spatial entry patterns of chum salmon in Kotzebue Sound. Informational Leaflet No. 238, Alaska Department of Fish and Game, Juneau, AK, 23 pp.

Bird, F.
1980. Chum salmon and other fisheries investigations in Kotzebue Sound in 1979. AYK Region NS/K Resources Report No. 6, Alaska Department of Fish and Game, Juneau, AK, 76 pp.

Bloom, G.L.
1964. Water transport and temperature measurements in the eastern Bering Strait, 1953–1958. Journal of Geophysical Research 69:3335-3354.

Burns, J.J., L.H. Shapiro, and F.H. Fay
1981. Ice as marine mammal habitat in the Bering Sea, pp. 781-797. In: The eastern Bering Sea shelf: oceanography and resources, Vol. 2 (D.W. Hood, and J.A. Calder, eds.), U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Juneau, AK.

Coachman, L.K., and K. Aagaard
1981. Re-evaluation of water transport in the vicinity of Bering Strait, pp. 95-110. In: The eastern Bering Sea shelf: oceanography and resources, Vol. 1 (D.W. Hood, and J.A. Calder, eds.), Office of Marine Pollution Assessment, National Oceanic and Atmospheric Administration, Juneau, AK.

Coachman, L.K., K. Aagaard, and R.B. Tripp
1975. Bering Strait: the regional physical oceanography. University of Washington Press, Seattle, WA, 172 pp.

French, R.R., R.G. Bakkala, and D.F. Sutherland
1975. Ocean distribution of stocks of Pacific salmon *Oncorhynchus* spp. and steelhead trout *Salmo gairdneri* as shown by tagging experiments. Technical Report SSRF-689, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, WA, 89 pp.

Frost, K.J., and L.F. Lowry
1983, Demersal fishes and invertebrates trawled in the northeastern Chukchi and western Beaufort seas, 1976-77. Technical Report SSRF-764, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, WA, 22 pp.

Jewett, S.C., and H.M. Feder
1980. Autumn food of adult starry flounder *Platichthys stellatus* from the northeastern Bering Sea and the southeastern Chukchi Sea. Journal du Conseil International pour l'Exploration de la Mer 39:7-14.

Merritt, M., and J.A. Raymond
1981. Early life history of chum salmon in Kotzebue Sound and in the Noatak River. FRED Report No. 1, Alaska Department of Fish and Game, Juneau, AK, 56 pp.

Neave, F.T., T. Yonemori, and R.G. Bakkala
1976. Distribution and origin of chum salmon in offshore waters of the North Pacific Ocean. Bulletin No. 35, International North Pacific Fisheries Commission, Vancouver, BC, Canada, 79 pp.

NOAA (National Oceanic and Atmospheric Administration)
1974-78. Experimental ice analysis (weekly maps). NOAA, NESS-EPG, WWB, Washington, D.C.

Pruter, A.T., and D.L. Alverson
1962. Abundance, distribution and growth of flounders in the southeastern Chukchi Sea. Journal du Conseil International pour l'Exploration de la Mer 27:81-89.

Quast, J.C.
1972. Preliminary report on the fish collected on WEBSEC-70, pp. 203–206. In: WEBSEC-70, an ecological survey in the eastern Chukchi Sea, September–October 1970, Oceanographic Report No. 50 (CG 373-50), U.S. Coast Guard, Washington, D.C.

Raymond, J.A., M. Merritt, and C. Skaugstad
1984. Nearshore fishes in Kotzebue Sound in summer. FRED Report No. 37, Alaska Department of Fish and Game, Juneau, AK, 31 pp.

Shapiro, L.H., and J.J. Burns
1975. Major late winter features of ice in northern Bering and Chukchi seas as determined from satellite imagery. Sea Grant Report No. 7508, Geophysical Institute, University of Alaska, Fairbanks, AK, 7 pp.

Smith, H.D., A. Seymour, and L.R. Donaldson
1966. The salmon resources, pp. 861-876. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.), U.S. Atomic Energy Commission, Washington, D.C.

Walters, V.
1955. Fishes of western arctic America and eastern arctic Siberia. Bulletin American Museum of Natural History 106:257-368.

Whitmore, D.C., and D.J. Bergstrom
1983. Assessment of herring stocks in southeastern Chukchi Sea, 1980-1981. Informational Leaflet No. 210, Alaska Department of Fish and Game, Juneau, AK, 27 pp.

Wilimovsky, N.J.
1974. Fishes of the Bering Sea: the state of existing knowledge and requirements for future effective effort, pp. 243–256. In: Oceanography of the Bering Sea (D.W. Hood, and E.J. Kelley, eds.), Institute of Marine Science, University of Alaska, Fairbanks, AK.

Wolotira, R.J., T.M. Sample, and M.M. Morin, Jr.
1977. Demersal fish and shellfish resources of Norton Sound, the southeastern Chukchi Sea, and adjacent waters in the baseline year 1976. Processed Report, National Marine Fisheries Service, National Oceanic and AtmosphericAdrninistration, Seattle, WA, 292 pp.

Yanagawa, C.M.
1970. Kotzebue Sound salmon tagging project, 1966-1968., AYK Region Fisheries Bulletin No. 7, Alaska Department of Fish and Game, Juneau, AK, 30 pp.

Yonemori, T., and T. Takahashi
1966. Distribution of salmon in the Chukchi Sea, 1966. Unpublished report, Far Seas Fisheries Laboratory, 20 pp. (in Japanese)

8

Pelagic and Coastal Birds

G. J. Divoky
A.M. Springer

8.1 SEABIRDS

8.1.1 *Introduction* The southern Chukchi Sea is a major transition area for pelagic seabirds. Although a part of the Arctic Basin, which has low bird densities (reflecting the area's low productivity), it is adjacent to the northern Bering Sea, with its abundant and diverse pelagic avifauna. The area is ice-covered from approximately November through June, and pelagic bird populations can be expected to be small during those months. For the remainder of the year, however, the southern Chukchi Sea can be expected to have moderate to high densities of migrant, breeding, and summering birds. The area is located along a major migratory pathway for birds, as all seabirds moving to the Chukchi Sea or adjacent parts of the Arctic Ocean pass through a narrow constriction at the Bering Strait. During spring migration, in May and early June, seabirds are generally restricted to the open waters of the lead that extends from the Bering Strait north to Cape Lisburne. During the time of ice decomposition in June and early July, densities at sea can be expected to be low, except near seabird cliffs. In late summer and early fall, when many of the sea-cliff-nesting species are still raising young and post-breeding migration is underway for many other species, the area can be expected to support the maximum numbers of feeding seabirds.

8.1.2 ***Available /formation*** While most areas of the Chukchi Sea have been overlooked in the pelagic bird censusing programs that have been conducted in Alaskan waters during the past 15 years, the southern Chukchi Sea and Kotzebue Sound avifauna has especially been ignored. Observations from a vessel conducting research as part of the Cape Thompson study provided the first information on the offshore distribution of birds, although the observations lacked much quantitative information (Swartz 1967). As part of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), aerial observations were conducted by Drury and Ramsdell (1985) and Harrison (1977). Shipboard observations conducted as part of a larger study of birds associated with the pack ice are presented herein. These latter observations were primarily made on an opportunistic basis while the vessel was underway to other study areas. Preliminary maps of the cruises and observations discussed herein can be found in Divoky (1978, 1979).

8.1.3 ***Sources* of Data** Data from three cruises are reported herein to characterize the avifauna of the area. Whenever possible, the data are supplemented with information from the few preciously published reports. The data being reported are from 1-2 September 1975, 15-16 September 1976, and 28-29 September 1976. The cruise tracks are shown in Figure 8.1, and the sample size, specific locations where the observations were made, and bird frequency of occurrence in Tables 8.1-8.5.

8.1.4 ***Species Accounts***

Loons. Each of the three species of loon that breed in the Arctic—yellow-billed (*Gavia adamsii*), Pacific (G. *arctica*), and red-throated (G. *stellata*)—can be expected to migrate through the southern Chukchi Sea. Loons were seen in the southern Chukchi Sea only as migrants in September. Observations from the Beaufort Sea show that loons do not start to leave the area in large numbers until early September. While loons are primarily nearshore migrants and very uncommon offshore in the Chukchi Sea north of Cape Lisburne, they apparently move offshore south of Cape Lisburne, since they were commonly observed over water west of Pt. Hope in September. Similar densities were found in Kotzebue Sound.

Northern fulmars. Northern fulmars (*Fulmarus glacialis*) breed as far south as St. Matthew Island, although non-breeders are common in summer and early fall north to Pt. Barrow. The present observational data indicate that they are absent from Kotzebue Sound but are common in the Bering Strait region in early August and in the Pt. Hope region in September.

Shearwaters. All shearwaters seen in the Chukchi Sea are presumably short-tailed shearwaters (*Puffinus tenuirostris*). This is the most abundant seabird in the Bering Sea in summer, with large concentrations found as far north as St. Lawrence Island (Woodby and Divoky 1983). Small numbers of shearwaters apparently move into the Chukchi Sea annually. Observations at Pt. Barrow indicate high variability in their numbers in the Chukchi Sea, with over 500,000 birds present in some years.

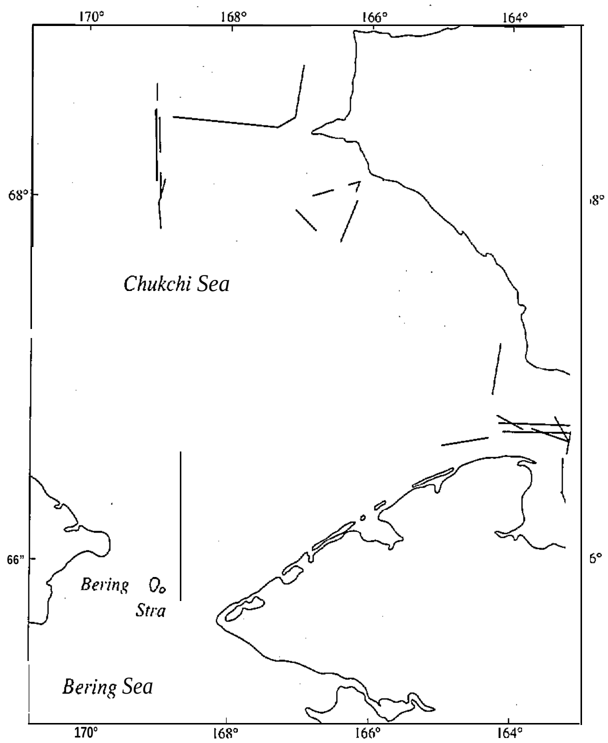

Figure 8.1 Location of pelagic bird observations in the southern Chukchi Sea.

Table 8.1 Densities and percent frequencies of occurrence of seabirds in Kotzebue Sound, 15–16 September 1976.

Species or species group	Density (birds/km²)	Percent frequency of occurrence
Loons	.4	20
Northern fulmar	0	0
Short-tailed shearwater	.1	2
Oldsquaw	.1	2
Eiders	0	0
Phalaropes	.7	4
Glaucous gull	.1	5
Black-legged kittiwake	.9	31
Ross Gull	0	0
Murres	.1	6
Crested auklet	.1	6
Least auklet	0	0
Parakeet auklet	.1	6
Horned puffin	.1	6
Total	2.7	51

n = 65

Table 8.2 Densities and percent frequencies of occurrence of seabirds in the Bering Strait, 1 August 1975.

Species or species group	Density (birds/km²)	Percent frequency of occurrence
Loons	0	0
Northern fulmar	1.3	65
Short-tailed shearwater	0	0
Oldsquaw	0	0
Eiders	0	0
Phalaropes	19.4	82
Jaegers	.4	29
Glaucous gull	.1	6
Black-1 egged kittiwake	.7	35
Murres	29.0	100
Crested auklet	1.0	24
Least auklet	2.3	52
Parakeet auklet	.9	24
Horned auklet	1.8	65
Tufted puffin	1.3	59
Total	58.2	100
n = 17		

Table 8.3 Densities and percent frequencies of occurrence of seabirds west of Pt. Hope, 2 August 1975.

Species or species group	Density (birds/km²)	Percent frequency of occurrence
Loons	0	0
Northern fulmar	.4	12
Short-tailed shearwater	o	0
Oldsquaw	o	0
Eiders	10.8	19
Phalaropes	1.3	23
Jaegers	.1	12
Glaucous gull	.2	12
Black-legged kittiwake	1.6	46
Murres	13.2	100
Crested auklet	.1	7
Least auklet	.1	7
Parakeet auklet	.1	7
Horned puffin	.2	15
Tufted puffin	.1	7
Total	28.2	100
n = 26		

Table 8.4 Densities and percent frequencies of occurrence of seabirds west of Pt. Hope, 28 September 1976.

Species or species group	Density (birds/km²)	Percent frequency of occurrence
Loons	.3	21
Northern fulmar	.7	42
Short-tailed shearwater	.7	29
Oldsquaw	1.8	21
Eiders	.9	25
Phalaropes	62.9	92
Glaucous gull	.5	34
Black-legged kittiwake	.5	38
Ross gull	1.1	34
Murres	.2	17
Crested auklet	.7	42
Least auklet	.1	4
Parakeet auklet	.2	13
Horned puffin	0	0
Total	70.6	100
n = 24		

Table 8.5 Densities and percent frequencies of occurrence of seabirds south of Cape Thompson, 29 September 1976.

Species or species group	Density (birds/km²)	Percent frequency of occurrence
Loons	.1	6
Northern fulmar	.1	6
Short-tailed shearwater	.1	6
OldSquaw	.6	24
Eiders	.1	6
Phalaropes	1.3	47
Glaucous gull	.5	35
Black-legged kittiwake	.8	35
Ross gull	0	0
Murres	.1	12
Crested auklet	0	0
Least auklet	0	0
Parakeet auklet	0	0
Horned puffin	0	0
Total	3.7	94
n = 17		

Shearwaters apparently move into the Chukchi Sea in late August. None was seen directly north of the Bering Strait in early August 1975, but they were common to abundant directly south of the strait. Observations in September showed that shearwaters were abundant in the Pt. Hope area, and uncommon south of Pt. Hope and at the mouth of Kotzebue Sound. The distribution of this species in the Chukchi Sea is apparently closely related with inflowing water from the Bering Sea or with fronts associated with that water.

Waterfowl. Eiders (*Somateria* spp.) and oldsquaw (*Clangula hyemalis*) are common migrants in Kotzebue Sound and the southern Chukchi Sea. Because they tend to migrate in nearshore habitats it is surprising that they were not encountered in Kotzebue Sound in September. They were regularly encountered south of Cape Thompson and west of Pt. Hope. They are present in offshore waters only as migrants.

Phalaropes. Two species of phalarope—red phalarope (*Phalaropus fulicarius*) and red-necked phalarope (*P. lobatus*)—migrate through the southern Chukchi Sea to and from their breeding areas in the tundra. It has generally not been possible to distinguish between the two species in most pelagic sightings. It is likely, however, that most at-sea observations are of red phalaropes.

Phalaropes were found to be uncommon in Kotzebue Sound but are a regular and sometimes abundant seabird in the remainder of the southern Chukchi Sea. They were abundant in the Bering Strait in early August but uncommon in the Pt. Hope area a day later. The population density in the Pt. Hope area during late September, 62.9 birds/km^2, was found to be the highest of any seabird species in the southern Chukchi Sea. The species seems to be closely associated with inflowing water from the Bering Sea because it was regularly encountered in waters south of Cape Thompson, with average densities of 1.3 birds/km^2.

Jaegers. Jaegers (*Stercorarius* spp.) were seen only during the early August cruises and then only in small numbers. They were observed along a quarter of the transects north of the Bering Strait. Jaegers are rather early migrants from the Arctic, so their absence from September cruises is not surprising.

Glaucous gull. Glaucous gulls (*Larus hyperboreus*) are a ubiquitous part of arctic pelagic waters, being found in small numbers throughout the Beaufort and central Chukchi seas. In early fall as the tundra and later the nearshore waters freeze, this species moves into offshore areas. Our observations show that they are not common in Kotzebue Sound. They were uncommon in early August in both the Bering Strait and Pt. Hope areas, and, surprisingly, also in Kotzebue Sound in mid-September. The late-September observations in the Pt. Hope and Cape Thompson areas found moderate densities and frequencies of occurrence.

Black-1egged kittiwake. Black-legged kittiwakes (*Rissa tridactyla*) are common breeders at the cliff colonies in the central and southern Chukchi Sea. Non-breeders are regularly encountered away from the colonies, so that the species is regularly seen throughout arctic and sub-arctic waters. Their frequency of occurrence was remarkably uniform throughout the Chukchi Sea and Kotzebue Sound, ranging from 31 to 46%. Average densities ranged from 0.5 to 1.6 birdsikm^2, with the highest densities found in the Pt. Hope area during the breeding season. It was the most abundant species in Kotzebue Sound.

Ross' gull. Ross' gulls (*Rhodostethia roses)* breed in north-central Siberia and migrate to the Pt. Barrow area in late September. They were encountered only in the Pt. Hope area in late September. It is not clear if these birds were moving east to the Barrow area through the southern Chukchi

Sea or if they were moving south to a Bering Sea wintering area. The wintering area of Ross' gulls is not known.

Murres. Murres (Uris spp.) are the most abundant species breeding in the southern Chukchi Sea, and during summer, non-breeders occur regularly in pelagic waters north to Pt. Barrow. Murres were extremely uncommon in Kotzebue Sound in mid-September, but this might have been due to the timing of the census there. In early August, murres were common in both the Bering Strait and Pt. Hope areas, but mid-September densities and frequencies of occurrence in the Pt. Hope and Cape Thompson area were low, indicating that their migration southward had already begun.

Other alcids. The three species of auklet and two species of puffin that breed in the Bering Strait region were all encountered in moderate numbers directly north of the strait. Farther north they were present only irregularly.

8.1.5 ***Total Densities*** Kotzebue Sound was found to have extremely low densities, with an average value of 2.7 birds/km^2. No birds were recorded during almost one-half of the observational periods. In this respect, the sound appears to be similar to Norton Sound, which had densities of 3.7 birds/km^2 (Woodby and Divoky 1983). As in Norton Sound, black-legged kittiwakes were the most abundant species in Kotzebue Sound, although their frequency of occurrence in Kotzebue Sound was much lower.

Waters directly outside the sound have slightly higher average bird densities, but the fauna is more diverse. Regularly encountered species, e.g., phalaropes, glaucous gulls, and black-legged kittiwakes, were observed during at least one-third of the transects sampled.

Highest bird densities in the southern Chukchi Sea *were* found in the Bering Strait and Pt. Hope areas, indicating their association with the northward-flowing waters moving through the strait. It is likely that bird densities were high in the area between Pt. Hope and the Bering Strait as well, but this area was not sampled. The nutrient-rich and biologically more productive Bering Sea water flowing into the Chukchi Sea apparently supports a large number of breeding birds north of the strait, and promotes the concentration of post-breeding migrants south of the strait.

8.2 COLONIAL SEABIRDS

8.2.1 ***Distribution*** Major colonies of seabirds (105 to 10^6 birds) are found on Little Diomede Island in the Bering Strait, and at Cape Thompson and Cape Lisburne in the eastern Chukchi Sea (Fig. 8.2). The colonies have been described by Biderman and Drury (1978), Swartz (1966), and Springer et al. (1985a). Although the seabird populations on Big Diomede Island are not known, it is thought that birds nest in large numbers there as well (Biderman and Drury 1978; C. Iapana[a]). Bird colonies at Fairway Rock in the Bering Strait, Puffin Island in Kotzebue Sound, and Cape Lewis number 10^4 to 10^5 birds (Biderman and Drury 1978; Sowls et al. 1978; Springer et al. 1985a). Four other colonies in Kotzebue Sound, located at Chamisso Island, Rex Pt., Toawlevic Pt., and Cape Deceit, each have 10^3 to 10^4 birds (Nelson and Sowls 1985). The total number of colonial seabirds at 16 locations in Kotzebue Sound (Fig. 8.3) is about 5 x 10^5 (Sowls et al. 1978; Nelson and Sowls 1985).

Thirteen species of seabirds breed on the islands in the Bering Strait (Biderman and Drury 1978). The most abundant are least auklets (*Aethia pusilla*), which number about 10^6 on Little Diomede Island and are about 10 times more numerous than crested auklets (*A. cristatella*), the next most abundant species. Black-legged kittiwakes, common murres (Uris *aalge*), thick-billed murres (*U. lomvia*), parakeet auklets

[a]C. Iapana, Little Diomede Island, AK, personal communication.

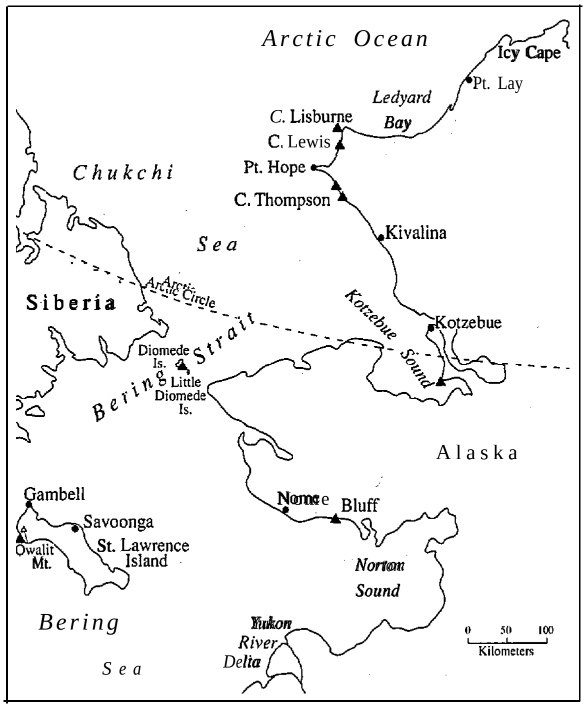

Figure **8.2** Locations of major seabird colonies (A) in the northern Bering and eastern Chukchi seas.

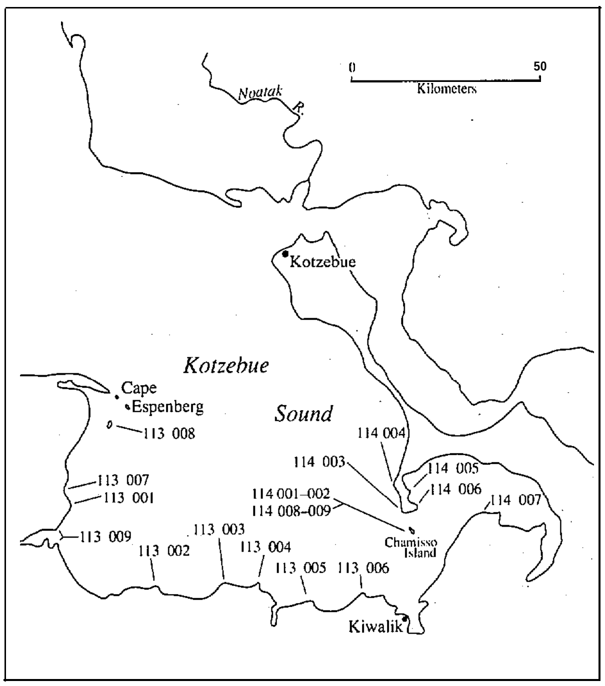

Figure **8.3** Locations of seabird colonies in Kotzebue Sound. Each seabird colony is identified with the U.S. Fish and Wildlife Service seabird colony numbering system (from Nelson and Sowls 1985).

(*Cyclorrhynchus psittacula*), and horned puffins (*Fratercula corniculata*) each number 2 to 3 x 10^5. The number of tufted puffins (*E. cirrhata*) *is 103*, whereas pelagic cormorants (*Phalacrocorax pelagicus*), glaucous gulls (*Larus glaucescens*), black guillemots (*Cepphus grylle*), and pigeon guillemots (c, *columba*) each number fewer than 300 birds. Dovekies (*Alle alle*) are uncommon but regular nesters in this region.

The most abundant species in Kotzebue Sound is the horned puffin, with about 1 x 10^5 birds on Puffin Island and 5 x 10^4 birds on Chamisso Island. Black-legged kittiwakes, common murres, and thick-billed murres each number about 1 x 10^4. The only other species nesting in Kotzebue Sound are pelagic cormorants, glaucous gulls, and tufted puffins.

Small colonies (tens of pairs) of glaucous gulls, arctic terns (*Sterna paradisaea*), and Aleutian terns (S. *aleutica*) occur at numerous locations in the southeastern Chukchi Sea (Sowls et al. 1978). The known population size of arctic terns north of the Bering Strait is in the order of 1,000, while the Aleutian tern population consists of about 100 to 200 birds.

8.2.2 *Breeding* ***Biology*** Murres and black-legged kittiwakes are the first to arrive at colonies in the Bering Strait in spring, followed by auklets and puffins. The dates of arrival and occupation of colonies vary by as much as 2 to 3 weeks between years (Kenyon and Brooks 1960; Biderman and Drury 1978), probably depending on the extent of sea ice cover and the amount of snow on the ground, The earliest arrival of murres is in late April, with the occupation of cliffs beginning about a week later. Black-legged kittiwakes arrive at the earliest about the middle of May, auklets about a week later, and puffins in late May to early June. Thus the complete arrival period in any year spans about 5 'weeks, with an interannual range of late-April to mid-June.

Arrival dates of seabirds at Cape Thompson (Swartz 1966) are about a week later than on Little Diomede Island, and occur in the same order for species nesting at both colonies. Murres arrived in early May in 1960 and 1961, with thick-billed murres preceding common murres. About 2 months elapsed before egg laying began, and the initial peak laying period continued for about 2 weeks. Incubation in these species lasts 4 to 5 weeks, and the chicks leave the cliffs 3 to 4 weeks later. The full period of occupation therefore spans from early May to mid-September, allowing for interannual variability of 2 to 3 weeks in the phenology (Table 8.6). Puffins, the last to arrive, do so in early June and do not complete their nesting cycle until late in September.

Table 8.6 Approximate date of first hatching of murre chicks at Cape Lisburne.

Year	First Hatching
1976	6 August
1977	1 August
1978	21 July
1979	22 July
1980	1 August
1981	26 July

The reproductive success of several of the species on Little Diomede Island, and at Cape Thompson and Cape Lisburne, varies considerably between years (Biderman and Drury 1978; Springer et al. 1985a,b,c; Springer et al.[b]). Black-legged kittiwakes, because of their accessibility to observations, are the best known. They experience large fluctuations between years in the numbers of eggs laid and chicks raised (Fig. 8.4) and in the growth rates of the chicks (Table 8.7), which are related to interannual differences in prey availability (Springer et al. 1984).

[b] A.M. Springer, Institute of Marine Science, University of Alaska, Fairbanks, AK 99701, unpublished data.

Studies in the Bering Strait region and in the eastern Chukchi Sea have revealed highly coherent patterns of interannual variability in black-legged kittiwake

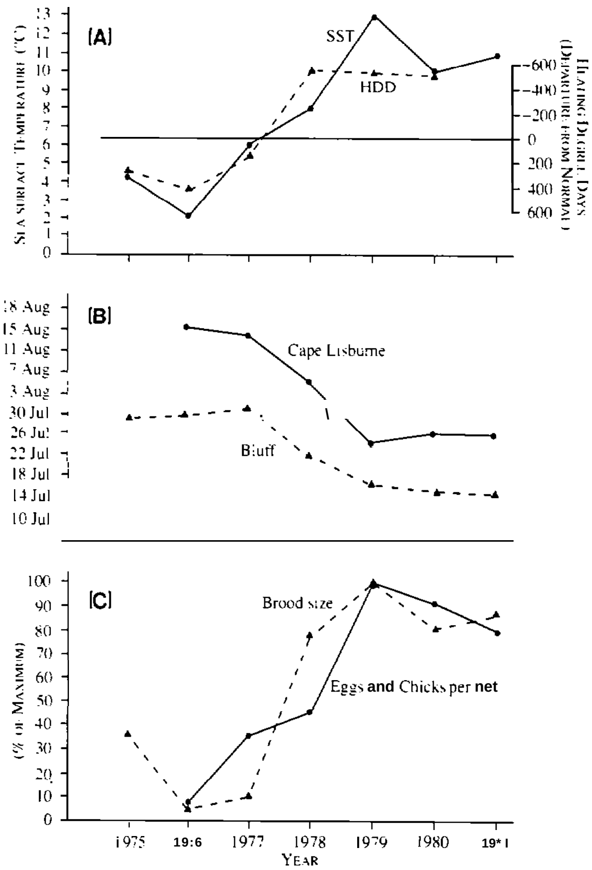

Figure 8.4 Relationships between environmental change, nesting phenology of black-legged kittiwakes, and estimates of black-legged kittiwake reproductive success at Cape Lisburne and Bluff: (a) sea-surface temperature near Cape Lisburne (mean date = 16 July, standard deviaton = 3 days), and departure from normal heating degree days in April to July at Nome; (b) mean date of hatch of black-legged kittiwake chicks; (c) numbers of black-legged kittiwake eggs and chicks per nest in the first week of hatching at Cape Lisburne (as a percentage of the maximum value, which was 1.7 eggs and chicks per nest) and black-legged kittiwake brood size in the late chick period at Bluff (as a percentage of the maximum value, which was 1.03 chicks per nest). Data for 1980 and 1981 at Bluff are from the early chick period; data for 1975-78 at Bluff are from Drury et al. 1981.

Table 8.'7 Growth rates of black-legged kittiwake chicks in northern Alaska.

Year	Colony			
	Bluff	Cape Thompson	Cape Lisburne	St. Lawrence 1.
1977	nd*	12.6 ± 3.6(16)t	19.3 ± 2.9 (18)	nd
1978	17.9* 4.1 (22)	nd	19.7 ± 6.7 (21)	nd
1979	20.4 ± 4.4(35)	20.2 ± 4.7(111)	18.3 ± 1.4 (24)	nd
1980	17.6 ± 7.4 (30)	nd	17.9 ± 3.7 (43)	nd
1981	15.6 *4.5 (31)	nd	14.3 * 3.0 (30)	21.0* 7.1 (15)
1982	nd	16.5 ± 3.2 (48)	nd	nd
1983	11.4 ± 5.0(12)	nd	15.9 ± 3.0 (45)	nd

"nd = no data.
†Mean growth rate (g/day) ± standard deviation (sample size).

reproductive success at most of the major colonies (Drury et al. 1981; Roseneau et al. 1985; Springer et al. 1985a,b,c; Springer et al.[b]; Murphy et al.[c]). At one of these colonies (Bluff, in Norton Sound) the reproductive success of common murres has been parallel to that of black-legged kittiwakes for the past decade (Murphy et al. 1986; Murphy et al.'), indicating that murres elsewhere in the region might experience similar patterns of variability between years.

8.2.3 ***Trophic Relationships*** There are two principal trophic levels represented in the seabird populations in the Bering Strait: planktivores and piscivores. Least and crested auklets feed nearly exclusively on zooplankton, particularly the large copepods *Neocalanus cristatus*, *N. plumchrus*, and *Calanus marshallae*, euphausiids (*Thysanoessa spp.*), and decapod larvae, while parakeet auklets feed on these and other zooplankters and on some small fishes (Bedard 1969a; Searing 1977; Springer and Roseneau 1985). All of the rest of the species there, as well as those at Cape Thompson and Cape Lisburne, feed primarily on fishes, particularly arctic cod (*Boreogadus saida*), saffron cod (*Eleginus gracilis*), sculpins (*Cottidae*), sand lance (*Ammodytes hexapterus*), and capelin (*Mallotus villosus*) (Swartz *1966;* Springer et al. 1984). Thick-billed murres, pelagic cormorants, and puffins supplement their diets with a variety of invertebrates, notably benthic amphipods, shrimps, and polychaete worms, more than do the other primarily piscivorous species. Glaucous gulls take a variety of prey besides fishes, including eggs, chicks, and adults of other birds. They also scavenge extensively on carrion and garbage.

The presence of oceanic zooplankton and planktivorous auklets in the Bering Strait is unexpected considering that the strait is shallow (water depth between 20 and 50 m), which was thought to have given the strait a coastal character (Iverson et al. 1979). It is now known that a portion of a water mass originating in the south along the continental shelf break exits the Bering Sea through the Bering Strait, into the Chukchi Sea (Coachman et al. 1975; Kinder et al. 1975). Zooplankton otherwise restricted to the oceanic and outer continental shelf domains (Cooney 1981; Smith and Vidal 1984) are accumulated in this water mass during its transit along the continental shelf break, and some are transported through the Bering Strait, where they support large populations of auklets (Springer and Roseneau 1985; Springer et al.[b]).

In contrast to this oceanic food web, a pelagic food web characteristically found in shallow waters provides a very important

[c]E.C. Murphy, Institute of Arctic Biology, University of Alaska, Fairbanks, AK 99775, unpublished manuscript.

energy pathway for several of the fish-eating species, particularly black-legged kittiwakes. Small copepods and cladocerans (e.g., *Acartia* spp., *Pseudocalanus* spp., *Podon* spp., and *Evadne* spp.) are preyed on by young age-classes of sand lance in summer, and the sand lance in turn are taken by seabirds (Springer et al. 1985c). There is a strong temporal relationship between the seasonal abundance of sand lance and their prey (Fig. 8.5). The abundance of sand lance varies considerably between years, paralleling environmental conditions and black-legged kittiwake reproductive success (Springer et al. 1984). Cold summers lead to low numbers of sand lance and to poor reproductive success of black-legged kittiwakes, while the opposite is true of warm summers. The copepods and cladocerans are also influenced similarly by temperature (Redburn 1974; Neimark 1979), and interannual differences in the timing of their reproductive cycles and numbers could contribute to variability in production at higher trophic levels.

8.2.4 Population *Dynamics* The number of murres at Cape Thompson apparently underwent a decline of approximately 40% between the early 1960's and 1976, and continue d to decline an additional 20% through 1982, the last year the colony was censused (Fig. 8.6). A similar decline apparently occurred at Bluff, in Norton Sound, where common murre numbers fell 40 to 60% between 1975 and the early 1980's (Fig. 8.7). In contrast, annual counts between 1976 and 1986 at Cape Lisburne indicate that murre numbers there have been stable during the past decade (see Table 8.8). A simulation model of the population at Bluff predicted that murre numbers would fall in the late 1970's in response to lowered reproductive success during the cold period of the mid-1970's, but would increase substantially by the mid- 1980's because of improved reproductive success during the ensuing warm-water period (Murphy et al. 1986).

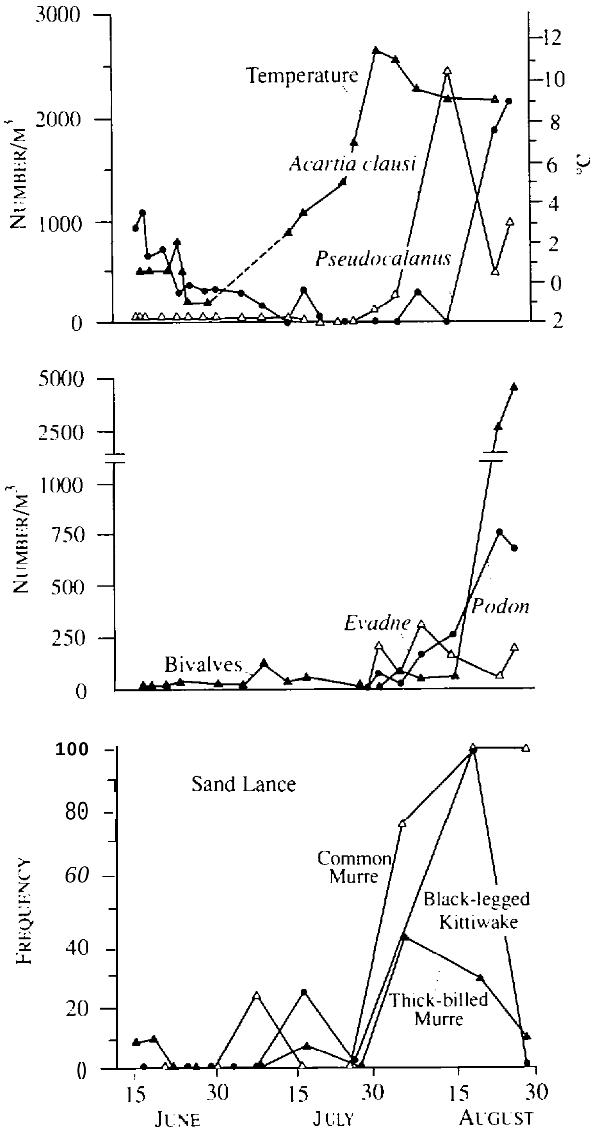

Figure 8.5 Relationships between water temperature, the abundance of zooplanktonic prey of sand lance, and the occurrence of sand lance in seabird diets. From Springer et al. (1985c).

The decline indicated by the census data, however, was steeper than that predicted by the model, and there has been no subsequent increase in the population size, which might implicate factors other than natality as a cause of the numerical change.

Black-legged kittiwakes have shown no long-term population declines as have murres, but black-legged kittiwake numbers do

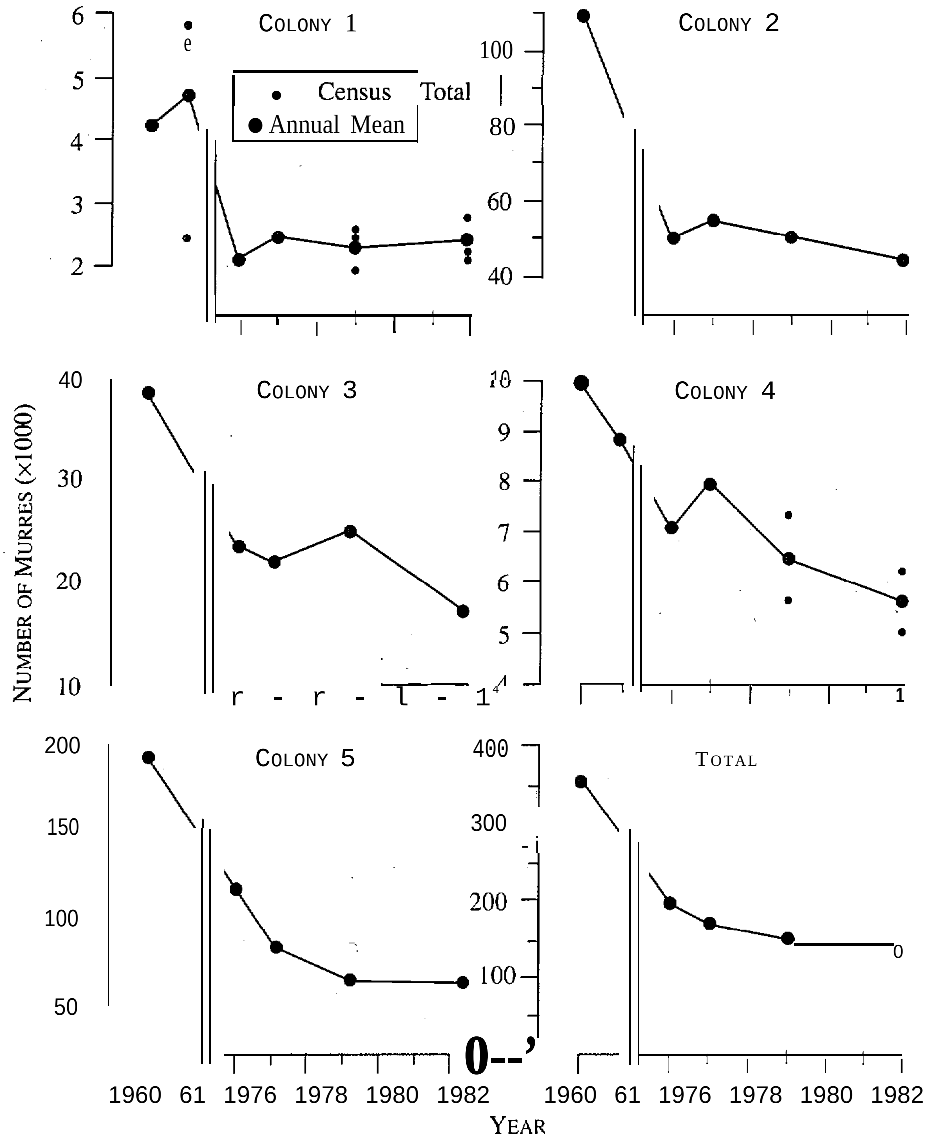

Figure 8.6 Numbers of murres at Cape Thompson.

change between years in parallel with reproductive success and phenology (Springer et al. 1985a; Murphy et al.'). In general, in cold summers fewer black-legged kittiwakes occupy the colonies, a smaller proportion attempts to nest, eggs are laid late in the season, and clutch sizes and brood sizes are both smaller than in warm years.

8.2.5 ***Information Needs*** Some 5×10^4 seabirds nest in Kotzebue Sound, yet little is known about them other than their distribution and generally rough estimates of their numbers (DeGange and Sowls 1978; Nelson and Sowls 1985). The principal colonies have been briefly studied only in two years, 1977 and 1981. The breeding season of 1981 was apparently a poor one—many birds appeared emaciated, and black-legged kittiwakes raised only 0.1 chicks per pair (Nelson and Sowls 1985). This is in striking contrast to the quality of the breeding season that year elsewhere in the region, which was very good (Roseneau et al. 1985; Murphy et al. 1986). At Bluff (in Norton Sound), St. Lawrence Island, and Cape Lisburne, for example, clutch sizes of black-legged kittiwakes were large, fledging success was good, and growth rates of chicks were high. Such a difference

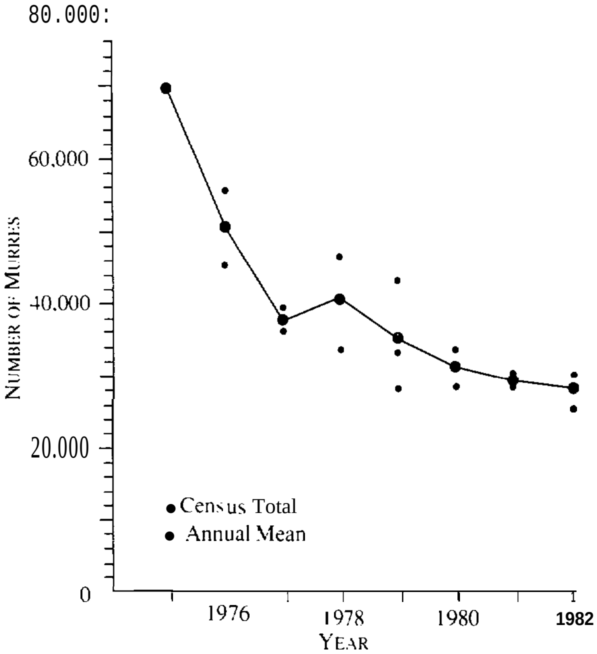

Figure *8.7* Numbers of murres at Bluff.

between this general pattern and the poor season in Kotzebue Sound suggests that, at least, some of the processes affecting food webs in the sound may be independent of those prevailing elsewhere in the region.

The colonies of least and crested auklets on Little Diomede Island and St. "Lawrence Island (in the order of 1 to 2 x 10^6 birds on each island) are probably the largest in Alaska, and hence the world (Bedard 1969b; Searing 1977; Biderman and Drury 1978; Sowls et al. 1978). Auklets have been censused using transect methodologies on St. Lawrence Island, and these data have been used to estimate total numbers as well as to provide for the monitoring of trends in population size. The last census was taken in 1976 (Searing 1977), and it indicated about a two-fold increase in numbers since the first census in the mid-1960's (Bedard 1969b). Unfortunately, data from the two censuses are not entirely comparable because the different investigators did not count the same plots within the nesting colonies. Variability in bird densities within a colony requires that the same plots be used to compare census data between years. Thus at St. Lawrence Island there are only two estimates of auklet numbers, separated by an interval of 10 years. Still, these estimates provide a better data base than that for Little Diomede Island, where censuses have been taken only by estimating the number of birds flying around the island (Biderman and Drury 1978). Because of the responsiveness of the auklet population in the Bering Strait region to changes in oceanic conditions and zooplankton abundance (Springer and Roseneau 1985; Springer et al. 1986) a greater emphasis should be placed on auklet biology.

Murres were last censused at Cape Thompson in 1982 by Springer et al. (1985c). Sufficient time has now elapsed to warrant

Table 8.8 Summary of murre census results at Cape Lisburne.

	Uncompensated scores		Compensated scores	
Year	Sample A*	Sample B†	Sample A	Sample B
1976	9,925	14,100	na‡	na
1977	10,106	15,501	14,779	22,138
1978	9524	na	14,094	na
1979	10,390	16,123	17,342	26,050
1981	10,108	14,236	11,968	17,735
1983	9,401	16,395	15,110	25,151
1984	11,228	16,283	22,148	30,622

*Plots 11,12,25,26,30, and 32.

†Plots 11, 12,25, 26, 30, 32, 65, 66, 70, and 72.

‡na = not available.

another census (see Anonymous 1985), especially in light of the declining trend in their numbers during the past 20 years. Also, because of this decline and that observed at Bluff, information from other colonies in the region would be valuable to elucidate regional versus local trends in the population size of colonial seabirds.

8.3 SHOREBIRDS

8.3,1 ***Distribution*** The coast between Cape Lisburne and Norton Sound is varied in its environments, with a general lack of wetland resulting in the area being underutilized by shorebirds (Connors 1985; Connors and Connors 1985, and references cited therein). Coastal lowland tundra is less common here than on the Arctic coastal plain, and the most prevalent upland tundra supports lower densities of nesting shorebirds. Spits and barrier islands are fewer and not as heavily used by post-breeding red-necked phalaropes (*Phalaropus lobatus*), red phalaropes (2? *fulicaria*), sanderlings (*Calidris alba*), and ruddy turnstones (*Arenaria interpres*) as they are on the Beaufort Sea coast. However, mud flats and salt marshes are much more extensive and are used for feeding areas in late summer and fall by, very large numbers of several species of shorebirds, particularly semipalmated sandpipers (*Calidris pusilla*), western sandpipers (C. *mauri*), pectoral sandpipers (C'. *melanotos*), dunlins (C. *alpina*), and long-billed dowitchers (*Limnodromus scolopaceus*).

Habitats suitable for shorebirds are located in Kotzebue Sound near the mouth of the Noatak River and along the north coast of the Seward Peninsula (Connors and Connors 1985) and in the vicinity of Cape Espenberg (Schamel et al. 1979). Schamel et al. (1979) noted that at Cape Espenberg, shorebird numbers on mud-flats peaked twice, first in late July and early August with about 650 birds/km^2, and then in late August through mid-September with about 1,000 to 2,300 birds/km^2. The first peak mainly comprised semipalmated and western sandpipers, and the second one mainly dunlins. Smaller numbers of several other species (hundreds of each at the maximum) were also present during the time of peak activity. The largest area of salt marsh and mud flats is the lagoon system near Shishmaref, which is about 160 km long. Here, peak densities estimated along census transects indicate that some 2.5 to 3.5 x 10^5 birds feed in this area during late summer (Connors and Connors 1985).

Although barrier island-lagoon systems are fewer in the southeastern Chukchi Sea in comparison with the Beaufort Sea, the barrier-island strip along the north coast of the Seward Peninsula is heavily used in the fall by golden plovers (*Pluvialis dominica*) (Connors and Connors 1985). The peak population density in August 1978 was estimated to be nearly 14,000, almost all of which were juveniles of the sub-species *P. dominica fulva*. This value is similar to the estimated regional production of the sub-species. However, because additional birds also used salt marshes and tundra, the combined population size of fall migrants was probably considerably larger than the production, suggesting an influx of juveniles from areas such as eastern Siberia.

The use of littoral habitats by shorebirds in the southeastern Chukchi Sea can be heavier earlier in the summer than in the Beaufort Sea, presumably because earlier ice break-up provides open-water feeding areas for northward migrants (Connors and Connors 1985). At Cape Krusenstern during June and July, salt marsh and mud flat areas are used by large numbers of several species of migrating shorebirds as well as by those nesting on nearby tundra.

8.3.2 ***Trophic Relationships*** In late May to early June, lagoons in the Noatak River delta and Shesualek area of northern Kotzebue Sound are very important feeding areas for migrant shorebirds and waterfowl

(Connors and Connors 1985). During break-up, ice covering the lagoons frequently contains a layer of sediment that varies in thickness over tens of centimeters. Shorebirds seek out these areas, which vary in location during this period depending on the pattern of ice melt, and feed on vegetation and over-wintering chironomid larvae.

The most important feeding areas of shorebirds during summer and fall are salt marsh and saline pool habitats (Schamel et al. 1979; Connors and Connors 1985). The majority of species feed on insect larvae and adults, particularly chironomids, as well as on isopods, mysids, and annelids.

Shorebirds that utilize open coastlines of the southeastern Chukchi Sea take similar kinds of zooplankton, as in the Beaufort Sea, with one important exception: Copepods (*Calanus* spp.) and amphipods are important in both regions, but euphausiids, which make up the bulk of the diet of shorebirds in late summer along the Beaufort Sea coast, apparently are not common in the southeastern Chukchi Sea. It is likely that this difference accounts for the differences in shorebird utilization of the nearshore habitat in these two areas. Springer et al. (1984) reported a similar lack of euphausiids in diets of murres and black-legged kittiwakes at Cape Thompson, while they were occasionally common in diets at Cape Lisburne.

8.3.3 ***information Needs*** The importance of ice-lifted sediments to feeding habits of migrant shorebirds and waterfowl is not well known. The physical processes responsible for lifting the bottom sediment layer to the surface of floating ice may further be related to the winter kill of benthic fishes, particularly *Lumpenus* spp., over the mud flats. In spring, migrant terns, jaegers, and black-legged kittiwakes feed on the carcasses of these fishes, which appear to be the major food source at that time (B. Uhl[d]). Winter-kill *Lumpenus* sp. are eaten by spring migrant seabirds on the Yukon-Kuskokwim Delta (V. Byrd[e]). This phenomenon is probably widespread.

Because mud flats are important bird habitats they should be studied to examine their roles in seabird, shorebird, and waterfowl ecology and to determine their susceptibility to pollution. The significance of the ice-lifting of sediment needs to be established.

8.4 LITERATURE CITED

Anonymous
1985. Monitoring seabird populations in the Alaska outer continental shelf region. OCS Study Report (MMS 85-0005), U.S. Department of the Interior, Minerals Management Service, Anchorage, AK, 27 pp.

Bedard, J.
1969a. Feeding of the least, crested, and parakeet auklets around St. Lawrence Island, Alaska. Canadian Journal of Zoology 47:1025-1050.

Bedard, J.
1969b. The nesting of the crested, least, and parakeet auklets on St. Lawrence Island, Alaska. Condor 71:386-398.

Biderman, J.O., and W.H. Drury
1978. Ecological studies in the northern Bering Sea: Studies of seabirds in the Bering Strait, pp. 751-838. In: Final Reports of Principal Investigators, Vol. 2, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Coachman, L.K., K. Aagaard, and R.B. Tripp
1975. Bering Strait: the regional physical oceanography. University of Washington Press, Seattle, WA, 172 pp.

[d] B. Uhl, Kotzebue, AK, personal communication.

[e] V. Byrd, U.S. Fish and Wildlife Service, Homer, AK, personal communication.

Connors, P.G.
1985. Regional patterns in coastal shorebird communities of arctic and sub-arctic Alaska, pp. 59-95. In: Final Reports of Principal Investigators, Vol. 35, U.S. Department of Commerce; National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK

Connors, P.G., and C.S. Connors
1985. Shorebird littoral zone ecology of the southern Chukchi coast of Alaska, pp. 1-57. In: Final Reports of Principal Investigators, Vol. 35, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment program, Anchorage, AK.

Cooney, R.T.
1981. Bering Sea zooplankton and micronekton communities with emphasis on annual production, pp. 947–974. In: The Eastern Bering Sea shelf: oceanography and resources, Vol. 2, (D.W. Hood and J.A. Calder, eds.), U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Juneau, AK.

DeGange, A.R., and A.L. Sowls
1978. A survey of Chamisso Island National Wildlife Refuge. Unpublished administrative report, U.S. Fish and Wildlife Service, Anchorage, AK, 17 pp.

Drury, W.H., C. Ramsdell, and J.B. French, Jr.
1981. Ecological studies in the Bering Strait region, pp. 175-488. In: Final Reports of Principal Investigators, Environmental Assessment of the Alaskan Continental Shelf, Vol. 11 (Biological Studies), U.S. Department of Commerce, National Oceanic andAtmosphericAdministration, 'Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Drury, W.H., and C. Ramsdell
1985. Ecological studies in the Bering Strait region, appendices I-X, pp. 1-688. In: Final Reports of Principal Investigators, Vol. 31, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK.

Iverson, R.L., L.K. Coachman, R.T. Cooney, T.S. English, J.J. Goering, G.L. Hunt, Jr., M.C. Macauley, C.P. McRoy, W.S Reeburg, and T.E. Whitledge
1979. Ecological significance of fronts in the southeastern Bering Sea, pp. 437-466. In: Ecological Processes in Coastal and Marine Systems (R.J. Livingston, cd.), Plenum Press, New York, NY.

Kenyon, K.W., and J.W. Brooks
1960. Birds of Little Diomede Island, Alaska. Condor 62:457-463.

Kinder, T.H., L.K. Coachman, and J.A. Gait
1975. The Bering slope current system. Journal of Physical Oceanography 83:4551-4559.

Murphy, E.C., A.M. Springer, and D.G. Roseneau
1986. Population status of *Uria aalge* at a colony in western Alaska: results and simulations. Ibis 128:348-363.

Neimark, L.M.
1979. Zooplankton ecology of Norton Sound, Alaska. M. SC. thesis, University of Alaska, Fairbanks, AK, 93 pp.

Nelson, J.W., and AL. Sowls
1985. Breeding seabird survey of Chamisso Island, southern Kotzebue Sound, 8–20 August 1981. U.S. Fish and Wildlife Service, Anchorage, AK, 38 pp.

Redburn, D.R.
1974. The ecology of the inshore marine zooplankton of the Chukchi Sea near Point Barrow, Alaska. M. SC. thesis, University of Alaska, Fairbanks, AK, 171 pp.

Roseneau, D.G., **A.M.** Springer, **E.C.** Murphy, and **M.I.** Springer
1985. Population and trophies studies of seabirds in the northern Bering and eastern Chukchi seas, 1981, pp. 1-58. In: Final Reports of Principal Investigators, Vol. 30, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK.

Schamel, D., D. Tracy, **P.G. Mickelson,** and S. **Seguin**
1979. Avian community ecology at two sites on Espenberg Peninsula in Kotzebue Sound, Alaska, pp. 289-607. In: Final Reports of Principal Investigators, Vol. 5 (Biological Studies), U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Searing, G.
1977. Some aspects of the ecology of cliff-nesting seabirds at Kongkog Bay, St. Lawrence Island, Alaska during 1976, pp. 263412. In: Annual Reports, Vol. 5, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Smith, S.L., and J. **Vidal**
1984. Spatial and temporal effects of salinity, temperature and chlorophyll on the communities of zooplankton in the southeastern Bering Sea. Journal of Marine Research 42:221-257.

Sowls, A.L., S.A. Hatch, and **C.J.** Lensink
1978. Catalog of Alaskan seabird colonies. Biological Services Program, U.S. Fish and Wildlife Service, Anchorage, AK, 196 pp.

Springer, A.M., **D.G. Roseneau, E.C.** Murphy, and **M.I.** Springer
1984. Environmental controls of marine food webs. Canadian Journal of Fisheries and Aquatic Sciences 41:1202-1215.

Springer, **A.M.,** and **D.G. Roseneau**
1985. Copepod-based food webs: auklets and oceanography in the Bering Sea. Marine Ecology Progress Series 21:229-237.

Springer, **A.M., D.G. Roseneau, E.C.** Murphy, and **M.I.** Springer
1985a. Population status, reproductive ecology and trophic studies of seabirds in northwestern Alaska, pp. 127–242. In: Final Reports of Principal Investigators, Vol. 30, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK

Springer, A.M., D.G. Roseneau, **E.C.** Murphy, and **M.I.** Springer
1985b. Population and trophic studies of seabirds in the northern Bering and eastern Chukchi seas, 1982, pp. 69–126. In: Final Reports of Principal Investigators, Vol. 30, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK.

Springer, A.M., D.G. Roseneau, B.A. Cooper, S. Cooper, P. Martin, E.C. Murphy, A.D. McGuire, and G.V. van Vliet
1985c. Population and trophic studies of breeding seabirds in the northern Bering and eastern Chukchi seas, 1983, pp. 243–305. In: Final Reports of Principal Investigators, Vol. 30, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK

Springer, A.M., D.G. Roseneau, D.S. Lloyd, C.P. McRoy, and E.C. Murphy
1986. Seabird responses to fluctuating prey availability in the eastern Bering Sea. Marine Ecology Progress Series 32:1-12.

Swartz, L.G.
1966. Sea-cliff birds, pp. 611-678. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.), U.S. Atomic Energy Commission, Washington, D.C.

Swartz, L.G.
1967. Distribution and movements of birds in the Bering and Chukchi seas. Pacific Science 21:332-347.

Woodby, D.A., and G.J. Divoky
1983. Bird use of coastal habitats in Norton Sound, pp. 353-704. In: Final Reports of Principal Investigators, Vol. 18, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Juneau, AK.

9

Marine Mammals

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9.1 INTRODUCTION

This review focuses on the existing data base regarding the biology and distribution of marine mammals in Kotzebue Sound. For most species there are virtually no published data for Kotzebue Sound per se. Therefore, we have included information from adj scent waters of the Chukchi Sea, and have defined the **area of interest as** the region east of a line extending from Point Hope to Cape Prince of Wales, also referred to as the Hope Basin.

All species using the study area are highly mobile and move freely into and out of the region on a seasonal basis. Generally, the southeastern Chukchi Sea constitutes only part of **a** species' range. Much of the significant biological data have therefore been collected in other areas, particularly the Bering and Beaufort seas. In this review we have confined ourselves to references dealing directly with the study area and have not attempted to completely describe the biology of each species. Significant references dealing with the general biology of species that occur in the area, and major studies conducted in other areas, are as follows: Rice and Wolman (1971) and Jones et al. (1984) on gray whales; Braham et al. (1980) on bowhead whales; Lowry et al. (1982) on 26 marine mammal species; Frost and Lowry (1981) on ringed seals; Burns **(1981)** on bearded seals; Fay (1982) on walruses; Fay and Fedoseev (1984) on pinnipeds; and Burns et al. (1985) on 10 marine mammal species.

We have included 11 species of marine mammals that are known to regularly occur in the study area (Table 9.1). Johnson et al. (1966) indicated that 16 species are known to

Table 9.1 Common and scientific names of marine mammals that occur regularly in the Kotzebue Sound region.

Common name	Scientific name
Cetaceans	
Belukha whale	*Delphinapterus leucas*
Killer whale	*Orcinus orca*
Harbor porpoise	*Phocoena phocoena*
Gray whale	*Eschrichtius robustus*
Minke whale	*Balaenoptera acutorostrata*
Bowhead whale	*Balaena mysticetus*
Pinnipeds	
Ringed seal	*Phoca hispida*
Spotted seal	*Phoca largha*
Bearded seal	*Erignathus barbatus*
Walrus	*Odobenus rosmarus*
Carnivores	
Polar bear	*Ursus maritimus*

occur in the Chukchi Sea. Of the five additional species, the occurrence of narwhals (*Monodon monoceros*) and northern fur seals (*Callorhinus ursinus*) is clearly beyond their usual ranges in the eastern Arctic Ocean and southern Bering Sea, respectively. Recent data indicate that humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), and sei whales (*B. borealis)* do not now regularly occur in the southeastern Chukchi Sea.

9.2 BELUKHA WHALES

General accounts of the distribution of belukhas in Alaskan waters have been presented by Nelson (1887), Gurevich (1980), Seaman and Burns (1981), and Seaman et al. (1986). Belukha whales are widely, though not uniformly, distributed throughout seasonally ice-covered waters of Alaska. They spend the winter in offshore waters associated with drifting ice. In spring, they move toward the coast, and most appear to spend the summer in coastal waters, concentrating in shallow bays or estuaries of large rivers.

Belukhas are not uncommon during winter in the southern Chukchi Sea in years with 'light" ice conditions. Eskimo hunters from Wales see them in nearshore leads throughout winter, and they are sometimes seen during winter by hunters from Shishmaref (Frost et al. 1983; Seaman et al. 1986).

During spring, particularly April and May, belukhas migrate north through the same lead system used by bowhead whales. Numerous aerial survey efforts directed primarily at bowheads have also documented the presence of belukhas (Braham et al. 1984; Ljungblad 1981; Ljungblad et al. 1982; Ljungblad et al. 1985). Large numbers undoubtedly pass along the north side of the Seward Peninsula in spring on their way to Kotzebue Sound and locations further north. Although belukhas have been infrequently sighted near Shishmaref in recent years, it is probably because the migration is far enough offshore to pass unnoticed by coastal residents (Seaman et al. 1986).

Belukhas have been reported as common summer residents of Kotzebue Sound for as long as there are published records for the area (Nelson 1887; Curtis 1930; Foote and Cooke 1960; Ray 1964, 1975; Foote 1965; Foote and Williamson 1966; Saario and Kessel 1966; Giddings 1967; Hall 1975; Seaman and Burns 1981; Frost et al. 1983). Belukhas arrive in Kotzebue Sound in late May to mid-June, usually during or shortly after breakup, when ice is still present but is broken and scattered. They are often first seen in pockets of open water in the northern part of the sound from Shesualek to Cape Blossom.

In 1978 and 1979 the first confirmed sightings in Kotzebue Sound were made in early June. These sightings were probably somewhat earlier than usual, since in both years the winters and springs were unusually warm, and breakup occurred early. Foote and Cooke (1960) found that the first belukhas usually appeared near Shesualek in mid- to late June. Ljungblad et al. (1982) reported belukhas along the coast from Shesualek to Cape Krusenstern in mid-June.

Eschscholtz Bay is a large shallow bay in the southeastern corner of Kotzebue Sound, about 85 km southeast of Kotzebue. Belukhas normally appear in Eschscholtz Bay in mid-June, slightly later than in northern Kotzebue Sound, and may remain there until at least mid-July (Seaman et al. 1986).

The movements of belukhas in Kotzebue Sound appear to be markedly different today than in the early 1900's and even the 1960's (Seaman and Burns 1981; Seaman et al. 1986). Fewer belukhas come into the shallows near Kotzebue and Shesualek, although they are still common offshore. Many people from Kotzebue believe that the noises associated with modernization have caused the change. Changes have also occurred in the movement patterns" of belukhas in Eschscholtz Bay (Seaman et al. 1986). Hunters are of the opinion that increased boat traffic in June and early July has reduced the number of belukhas entering Eschscholtz Bay.

Belukhas appear off Kivalina and Point Hope, which are along the migratory route of whales headed to the eastern Beaufort Sea, much earlier than they do in Kotzebue Sound. The northward spring migration past Point Hope has been documented by Foote (1960), Fiscus and Marquette (1975), Marquette (1976, 1977, 1979), Braham and Krogman (1977), and Braham et al. (1984). At Point Hope belukhas are seen moving north through leads in the ice as early as March (Seaman et al. 1986). They are commonly seen throughout April and May (Marquette 1977; Braham and Krogman 1977). Most sightings near Kivalina are in April and May and again in late June and early July (Frost et al. 1983; Seaman et al. 1986).

Hunters from Point Hope frequently see belukhas while hunting seals among the ice floes in late June and early July. During July through early September, belukhas are occasionally seen along the coast between Kotzebue Sound and Point Hope, and in September and October they are seen moving southward by Point Hope (Nelson 1887; Foote 1960; Frost et al. 1983; Seaman et al. 1986). Residents of Kivalina commonly see belukhas during the first part of September, usually swimming northwest along the coast toward Point Hope; they are rarely seen after that time. Belukhas are uncommon off Point Hope during mid-winter, although they are occasionally seen south of there in January and February, following periods of strong northerly winds that form leads and polynyas in the ice (Seaman et al. 1986).

The natural history of belukhas in western Alaska has been described based on 617 specimens examined during 1977-83 (Burns and Seaman 1986). Most specimens were from Eschscholtz Bay and Point Hope. Female belukhas first gave birth at 5 to 8 years of age. Births occurred during April–August, with a peak in June-July. Calving was reported in all coastal regions of Kotzebue Sound, but most observations were from near Shesualek and from Eschscholtz Bay (Seaman et al. 1986). The peak of breeding activity was probably in March (Burns and Seaman 1986).

Belukhas of the Bering, Chukchi, Beaufort, and East Siberian seas were considered by Burns and Seaman (1986) to belong to a single population, with a minimum of 16,000 to 18,000 animals occurring in waters off western Alaska in spring and summer. Seaman et al. (1986) estimated that the peak number of whales in Kotzebue Sound during summer ranged from 500 to perhaps 2,000+ with considerable year-to-year variability. Their estimate was based primarily on observations made in southeastern Kotzebue Sound.

The feeding ecology of belukha whales in Hope Basin/Kotzebue Sound was described by Seaman et al. (1982). Spring foods at Point Hope included arctic cod (*Boreogadus saida*), shrimps, and octopus (*Octopus* sp.). In coastal areas such as southeastern Kotzebue Sound, summer foods included saffron cod (*Eleginus gracilis*), sculpins (family Cottidae), Pacific herring (*Clupea harengus pallasi*, smelt (family Osmeridae) capelin (*Mallotus villosus*), salmon (*Oncorhynchus* spp.), char (*Salvelinus alpinus*), shrimps, and octopus. Saffron cod was the primary prey species there in June. Other species of fishes were eaten in relation to their seasonal patterns of distribution and abundance.

Belukha whales are an important subsistence species in Hope Basin and Kotzebue Sound. The average total belukha whale harvest in western Alaska for 1977–79 was 187 whales, of which 106 were taken from the Kotzebue Sound region, principally near Point Hope, and in Eschscholtz Bay (Seaman and Burns 1981). The largest harvest generally occurs in Eschscholtz Bay, although the number of whales harvested each year varies considerably. The harvest varied from

105 to 5 in 1977–1979 and from 129 to O in 1982-84.

Average annual harvests in the study area from 1980-84 were as follows: southeastern Kotzebue Sound, including Eschscholtz Bay-63; northeastern Kotzebue Sound, including Shesualek-19; Kivalina–14; and Point Hope-15 (Burns and Seaman 1986). Harvest levels varied considerably at all localities.

Some aspects of the subsistence hunt for belukhas at Eschscholtz Bay, including harvest levels and the value of products obtained, were discussed by Feldman (1984). Burch (1985) described the harvest of subsistence resources at Kivalina. He noted that there was significant annual variation in the harvest of belukhas there, and that there has been a substantial increase in the Kivalina belukha harvest since 1980. Most belukhas are now harvested in spring, especially late April.

9.3 KILLER WHALES

Killer whales occur in the southern Chukchi Sea in August and September (Tomilin 1957; Dahlheim 1981). Ivashin and Votorogov (1981a) noted that killer whales were relatively scarce in the Chukchi Sea. Frost et al. (1983) concluded that killer whales were present every year in low numbers in the southern Chukchi Sea, where they were seen by coastal residents near Shishmaref, Eschscholtz Bay, Kivalina, and Point Hope. They were often seen chasing belukhas or gray whales.

There is no information on the natural history or food habits of killer whales that is specific to Hope Basin. Natural history information for other areas is summarized in Dahlheim (1981), Killer whales are not harvested by coastal residents in Hope Basin.

9.4 HARBOR PORPOISES

There are few published records of harbor porpoises north of the Bering Strait, Tomilin (1957) and Leatherwood and Reeves (1978) indicated that they occasionally occur in the Chukchi Sea. Burns and Morrow (1975), based on personal observations and conversations with Eskimo residents, indicated that harbor porpoises probably occur in low numbers in the Chukchi Sea every summer. Frost et al. (1983) listed all known sightings of harbor porpoises in Hope Basin. These included sightings by local residents of Kotzebue Sound during summer, and a sighting of two' harbor porpoises off Cape Thompson in September 1981. Residents reported that harbor porpoises were sometimes caught in salmon nets.

No published information is available on the natural history, vital parameters, or food habits of harbor porpoises in Hope Basin. Harbor porpoises are not intentionally harvested by humans in this region.

9.5 GRAY WHALES

The eastern Pacific stock-of gray whales winters in the coastal waters of Baja California and the southern Gulf of California. Gray whales migrate north in late February to May and spend the summer feeding in shallow waters of the northern Bering Sea and the Chukchi Sea (Pike 1962; Rice and Wolman 1971). Gray whales do not move into the Chukchi Sea until the ice leaves, but they are abundant along the Chukchi coast from July through September (Pike 1962). Pike reported northward-migrating gray whales off Cape Thompson in early July, and southward-migrating whales as early as August; he concluded, based on his own observations and those of others, that gray whales feed in the southern Chukchi Sea.

Wilke and Fiscus (1961) described sightings of groups of approximately 100 whales engaged in feeding in the southeastern Chukchi Sea during August 1959. Marquette and Braham (1982) discussed the distribution and catch of gray whales by Alaskan Eskimos. They noted that gray whales are common in the Chukchi Sea, mostly in offshore areas, in July through September.

Results of more recent studies regarding gray whale distribution have been reported by Frost et al. (1983), Moore and Ljungblad (1984), Braham (1984), and Ljungblad et al. (1985). Gray whales first move north by Cape Prince of Wales in May through July, and feed in that area in June through August (Frost et al. 1983). Most southeastern Chukchi Sea sightings have been clustered near and just north of Cape Prince of Wales and in the area between the Bering Strait and the coast between Point Hope and Kivalina (Moore and Ljungblad 1984; Braham 1984; Ljungblad et al. 1985). Numerous sightings have been reported between Cape Thompson and Point Hope in July and August (Springer and Roseneau 1977; Durham 1979; Hobbs and Goebel 1982; Fay and Kelly 1982). A few summer sightings have been made in Kotzebue Sound near Cape Espenberg, Cape Blossom, Kotzebue, and Cape Thompson (Frost et al. 1983; Braham 1984).

Most gray whale sightings in the southern Chukchi Sea occur in the western area along the coast of the Chukchi Peninsula (Berzin 1984; Braham 1984). During an August 1982 cruise in the southern Chukchi Sea, 10 gray whales were observed along the cruise track through the Hope Basin, compared to many hundreds off the Soviet coast (Berzin 1984). Most gray whales along the Chukchi Peninsula are found within 30 to 50 km of the coast, generally in areas where benthic biomass exceeds 100 g/m^2 (Yablokov and Bogoslovskaya 1984). In Soviet surveys conducted from 1968-75, the highest gray whale densities were near Mys Inchoun and Mys Serdtse-Kamen' (Blokhin 1979; Zimushko and Ivashin 1980). However, distribution and abundance in a particular area may vary considerably from year to year as well as within the same season (Votrogov and Bogoslovskaya 1980). Younger animals occur close to the coast, while older animals may occur much farther offshore.

No studies of the natural history and biology of gray whales have been conducted specific to Hope Basin. Rice and Wolman (1971) presented a general review of gray whale biology. Many Soviet investigators have obtained biological information from gray whales hunted and collected off the coast of the Chukchi Peninsula, in both the northern Bering and southern Chukchi seas (Zimushko and Ivashin 1980; Blokhin 1984; Yablokov and Bogoslovskaya 1984).

Gray whales are known to feed mainly on infaunal benthic amphipods in relatively shallow waters. Reviews of gray whale feeding in northern Bering and southern Chukchi sea waters can be found in Lowry et al. (1982), Yablokov and Bogoslovskaya (1984), and Nerini (1984). The distribution of gray whales on these northern feeding grounds generally coincides with the presence of extensive amphipod communities, particularly *Ampelisca macrocephala*. Concentrations of 14,000 to 24,000 amphipods/m^2, the highest benthic biomass found on the Bering/Chukchi shelf, have been found in the southern Chukchi Sea (Zimushko and Lenskaya 1970; Stoker 1978; Nerini et al. 1980; Nerini 1984). Dominant genera include *Ampelisca, Photis*, and *Pontoporeia* (Coyle 1981).

Zenkovich (1934) was the first to report on the food of gray whales in the Bering and Chukchi seas. He found the stomachs of gray whales taken along the Chukchi coast "packed with amphipods; *Ampelisca macrocephala* was the predominant species. Other Soviet investigators who examined the stomachs of gray whales killed in the Chukchi Sea also found amphipods, especially *Ampelisca macrocephala*, to be the major food item (Tomilin 1957; Zimushko and Lenskaya 1970; Zimushko and Ivashin 1980; Bogoslovskaya et al. 1981; Coyle 1981).

Gray whales are harvested by the Soviets in the southwestern Chukchi Sea (Blokhin 1979; Zimushko and Ivashin 1980). Few, if any, are harvested each year by Alaskan Eskimos in the Hope Basin (Wolman and Rice 1979). The residents of Point Hope harvest bowheads but not gray whales. The residents of Wales and Little Diomede occasionally harvest gray whales, and sometimes salvage stranded animals (Marquette and Braham 1982). A single gray whale was harvested at Shesualek in 1980 (Marquette et al. 1982).

9.6 MINKE WHALES

Pacific minke whales are distributed widely in inshore waters; however, there is little specific information on their distribution in the coastal waters of western Alaska. Tomilin (1957) reported that minke whales occur along the west coast of North America from Kotzebue Sound to California. Most northern sightings were in August and early September, and Tomilin believed that whales occurring in the Chukchi Sea migrated south in winter, Ivashin and Votrogov (1981b) described sightings of minke whales in the southwestern Chukchi Sea along the Chukchi Peninsula. They found minke whales to be present in the coastal zone from about June to October, usually within 24 km of shore. Their sightings suggested that minke whales in the Chukchi Sea are present in low numbers and that they occur mostly as solitary individuals.

Frost et al. (1983) reported only two sightings of minke whales in Hope Basin. In autumn 1978 or 1979, two of these whales were reported to be beached in the mouth of the Buckland River. A resident of Kotzebue reported that whales fitting the description of minke whales are sometimes present in summer in Kotzebue Sound.

There is no information on the natural history or food habits of minke whales that is specific to Hope Basin. General accounts of their biology can be found in Tomilin (1957) and Omura and Sakiura (1956).

9.7 BOWHEAD WHALES

A considerable effort has been devoted to aerial surveys designed primarily to delineate the distribution, abundance, and movements of bowhead whales. Much of this information has been summarized in Braham et al. (1984) and Ljungblad et al. (1985). Results indicate that during their spring migration most bowhead whales move directly through the lead system extending from the Bering Strait to Point Hope. Occasional sightings and harvest records confirm that some of the whales head slightly to the northeast after passing through the Bering Strait, and reach the coast near Kivalina where they turn northwest and follow nearshore leads to Point Hope. During spring migration, the whales pass this area in April and May, often accompanied by belukha whales. They are not known to regularly frequent Kotzebue Sound (east of 164°00′W) (Braham et al. 1984; Ljungblad et al. 1985).

Bowheads are generally found west of the Hope Basin during autumn. They are common in the southwestern Chukchi Sea between Mys Serdtse-Kamen' and Uelen in October and November (Bogoslovskaya et al. 1982).

It is generally thought that bowheads feed little if at all on their northward migration. Johnson et al. (1966) examined the stomachs of two bowheads taken at Point Hope in April 1960 and May 1961. One stomach was empty; the other contained fragments of polychaetes, crabs, snails, crustaceans, and echinoderms. Of six bowheads landed at Point Hope since 1979, only two have contained food: a single amphipod in one and a single snail in the other (Lowry and Frost 1984). In the Beaufort Sea near Barrow and Kaktovik, bowheads primarily eat euphausiids, copepods, and hyperiid amphipods (Lowry and Frost 1984).

In Hope Basin, bowhead whales are harvested by residents of the villages of Wales, Little Diomede, Kivalina, and Point Hope, primarily during April (Marquette 1977; Marquette and Braham 1982; Dronenburg et al. 1984). The principal bowhead whaling village of the region is Point Hope, which has generally harvested one to six whales per year during the spring hunt (Marquette 1977; Durham 1979).

Braund et al. (1984) summarized bowhead hunting in Alaska, and discussed the number of whales harvested, the number of crews engaged in whaling, and recent International Whaling Commission quotas. Since 1981, Wales has had a quota of one bowhead, Kivalina one to two, and Point Hope three to five. Between 1962 and 1982, Wales and Kivalina each landed bowheads in 4 years. Point Hope landed bowheads in all years except one, with annual harvests ranging from 1 to 14 whales.

Burch (1985) reviewed subsistence hunting at Kivalina and noted that bowhead hunting as it exists today began in 1966, with the first whale taken in 1968. Whalers from Kivalina often join crews at Point Hope, where conditions are generally more favorable (Durham 1979).

9.8 SEALS

The first published study of marine mammals of the Kotzebue Sound region was that of Johnson et al. (1966). During 1960-61 they conducted investigations at Point Hope and Kivalina in conjunction with "Project Chariot." They noted that the marine mammal fauna of the area was highly migratory. The animals of greatest importance to the local communities were the ice-associated species that generally occurred in greatest abundance during April-June. Although nine species were encountered during the field work, only ringed seals and bearded seals were sufficiently common to allow detailed studies. The data collected from 2,028 ringed seals and 208 bearded seals allowed the first description of the basic biology of those species in Alaskan waters.

Ringed seals were present from November through June, with greatest numbers taken by hunters in February and June. Males became sexually mature at 7 years of age and were most reproductively active from March to early May. Females first ovulated at 6 to 8 years of age. Pups were born in late March, and breeding occurred in April and May. The pregnancy rate was 86.770. Sex ratio of fetuses was 1:1, while males predominated in the harvest.

Bearded seals were common only in June. At the time of their study, Johnson et al. (1966) did not consider age-determination techniques to be adequate for bearded seals, and consequently the biological data for this species were quite general. Of six "adult" bearded seals examined, five were pregnant. Pups were born in the latter part of April.

Burns (1967) described the distribution and natural history of bearded seals in northern Alaska based on studies conducted in 1962-66. He indicated that bearded seals are sparsely distributed throughout the Chukchi and northern Bering seas from January to April, particularly in areas of strong currents and shifting ice where open water is found, and that during summer most move north and remain along the permanent ice pack of the Chukchi Sea. He noted that large numbers of subadult bearded seals periodically occur in Kotzebue Sound during the ice-free period.

Burns (1970) described some aspects of the distribution and natural history of ice-associated pinnipeds in the Bering and Chukchi seas. He noted that during the pupping and breeding season adult ringed seals occupied regions covered by extensive land-fast ice, which occurs throughout inner Kotzebue Sound and along the adjacent coastline, whereas bearded seals were widely distributed in the pack ice occurring to the west in the Chukchi Sea.

During the reproductive period spotted seals occurred principally in the Bering Sea; many moved north through the Bering Strait to the Chukchi Sea during or after break-up of the ice.

OCSEAP studies of the natural history of ringed and bearded seals began in 1976. A preliminary description of the natural history of Alaskan ringed seals was given by

Burns and Eley (1978), and results of OCSEAP ringed seal studies were summarized in Frost and Lowry (1981). A detailed description of bearded seal biology is presented in Burns and Frost (1983) and summarized in Burns (1981). These studies included specimens collected in the Kotzebue Sound region, primarily Shishmaref and Point Hope, and generally confirmed and elaborated on the basic biological parameters described by Johnson et al. (1966).

Burns and Eley (1977) reported results of June 1976 aerial surveys of ringed seals in Kotzebue Sound. The overall density of seals hauled out on the ice was 0.73/nmi^2, which, when extrapolated to the area of ice, gave an estimated abundance of 2,000 seals in the area. Those data were re-analyzed by Frost et al. (1985a), who calculated a density of 0.93 seals/nmi^2 for Kotzebue Sound in June 1976. Ringed seal surveys were flown in the area again in May 1985 and 1986. The densities were much greater. In 1985 there were 3.08 seals/nmi^2, which gave an estimate of between 6,467 and 9,513 ringed seals hauled out in Kotzebue Sound (Frost et al. 1985b). In 1986, the density of hauled-out seals was 5.77 seals/nmi^2, for an estimated 12,600 to 16,500 seals in the sound (Frost et al. 1987).

Frost et al. (1983) presented a compilation of summer-autumn sightings of marine mammals in the coastal zone of the eastern Chukchi Sea. Spotted seals were the most commonly reported seals in Kotzebue Sound. They appeared to be most common in August-September.

Burns and Frost (1983) reported that bearded seals migrated through the Hope Basin in spring and fall and that they were abundant in the Hope Basin in suitable areas of drifting ice from late fall to summer. They noted that polynyas and lead systems occurred predictably along the northwestern part of the Hope Basin (from Cape Krusenstern to Point Hope) throughout winter and spring, providing favorable conditions for bearded seals. Ice persists along the northwestern coast of the Seward Peninsula as late as the end of July, and Kotzebue Sound also sometimes traps drifting ice; bearded seals congregated in those areas as long as the ice persisted.

Prior to OCSEAP-funded studies, the only published report on the diet of marine mammals in the Kotzebue Sound region was that of Johnson et al. (1966). They found that stomach contents of ringed seals taken near Point Hope consisted mostly of arctic cod during winter and crustaceans (shrimps, amphipods, and mysids) in spring. The bearded seal diet was found to be quite diverse, but consisted mostly of shrimps, crabs, and clams. Clams occurred only in seals taken in June.

Data collected on food habits and trophic relationships of seals in the Chukchi Sea were presented in Lowry et al. (1981). The feeding ecology of various individual species in western and northern Alaska was discussed in Lowry et al. (1980a) for ringed seals and Lowry et al. (1980b) for bearded seals. Within Kotzebue Sound, arctic cod was the most important food of ringed seals. Saffron cod were commonly eaten in spring and fall, while crustaceans (shrimps, amphipods, and mysids) contributed significantly to the seal diet in spring and summer. Spotted seals fed on shrimps and on a variety of fishes, especially saffron cod, herring, rainbow smelt (*Osmerus mordax*), sand lance (*Ammodytes hexapterus*), and sculpins. Bearded seals at Shishmaref primarily ate crangonid shrimps, brachyuran crabs, and clams. Pups ate more shrimps and isopods than did adults, whereas adults ate more clams and crabs (Lowry et al. 1980b).

Bearded, ringed, and spotted seals are utilized by residents of all Hope Basin/Kotzebue Sound coastal villages. During November 1960 through June 1961 residents of Point Hope harvested a total of 2,200 ringed seals and 203 bearded seals (Johnson et al. 1966). Burns and Frost (1983) reported on harvests of bearded seals, by state Game

Management Unit (GMU). For the 18-month period from 1 January 1977 through 30 June 1978, the recorded harvest was 2,706 for GMU 22 (Seward Peninsula, including Shishmaref) and 964 for GMU 23 (Kotzebue Sound, including Point Hope).

Braund et al. (1984) studied the subsistence harvests in the southern Chukchi Sea villages of Wales, Kivalina, and Point Hope. They estimated that Wales harvested about 150 bearded seals and over 300 hair seals (ringed and spotted combined) annually; Kivalina took 40 to 220 bearded seals and over 500 hair seals; and Point Hope harvested over 700 hair seals (no estimates were given for bearded seals). Estimates were based on data collected in 1977 or earlier.

Burch (1985) described the harvest of subsistence resources at Kivalina. Seals, particularly ringed seals and bearded seals, were important to the village economy. In 1983-85, the annual harvest at Kivalina was 100 to 200 ringed seals and 50 to 150 bearded seals. Spotted seals were harvested only occasionally. Most marine mammal hunting occurred during the months of January through July, and ice conditions greatly affected hunting success.

9.9 PACIFIC WALRUSES

Pacific walruses inhabit the broad continental shelf of the Bering and Chukchi seas. They migrate seasonally from wintering areas in the Bering Sea to summering grounds on the coast of the Bering and Chukchi seas and the Chukchi Sea ice edge. Subadults and females with young follow the retreating ice edge northward and summer primarily in the northern Chukchi Sea (Estes and Gilbert 1978; Krogman et al. 1979; Fay 1982). Adult males form large herds on hauling grounds in Bristol Bay, the Bering Strait, and along the Chukchi Peninsula (Gel'tsev 1972, 1976; Fay 1982).

Fay (1957) summarized the historical and present status of walruses and reported that in the 1930's, walrus herds were present on hauling grounds at Cape Thompson, Cape Lisburne, and Icy Cape. By the 1950's, however, there were no regular hauling grounds in the eastern Chukchi Sea. Frost et al. (1983), citing other references, reported a few summer-autumn sightings of walruses hauled out at Kivalina and Point Hope.

The best synoptic overview of walrus distribution in Alaska was provided by Fay (1982), in which he mapped and discussed distribution by month. Distribution maps in Fay (1982) indicate that walruses are not common in eastern Hope Basin and Kotzebue Sound. Fay stated that solitary animals may overwinter near Point Hope, but that most walruses migrate southward through Bering Strait in October–December. Most return northward in April-July to spend the summer in the pack ice of the Chukchi Sea. From July through September, many are concentrated in the ice off the coast from Icy Cape to Barrow. Fay reported no recently used haulouts along the Alaskan Chukchi Sea coast.

We know of no information on the diet of walruses that is specific to Kotzebue Sound or Hope Basin. Fay (1982) reviewed information on seasonal and regional aspects of their diet in other areas. He reported that walruses taken in the Bering Strait region in spring fed on clams, predominantly *Mya* spp., *Hiatella arctica*, and *Serripes groenlandicus*, as well as other clams, priapulids, polychaete worms, snails, and sea cucumbers.

Walruses are harvested in several Hope Basin villages. According to Braund et al. (1984) walruses provided the largest input to the subsistence economy of Wales. The average walrus harvest at Wales from 1962 through 1982 was 77 animals retrieved, with a range of 4 to 257. At Kivalina, the harvest may have increased recently: 20 walruses were landed in 1979, compared to 51 in 1982. At Point Hope between 1963 and 1979, the last year for which harvest figures were available, the retrieved take ranged from 1 to 69.

Burch (1985) reported that walruses were not a significant factor in the Kivalina subsistence economy, although in some years they were taken in significant numbers. For example, the 1982-83 harvest was 51, compared to only 4 in 1983-84. Burch considered a normal harvest to consist of four animals.

Alaska Department of Fish and Game (ADF&G) records indicate annual walrus harvests between 1967 and 1977 of 4 to 146 at Wales, O to 145 at Shishmaref, and 3 to 69 at Point Hope (ADF&G[a]). Unpublished records of the U.S. Fish and Wildlife Service (USFWS) indicate annual harvests since 1978 of 67 to 271 retrieved walruses at Wales, the only Hope Basin village that it monitors (USFWS[b]).

9.10 POLAR BEARS

There is no published information on the distribution of polar bears that relates specifically to Hope Basin. During winter, polar bears occur along the Alaska coast from the Bering Strait north and northeastward to the Canadian border, with the exception of Kotzebue Sound (Lentfer 1983; Amstrup and DeMaster 1986). Polar bear maternity dens have been located near Point Hope, and sows with cubs newly emerged from dens have been observed north of Shishmaref (Lentfer and Hensel 1977). Polar bears make extensive north-south migrations in relation to the position of the southern edge of pack ice. As ice breaks up and recedes north in spring, polar bears move north and remain on drifting pack ice during summer.

During 1959-69, reports of polar bear sightings by hunters using aircraft suggested that the highest bear densities in the Chukchi Sea were near the Bering Strait and out of Kotzebue. Hunters from Point Hope observed almost 50% fewer bears per hour flown than did hunters from Teller and Shishmaref (Amstrup et al. 1986).

There are no studies of the diet of polar bears in Hope Basin. Eley (1978) reported on polar bear kills examined in March and April near Cape Lisburne, just north of Hope Basin. He found that 92% of the kills were ringed seals, 7% were bearded seals, and 1% were walruses.

Recent (1980-86) annual harvests of polar bears at Hope Basin villages have been as follows: Wales-6 to 20; Shishmaref–11 to 80; Point Hope–7 to 21; and Kivalina–0 to 3 (Braund et al. 1984; USFWS[b]). Polar bears are uncommon near Kivalina because of prevailing ice conditions and consequently are seldom harvested there (Saario and Kessel 1966; Burch 1985).

[a]ADF&G, 1300 College Rd., Fairbanks, AK 99701, unpublished records.

[b]USFWS, 1412 Airport Way, Fairbanks, AK 99701, unpublished records.

9.11 LITERATURE CITED

Amstrup, S.C., and **D.P.** DeMaster
1986. Polar bear (*Ursus maritimus*). Draft species report for the Marine Mammal Commission, Washington, D. C., 28 pp.

Amstrup, S.C., I. Stirling, and **J.W.** Lentfer
1986. Past and present status of polar bears in Alaska. Wildlife Society Bulletin 14:241-254.

Berzin, A.A.
1984. Soviet studies of the distribution and numbers of the gray whale in the Bering and Chukchi seas, from 1968 to 1982, pp. 409-419. In: The gray whale *Eschrichtius robustus* (M.L. Jones, S.L. Swartz, and S. Leatherwood, eds,), Academic Press, Orlando, FL.

Blokhin, S.A.
1979. On the status ofgray whale stocks in the coastal waters of the Chukotka Peninsula. Report of the International Whaling Commission 29:335-336.

Blokhin, S.A.
1984. Investigations of gray whales taken in the Chukchi coastal waters, U. S. S. R., pp. 487-509. In: The g-ray whale *Eschrichtius robustus* (M.L. Jones, S.L. Swartz, and S. Leatherwood, eds.), Academic Press, Orlando, FL.

Bogoslovskaya, L.S., **L.M.** Votrogov, and **T.N. Semenova**
1981. Feeding habits of the gray whale off Chukotka. Report of the International Whaling Commission 31:507-510.

Bogoslovskaya, L.S., **L.M.** Votrogov, and LI. **Krupniks**
1982. The bowhead whale off Chukotka: migrations and aboriginal whaling. Report of the International Whaling Commission 31:391-399.

Braham, H.W.
1984. Distribution and migration of gray whales in Alaska, pp. 249–266. In: The gray whale *Eschrichtius robustus* (M.L. Jones, S.L. Swartz, and S. Leatherwood, eds.) Academic Press, Orlando, FL.

Braham, H.W., and **B.D. Krogman**
1977. Population biology of the bowhead (*Balaena mysticetus*) and beluga (*Delphinapterus leucas*) whales in the Bering, Chukchi and Beaufort seas. Processed Report, Northwest and Alaska Fisheries Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA, 29 pp.

Braham, H.W., W.M. Marquette, **T.W.** Bray, and **J.S. Leatherwood (eds.)**
1980. The bowhead whale: whaling and biological research. Marine Fisheries Review 42(9-10):1-96.

Braham, H.W., B.D. Krogman, and **G.M. Carrolls**
1984. Bowhead and white whale migration, distribution, and abundance in the Bering, Chukchi, and Beaufort seas, 1975-78. Technical Report SSRF-778, U.S. Department of Commerce, National Marine Fisheries Service, Seattle, WA, 39 pp.

Braund, S., **H.** Armstrong, and S. Stoker
1984, Subsistence study of Alaska Eskimo whaling villages. Report prepared for the U.S. Department of the Interior, by Alaska Consultants, Inc., with Stephen Braund and Associates, Anchorage, AK, 249 pp. and appendices.

Burch, E.S., Jr.
1985. Subsistence production in Kivalina, Alaska: a twenty-year perspective. Technical Paper No. 128, Division of Subsistence, Alaska Department of Fish and Game, Juneau, AK, 339 pp.

Burns, **J.J.**
1967. The Pacific bearded seal. Alaska Department of Fish and Game, Juneau, AK, 66 pp.

Burns, J.J.
1970. Remarks on the distribution and natural history of pagophilic pinnipeds in the Bering and Chukchi seas. Journal of Mammalogy 51:445-454.

Burns, **J.J.**
1981. Bearded seal, pp. 145-170. In: Handbook of marine mammals, Vol. 2. Seals (S.H. Ridgway and R.J. Harrison, eds.). Academic Press, London, England.

Burns, J.J., and **T.J. Eley.**
1977. The natural history and ecology of the bearded seal (*Erignathus barbatus*) and the ringed seal (*Phoca hispida*), pp. 226-302. In: Annual Reports of Principal Investigators, Vol. 1, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Burns, **J.J.,** and **T.J.** Eley
1978. The natural history and ecology of the bearded seal (*Erignathus barbatus*) and the ringed seal (*Phoca hispida*), pp. 99–162. In: Annual Reports of Principal Investigators, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Burns, J.J., and **K.J.** Frost
1983. The natural history and ecology of the bearded seal, *Erignathus barbatus*, pp. 331-392. In: Final Reports of Principal Investigators, Vol. 19, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Burns, J.J., and **J.E. Morrow**
1975. The Alaskan arctic marine mammals and fisheries, pp. 561-582. In: Arctic oil and gas problems and possibilities (J. Malaurie, cd.), Mouton and Co., Paris, France.

Burns, **J.J.,** and **G.A.** Seaman
1986. Investigations of belukha whales in coastal waters of western and northern Alaska, Part 11. Biology and ecology. OCSEAP Final Report (Research Unit 612), U.S. Department of Commerce, National Oceanic andAtmosphericAdministration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK, 129 pp.

Burns, J.J., **K.J.** Frost, and **L.F. Lowry (eds.)**
1985. Marine mammals species accounts. Game Technical Bulletin No. 7, Alaska Department of Fish and Game, Juneau, AK, 96 pp.

Coyle, K.
1981. The oceanographic results of the cooperative Soviet-American cruise to the Chukchi and East Siberian seas aboard the Soviet whale-hunting ship *Razyashchii,* September–October 1980. Unpublished report, Institute of Marine Science, University of Alaska, Fairbanks, AK.

Curtis, **E.S.**
1930. The North American Indian, Vol. 20, The Alaskan Eskimo. University Press, Cambridge, MA, 320 pp.

Dahlheim, M.E.
1981. A review of the biology and exploitation of the killer whale, *Orcinus orca,* with comments on recent sightings from Antarctica. Report of the International Whaling Commission 31:541-546.

Dronenburg, R., G.M. Carroll, and **J.C.** George
1984. Final report of the 1983 springbowhead whale census and harvest monitoring including the 1982 fall harvest results. Report of the International Whaling Commission 34:433-444.

Durham, **F.E.**
1979. Personal comments on harvesting gray whales for subsistence living and on better utilization of marine mammal products in arctic Alaska. Unpublished manuscript presented to the Panel Meeting (NMFS-IWC) in Seattle, 5–9 February 1979, and revised 24 March 1979,3 pp.

Eley, T.J.
1978. An analysis of polar bear predation on Alaskan ice-inhabiting pinniped populations. Unpublished manuscript, Alaska Department of Fish and Game, Fairbanks, AK, 12 pp.

Estes, **J.A.,** and **J.R.** Gilbert
1978. Evaluation of an aerial survey of Pacific walruses (*Odobenus rosmarus divergent).* Journal of the Fisheries Research Board of Canada 34:1130-1140.

Fay, **F.H.**
1957. History and present status of the Pacific walrus population, pp. 431-455. In: Transactions of the 22nd North American Wildlife Conference, Wildlife Management Institute, Washington, D.C.

Fay, **F.H.**
1982. Ecology and biology of the Pacific walrus, *Odobenus rosmarus divergens* Illiger. North American Fauna, U.S. Fish and Wildlife Service 74:1-279.

Fay, F.H., and **G.A.** Fedoseev **(eds.)**
1984. Soviet-American cooperative research on marine mammals, Vol. 1—Pinnipeds. Technical Report NMFS 12, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA, 104 pp.

Fay, F.H., and **B.P.** Kelly
1982. Herd composition and response to disturbance of walruses in the Chukchi Sea. Unpublished cruise report for *KS Entuziast,* 25 July–23 August 1982 (Research Unit 611), University of Alaska, Fairbanks, AK, 13 pp.

Feldman, **K.D.**
1984. Subsistence beluga whale hunting in Alaska: a view from Eschscholtz Bay. Unpublished manuscript, University of Alaska, Anchorage, AK, 40 pp.

Fiscus, C.H., and **W.M.** Marquette
1975. National Marine Fisheries Service field studies relating to the bowhead whale harvest in Alaska, 1974. Processed Report, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA, 23 pp.

Foote, **D.C.**
1960) The Eskimo hunter at Point Hope, Alaska, September 1959 to May 1960. Report submitted to the U.S. Atomic Energy Commission, Oak Ridge, TN, Contract No. AT(04-3)-315, 56 pp.

Foote, **D.C.**
1965) Exploration and resource utilization in northwestern arctic Alaska before 1855. Ph.D. dissertation, McGill University, Montreal, PQ, Canada, 400 pp.

Foote, D.C., and A. Cooke
1960) The Eskimo hunter at Noatak, Alaska; winter 1960. Report submitted to U.S. Atomic Energy Commission, Oak Ridge, TN, Contract No. AT(04-3)-315, 57 pp.

Foote, D.C., and **H.A.** Williamson
1966. A human geographical study, pp. 1041–1107. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.), U.S. Atomic Energy Commission, Washington, D.C.

Frost, **K.J.,** and **L.F.** Lowry
1981. Ringed, Baikal, and Caspian seals, pp. 29-53. In: Handbook of marine mammals, Vol. 2. Seals, (S.H. Ridgway and R.J. Harrison, eds.), Academic Press, London, England.

Frost, K.J., **L.F.** Lowry, and **J.J.** Burns
1983. Distribution of marine mammals in the coastal zone of the eastern Chukchi Sea during summer and autumn, pp. 563–650. In: Final Reports of Principal Investigators, Vol. 20, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Juneau, AK

Frost, K.J., L.F. Lowry, and J.J. Burns
1985a. Ringed seal monitoring relationships of distribution, abundance, and reproductive success to habitat attributes and industrial activities. Progress Report, Research Unit 667, U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Outer Continental Shelf Environmental Assessment Program, Anchorage, AK, 15 pp.

Frost, K.J., L.F. Lowry, and J.J. Burns
1985b. Ringed seal monitoring relationships of distribution, abundance, and reproductive success to habitat attributes and industrial activities. Interim Report, Research Unit 667, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK, 85 pp.

Frost, K.J., L.F. Lowry, and J.R. Gilbert
1987. Ringed seal monitoring: relationships of distribution, abundance," and reproductive success to habitat attributes and industrial activities. Interim Report, Research Unit 667, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Anchorage, AK, 53 pp.

Giddings, J.L.
1967. Ancient men of the Arctic. Alfred A. Knopf, New York, NY, 391 pp.

Gol'tsev, V.N.
1972. Distribution and assessment of the numbers of the Pacific walrus in the autumn of 1970, pp. 146-148. In: 5th All-Union Conference Study of Marine Mammals, 19-21 September 1972, Makhachkala. Akademii Nauk SSSR. (In Russian. Translated by F.H. Fay and B.A. Fay, University of Alaska, Fairbanks, AK, 1974,3 pp.)

Gol'tsev, V.N.
1976. Aerial surveys of Pacific walrus in the Soviet sector during fall, 1975. Processed Report, TINRO, Magadan, USSR. (In Russian. Translated by J.J. Burns, Alaska Department of Fish and Game, Fairbanks, AK, 18 pp.)

Gurevich, V.S.
1980. Worldwide distribution and migration patterns of the white whale (beluga), *Delphinapterus leucas*. Report of the International Whaling Commission 31:465-480.

Hall, E.S., Jr.
1975. The Eskimo storyteller. University of Tennessee Press, Knoxville, TN, 491 pp.

Hobbs, L.J., and M.E. Goebel
1982. Bowhead whale radio tagging feasibility study and review of large cetacean tagging. Technical Memorandum NMFS F/NWC-21, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA, 68 pp.

Ivashin, M.V., and L.M. Votrogov
1981a. Killer whales, *Orcinus orca*, inhabiting inshore waters of the Chukotka coast. Report of the International Whaling Commission 31:521.

Ivashin, M.V., and L.M. Votrogov
1981b. Minke whales, *Balaenoptera acutorostrata davidsoni*, inhabiting inshore waters of the Chukotka coast. Report of the International Whaling Commission 31:231.

Johnson, M.L., C.H. Fiscus, B.T. Ostenson, and M.L. Barbour
1966. Marine mammals, pp. 897–924. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.), U.S. Atomic Energy Commission, Washington, D.C.

Jones, **M.L., S.L.** Swartz, and S. **Leatherwood**
1984. The gray whale *Eschrichtius robustus.* Academic Press, Orlando, FL.

Krogman, B.D., **H.W. Braham, R.M. Sonntag,** and **R.G. Punsly**
1979. Early spring distribution, density, and abundance of the Pacific walrus (*Odobenus rosmarus*) in 1976. Final Report, Subcontract R 7120804 under Research Unit 14, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO, 47 pp.

Leatherwood, S., and **R.R.** Reeves
1978. Porpoises and dolphins, pp. 97-111. In: Marine mammals of eastern North Pacific and arctic waters (D. Haley, cd.), Pacific Search Press, Seattle, WA

Lentfer, **J.W.**
1983. Alaskan polar bear movements from mark and recovery. Arctic 36:282-288.

Lentfer, J.W., and **R.J. Hensel**
1977. Alaskan polar bear denning. Paper presented at the Fourth International Conference of Bear Research and Management, Kalispell, MT, 20-24 February 1977. U.S. Fish and Wildlife Service, Anchorage, AK.

Ljungblad D.K.
1981. Aerial surveys of endangered whales in the Beaufort Sea, Chukchi Sea and northern Bering Sea. NOSC Technical Document 449, June 1981, Naval Ocean Systems Center, San Diego, CA, 49 pp. and appendices.

Ljungblad, D.K., S.E. Moore, **J.T.** Clarke, **D.R.** Van **Schoik,** and **J.C.** Bennett
1985. Aerial surveys of endangered whales in the northern Bering, eastern Chukchi, and Alaskan Beaufort seas, 1984: with a six-year review, 1979–1984. NOSC Technical Report 1046, Naval Ocean Systems Center, San Diego, CA, 104 pp. and appendices.

Ljungblad, D.K., S.E. Moore, **D.R.** Van **Schoik,** and **C.S. Winchell**
1982. Aerial surveys of endangered whales in the Beaufort, Chukchi, and northern Bering seas. NOSC Technical Document 486, Naval Ocean Systems Center, San Diego, CA, 73 pp. and appendices.

Lowry, L.F., and **K.J.** Frost
1984, Foods and feeding of bowhead whales (*Balaena mysticetus*) in western and north Alaska. Scientific Report of the Whales Research Institute 35:1-16.

Lowry, L.F., **K.J.** Frost, and **J.J.** Burns
1980a. Variability in the diet of ringed seals, *Phoca hispida*, in Alaska. Canadian Journal of Fisheries and Aquatic Sciences 37:2254-2261.

Lowry, L.F., **K.J.** Frost, and **J.J.** Burns
1980b. Feeding of bearded seals in the Bering and Chukchi seas and trophic interaction with Pacific walruses. Arctic 33:330-342.

Lowry, L.F., **K.J.** Frost, and **J.J. Burns**
1981. Trophic relationships among ice-inhabiting phocid seals and functionally related marine mammals in the Chukchi Sea, pp. 37–95. In: Final Reports of Principal Investigators, Vol. 11, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Lowry, L.??., K.J. Frost, D.G. Calkins, G.L. Swartzman, and S. Hills
1982. Feeding habits, food requirements, and status of Bering Sea marine mammals. Council Document #19, North Pacific Fishery Management Council, Anchorage, AK, 292 pp.

Marquette, W.M.
1976. Bowhead whale field studies in Alaska, 1975. Marine Fisheries Review 38:9-17.

Marquette, W.M.
1977. The 1976 catch of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos, with a review of the fishery, 1973–1976, and a biological summary of the species. Processed Report, Northwest and Alaska Fisheries Center, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA, 80 pp.

Marquette W.M.
1979. The 1977 catch of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos. Report of the International Whaling Commission 29:281-289.

Marquette, W.M., and H.W. Braham
1982. Gray whale distribution and catch by Alaskan Eskimos: a replacement for the bowhead whale? Arctic 35:386-394.

Marquette, W.M., H.W. Braham, M.K. Nerini, and R.V. Miller
1982. Bowhead whale studies, Autumn 1980-Spring 1981: harvest, biology and distribution. Report of the International Whaling Commission 32:357-370.

Moore, S.E., and D.K. Ljungblad
1984. Gray whales in the Beaufort, Chukchi, and Bering seas: distribution and sound production, pp. 543-559. In: The gray whale *Eschrichtius robustus* (M.L. Jones, S.L. Swartz, and S. Leatherwood, eds.), Academic Press, Orlando, FL.

Nelson, E.W.
1887. Report upon natural history collections of Alaska between the years 1877 and 1881, pp. 227-293. In: Part H, Arctic Series Publication No. 3, Signal Service, U.S. Army, G. P. O., Washington, D.C.

Nerini, M.
1984. A review of gray whale feeding ecology, pp. 423450. In: The gray whale *Eschrichtius robustus* (M.L. Jones, S.L. Swartz, and S. Leatherwood, eds.), Academic Press, Orlando, FL.

Nerini, M., L. Jones, and H.W. Braham
1980. Feeding ecology of the gray whale in the northern Bering Sea, pp. 163–207. In: Final Reports of Principal Investigators, Vol. 43, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK

Omura, H., and H. Sakiura
1956. Studies on the little piked whale from the coast of Japan. Scientific Reports of the Whales Research Institute 11:1-37.

Pike, G.C.
1962. Migration and feeding of the gray whale. Journal of the Fisheries Research Board of Canada 19:815-838.

Rice, D.W., and A.A. Wolman
1971. The life history and ecology of the gray whale (*Eschrichtius robustus*). Special Publication No. 3, American Society of Mammalogists, 142 pp.

Ray, D.J.
1964. Nineteenth century settlement and subsistence patterns in Bering Strait, Arctic Anthropology 2:61-94.

Ray, D.J.
1975. The Eskimos of Bering Strait, 1650-1898. University of Washington Press, Seattle, WA, 305 pp.

Saario, D.J., and B. Kessel
1966. Human ecological investigations at Kivalina, pp. 969–1039. In: Environment of the Cape Thompson region, Alaska (N.J. Wilimovsky and J.N. Wolfe, eds.) U.S. Atomic Energy Commission, Washington, D.C.

Seaman, **G.A.,** and **J.J. Burns**
1981. Preliminary results of recent studies of belukhas in Alaskan waters. Report of the International Whaling Commission 31:567-574.

Seaman, **G.A., L.F.** Lowry, and **K.J.** Frost
1982. Foods of belukha whales (*Delphinapterus leucas*) in western Alaska. Cetology 44:1-19.

Seaman, **G.A., K.J. Frost,** and **L.F.** Lowry
1986. Investigations of belukha whales in coastal waters of western and northern Alaska. Part I: Distribution, abundance, and movements. Research Unit 612 Final Report, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Anchorage, AK, 60 pp.

Springer, A.M., and **D.G. Roseneau**
1977. A comparative sea-cliff bird inventory of the Cape Thompson vicinity, Alaska, pp. 206-262. In: Annual Reports of Principal Investigators, Vol. V, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Stoker, **S.W.**
1978. Benthic invertebrate macrofauna of the eastern continental shelf of the Bering and Chukchi seas. Ph.D. dissertation, University of Alaska, Fairbanks, AK, 259 pp.

Tomilin, A.G.
1957. Mammals of the USSR and adjacent countries, Vol. 9. Cetacea. Izvestia Akademii Nauk SSSR, Moscow. (Translation by Israel Program for Scientific Translation, 1967, 717 pp., NTIS No. TT 65-50086.)

Votrogov, **L.M.,** and **L.S. Bogoslovskaya**
1980. Gray whale off the Chukotka peninsula. Report of the International Whaling Commission 30:435-438.

Wilke, F., and **C.H. Fiscus**
1961. Gray whale observations. Journal of Mammalogy 42:108-109.

Wolman, A.A., and **D.W.** Rice
1979. Current status of the gray whale. Report of the International Whaling Commission 29:275-279.

Yablokov, A.V., and **L.S. Bogoslovskaya**
1984. Areview of Russian research on the biology and commercial whaling of the gray whale, pp. 465-485. In: The gray whale *Eschrichtius robustus* (M.L. Jones, S.L. Swartz, and S. Leatherwood, eds.), Academic Press, Orlando, FL.

Zenkovich, B.A.
1934. Research data on cetacea of far eastern seas. Bulletin Far East Academy of Sciences, USSR, No. 10. (In Russian. Translated by F. Essapian, Miami, FL, 34 pp.)

Zimushko, V.V., and **M.V. Ivashin**
1980. Some results of Soviet investigations and whaling of gray whales (*Eschrichtius robustus*, Lilljeborg, 1961). Report of the International Whaling Commission 30:237.

Zimushko, V.V., and **S.A.** Lenskaya
1970. Feeding of the gray whale (*Eschrichtius gibbosus* Erx.) at foraging grounds. Ekologiya 1: 26-35. (In Russian. Translated by Consultant's Bureau, Plenum Publ. Corp., New York, NY, 1971,8 pp.)

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