CHAPTER 1

The Coastal Biota and Its Environment--A Review, An Interregional Comparison of Biological Use, A Characterization, and A Comparison of Vulnerabilities

by

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SUMMARY AND CONCLUSIONS

This chapter describes the general abundances and distributions of the common vertebrates and their food web components in the Alaskan Beaufort Sea. It discusses and compares among coastal segments, the important physical and biological processes that maintain the vertebrates and their food webs. It characterizes the nearshore environment of the Beaufort Sea in terms of the qualities important to biota, and assesses the relative vulnerabilities of the various types of nearshore areas to perturbation from petroleum development activities.

Important findings are as follows:

1. For most vertebrate species, the nearshore environment is simply a summer/fall foraging habitat. In most cases life functions related to breeding and reproduction are carried out in adjacent terrestrial or freshwater environments, in ocean areas outside the Alaskan Beaufort Sea, or in deeper offshore areas of the Alaskan Beaufort Sea.

2. The primary food web bases of vertebrates are epibenthic crustaceans and zooplankton in the nearshore shelf areas and zooplankton in the offshore areas. Amphipods, mysids and copepods comprise the major portions of diets of essentially all vertebrates in the nearshore zone, despite the apparent abundance of alternative foods. Euphausiids and copepods are the primary offshore food web constituents, though in offshore areas there are additional trophic levels to those in the nearshore (i.e. vertebrates sometimes feed on other vertebrates). Marine primary production (primarily pelagic production by phytoplankton) is the major carbon source for both nearshore and offshore food webs.

3* Ice is a dominant force in determining whether, when, and how biota use the nearshore Beaufort Sea. In winter, ice forces essentially all birds, many mammals, and most anadromous fishes to leave coastal waters. In summer, ice influences where whales and birds migrate, when birds feed in the nearshore zone, and where seals and polar bears feed. Some vertebrate species appear to be largely or completely excluded from major portions of coastal waters simply because they cannot accommodate to the ice conditions.

4. There are great differences in animal use between shallow nearshore and deeper offshore parts of the Beaufort Sea shelf, but relatively few differences among segments of the coast. The nearshore shallows that are measurably warmer and less saline in summer than the marine waters beyond have species assemblages, seasons and types of animal use, and physical properties of importance to animals that are different from those of waters beyond about 20 m deep. Differences in animal use among east-west segments of the shelf waters are less striking, but include: (a) protected lagoons appear to be used more heavily than waters along open coasts by birds, and probably by fish; (b) a greater abundance and diversity of birds has been reported in extreme western parts near Barrow; and (c) some anadromous fish are not uniformly distributed among major segments of the coast.

   On a species basis, ringed seals, oldsquaws, shorebirds (as a group), arctic char, arctic cisco, arctic cod, arctic flounder, and fourhorn sculpin show generally few differences in abundance among major east-west parts of the nearshore zone. The crustacean prey base (mainly mysids and amphipods) of these vertebrates likewise appears abundant throughout the nearshore zone. Other vertebrates--spotted seals, common eiders, brant, Canada goose, the gulls and alcids, least cisco, broad and lake whitefishes, and boreal smelt--show marked differences in abundance among coastal regions.

5* The primary factors that regulate the distribution of animals using the nearshore zone appear to be (a) physical habitat features within the nearshore environment and (b) the proximity of locations where animals breed, molt, or overwinter outside the nearshore environment. Differences in food availability among the segments of the nearshore zone appear to not influence vertebrate distribution.

Even though animals and their prey may be more or less equally abundant among major segments of the coast, they are frequently not uniformly distributed. Here again, the factors that cause this uneven distribution appear to be (a) physical phenomena--ice dynamics, emergent landform configuration, water temperature and salinity--or (b) phenomena originating outside the Beaufort Sea--river discharge, breeding and overwintering sites of biota--rather than food supply within the nearshore zone.

6. Factors that influence vulnerabilities of biota to OCS development in the Alaskan Beaufort Sea nearshore zone are too many, and require too many arbitrary value judgments, to justify presenting a precise rating system to compare vulnerabilities among coastal regions. But in general, for most of the relevant development considerations and vertebrate species, open lagoons appear more vulnerable than closed lagoons, and both lagoon types appear more vulnerable than open coastal waters. At river delta fronts, which may ocurr on open coasts or in open or closed lagoons, birds are particularly vulnerable to oil spills during spring migration, and their delta feeding habitats are vulnerable to oil introduced by storm surge. Several coastal stretches are used by animals more heavily than are others because of outside influences--animal, populations or adjacent seas that are nearby. These stretches are more vulnerable than others only by virtue of the presence of the animals and not because of intrinsic characteristics of the coastal environment.

INTRODUCTION

The following chapters of this report describe research conducted in 1982 on physical properties and biological uses of a barrier island-lagoon system in the eastern part of the Alaskan Beaufort Sea. They present findings of field studies and compare the findings with findings of similar studies conducted elsewhere in the nearshore Beaufort Sea.

This chapter has three general purposes. First, it provides a review of the current state of knowledge concerning biological use of nearshore Beaufort Sea waters and of the physical processes affecting this use. Then, using results presented in the following chapters, it compares biological use among coastal regions and discusses factors causing differences in use among regions. Finally, it characterizes nearshore Beaufort Sea environments and compares levels of vulnerability of the various coastal areas to adverse impact from oil and gas development.

Scope of Study

The ultimate purpose of this program is to describe how the nearshore environment is used by animals, so that the vulnerability of the animals to man's activities in the region can be better evaluated. The subjects reviewed in this chapter are the vertebrate animals of primary concern to the public and the food chains, habitat features, and physical processes that affect the use of nearshore environments by the animals.

Of primary concern in this chapter are the physical characteristics and biological uses of the lagoons and other very shallow nearshore waters, as opposed to those of the adjoining terrestrial regionsto the south and the deeper marine environments to the north. A secondary interest lies in the deeper watersof the continental shelf. There are two reasons for this interest in deeper waters. First, some of the vertebrates that inhabit these deeper areas--whales, seals, marine fishes--are of concern relative to the effects of oil and gas development in nearshore waters. Second, some of the physical and biological processes that occur in these deeper waters influence the biological productivity and utilization of the lagoons and other shallow waters.

This chapter will address primarily the lagoons and other shallow coastal waters, and secondarily the deeper marine environment. We will use the term "nearshore" to refer to areas where water depths are less than about 20 m (6o ft), and 'offshore" to refer to waters beyond those depths.

Approach

This chapter first provides a general review of the existing knowledge about animal populations and how they are affected by various coastal features and processes. Treated in sequence in this review are the important vertebrates, the important parts of their food webs, and the physical. processes and habitat features that appear to be important to the vertebrates and their food web components.

Following the review, a synthesis and interpretation of information from the review and from the research reports of this program is provided. Biological uses of Beaufort Sea lagoons and other shallow coastal areas, and the physical and biological processes influencing those uses, are compared among coastal segments. The main objective is to show how the physical and biological qualities of coastal. areas affect their utility to biota, so that criteria for characterizing the areas can be developed and they can be rated in terms of their relative vulnerabilities to OCS oil and gas development.

Finally, based upon the review and on comparisons made of biological use among coastal segments, a characterization and a comparison of vulnerabilities is presented. The characterization uses descriptive criteria that reflect habitat qualities to which vertebrates and their food-web components respond. The comparison of vulnerabilities discusses levels of vulnerability of the various coastal sites to perturbations that are likely to adversely affect biota.

CURRENT STATE OF KNOWLEDGE--A REVIEW

The Coastal Region

The Beaufort Sea coast of Alaska extends from Pt. Barrow (156 °30'W, 71 °25'N) to the Alaska-Yukon border (141 °0'W, 69 °40'N). The airline distance between these two points is about 600 km (365 mi); the distance along the coastline is much farther because of the many bays, inlets and other irregularities along the coast (Aagaard 1981) (Fig. l-l).

Landward of the coastline, the Arctic Coastal Plain rises gradually to the foothills of the Brooks Range. The coastal plain landform is submerged seaward of the coastline and extends to the continental. shelf break. The slopes of both the coastal plain and the adjoining nearshore sea shelf are less in the west (on the order of 0.55 m/km = 3 ft/mi) than they are in the east (on the order of 5.5 m/km = 30 ft/mi) (Selkregg 1975). The shelf is relatively narrow, with the shelf break typically 60-90 km (35-55 mi) offshore.

Discontinuous chains of barrier islands skirt about 50% of the coastline. Most of these islands appear to have been formed by submergence of low-lying areas behind coastal ridges as the sea level has risen, but extensively modified thereafter by ice and wave action and longshore transport of sand (Cannon and Rawlinson 1978).

The climate is extreme. Means of both the temperature and the precipitation are low. Temperatures generally range from about -45°C (-50°F) in winter to about 24°C (75°F) in summer. Mean annual precipitations on the orderof 13 cm (5 in). Surface winds are strong and persistent (Selkregg 1975, Brown et al. 1975, Walker et al. 1980).

The surface of the coastal waters is frozen for about nine months of the year. The water begins to freeze in late September or early October. The ice reaches thicknesses of 2 m (6 ft) or more by April or May, and substantial remnants of ice may remain in coastal waters until late July. Several tens of kilometers seawardof the coast, sea ice persists year-round as the multi-year ice pack (Barry 1979, Kovacs and Mellor 1974).

The abundance and distribution of the biota are strongly influenced by the cold climate and other physical constraints of the environment. Much of the biological use of the region is highly seasonal. Th e

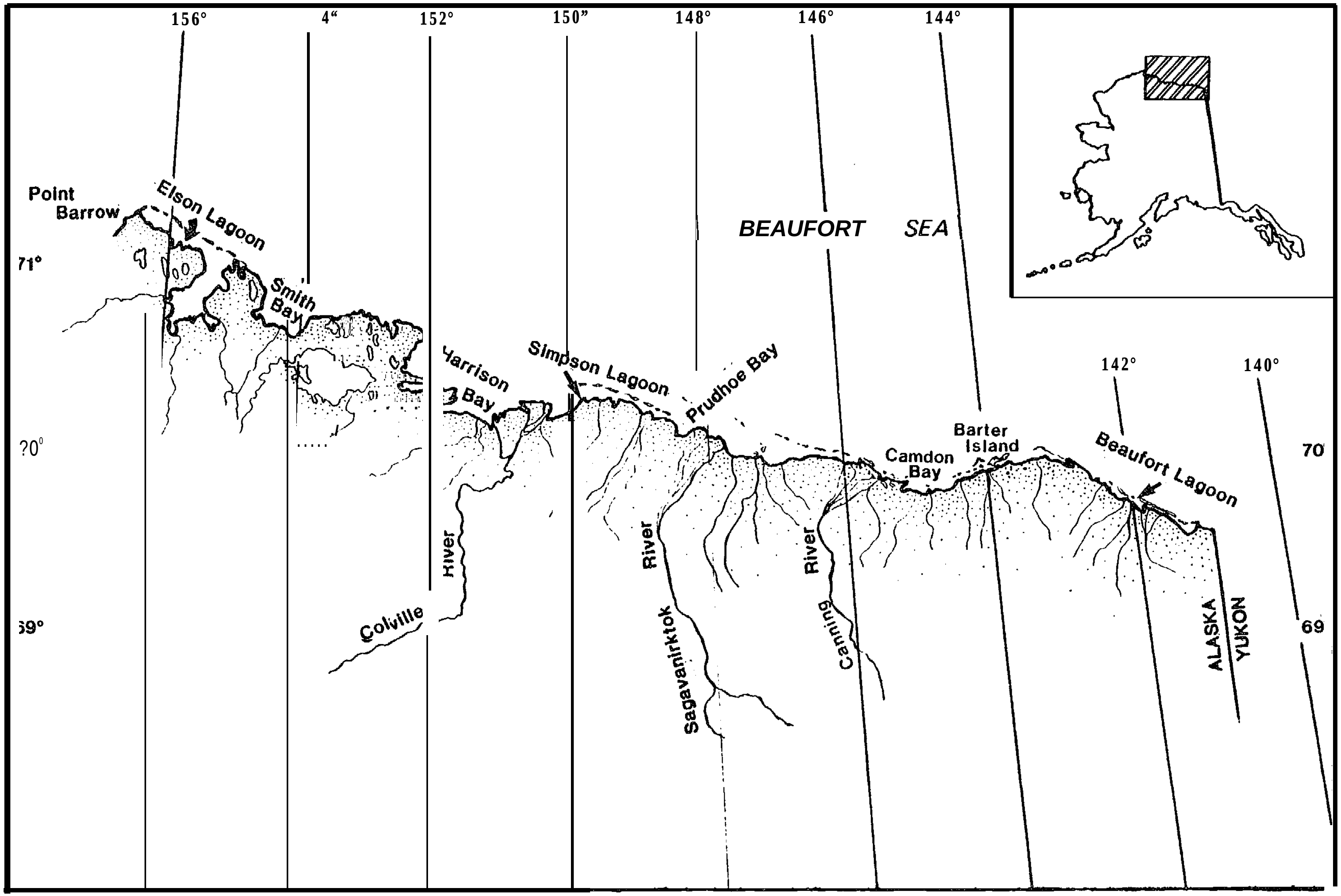


Figure 1-1. The Alaskan Beaufort Sea coast, Pt. Barrow to Yukon Territory.

diversity and productivity of biota are low in comparison with the biological diversity and productivity of more temperate coastal oceans.

Marine Mammals

Following are discussions of seals (ringed, bearded and spotted), whales (bowhead and beluga) and the polar bear. Each of these species is important because it is used for subsistence, is considered to be rare and endangered, and/or is otherwise of concern to the public.

Ringed Seal (*Phoca hispida*)

The ringed seal is Holarctic in distribution. It occurs in Arctic and subarctic waters south to the Gulf of St. Lawrence in eastern North America, the Baltic Sea in Eurasia, and Hokkaido Island in the western Pacific (Banfield 1974:374). It is the most common seal in the Beaufort Sea (Lowry et al. 1979a).

Though ringed seals are present year-round in the Alaskan Beaufort Sea, many move west and south with the advancing ice in fall to winter in the Chukchi and Bering seas (Frost and Lowry in prep.). In summer at least, they are rather uniformly distributed from east to west in the Beaufort Sea, with no apparent preferences for particular segments of the coast (Burns and Harbo 1972).

The abundance of ringed seals in early summer in the Beaufort Sea appears to be low in comparison to seal abundance in the adjacent Chukchi Sea (Burns and Harbo 1972). These authors in 1970 found more than twice the density of seals in Chukchi Sea areas surveyed (about $12/km^2$ = $4.5/mi^2$) than they did in the Beaufort Sea (about $5/km^2$ = $1.8/mi^2$).

In winter the abundance of ringed seals in the Beaufort Sea may be half that of summer. Frost and Lowry (in prep.) made rough estimates of 80,000 ringed seals in the Alaskan Beaufort Sea in summer and 40,000 in winter.

The distribution of ringed seals in the Beaufort Sea varies seasonally, shifting with changing ice conditions. Landfast ice is apparently favored over moving ice farther from shore as winter habitat and as birthing habitat for seals in spring (Burns et al. 1981). Burns and Harbo (1972) found seal density in landfast ice to increase with distance from shore. During the open-water period (August-September), most seals are found farther offshore in the floating-ice or pack-ice zones (Lowry et al. 1979a). Ringed seals seldom inhabit shallow bays and lagoons.

As implied by seasonal shifts in seal distribution, both within the Beaufort Sea and between the Beaufort and Chukchi seas, sea ice condition is the most important factor regulating seal distribution and habitat use. They prefer to den in landfast ice (though many den in drifting ice). Open leads in ice in spring are needed for seals to haul out and molt. In late summer seals move offshore with the ice (Lowry et al. 1979a) and few are found in open water. Heavy ice years appear to cause declines in ringed seal density (Stirling et al. 1977, 1982).

Diets of ringed seals vary considerably, but more in response to season of year than to location within the Beaufort Sea (Lowry et al. 1979, Frost and Lowry in prep). They eat mostly invertebrates from April through June (euphausiids, mysids, isopods, and gammarid amphipods) and from July through September (euphausiids and hyperiid amphipods). They eat mostly arctic cod from November through March. There is some deviation from this pattern; for example, seals collected in summer in the central Beaufort Sea near Simpson Lagoon and in the eastern Beaufort Sea near Beaufort Lagoon had eaten mainly arctic cod (Frost and Lowry in prep.) .

Some within-season spatial variation in diet is evident. For example, seals taken near Prudhoe Bay in November 1978 had eaten mainly invertebrates (mysids and amphipods), but those taken near Barrow in November of that year had eaten mainly arctic cod (Frost and Lowry in prep.). (In November 1977, however, both the seals at Prudhoe and those at Barrow had eaten mainly arctic cod.) In August 1976 seals taken near Barrow had eaten mainly euphausiids; in August 1980 seals taken near Pingok Island had eaten mainly arctic cod; in September 1977 seals taken near Prudhoe had eaten mainly hyperiid amphipods; and in 1980 seal-s taken near Beaufort Lagoon had eaten mainly euphausiids and arctic cod (in about equal amounts) (Frost and Lowry in prep.). There is no obvious pattern to the spatial variation in diet; Frost and Lowry (in prep.) speculate that the differences are a consequence of differences in prey availability where ice conditions are favorable for seals.

Bearded Seal (Erignathus barbatus)

This species, like the ringed seal, is Holarctic in distribution. It inhabits North American seas south to the Aleutian Peninsula in Alaska and to southern Hudsonts Bay and northern Newfoundland in Canada. It is excluded from the polar ice-sheet (Banfield 1974:366). It is much less abundant in the Alaskan Beaufort Sea than is the ringed seal (Lowry et al. 1979a,b).

Bearded seals are less adapted to survival in thick landfast ice or other ice without open leads than are ringed seals, which partly explains their low numbers in the Beaufort Sea. In winter, they are more common in the Barrow area than they are farther east. At Barrow the shore ice is not extensive and the pack ice moves more regularly and has more persisting leads than it does in the central and eastern portions of' the Alaskan Beaufort Sea (Lowry et al. 1979a). In summer there is an influx of bearded seals into the Beaufort Sea from the Chukchi Sea as the ice recedes north, but a relatively small proportion of the Chukchi Sea population ever reaches the Beaufort Sea.

Distribution of bearded seals in the Beaufort Sea is strongly tied to ice conditions (as is ringed seal distribution) and to water depth (Lowry et al. 1979a). They are most common in the transition and offshore pack ice zones; they seldom occur in the fast-ice zone. They are benthic feeders and seldom occur beyond 100 m (300 ft) depths because they have difficulty diving to the bottom to feed in deeper areas (Lowry et al. 1979a). These authors speculate that physical conditions in the Beaufort Sea (typically wide landfast ice zone and relatively narrow moving ice zone within the 100-m depth contour in winter, and a relatively narrow zone that has floating ice within the 100-m depth zone in summer) severely limit the ability of bearded seals to survive there.

As noted above, bearded seals are benthic feeders. In the Beaufort Sea they feed on decapod crustaceans (shrimps and spider crabs) and to a lesser extent on clams, hermit crabs, octopus, gammarid amphipods, isopods and fish. Though data are scarce bearded seal diets appear to be similar in all parts of the Beaufort Sea where they have been collected; indeed, their diets appear to be similar throughout their range (Lowry et al. 1979a,b).

Spotted Seal (*Phoca largha*)

The distribution of spotted seals is confined to northern waters of the North Pacific Ocean, primarily the Bering, Okhotsk, and Chukchi seas (Shaughnessy and Fay 1977, Burns 1978). In late spring a very few migrate north and east into the Beaufort Sea; these normally stay near shore, oftenat or in the mouths of rivers, until fall when they move back into the Chukchi or Bering seas (Lowry et al. 1979a). Two places in the Beaufort Sea that appear to be particularly attractive in summer to spotted seals are locations in Dease Inlet and in the Colville River Delta (K. Frost, pers. comm.). Apparently the severe ice conditions prevent spotted seals from living year-round in the Beaufort Sea. Why they are restricted to the few coastal locations in summer is not known.

Adult spotted seals are known to feed mainly on pelagic and demersal fish, octopus, and crustaceans (Lowry et al. 1979a,b). Presumably in the Beaufort Sea they feed mainly on anadromous and marine fishes (ciscoes, whitefishes, char, fourhorn sculpin, arctic flounder) that typically occupy nearshore lagoons and river deltas.

Bowhead Whale (*Balaena mysticetus*)

The bowhead whale is considered to be an endangered species. The western Arctic population of bowheads is classed as a 'protection" stock by the International Whaling Commission (IWC), though an important subsistence hunt for bowheads occurs in Alaskan waters.

The western Arctic stock of bowheads was greatly depleted by commercial whaling in the late 1800's and early 1900's; commercial exploitation ended about 1915. The recovery of the population has been slow. The present population size is not certain, but the Scientific Committee of the IWC (in press) has accepted as a "best" estimate 3857 (range 3390-4325). Aerial surveys made on the summering grounds (Canadian Beaufort Sea) of this population yielded numbers of at least 2983-3842 in the surveyed area (Davis et al. 1982).

Bowheads winter in the Bering Sea and summer in the Canadian Beaufort Sea. In spring they migrate through the coastal lead along the northwest Alaskan coast (Chukchi Sea) and pass Pt. Barrow from mid-April to early June (see Krogman et al. 1982). From Pt. Barrow they move east and northeast through leads in the offshore pack ice (Braham et al. 1980, Ljungblad 1981, Ljungblad et al. 1980). During this migration, they keep well beyond 100 km (60 mi) from the coast after passing the extreme western portion of the Beaufort Sea near Barrow.

Although the main summer range of these whales is in the Canadian Beaufort Sea, during the course of the summer they shift westward, entering the extreme eastern Alaskan Beaufort Sea in August and September. The principal. fall migration of bowheads through the Alaskan Beaufort Sea occurs in the second half of September and in October. It is not known what proportion of the animals use nearshore as opposed to offshore migration routes. Data from Ljungblad et al. (1980) and Ljungblad (1981) show that all observations made by these authors of westward-migrating bowheads were in waters greater than 18 m (60 ft) deep. Most bowheads have left Beaufort Sea waters by November.

During late summer and early fall, the only time that bowheads occupy inner continental. shelf areas of the Alaskan Beaufort Sea to any extent, they feed mainly on copepods and euphausiids (Frost and Lowry in prep., Lowry et al. 1979a, Lowry and Burns 1980). Either _Thysanoessa raschii_ (euphausiid) or _Calanus hyperboreus_ (copepod) usually dominates the diet. Although they consume a variety of other prey, the quantities are not great. K. Frost and L. Lowry (pers. comm.) believe bowheads may pausein their fall migration to feed in areas east of Barter Island, perhaps because of a concentration of prey there.

Belukha Whale (_Delphinapterus leucas_)

The belukha or white whale is found throughout the Arctic and subarctic regions of North America, Europe, and Asia (Harrison and Hall 1978). Belukhas are largely transient in the Alaskan portion of the

Beaufort Sea, moving through in spring and fall on their way between overwintering areas in the Bering Sea and summer habitat in Amundson Gulf and the Mackenzie River estuary in Canada (Seaman and Burns 1981, Frost and Lowry in prep., Fraker 1978a).

An estimated 5500-6500 belukhas migrate annually through the Alaskan Beaufort Sea (Fraker 1978b, Frost and Lowry in prep.). Existing evidence suggests that they move quickly through the Alaskan waters, perhaps spending as much as a month in transit in spring and a month in fall (Frost and Lowry in prep.].

Movement patterns of belukhas through the Alaskan Beaufort Sea appear to be similar year after year, and similar to bowhead migration patterns. In spring they migrate northeastward from the Bering Sea, following ice leads in the Chukchi Sea, and pass Pt. Barrow between late April and early June. From Barrow they continue northeastward along ice leads that are mostly far offshore in the pack ice, eventually intercepting the western shores of Banks Island. Then they proceed southward to Amundsen Gulf and the Mackenzie estuary regions of Canadian waters, where they remain until late August (Fraker 1978).

Belukhas move westward through the Alaskan Beaufort Sea between late August and early November (Frost and Lowry in prep.). They move through open water much closer to the Alaskan coast than they do during spring migration, and frequently closer than bowheads come at any time. During September belukhas have been reported moving westward near Herschel Island, Yukon Territory; near Pingok Island in the central Alaskan Beaufort Sea; and east of Barrow near the edge of the pack ice (Fraker et al. 1978:41, Johnson 1979). Johnson (1979) observed 75-100 belukhas in fall within a few hundred meters of Pingok Island in waters several meters deep. Recent sightings made north and east of Barrow near the pack ice suggest that belukhas may tarry there in late September and early October before continuing southwestward toward the Bering Sea (K. Frost, pers. comm.) .

Frost and Lowry (in prep.) speculate that belukhas feed while in transit through the Alaskan Beaufort Sea. Frost (pers. comm.) believes that they may stop specifically to feed offshore in the Barrow area during their fall migration. What they eat in Alaskan waters is not documented extensively. Frost and Lowry (in prep.) evaluate their feeding habits elsewhere and assume that they eat primarily arctic cod (~80% of diet) and secondarily shrimps, cephalopods and other fishes. Because of belukha migration patterns, inner continental shelf waters off Alaska are feeding areas for belukhas only in early fall (mainly September). Except for possibly offshore areas near Barrow, they are not known to prefer particular sites for feeding.

Polar Bear (Ursus maritimus)

Eley and Lowry (1978) estimate there to be about 2500 polar bears in the Beaufort Sea region of Alaska, of a total Alaskan polar bear population estimated at 5000-7000 (J. Lentfer, pers. comm. 1981). The distribution of polar bears coincides with that of their principal prey, the ringed seal, and extends in the Beaufort Sea from the coastal fringe to far north in the pack ice.

Except for instances when females den on land in winter, polar bears are usually associated with sea ice. In summer they are most common along the fringes of the multi-year ice pack (Burns et al. 1981). In winter they are distributed more widely; at this time males and subadults appear to be most mobile and move relatively long distances. Maternity dens of females (used in winter) are widely distributed; they have been found up to 50 km (30 mi) inland, along the coast, on offshore islands, on shorefast ice and on drifting sea ice (Lentfer and Hensel 1980).

Polar bears generally first appear along AlaskaTs north coast in October, when shorefast ice enables them to travel from drifting pack ice to the beach (Lentfer 1972), but they may commonly appear along the beach during summer if ice moves in near the coast. In winter they may be attracted to shorefast ice by beach carrion, or for denning, as noted above, but drifting pack ice probably supports greater concentrations of polar bears in winter than either shorefast or polar pack ice (Lentfer 1972).

As noted above, polar bears depend mainly on ringed seals for food in the Beaufort Sea. Their abundance and distribution is strongly tied to the abundance of ringed seals (Stirling et al. 1975, 1982). Polar bears are probably most abundant in drifting pack ice in winter and at the pack ice edge in summer because of the coincident abundance of seals in these areas (Lentfer 1972, Burns et. al. 1981). Stirling et al. (1982) reported both ringed seal and polar bear numbers to be reduced in the southeastern Beaufort Sea during and immediately following heavy ice years.

Birds

Bird species that use the Alaskan Beaufort Sea nearshore waters in sufficient abundance to be included in this review are waterfowl, shorebirds; glaucous gull, arctic tern, and a few other species that frequent the Pt. Barrow area. Birds restricted mostly to offshore environments are not included.

Waterfowl

Waterfowl that commonly use nearshore habitats include common and king eiders, oldsquaw, brant and Canada goose. Although species in addition to these breed on the adjacent Arctic Coastal Plain, relatively few individuals use the Beaufort Sea environment (Derksen et al. 1979, 1981; Johnson and Richardson 1981; Divoky in prep.).

Common Eider (*Somateria molissima*). The Alaskan Beaufort Sea population of nesting common eiders is small in comparison to the size of the species population. But because the individuals in the Beaufort Sea are largely restricted to coastal barrier islands for nesting, there has been considerable interest in their welfare relative to oil and gas development in this zone.

Common eiders are circumpolar in their range (Bellrose 1976:356). In Alaska they breed from southeast Alaska around the coastal perimeter of the state to Canada; their principal breeding ground is in the Yukon River Delta. In the Beaufort Sea, migrant birds may be seen all along the coast and far offshore (Richardson and Johnson 1981), but essentially all nests are east of central Harrison Bay (Divoky 1978). (Many of the migrants that pass through the Alaskan Beaufort Sea area nest in Canada.) Eiders are present in the Alaskan Beaufort Sea from May through September.

There are an estimated 1.5-2.0 million common eiders in the world (Bellrose 1976:356). Of these, an estimated few hundred thousand migrate through the Alaskan Beaufort Sea (Bellrose 1976:365), but only 400 pairs nest there.

Habitat use by eiders in the Beaufort Sea is of two kinds--use of open water by migrants and use of barrier islands by nesting birds. Most spring migrants travel far offshore along leads in the pack ice (Richardson and Johnson 1981) but some follow the coastline. The ones that follow the coast frequently land near river deltas where flooding has either melted the sea ice or covers the ice (Richardson and Johnson 1981, Schamel 1978). Birds begin nesting on barrier islands in June; in late July nests hatch, and females and young move to the adjacent lagoons and bays to feed (Schamel 1977).

Common eiders appear to select islands on which to nest that are relatively predator-free (Johnson and Richardson 1981), and Divoky (1978) shows that they prefer islands from which entry of arctic foxes Is prevented by river overflow in spring. Foxes on islands appear to be a major detriment to brood production and survival.

King Eider (Somateria spectabilis). The king eider's range is circumpolar; these eiders winter as far north as the seas remain ice-free. Unestimated three-fourths of the North American population of 1.0-1.5 million king eiders migrates each spring and each fall through the Alaskan Beaufort Sea (Bellrose 1976:365).

During spring migration, the birds pass Pt. Barrow in May and early June and head northeastward. From Barrow most appear to follow ice-free leads in the pack ice far offshore (Richardson and Johnson 1981), though some, like common eiders, follow the coast eastward (Richardson and Johnson 1981, Bergman et al. 1977). Most that pass through the Alaskan Beaufort Sea in spring nest in Canada though some seek freshwater ponds on the 'Alaskan Arctic Coastal Plain to nest (Derksen et al. 1981).

King eiders spend relatively little time staging in coastal waters following nesting. In late summer the males fly rapidly to the coast and westward along the coast toward molting areas in the Bering Sea (Derksen et al. 1981) and in early fall the females and young follow. By early September most of those that nested in Canada and northern Alaska have passed Pt. Barrow (Thompson and Person 1963) on their way out of the Beaufort Sea.

In summary, the Alaskan Beaufort Sea waters are used little by king eiders except for resting during migration. Both the offshore leads and the open waters at river mouths along the coast attract migrants in May and early June, and in late summer and early fall eiders pass briefly offshore of the coast toward molting or wintering areas elsewhere (Derksen et al. 1981).

King eiders occasionally suffer large mortalities, most of which are associated with unseasonable weather. Barry (1968) estimated that in the spring of 1964 about 100,000 king eiders died from starvation related to a late thaw in the Beaufort Sea area. This author reported other instances in which unseasonable fall weather caused large mortalities. But he implied that most of the spring and fall losses occurred near nesting areas and not along migration routes. He noted that, in contrast to these large weather-caused mortalities, the traditional fall harvest of eiders by natives at Barrow takes a small proportion of the population.

Oldsquaw (Clangula hyemalis). The oldsquaw is the most common species of waterfowl that uses nearshore waters of the Alaskan Beaufort Sea (Divoky in prep., Johnson and Richardson 1981). It is the most common breeding duck on the Alaskan Arctic Coastal Plain.

The breeding range of oldsquaws is circumpolar; it extends as far north as land occurs and as far south as the tundra persists (Bellrose 1976:387). Oldsquaws nest in greater numbers in the High Arctic than any other duck. In the Alaskan Beaufort Sea region, they nest throughout the Arctic Coastal Plain. In coastal waters they occur as spring migrants, summer molting flocks and fall migrants from Barrow to Demarcation Point. Their level of use of the nearshore region is generally similar for all portions of the coastline, except that Harrison Bay seems to support consistently low numbers (Divoky in prep.).

Bellrose (1976:386) estimates the pre-nesting North American population of oldsquaws to be 3-4 million individuals; the Alaskan Arctic Slope supports an estimated 125,000 nesters. Probably most of these Arctic Slope birds and additional ones from elsewhere move to Alaskan Beaufort Sea coastal lagoons and bays after breeding. Johnson and Richardson (1981) estimate that over one-half million oldsquaws may occupy the north coast of Alaska during the post-breeding period. They suggest that densities and numbers of' post-breeding oldsquaws are higher in the eastern half of the Alaskan Beaufort Sea than they are in the western half, primarily because greater proportions of the eastern shallows are protected by barrier island chains.

Beaufort Sea coastal waters are used by oldsquaws mainly during three periods--spring migration (early June), mid-summer molt (mid-July to mid-August), and fall migration (late September) (Johnson and Richardson 1981). The period of lightest use is spring migration, when most coastal waters remain frozen. At this time migrating oldsquaws frequently land and feed in open water near the mouths of flooding rivers, or in river water that has overflowed the nearshore ice. The mid-summer molt period sees males (and a small percent of non-breeding females) coming from tundra nesting areas to assemble in lagoons and bays for the post-nuptial molt. They become flightless at this time and tend to congregate in the lee of spits and barrier islands, especially when winds are strong. Between mid-August and mid-September, use of nearshore waters is reduced, presumably because many post-molting males leave. In late September, numbers again increase as females and young move from tundra lakes to begin their migration along the coast to wintering areas farther south.

Migrating and molting oldsquaws show a marked preference for coastal lagoons and bays bounded by spits of land or barrier islands, as opposed to open coasts or deeper marine waters (Johnson and Richardson 1981, Johnson 1982a,b). It is presumed that they show such preferences because these habitats offer protection from wind and waves [indeed, molting oldsquaws frequently assemble near or on the lee sides of islands during strong winds (see Johnson and Richardson 1981)], and because, as diving feeders, they find their epibenthic prey much more accessible in shallow waters (Divoky in prep.).

Prey of oldsquaws along the Beaufort Sea coast is mainly epibenthos. Mysids and amphipods seem to form the preponderance of their diet, though small fish and molluscs are occasionally consumed (Johnson and Richardson 1981).

Black Brant (Branta bernicula nigricans). Most black brant are indigenous to the western coast of North America, although a few breed in Siberia. The North American birds breed near the west and north coasts of

September, migrants from both Canada and Alaska move westward very near the coast, flying over and resting in nearshore shallows and feeding in salt marshes and other low-lying plant communities.

These fall migrants move in a concentrated stream very near the coastline (Johnson and Richardson 1981, Richardson and Johnson 1981), frequently stopping to rest in lagoons and bays and feed on vegetation of coastal wetlands (Bergman et al. 1977, Kiera 1979). Most of them apparently do not reach Barrow, but instead follow Dease Inlet southward and cross over land to the Chukchi Sea (Pitelka 1974).

Along the Beaufort Sea coast brant feed mostly on vascular plants in salt marshes and other coastal wetlands (Bergman et al. 1977, Kiera 1979).

Canada Goose (Branta canadensis). Canada geese are relatively scarce as breeders on the Alaskan Arctic Coastal Plain. Derksen et al. (1981) found no evidence of them breeding on the National Petroleum Reserve-Alaska. A few breeders have been observed near Prudhoe Bay (Gavin 1974, 1978; Bergman et al. 1977), and 200-300 pairs have been reported to breed inland along the Colville River (Kessel and Cade 1958).

Beaufort Sea coastal waters are used mainly by non-breeding Canada geese that molt in selected locations along the coast or on the coastal Plain, primarily in the Cape Halkett-Teshekpuk Lake brant molting area discussed above. King (1970) estimated there to be 15,000 molting Canada geese along the Beaufort Sea coast in mid-summer from Smith Bay to the Canning River, mostly in the area north of Teshekpuk Lake. Derksen et al. (1979) reported there to be nearly 15,000 Canada geese inthe Teshekpuk Lake area in 1977 and 1978. These geese molt mostly on inland lakes, then move in late July and early August to stream deltas, sea-breached lakes, and other coastal wetlands in the area from Smith Bay to western Harrison Bay. Here they rest and feed on vegetation on nearby shores. Other coastal areas are used by very few Canada geese.

Canada geese are grazers in the Beaufort Sea area. They feed on vascular plants in low-lying coastal areas in much the same manner as brant.

Shorebirds

The most abundant shorebirds that use the Alaskan Beaufort Sea coast are phalaropes. Other relatively common shorebirds are ruddy turnstone, dunlin, sanderling and pectoral sandpiper (Johnson and Richardson 1981; Connors and Risebrough 1976, 1977, 1978, 1979). The focus of this section is mainly on phalaropes, because of their abundance and their use of nearshore waters for feeding (phalaropes are surface feeders, other shorebirds are shoreline foragers).

Shorebird species share a general pattern of habitat use in the coastal Beaufort Sea. They arrive in late May and early June making little use of the still-frozen coastal waters or shorelines, and proceed directly to coastal plain nesting sites. Eggs hatch in tundra nests from late June through mid-July. From July to mid-September, various sex and age groups of various species move to littoral beaches and lagoon edges to forage prior to southward migration (Connors in prep.). Thus the primary use that shorebirds make of the Beaufort Sea environment is for feeding in mid- to late summer following nesting.

Red Phalarope (*Phalaropus fulicarius*). The most common of the two phalaropes that use Alaskan Beaufort Sea coastal waters, the red phalarope is a cosmopolitan species that nests in both Alaskan and Canadian areas adjacent to the Beaufort Sea (Johnson et al. 1975:124). By far the most common shorebird to use the coastal environment in the Beaufort Sea near Barrow (Connors and Risebrough 1978), it diminishes in abundance eastward until it is uncommon on the Canadian mainland east of the Yukon North Slope (Johnson et al. 1975:124).

Red phalaropes exhibit differences between sex and age groups in their use of the coastal zone. Adult females seldom use the coast; they depart directly southward from breeding sites soon after the eggs are laid. The males incubate the eggs (Johnson et al. 1975:125), abandoning the young shortly before they fledge and leaving the nesting sites in early to mid-August. Along much of the Beaufort Sea coast males, similarly to adult females, appear to depart southward without using the coastal zone at all, but post-nesting males have foraged in littoral zones near Barrow in years when nearshore ice melted early (Connors and

Risebrough 1978). In general though, young of the year are the only individuals to make significant use of the coast (Johnson and Richardson 1981).

Red phalarope young move to the coast about the first of August; the last ones have usually departed southward by mid-September (Connors and Risebrough 1978, Johnson and Richardson 1981). During this time these birds typically feed in very shallow waters within a few meters of shore, picking food from the water's surface. Where barrier islands parallel the coast, the birds seem to prefer oceanside island beaches, lagoonside island beaches, and mainland beaches, in that order, as foraging habitat (Johnson and Richardson 1981) .

Phalarope diets in coastal areas appear to vary with food availability (Connors in prep.). Johnson and Richardson (1981) found that they fed mostly on copepods and amphipods, and secondarily on mysids, in the Simpson Lagoon area. Connors and Risebrough (1978) found them to eat copepods, amphipods and (in areas near terrestrial food sources) chironomid fly larvae.

Red necked Phalarope (Phalaropus lobatus). The red-necked phalarope, like the red phalarope, is a circumpolar breeder that nests in both the Alaskan and Canadian portions of the Arctic. In converse pattern to the red phalarope, however, the red-necked phalarope is only an occasional breeder at Barrow and increases in abundance eastward. It is most abundant in the Canadian portion of the Beaufort Sea, where it far outnumbers the red phalarope (Johnson et al. 1975:126).

The nesting, fledging, coastal use patterns, and diet of this species are generally similar to those of the red phalarope (Johnson et al. 1975:127). As in red phalaropes, few adults appear to forage along the Beaufort Sea coast. The juveniles begin arriving on the coast about the first of August, similarly to red phalaropes, and are mostly gone by mid-September (Johnson and Richardson 1981). In apparent contrast to red phalaropes, many appear to migrate eastward, rather than westward, along the Beaufort Sea coast (Gollop and Davis 1974). The diets of red and red-necked phalaropes in Beaufort Sea coastal areas appear to be similar (Connors and Risebrough 19'78, Johnson and Richardson 1981).

Other Shorebirds. Although the two phalarope species normally comprise the majority of individual shorebirds using the Alaskan Beaufort Sea littoral zone, 10-20 species regularly use this zone in August and September following breeding (Connors and Risebrough 1978, 1979; Connors et al. 1979; Johnson and Richardson 1981). [Small numbers of pre-breeding or breeding adults of several species may forage along beaches, around saline pools, or on mudflats near sloughs in early and mid-summer, as noted earlier (Connors and Risebrough 1978).] The period of heaviest littoral zone use is in August (Connors and Risebrough 197 8). Existing data suggest that more individuals and more species may use beaches in early and mid-summer in the western Beaufort Sea near Barrow than use beaches farther east (cf. Connors and Risebrough 1978, Johnson and Richardson 1981). This is not certain, however, because sampling methods and intensities of studies at the two areas were different.

Existing data show that all shorebirds use the littoral zone almost exclusively for feeding (Connors and Risebrough 1976, 1977, 1978, 1979; Johnson 19'78, 1979b; Johnson and Richardson 1981). The large majority of the shorebird diet in this zone is marine zooplankton (Connors and Risebrough 1979) in the shallow water or that has been deposited on the shore. There is little difference in prey selectivity among bird species that feed in the same portions of this zone. But shorebird diets sometimes vary greatly between times and places, apparently because of variability in the composition and abundance of available zooplankton prey (Connors and Risebrough 1978, Connors in prep.).

Gulls, Terns and Alcids

The glaucous gull and arctic tern are the only species in this group that are widespread and abundant along the Alaskan Beaufort Sea coast (Johnson et al. 1975, Divoky 1979, Johnson and Richardson 1981). Other species--Sabine's gull, Ross' gull, black guillemot, thick-billed murre--are common only in the extreme western Beaufort Sea near Barrow (Divoky 1979 in prep.).

Glaucous Gull (Larus hyperboreus). The glaucous gull is the most abundant gull in the Beaufort Sea, occurring in the western Arctic as far north as northern Ellesmere Island (Johnsonet al. 1975). It breeds all along north coastal Alaska; both breeders and non-breeders are common along the Beaufort Sea coast from late May to late September (Connors and Risebrough 1978, Johnson and Richardson 1981, U.S. Fish and Wildlife Service 1982).

Patterns of use of the coastal environment by glaucous gulls are not clear. Divoky (in prep.) observed greater numbers of glaucous gulls in summer in the Plover Islands region near Barrow than in other parts of the coastal zone, but Divoky (1978) found more gull nests between the Colville River and Camden Bay (glaucous gulls usually nest on barrier islands or spits). Johnson and Richardson (1981) noticed that glaucous gull numbers appeared to increase in the nearshore zone of the central Alaskan Beaufort Sea (Simpson Lagoon) as summer progressed. Because several years pass before gull maturity, a large proportion of the coastal population of glaucous gulls is composed of non-breeders; this portion is apparently transient along the coast in summer.

Glaucous gulls are surface feeders and scavengers (Divoky in prep., Johnson and Richardson 1981). In the central Beaufort Sea, Johnson and Richardson (1981) found them eating mostly isopods and amphipods, and to a lesser extent, small birds and fish. It is not known what regulates gull numbers in the Beaufort Sea, but Divoky and Good (1979) speculate that their populations have increased in the last several years, perhaps as a consequence of increased availability of garbage.

Arctic Tern (Sterna paradisaea). The breeding range of the arctic tern is circumpolar in Arctic and subarctic coastal (and inland) areas (Johnson et al. 1975). The arctic tern is a common summer resident throughout the coastal regions of the Beaufort Sea; it winters in Antarctica and subantarctic areas. In the coastal Beaufort Sea it appears to be more commonly observed in the Plover Islands region near Barrow than elsewhere (Divoky in prep.), but is common at all sites along the coast (Divoky and Good 1979, Johnson and Richardson 1981, U.S. Fish and Wildlife Service 1982).

The arctic tern nests on gravel substrates of coastal beaches, barrier islands and spits, and inland lake shores (Johnson et al. 1975). It, like the glaucous gull, is a common nester on barrier islands along the Beaufort Sea coast (Divoky 1978, Johnson and Richardson 1981, U.S. Fish and Wildlife Service 1982). Its main nesting concentration appears to be in the Plover Islands near Barrow.

Arctic terns feed in nearshore habitats all along the Beaufort Sea coast in summer (Johnson and Richardson 1981, U.S. Fish and Wildlife Service 1982). In the Barrow area nearshore, Divoky (in prep.) found them to feed on small fish (mostly arctic cod), amphipods and mysids.

Other Species. The Plover Islands area near Barrow attracts feeding birds of several species that are not commonly found elsewhere in the Beaufort Sea. Included are black-legged kittiwake (Rissa tridactyla), Sabine's gull (Xema sabini), Ross' gull (Rhodostethia rosea), black guillemots (Cepphus grylle), and occasionally thick-billed murres (Uria lomvia) (Divoky and Good 1979, Divoky in prep.). Kittiwakes and Sabine's gulls (along with phalaropes and arctic terns) form large flocks to feed on zooplankton in the Plover Islands area in late July and early August (Divoky and Good 1979). A large proportion of the world's Ross' gull population assembles to feed on zooplankton in late September and early October in the nearshore region from Barrow to Tangent Point (Divoky pers. comm.). A few black guillemots nest in summer on the Plover Islands, and feed on zooplankton in nearby waters (Divoky 1978, in prep.). Divoky (in prep.) found an abundance of thick-billed murres in the Plover Islands region in summer, 1978, presumably feeding on arctic cod.

Fish

Discussions of anadromous and marine fishes commonly abundant in nearshore waters of the Alaskan Beaufort Sea are included in this section.

Anadromous Fishes

Individuals of anadromous fish species typically spend summer months in the nearshore Beaufort Sea and winter months in freshwater streams or lakes, or in river deltas. Species abundant in nearshore waters in summer are arctic and least ciscoes, lake (humpback) and broad whitefishes, and arctic char (Craig 1983). Boreal smelt are sometimes abundant locally.

Arctic Cisco (Coregonus autumnalis). The arctic cisco ranges from northern Europe and Siberia to western Arctic North America (Gallaway et al. 1983). In Alaska it is distributed along the Arctic coast from about Pt. Barrow to the Alaska-Yukon border; it ranges into the Canadian Beaufort Sea to Bathurst Inlet, Northwest Territories (see Roguski and Komarek 1972, Griffiths et al. 1977, Morrow 1980, Craig and Haldorson 1981, Griffiths and Gallaway 1982). In Alaska it occupies lagoons, bays, and other coastal. shallows from June to October; in winter it seems mostly restricted to the Colville River Delta region (Craig and Haldorson 1979, 1981; McElderry and Craig 1981; Gallaway et al. 1983). Craig and Haldorson (1981) estimated there to be about 110,000 harvestable arctic cisco in the Colville Delta in 1979; Gallaway et al. (1983) suggests their abundance to vary greatly among years and to be normally greater than this estimate.

There are two patterns of habitat use by arctic cisco in the Alaskan Beaufort Sea--a summer pattern and a winter pattern. In June of each year, as ice in nearshore areas begins to melt, arctic cisco invade the shallow bays, lagoons, and other coastal areas (Craig and Haldorson 1981). From then until October or November they feed and grow here, appearing to prefer waters measurably warmer and less saline than the marine waters offshore (Craig and Haldorson 1981, Fechhelm et al. 1982, Fechhelm and Gallaway 1982). They range widely in these shallows, from Pt. Barrow in the west to Canadian waters in the east (Craig 1983). In October and November they leave the coastal waters and in Alaska become restricted to the Colville River Delta (and perhaps a few other areas) until the following June (Alt and Kogl 1973; Kogl and Schell 19'74; Craig and Haldorson 1979, 1981). They apparently do not commonly go farther up the Colville than about 175 km (110 mi) (see Bendock 1979, McElderry and Craig 1981, Gallaway et al. 1983).

During summer while they are in these nearshore Beaufort Sea waters, arctic cisco feed mainly on epibenthic crustaceans--mysids and amphipods (Craig and Haldorson 1981). In the central Beaufort Sea at least, and perhaps in other areas, the abundance of this prey appears to be excessive to the needs of the fish (Griffiths and Dillinger 1981).

Least Cisco (Coregonus sardinella). The least cisco is found in coastal waters and some freshwater areas in northern Europe, Asia, and North America (U.S. Fish and Wildlife Service 1982). It is abundant along the Alaskan Beaufort Sea coastline only from Barrow to Prudhoe Bay (Craig and Haldorson 1981, Craig 1983). Similarly to arctic cisco, least cisco are found in coastal waters from June to October, where they feed and grow. They overwinter in freshwater lakes and streams from Barrow to the Colville River (Hablett 1980); this winter range and their apparent reluctance to move long distances in summer probably explains why they are scarce east of Prudhoe Bay (Craig 1983). No estimates of their numbers between Prudhoe and Barrow are available but Craig and Haldorson (1981) estimated a population of approximately 1,773,000 least ciscoes in the Colville Delta region in fall 1979.

The seasonal and spatial patterns of habitat use by least ciscoes in the western Alaskan Beaufort Sea are similar to patterns of summer use described above for arctic cisco. Likewise their summer diets appear to be similar to those of arctic cisco (Craig and Haldorson 1981).

Lake Whitefish (Coregonus clupeaformis). Although lake (humpback] whitefish have been caught in summer in nearshore areas such as Simpson Lagoon (Craig and Haldorson 1981, Schmidt et al. 1983) they are not commonly reported in nearshore catches. Nowhere are they commonly found in nearshore habitats except near the mainland shore (Craig 1983). Like broad whitefish, they are closely tied to freshwater systems and range only short distances into coastal waters to feed in summer. Their diet in coastal waters of the Beaufort Sea appears to be similar to that of the ciscoes and the broad whitefish (Craig and Haldorson 1981).

Arctic Char (Salvelinus alpinus). The arctic char has a circumpolar distribution; it is a common species along the Alaskan Beaufort Sea coastline (Craig 1983) from Barrow to Canada (Craig and Haldorson 1981, U.S. Fish and Wildlife Service 1982, Griffiths et al. 1977). Its use of nearshore waters is similar in time to that of the other anadromous species, occurring from early summer to fall (Craig and Haldorson 1981).

The general pattern of arctic char dispersal from freshwater streams and its occurrence in nearshore waters resembles most closely that of arctic cisco. It travels widely from its stream of origin. It tends to venture farther into marine-type habitats than do other anadromous fish, even arctic cisco (Craig 1983). For example char have been caught as far offshore as Cross Island, which lies 18 km (11 mi) off the mouth of the Sagavanirktok River (Bendock 1979). Similarly to other anadromous species, char eat mostly mysids and amphipods while they are in the nearshore environment (Craig and Haldorson 1981), but fish are known to be important in diets of larger individuals (B.J. Gallaway pers. comm.).

Boreal Smelt (Osmerus eperlanus). Little is known about the distribution of boreal smelt in the Beaufort Sea. It appears to be anadromous in habit, living in marine waters as adult and entering fresh water in springtime to spawn (Craig and Haldorson 1981). It is a relatively minor component of the nearshore fish community in summer, but because few other anadromous fish overwinter in the marine environment, it is locally abundant (relative to other fish) in winter. The only place where it has been commonly found is in Harrison Bay; it is assumed that its winter concentration there is a prelude to a spring spawning migration into the Colville River (Craig 1983). Similarly to other anadromous species, it feeds on mysids and amphipods; small fish also appear to be an important part of its diet (Craig and Haldorson 1981).

Marine Fishes

Marine species frequently common in the nearshore environment are arctic cod, fourhorn sculpin, and arctic flounder. They appear to be most abundant in the nearshore areas in summer, and some overwinter in the deeper parts of the nearshore environment.

Arctic Cod (Boreogadus saida). The arctic cod is widespread in waters of the Arctic (Andriyashev 1954, Craig et al. 1982). In terms of both numbers and biomass, it is the dominant fish species in the Alaskan Beaufort Sea (Frost et al. 1978, Frost and Lowry 1981, Frost and Lowry in prep.). Few data are available on its general distribution and abundance there (Frost and Lowry in prep.).

Cod are most abundant in nearshore lagoons and bays during the open-water season (Craig and Haldorson 1981, Craig et al. 1982), but their occurrence and abundance during this period are highly erratic (Craig et al. 1982). They appear to move shoreward in late summer and fall; few are found near shore in spring or early summer. Their main use of the shallow nearshore areas appears to be for feeding, though some spawn in deeper nearshore areas such as Stefansson Sound.

What features of the nearshore region attract arctic cod are not known, though cod seem to be reported more commonly in baysand lagoons that are relatively open to the sea and/or have less brackish waters (e.g. Simpson Lagoon, Prudhoe Bay, Stefansson Sound) than they are in relatively closed and brackish bays and lagoons (see Craig and Haldorson 1981, Craig et al. 1982). Craig et al. (1982) suspect that they prefer high-salinity waters and tend to avoid brackish areas.

The diet of arctic cod in nearshore habitats appears similar to diets of most anadromous species. Craig and Haldorson (1981) found them to eat mostly mysids, secondarily amphipods, and occasionally large amounts of copepods in nearshore waters of the central Beaufort Sea. Lowry and Frost (1981) found them to eat mainly copepods, amphipods, mysids, and other zooplankton, in that order of importance in deeper (40-400 m) waters.

Fourhorn Sculpin (Myoxocephalus quadricornis). The fourhorn sculpin is one of the most widespread and numerous fishes along the Alaskan Beaufort Sea coast. It is found in virtually all nearshore habitats, from almost-fresh lakes occasionally connected to the ocean by water overflow to the deeper marine waters not frequented by anadromous species (Craig and Haldorson 1981). Fourhorn sculpin are common in Simpson Lagoon in the central Beaufort (Craig and Haldorson 1979, 1981), Kaktovik Lagoon in the eastern Alaskan Beaufort (Griffiths et al. 1977), Nunaluk Lagoon on the Yukon coast (Griffiths et al. 1975), and in the nearshore zone of the western Alaskan Beaufort (Schmidt et al. 1983).

Fourhorn sculpins appear to be most abundant in shallow lagoons and bays in summer and early fall, at which time waters are not frozen (Craig and Haldorson 1981). But some apparently overwinter in relatively shallow nearshore areas, both brackish and marine (see Craig and Haldorson 1981, Kogl and Schell 1974, Percy 1975, Kendel et al. 1975). Presumably there is a shift of populations seaward as winter progresses, though in general this species appears to be relatively sedentary.

Fourhorn sculpins eat primarily amphipods and mysids, though isopods may occasionally be a large part of the diet (Craig and Haldorson 1981; Percy 1975; Kendel et al. 1975; Griffiths et al. 1975, 1977). The relative abundance of isopods in the diets of sculpins in nearshore waters appears to increase in winter (Craig and Haldorson 1981).

Arctic Flounder (Liopsetta glacialis). The arctic flounder is a shallow-water flatfish that frequents brackish coastal waters (Craig and Haldorson 1981). Relatively small numbers have been found at several locations from Barrow to Canada (Griffiths et al. 1975, 1977; Craig and Haldorson 1981; Schmidt et al. 1983). Bendock (1979) and Craig and Haldorson (1981) suspected that their numbers were greater around the Colville River Delta than in coastal *waters* farther east, but their speculations were based on catches by gill nets (which do not catch flounder effectively) in the locations east of Prudhoe Bay. (Catches in the area between the Colville Delta and Prudhoe Bay were made largely by fyke nets).

Because large numbers of flounders have not been caught at more than a few locations, little is known of their habitat preferences within the nearshore zone. Amphipods, isopods, and to some extent mysids, were their main prey in Simpson Lagoon and Prudhoe Bay in the central Beaufort (Bendock 1979, Craig and Haldorson 1981).

In this section we review information about the important components of food webs that support the animals discussed in the preceding section. In keeping with the primary objectives of this program, emphasis is on vertebrates and their food web components in the nearshore zone (within the 20-m depth contour) and particularly in coastal lagoons. Figure 1--2 depicts important food web components and linkages as defined by existing information. Important trophic levels are vertebrates (discussed in previous sections), aquatic invertebrates (epibenthos and zooplankton), primary producers (mostly phytoplankton), and nutrients (nitrogen, phosphorus).

There are some striking similarities among patterns of food webs of vertebrates in the Beaufort Sea. In the nearshore region, the major food base for nearly all vertebrates is epibenthic crustaceans (primarily mysids and amphipods), with some contribution from marine zooplankton. This is true despite equivalent availability of other invertebrate groups (Craig and Haldorson 1981). In the pelagic (offshore) environment, the main food base of vertebrates is zooplankton (with the notable exception of foods of the bearded seal, a benthic feeder). Here, although rigorous comparisons between the abundance of zooplankton and benthic invertebrates have not been made, both diversity and biomass of benthos appears to increase with distance beyond the 20-m depth contour (Carey et al. 1974; Carey 1977, 1978), suggesting that benthos is largely an available but uncropped resource. Note that sometimes in the nearshore and frequently in the offshore environments, vertebrates may eat vertebrates, as discussed in previous" sections.

The Nearshore Environment

The invertebrates important in nearshore food webs are primarily epibenthic mysids and amphipods, and in some cases zooplankton, isopods, and fish.

Mysid species of primary importance in the Beaufort Sea nearshore zone are *Mysis litoralis* and *M. relicta*. In summer, mysids were found to be a large proportion of the nearshore epibenthos in Simpson Lagoon (Crane

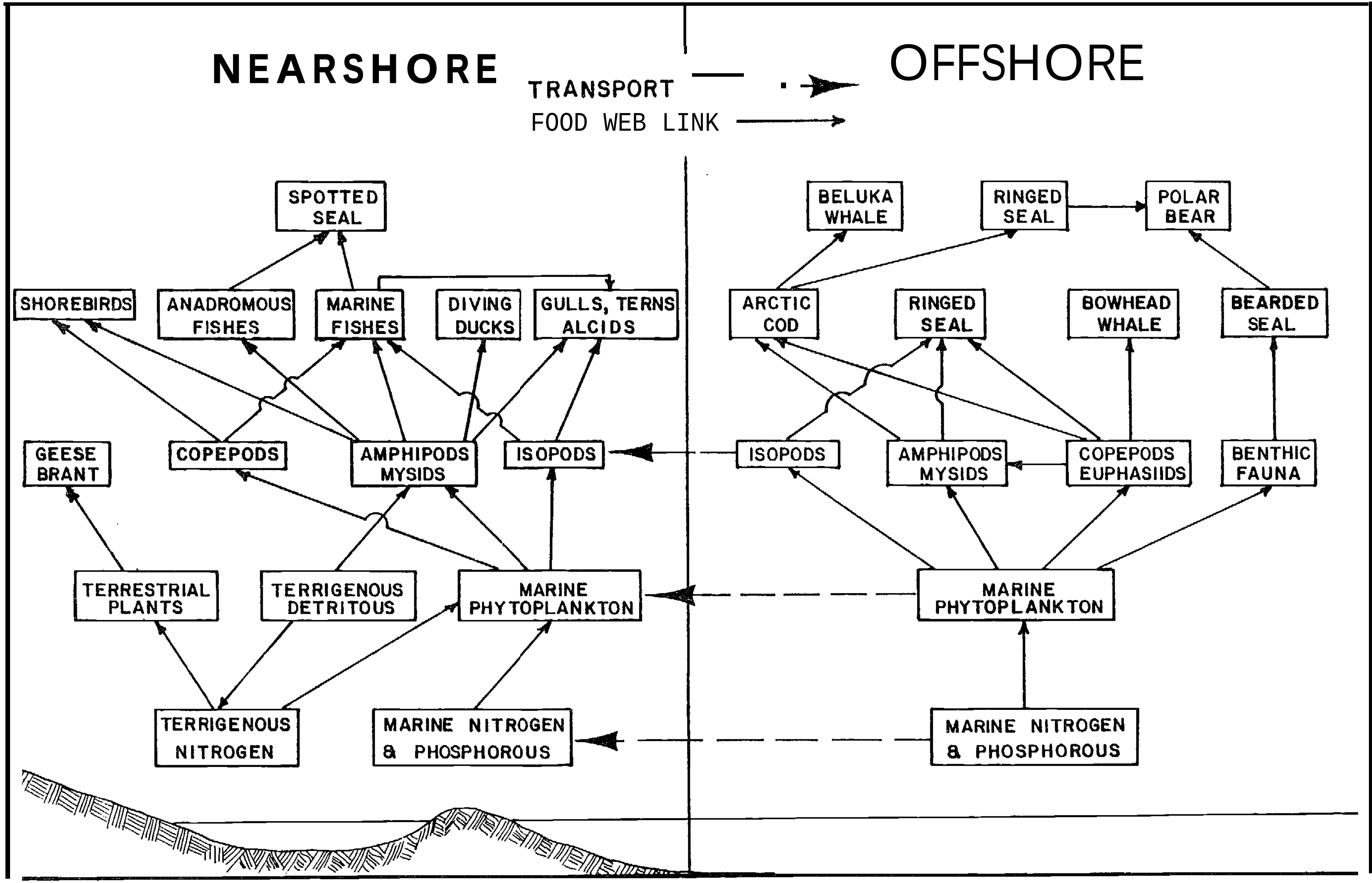


Figure 1-2. A generalized food web of the Alaskan Beaufort Sea.

and Cooney 1974, Griffiths and Dillinger 1981), in Harrison Bay and Prudhoe Bay (Craig and Griffiths 1981), and as far east as the Mackenzie River estuary in Canada (Wacasey 1974, 1975). In the central Beaufort Sea, mysids were a major portion of the lagoon epibenthos biomass during summer and early fall. They were scarce or absent in shallow lagoons (i.e. Simpson Lagoon) in winter and spring (Griffiths and Dillinger 1981), but apparently overwintered in the deeper nearshore areas where the salinity does not rise appreciably above that of seawater (see Craig and Griffiths 1981). Mysids appear to be mainly herbivorous, feeding on plankton (Schneider 1980). They are major food sources in summer for oldsquaw ducks and anadromous and marine fishes.

The amphipod species of importance in nearshore food webs are epibenthic. They are abundant in the central Alaskan Beaufort (Griffiths and Dillinger 1981, Craig and Griffiths 1981, Feder and Schamel 1976, Feder et al. 1976), as well as in most other coastal areas of the Alaskan Beaufort Sea (Broad 1977, 1979) and in the southern Canadian Beaufort Sea (Wacasey 1974, 1975; F.F. Slaney and Co. 1975). Common species are _Onisimus glacialis_, _O. litoralis_ and _Gammarus setosus_ (Broad 1977, Griffiths and Dillinger 1981). The amphipods as a group appear to be able to accommodate wider ranges of water quality and food types than do mysids. _O. littoralis_ inhabits waters that are nearly fresh to marine. _O. glacialis_ and _G. setosus_ are likewise euryhaline; the former commonly occupies hypersaline water in shallow lagoons throughout the winter as well as in summer. Most of the amphipods are highly omnivorous (R. Dillinger pers. comm.) and _G. setosus_ is even able to digest peat (Schneider 1980). Amphipods are major foods for waterfowl, shorebirds, anadromous and marine fishes, and sometimes ringed seals.

Zooplankton that feeds vertebrates in nearshore environments is both marine and estuarine in origin. Johnson and Richardson (1981) found copepods to be by far the most abundant zooplankters in shoreline waters of Simpson Lagoon in the central Beaufort. Griffiths and Craig (1978) found a cold-water marine copepod to be conspicuously present in shallow nearshore waters outside Simpson Lagoon. Divoky (in prep.) reported beached quantities of the euphausiid _Thysanoessa raschii_ regularly occurring on the Plover Islands in the western Alaskan Beaufort, and noted regular summer concentrations of birds there feeding primarily on

Thysanoessa and on Apherusa glacialis (a water-column and epontic amphipod). Connors (in prep.) found copepods and other marine zooplankton to be major prey items of shorebirds in the littoral zone at Barrow. Most of the zooplankton species found in nearshore habitats appear to be herbivorous, though some are omnivorous. In general zooplankton appears to be more important to shorebirds, gulls, and terns than to other vertebrate groups in the nearshore environment.

The epibenthic isopod Saduria entomon is the isopod normally consumed by vertebrates in the nearshore environment This species is ubiquitous in the nearshore zoneof the Beaufort Sea (Crane 1974; Broad 1977, 1979; Griffiths and Dillinger 1981); it is tolerant of a wide range of water salinities and temperatures (R. Dillinger pers. comm.). Crane (1974) thought that Saduria moved seaward from very shallow waters in winter, but Griffiths and Dillinger (1981) found them throughout the winter in Simpson Lagoon, where salinities reached 50-60 ppt. Saduria is mainly a feeder on planktonic detritus (Crane 1974). It sometimes is important in diets of marine bottom-dwelling fish (e.g. fourhorn sculpin, arctic flounder) and gulls (Craig and Haldorson 1981, Johnson and Richardson 1981).

Fish consumed by vertebrates in the nearshore zone appear to be mainly small individuals of marine species (fourhorn sculpin, arctic cod) and sometimes of anadromous species (Craig and Haldorson 1981, Johnson and Richardson 1981, Craig 1983). No studies to date have shown that fish are consistently important in diets of nearshore vertebrates.

The Offshore Environment

The main foods of vertebrates in waters beyond the 20-m depth contour appear to be zooplankton and other vertebrates. One exception is that bearded seals are specialized feeders on benthos (Lowry et al. 1979).

The prey base of ringed seals in spring and summer, of bowhead whales, of arctic cod, and in some cases, of seabirds, is zooplankton. Ringed seals in spring and summer eat mainly euphausiids and hyperiid amphipods, bowheads eat mainly euphausiids (primarily Thysanoessa raschii) and copepods (Calanus hyperboreus), cod eat mainly copepods, and euphausiids and copepods are the most important invertebrates in seabird diets (Frost and Lowry in prep.; Lowry et al. 1979a,b; Lowry and Burns

1980; Frost and Lowry 1981; Divoky 1979 in prep.). The main prey of ringed seals in fall and winter, of belukha whales, and of seabirds in most instances, is arctic cod (Frost and Lowry in prep.). These in turn feed mainly on zooplankton.

The zooplankton groups that support this marine vertebrate community are mainly herbivorous (copepods that feed on marine phytoplankton), omnivorous (euphausiids) or predatory on animals that in turn eat phytoplankton (hyperiid amphipods) (R. Dillinger pers. comm.). Thus the offshore community is a marine phytoplankton based ecosystem.

Carbon and Nutrient Sources

Because of the relatively large input of organic material (mainly peat) into the nearshore environment from land, via stream discharge and shoreline erosion (Cannon and Rawlinson 1978, Schell 1978), it has been hypothesized (Schell 1978) that terrigenous detritus (including peat) might contribute a large proportion of carbon to nearshore food webs. More recent studies conducted in the central Alaskan Beaufort Sea (Schell et al. 1982) strongly suggest this not to be the case, that nearshore food webs are fueled almost entirely by carbon fixed in the marine environment (i.e. by phytoplankton, ice algae and benthic algae).

At least part of the reason for this apparent incongruity between carbon availability and carbon use seems to be that few nearshore food web constituents appear capable of digesting cellulose readily (Schell et al. 1982), and most terrestrial carbon delivered to nearshore environments is largely cellulose. Peat is a large part of this detritus, and it is especially difficult to assimilate. Though Schneider (1980) demonstrated that at least one epibenthic invertebrate, Gammarus setosus, can digest peat and other terrigenous detritus, this species has not previously seemed important in food webs of abundant vertebrates (Craig and Haldorson 1981, Johnson and Richardson 1981).

Even though inputs of terrestrial detritus have not been found to make an important contribution of carbon to food webs of vertebrates, it is apparently an important source of nitrogen (Schell 1975, Schell et al. 1982) that contributes to primary production in the nearshore zone. In the Beaufort Sea, primary production nearshore and offshore is probably limited ultimately by the availability of nitrogen in the system (Schell et al. 1982).

Of the two major types of Beaufort Sea primary production--that by ice algae and that by phytoplankton--phy toplankton production appears to provide the majority of carbon to the food web (Schell 1982). Levels of both ice algae production (occurring mainly in spring) and phytoplankton production (occurring mainly in summer and early fall) are highly variable In space (Alexander 1974, Homer 1980, Homer and Schrader 1981, Schell 1982), but overall appear to be much lower in the Beaufort Sea than in more temperate oceans (Schell 1982).

The offshore Beaufort Sea appears to have a higher total annual primary productivity than does the nearshore zone. Schell et al. (1982) estimate that annual rates of carbon fixation in deep offshore areas may approach 50 g C/m^2, but in shallow nearshore areas may be on the order of 10 g C/m^2. Carbon fixation rates per water volume may be similar in nearshore and offshore areas. Few data are available to compare production levels among coastal sites.

Physical Processes

This section describes physical processes that influence the ability of the nearshore environment to support the vertebrates and food webs discussed in the preceding sections. Wind, water movement and transport, and ice dynamics are discussed; their effects on biota are summarized.

Wind

Winds along the Alaskan Beaufort Sea coast affect biota indirectly, by influencing water movements, and perhaps directly, by causing thermal stress to birds. Its most pervasive effects on biota seem to be indirect, via its effect on water.

Water in the nearshore responds most dramatically to wind when there is little or no ice cover (from early summer to early winter), though strong winds can influence water motion through considerable ice thicknesses. During the periods of little or no ice, surface winds are strong and persistent along the Beaufort Sea coast (mean speeds of 10-12 knots = 5-6 m/see) (Selkregg 1975). It is common for winds in summer to blow at speeds of 18-20 knots (8-10 m/see) for more than a week at a time (Wiseman and Short 1976). Storm winds commonly attain speeds of 40 knots (20 m/see) or more. During the early part of the open-water season (mid-summer) prevailing surface winds out to 30 km (20 mi) seaward of the coast (Kozo and Brown 1979) are from E or ENE. As fall progresses? winds from W or NW are more common. Winds at widely separated locations along the Beaufort Sea coast tend to be similar in speed and direction at any one time (Leavitt 1978, Kozo and Brown 1979).

Even in winter and spring in offshore areas, ice moves under the influence of wind (Aagaard 1981). The primary mode of movement is westward under easterly winds; the secondary mode is eastward under westerly winds.

Prevailing winds have several effects on nearshore water motion. First, they move shallow waters in the direction of the wind, at about 3% of the wind speed (Mungall 1978, Matthews 1979). Second, because of the orientation of the coastline and the prevailing wind direction, they may cause upwelling in waters several tens of meters deep (Aagaard 1981), such as that described by Hufford (1974). Third, winds from an easterly direction should promote rapid flushing of lagoons and bays during low synoptic conditions (Kozo and Brown 1979). Daily patterns of sea breezes that occur during summer months should increase the intensity and frequency of both upwelling and lagoon flushing (Kozo and Brown 1979; Kozo 1979, 1981, 1982). Surface water movements in the direction of the wind is well-documented; nearshore-offshore exchanges (upwelling, lagoon flushing) caused by wind have limited documentation. These will be discussed more thoroughly below.

The direct effects of wind on biota are speculative. They relate mainly to birds in the nearshore zone, which appear to seek protection from strong winds behind barrier islands, spits, and points of land (Johnson and Richardson 1981).

Water Movements

Water movements important to biota include general wind-driven movement of shallow waters, cross-shelf exchange, and intrusions of water from adjacent *seas.* Effect's on biota are direct (transport of invertebrates) and indirect (detritus and nutrient transport and temperature and salinity regulation).

Wind Driven Movement. As noted above, nearshore water movements during the open--water period are largely a consequence of wind direction and speed. Because prevailing summer winds are easterly all along the coast, water tends to move coastwise and westward (Mungall 1978, Matthews 1979)* In waters up to 20 m deep or so, this movement reaches to the bottom (Callaway and Koblinsky 1976, Kozo 1981), though the speed slackens near the bottom because of friction. Superimposed upon this relatively predictable flow of wind-driven water, however, are the effects of emergent and submerged landforms that drastically alter water flow in nearshore environments (Mooers 1976). Along the Beaufort coast, barrier islands, spits, man-made causeways, and submerged bars strongly affect the wind-driven flow (Mungall and Whitaker 1979, Woodward-Clyde Consultants 1982).

Cross-shelf Exchange. Though the longshore flow of wind-driven water is the dominant water movement patternin the nearshore environment, a less obvious mode of exchange, that operating perpendicular to the coast between shallow and deeper waters, is probably more important ecologically. There appear to be four distinct mechanisms of this exchange on the Beaufort Sea shelf-- (1) upwelling in deep shelf waters, (2) estuarine-tYPe exchange near stream mouths, (3) wind- and tide-driven exchange in shallow shelf waters, and (4) thermohaline convection under ice.

Upwelling appears to be a common phenomenon in summer in waters beyond about the 60 m isobath on the Alaskan Beaufort Sea shelf. Some of the upwelling effects observed (i.e. Hufford 1974, Mountain 1974) appear to be wind-driven, caused by Ekman flow under the influence of easterly winds. This type of' upwelling appears most prominent in the eastern half of the Alaskan Beaufort Sea. It may sporadically intrude to much nearer the coast than the 60 m isobath (Mountain 1974).

In many of the recent observations the upwelling phenomena appear to be independent of wind; moreover, the upwelling events appear to be widespread in the longshore direction along the coast and commonly recurring (Aagaard 1981). Typically in these cases, relatively saline water from offshore depths of 200 m or more move onto the shelf and landward. Aagaard (1981) has concluded that this latter type of upwelling is most common and that wind-driven Ekman transport within the bottom boundary layer is not a likely primary cause of upwelling, though possibly a contributing factor. The causes are yet to be quantified in detail.

During summer near river mouths, a typical estuarine-marine exchange pattern prevails. This pattern involves river discharge of fresh water that spreads seaward as a surface wedge (because the fresh water is less dense than the seawater) and seawater that moves landward at the bottom; it occurs wherever rivers discharge into the sea (Officer 1978). Estuarine exchange phenomena are characteristically intense in early summer in the coastal Beaufort Sea, because peak river discharges occur then (Aagaard 1981). It is operative even in June when surface ice is thick, because the fresh water discharged melts holes in the ice cover and spreads seaward beneath the ice (Walker 1974). The fresh water can move seaward as far as 10-15 km (6-9 mi) in front of the delta of the Colville River (which has the greatest discharge of all streams emptying into the Alaskan Beaufort); it may almost entirely replace seawater in lagoons and bays fronting intermediate-sized rivers such as the Kuparuk (Matthews 1979). River discharge and its consequent seaward influence slackens drastically in late summer and early fall.

Wind- and tide-driven exchanges between nearshore shallows (lagoons, bays, etc.) and deeper shelf waters are probably common during the open-water period, though longshore exchanges are dominant, as discussed above. When winds are from the east (at which time major water movement is westward and parallel to the coast), the sea level near the coast is lowered (Kozo 1981), the typically warm and brackish coastal waters are pulled seaward as a surface lens, and the colder and more saline waters intrude landward at the bottom (Wiseman et al. 1974, Wiseman and Short

1976). When westerly winds blow, cross-shelf exchange is in theory less; the water level rises and coastal waters are held against the coast (Wiseman et al. 1974). Field measurements documenting cross-shelf " exchange in very shallow shelf waters are few. Barnes et al. (1977) observed landward flow at the bottom in a shallow coastal area and suggested that such a pattern should be common given the prevailing easterly winds. Herlinveaux and de Lange Boom (1975) observed a prevailing landward component to bottom flow on the Canadian Beaufort Sea shelf.

In winter there appears to be a cross-shelf exchange opposite in motion to that in summer--highly saline water flows seaward at the bottom and less saline water moves landward near the top of the water-column (beneath the ice). The cause for this circulation pattern is the exclusion of solutes from ice during the freezing process (Schell 1975; Aagaard 1981; Matthews 1981a,b), resulting in highly saline, relatively dense water below the ice *in* shallow areas. This dense water flows downslope along the bottom into deeper marine areas of less dense water. Marine water flows landward at the top of the water-column to replace that which has thereby been lost. Currents caused by this process (thermohaline convection) have been measured in the central Beaufort Sea (Matthews 1981a,b); this author estimated that waters in Stefansson Sound in winter were exchanged completely in20 days because of thermohaline convection. Schell (1975) calculated that thermohaline convection (coupled with tidal flushing) could replace underice waters in Dease Inlet in the western Beaufort Sea in 7-10 days.

Influences From Outside. Waters from the Bering Sea, intruding around Pt. Barrow, have a major influence on the hydrography of the western Beaufort Sea (Hufford 1973, Mountain 1974, Aagaard 1981), and as we shall see later, on the biota of the area. Additionally there is occasional intrusion of Amundsen Gulf water into the Alaskan Beaufort Sea from the east (Mountain 1974) but the occurrence of this appears to be more sporadic, less measurable, and less biologically important.

The Bering Sea intrusion appears most pronounced in summer, and is composed of Bering Sea water and Alaskan coastal water (the latter is influenced greatly by discharge of the Yukon River) (Mountain 1974). This intrusion is nearest land in the Beaufort Sea at Pt. Barrow. From Barrow it moves northeastward into the Beaufort Sea; and thence eastward, following the outer continental shelf and slope (Aagaard 1981). The Alaskan coastal water dissipates by the time it reaches the central Alaskan Beaufort Sea, but the Bering Sea component can be traced eastward to Barter Island (Aagaard 1981). The biological implications of this intrusion (to be discussed later) appear to be related to the temperature and fertility of the intruding water mass, both of which appear to be higher than those of Beaufort Sea waters (Hufford 1973, Mountain 1974, Aagaard 1981, Schell et al. 1982).

Effects Of Water Movements On Biota. The major biological influences of the movement patterns of Beaufort Sea water appear to be related to transport and deposition of detritus, movements of invertebrates, and the effects of water movement on water quality. Biological influences of the Bering Sea intrusion are probably connected to the temperature and biological productivity of the intrusion.

Water movement patterns may cause nearshore lagoons and bays to act as traps or sinks for detritus from both terrestrial (peat, modern vegetation) and marine (plankton cells, etc.) sources. Truett (1981a) summarizes the circumstantial evidence and theory suggesting this to be true. The strongest evidence supporting the view that nearshore shallows accumulate detritus relates to the net landward flow of water near the bottom in summer; such flow typically causes detritus to move to and remain in nearshore bays and lagoons. Seaward flow of bottom waters in winter (thermohaline convection) probably does not have sufficient speeds to resuspend and transport detritus seaward (see Matthews 1981a). Accumulation of marine detritus appears to be very important to nearshore food webs, which have epibenthic detritus-feeders as their base.

Movements of important invertebrate zooplanktonic and epibenthic components of the nearshore food web are controlled or assisted by currents. Shorebirds along the coast feed mainly on marine zooplankton brought to nearshore shallows and beaches by water movement (Connors and Risebrough 1979, Johnson and Richardson 1981). Waterfowl and anadromous fishes in nearshore waters feed primarily on mysids and amphipods, at least some of which (mysids) appear to move annually into and out of nearshore waters with the prevailing bottom flow (Griffiths and Dillinger 1981) and may be dependent on this flow for such movements. Most of the vertebrates do not feed to any extent in deeper waters beyond the nearshore shallows, and thus are dependent on the annual movements of invertebrates into the lagoons and bays.

There is strong evidence that the temperature end to a lesser extent the salinity, of nearshore waters in summer may regulate the distribution of anadromous fishes in summer and perhaps the growth rates of both fishes and epibenthic invertebrates [see Truett (1981b) and more recent work by Fechhelm et al. (1982), Fechhelm and Gallaway (1982) and Craig (1983)]. The temperature of these waters in summer depends on input rates of relatively warm water from streams and on exchange rates between the typically warm nearshore waters and the typically colder marine waters. Salinity patterns, which may influence the distributions of some epibenthic invertebrates (Griffiths and Dillinger 1981; Truett 1981b), are regulated by the *same summer* processes, as well as by winter processes related to freezing of nearshore waters and thermohaline convection.

Observation of the distributions and abundances of some organisms suggest that the intrusion of Bering Sea waters has a strong effect on biota. Divoky and Good (1979) and Divoky (in prep.) report several bird species to heavily utilize coastal waters near Barrow in preference to places farther *east.* These authors speculate that the differing biological productivity of the Bering Sea waters and/or perhaps the physical effects of the Bering Sea waters meeting the Beaufort Sea waters, makes food more available to birds near Barrow than elsewhere. Reported concentrations of belukha whales in the western Beaufort near Barrow in fall (K. Frost pers. comm.) perhaps are also related to effects of the Bering Sea intrusion.

Ice Dynamics

In the previous discussions of biota, it is clear that the characteristics of sea ice strongly affect the distribution of and habitat use by all groups of vertebrates and many of the invertebrates. It is useful to discuss ice dynamics in the nearshore zone and offshore zone separately, because ice types and animal use differ greatly between the zones.

In winter a distinct boundary exists between relatively stable, unridged ice that is shorefast, and the intensely ridged, unstable pack ice immediately seaward. The water depth at which this boundary occurs varies widely among years and especially among geographic locations. For example, Burns and Harbo (1972) found landfast ice in late spring 1970 to extend about 9.8 km (6 mi) off Pt. Barrow (western Beaufort), about 4.9 km (3 mi) off Barter Island (eastern Beaufort), up to 78 km (48 mi) off Harrison Bay (central Beaufort), and to average 20-22 km (12-14 mi) off land from Barrow to Barter Island. This landfast ice is flat and relatively featureless throughout the Alaskan Beaufort Sea. Shapiro and Barnes (1981) thought the 15.5 m (50 ft) depth contour to be an average annual position for the boundary. Stringer (1974) estimated the mean outer limit to be at about 18 m. This boundary approximates that which we have defined as the outer limit of 'nearshore" for purposes of this report.

In the nearshore zone, ice begins to form on the surface in late September or early October. It reaches its maximum thickness of about 2 m (6 ft) in April or May. Note that the maximum seaward extent of fast ice is reached only in late winter or spring; in early winter the boundary is closer to land (Barry 1979). Ice is typically mostly gone from the nearshore zone by late July.

The pack ice zone beyond the shorefast ice is of two types--the seasonal pack ice and the polar pack ice. The seasonal pack ice begins with a narrow shear zone of ridged ice at the edge of the fast ice, and continues out to the toe of the continental shelf. The ice in this zone is mobile and often contains a large percentage of first-year ice. The polar pack ice beyond the seasonal ice consists mainly of thick multi-year floes surrounded in summer by open water or thin ice and in winter by first-year ice (Kovacs and Mellor 1974).

Both the shorefast ice and the pack ice can have open-water cracks (leads) in winter (Burns and Harbo 1972, Stringer 1974, Mellor and Kovacs 1974), but open-water fractures occur most frequently in the pack ice and at the boundary between pack ice and landfast ice (flaw leads). Flaw leads often recur from year to year in the same *areas* (Kovacs and Mellor 1974).

Ice exerts perhaps the most stringent controls on vertebrate and invertebrate distribution and abundance of any of the physical processes or features in the Beaufort Sea, particularly in the nearshore zone. Many ways in which ice affects biota have been discussed in previous sections. Spring migration routes of the belukha and bowhead whales and waterfowl are routed far out to sea where open leads in the ice are typically available for surfacing whales and resting waterfowl. Ringed seal distribution in the Beaufort Sea at all seasons is strongly influenced by ice type and condition, and bearded and spotted seals are restricted from using major portions of the Beaufort Sea because they can accommodate to only a limited range of ice conditions (superimposed on water depth in the case of bearded seals). Because of ice presence and associated conditions, all birds, most fish, and many invertebrates are prevented from using the lagoons and bays except in summer and early fall. But when the ice is gone all these groups assemble there in large numbers.

Annual differences in ice conditions may strongly affect population level's, productivity, and/or distributions of biota. In severe ice years, whales may have difficulty maintaining their *regular* schedule of migration (Zimmerman 1972:12); belukhas have even been known to become trapped in offshore leads and perish during winter (Lowry et al. 1979). Large numbers of waterfowl may perish at sea when spring thaw is late or winter comes early (Barry 1968). Years when ice is much more prevalent in summer than usual appear to adversely affect the abundance of ringed seals, and consequently that of polar bear (Stirling et al. 1982). Gallaway et al. (1983) speculate that annual differences in recruitment/survival of arctic cisco may be caused by annual differences in sea ice conditions.

Summary and Conclusions

This review has addressed the general abundance and distribution of the common vertebrates and their food web components on the Alaskan Beaufort Sea continental shelf, with emphasis on nearshore waters. It has discussed the patterns of *use* of these waters by the biota, and the physical and biological phenomena that appear to influence these uses. Some patterns of distribution and use appear evident as follows.

1. For most vertebrate species, the nearshore environment is simply a foraging habitat. Almost all vertebrates use the nearshore primarily to feed in summer and early fall. Life functions related to breeding and reproduction are carried out in adjacent terrestrial or freshwater environments, in ocean areas outside the Alaskan Beaufort Sea, or in deeper offshore areas of the Alaskan Beaufort Sea. There are a few exceptions: some marine fishes (fourhorn sculpin, arctic flounder) and a small proportion of the ringed seal and polar bear population reproduce in nearshore areas, but most of these have more important breeding habitats elsewhere.

2. The primary food web bases of vertebrates are epibenthic crustaceans and zooplankton in the nearshore shelf areas and zooplankton in the offshore areas. Amphipods, mysids and copepods comprise the major portions of diets of essentially all vertebrates in the nearshore zone, despite the apparent abundance of alternative foods. Euphausiids and copepods are the primary offshore food web constituents, though in offshore areas there are additional trophic levels to those in the nearshore, and vertebrates sometimes feed on other vertebrates. Marine primary production (primarily pelagic production by phytoplankton) is the major carbon source for both nearshore and offshore food webs.

3. Several important vertebrates use the Alaskan Beaufort Sea primarily as a migratory pathway between summer and winter habitats. Bowhead and belukha whales and king eiders are conspicuous examples. These species may feed to some extent in passage, but may or may not require such feeding to promote their well-being. Other transients (e.g. brant, Canada geese, shorebirds) that migrate through appear to

spend relatively more time stopping and feeding enroute. In all these cases the importance to the animal of feeding in the Beaufort Sea is speculative.

4. Ice is a dominant force in determining whether, when, and how biota use the nearshore Beaufort Sea. In winter, ice forces essentially all birds, many mammals, and most anadromous fishes to leave coastal waters. In summer, ice influences where whales and birds migrate, when birds feed in the nearshore zone, and where seals and polar bears feed. Some species (e.g. spotted and bearded seals) appear to be largely or completely excluded from major portions of coastal waters simply because they cannot accommodate to the ice conditions.

5. Nearshore water movement patterns superimposed on configurations of barrier islands, spits, and headlands bordering nearshore shallows act to maintain a benign feeding environment for birds and fish in summer. Water movement patterns appear to deliver food web materials from offshore environments (detritus, invertebrates) to nearshore lagoons and embayments. Coincidentally, these protected shallows are physically benign, holding relatively warm waters that fish prefer and providing diving ducks (e.g. oldsquaws) shelter from wind and waves and readily accessible (shallow) benthic environments for feeding. Existing evidence suggests that sheltered embayments and lagoons provide better feeding habitats for most birds and fish than do coasts openly exposed to the sea.

6. There are great differences in animal use between shallow nearshore and deeper offshore parts of the Beaufort Sea shelf, but relatively few differences among segments of the coast. The nearshore shallows that are measurably warmer and less saline in summer than the marine waters beyond have species assemblages, seasons and types of animal use, and

physical properties of importance to animals that are different from those of waters beyond about 20 m deep. Differences in animal use among east-west segments of the shelf waters are less striking; they include: (a) protected lagoons appear to be used more heavily than waters along open coasts by birds, and probably by fish, (b) a greater abundance and diversity of birds has been reported in extreme western parts near Barrow, and (c) some anadromous fishes are not uniformly distributed among major segments of the coast.

7. Most differences in animal use among segments of the Alaska Beaufort Sea nearshore zone appear to be related to major differences in configurations of coastal landforms or to influences from outside the Beaufort Sea. We noted above that animal use and important physical phenomena are different between protected and exposed coasts, apparently because of local landform effects. The different animal use of nearshore areas near Barrow is thought to be mainly because of the influence of Bering Sea water intruding into the Beaufort Sea there. The differences in fish use in different coastal regions seems to be a consequence of different distances from natal streams, and not of intrinsic differences among regions. Some birds (e.g. red and red-necked phalaropes) show different levels of use among coastal regions because their breeding numbers in terrestrial regions adjacent to the various coastal areas are different.

DISTRIBUTION AND REGULATION OF BIOLOGICAL USE

This section uses information from recent research (see following chapters of this report) and from past research (see the above review) to discuss what regulates biological use in the nearshore Beaufort Sea and to compare use among coastal regions. Figures 1-3 through 1-9 show nearshore coastal segments from Barrow to the Alaska-Yukon boundary. These will be referenced in the following discussions.

The Coastal Vertebrates

Bowhead Whale

Bowhead whales typically are found in waters deeper than 18 m along most of the Alaskan Beaufort coast (Ljungblad 1981; Ljungblad et al. 1980, 1982) except for the area adjacent to the Arctic National Wildlife Refuge, and especially the area east of Barter island (Johnson, this volume). Circumstantial evidence given by Frost and Lowry (1981) and Lowry and Burns (1980) suggests that these whales may linger through late September in this extreme eastern portion of the Alaskan Beaufort Sea to continue feeding before migrating out of the Alaskan Beaufort. Davis (LGL Ltd., pers. comm. 1983) has speculated that bowheads feed in areas where zooplankton concentrations are appreciably higher than in adjacent areas and these concentrations may be related to levels of salinity, temperature and nutrients, and to other physical characteristics of the Beaufort Sea such as water depth (location of the shelf break), circulation patterns (upwellings, convergent fronts, small gyres).

Spotted Seal

Of the marine mammals that use the Beaufort Sea, the spotted seal is the only one that appears to be restricted to the nearshore zone. It is absent in winter but in summer appears along the western and central Beaufort coasts, mainly at two locations--the Colville River Delta and inner Dease Inlet. Why spotted seals are largely restricted to these

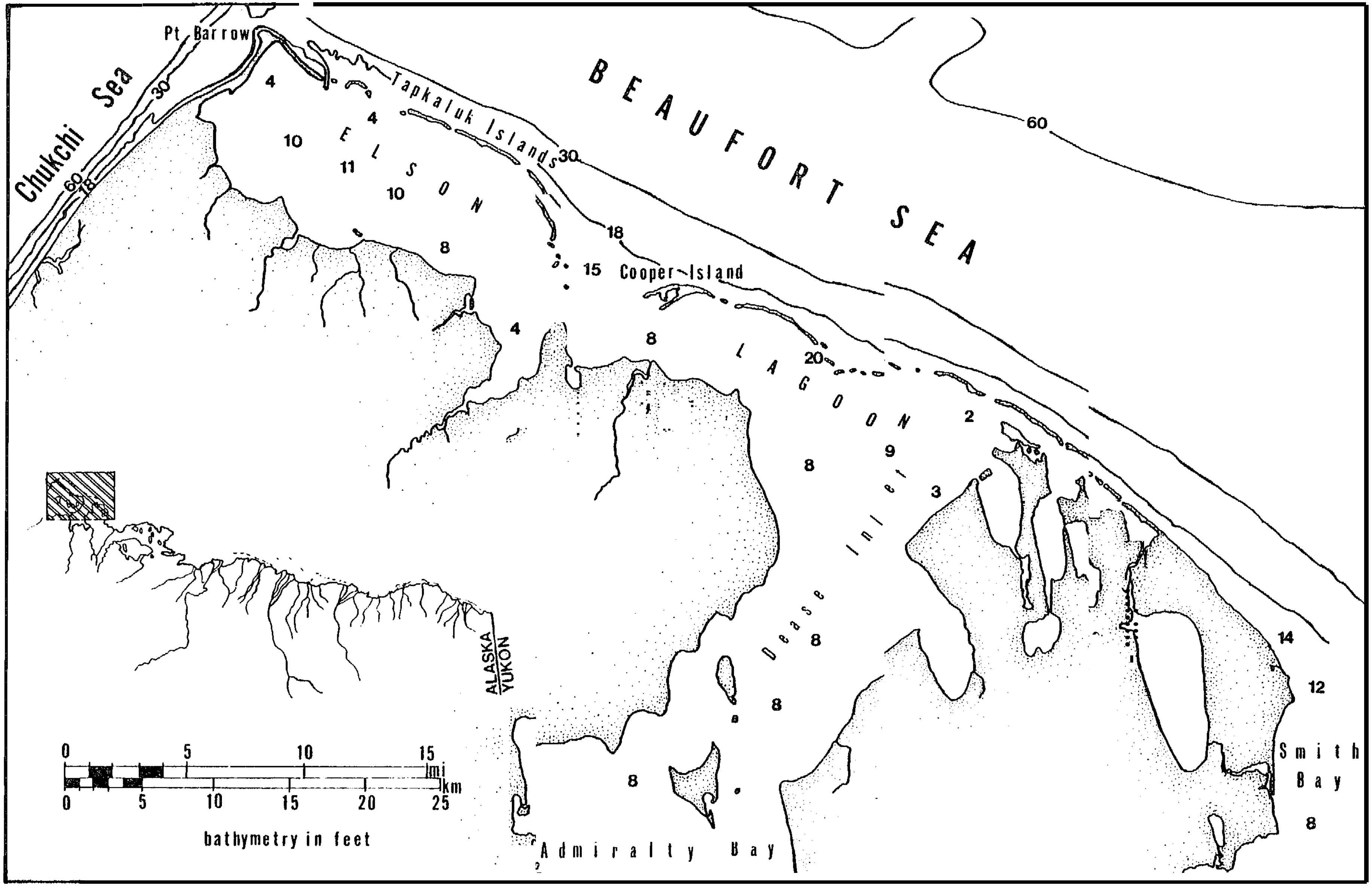


Figure 1-3. Nearshore environment, Pt. Barrow to Smith Bay, Beaufort Sea coast, Alaska.

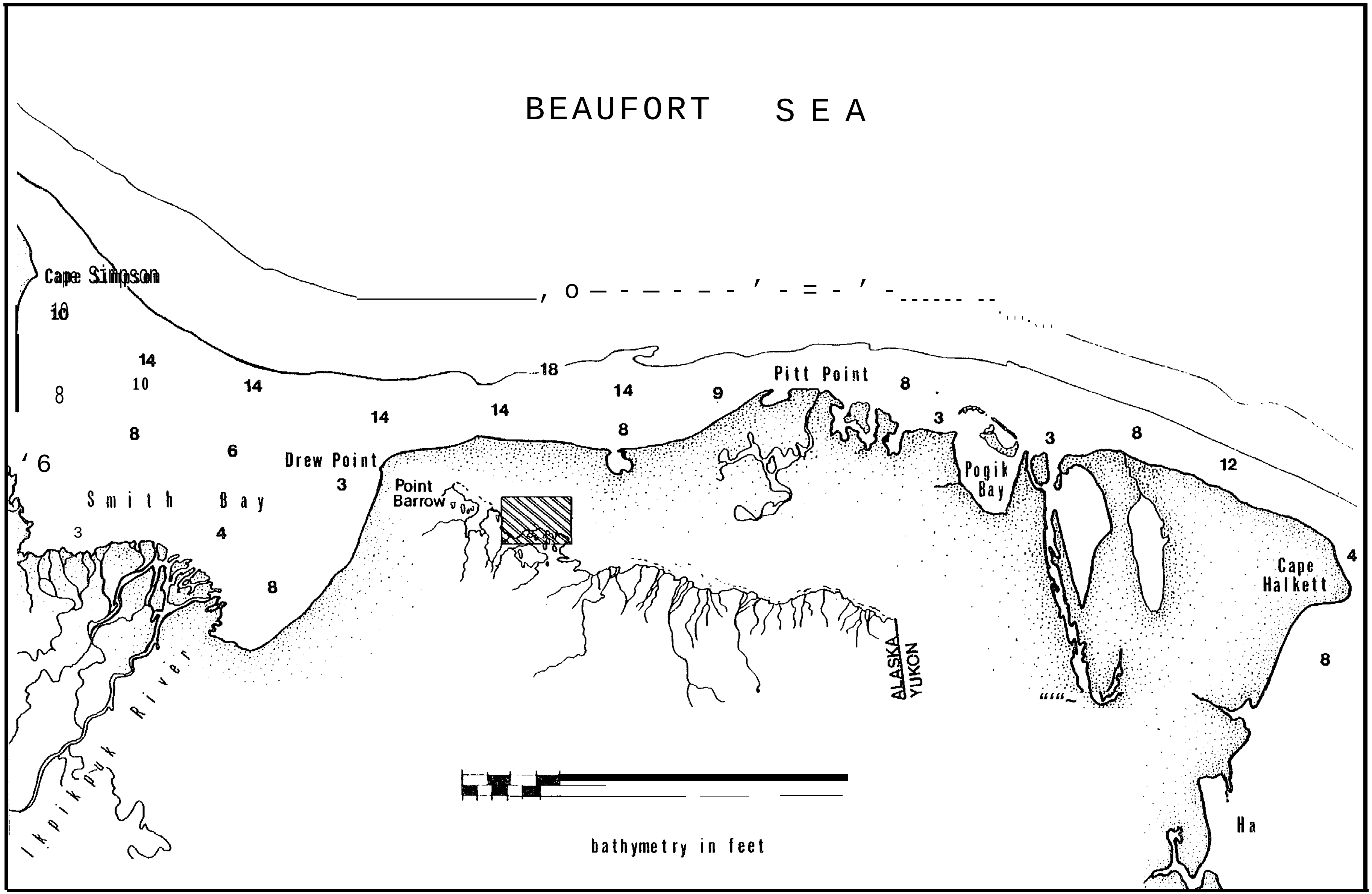


Figure 1-4. Nearshore environment, Smith Bay to Harrison Bay, Beaufort Sea coast, Alaska.

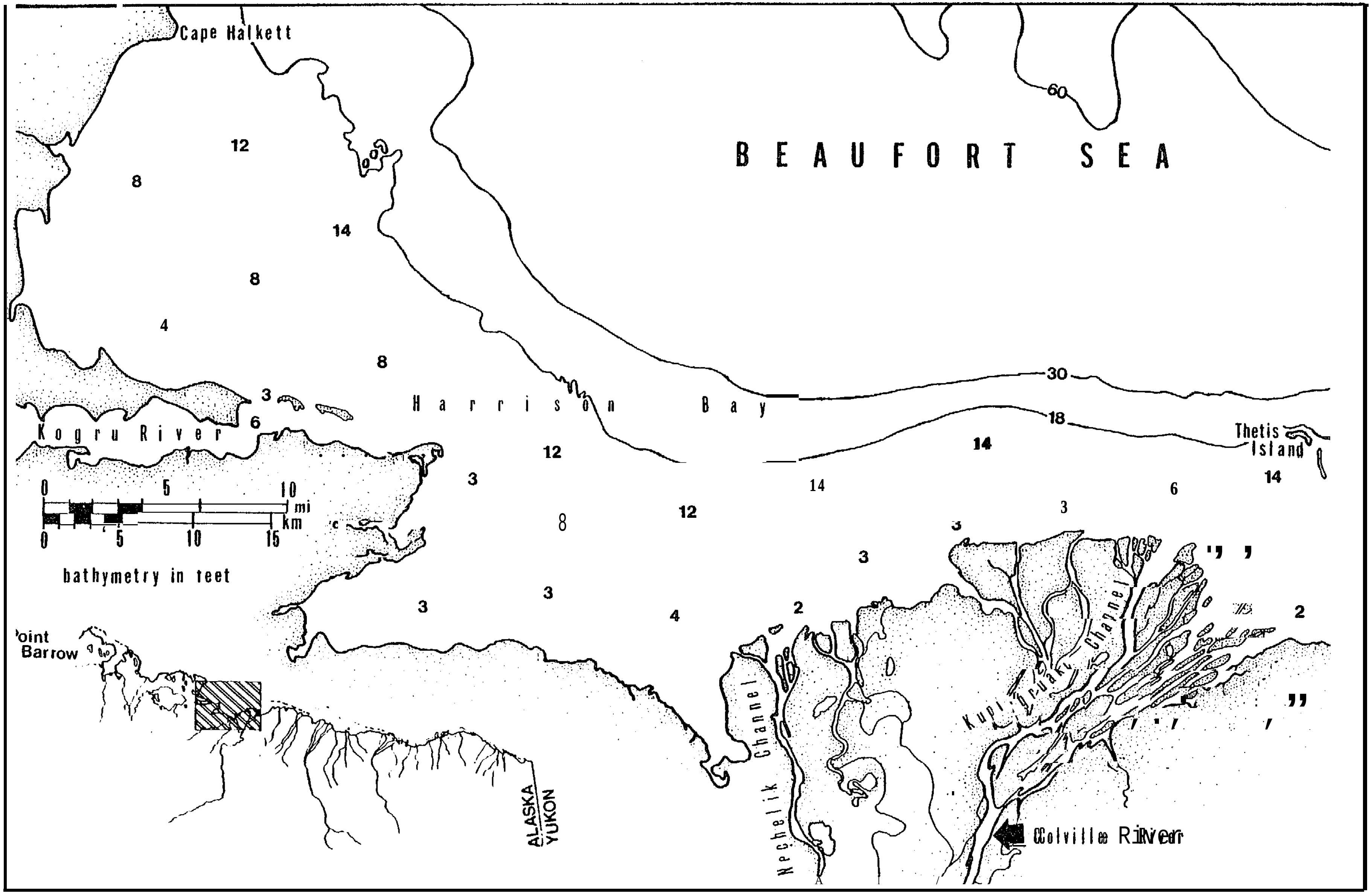


Figure 1-5. Nearshore environment, Harrison Bay, Beaufort Sea coast, Alaska.

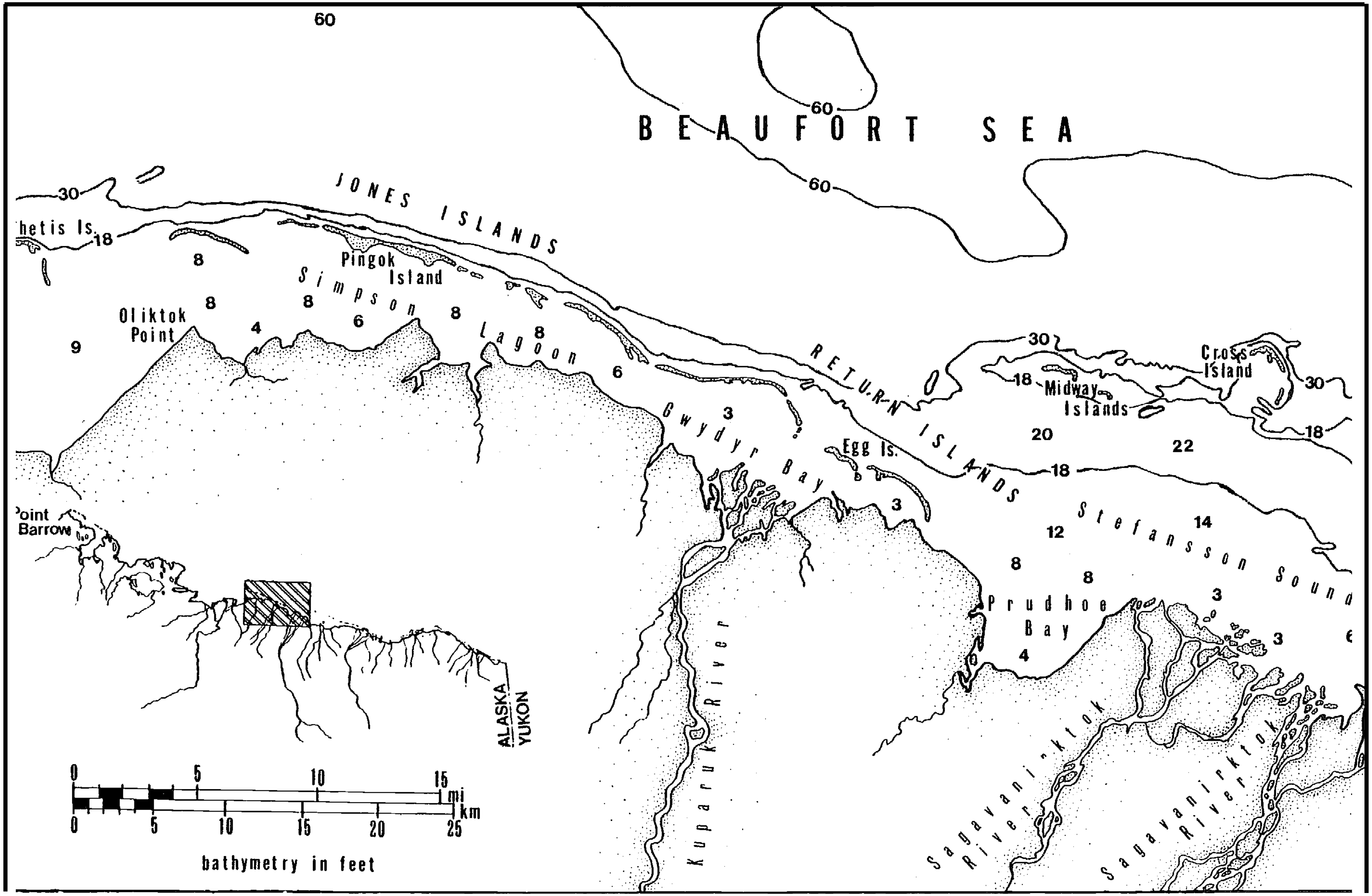


Figure 1-6. Nearshore environment, Simpson Lagoon-Stefansson Sound, Beaufort Sea coast, Alaska.

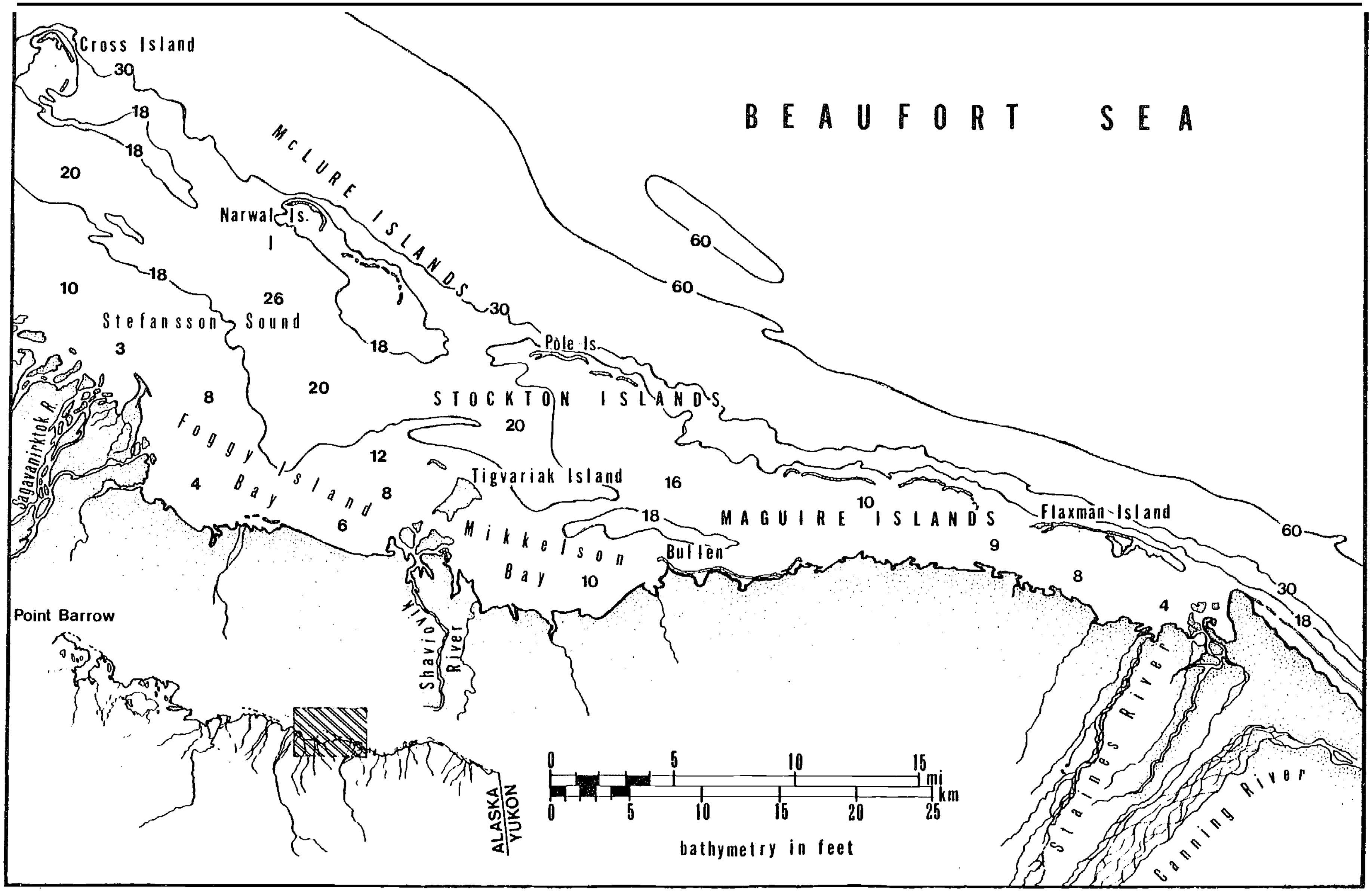


Figure 1-7. Neashore environment, Stefansson Sound to Flaxman Island, Beaufort Sea coast, Alaska.

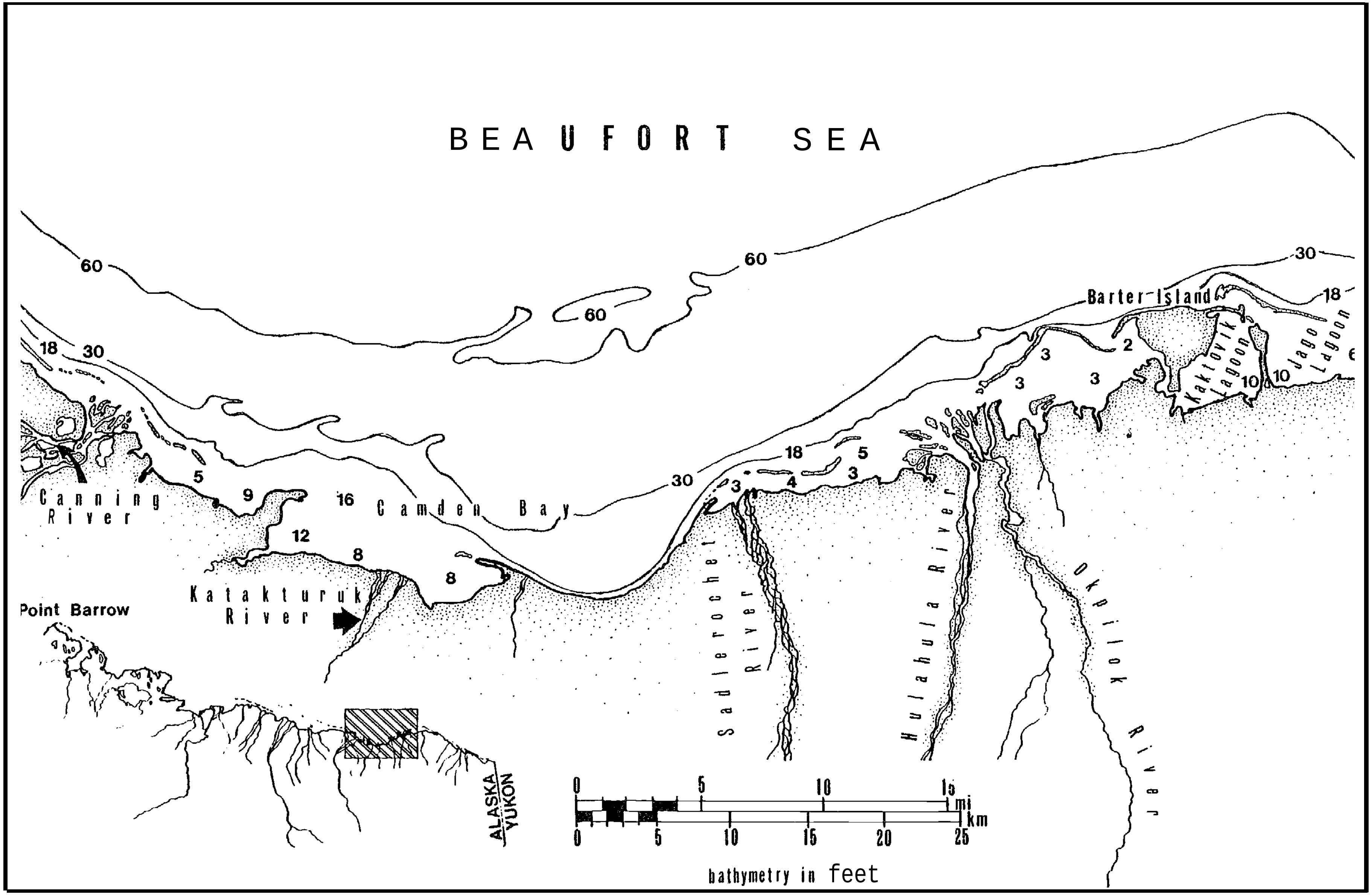
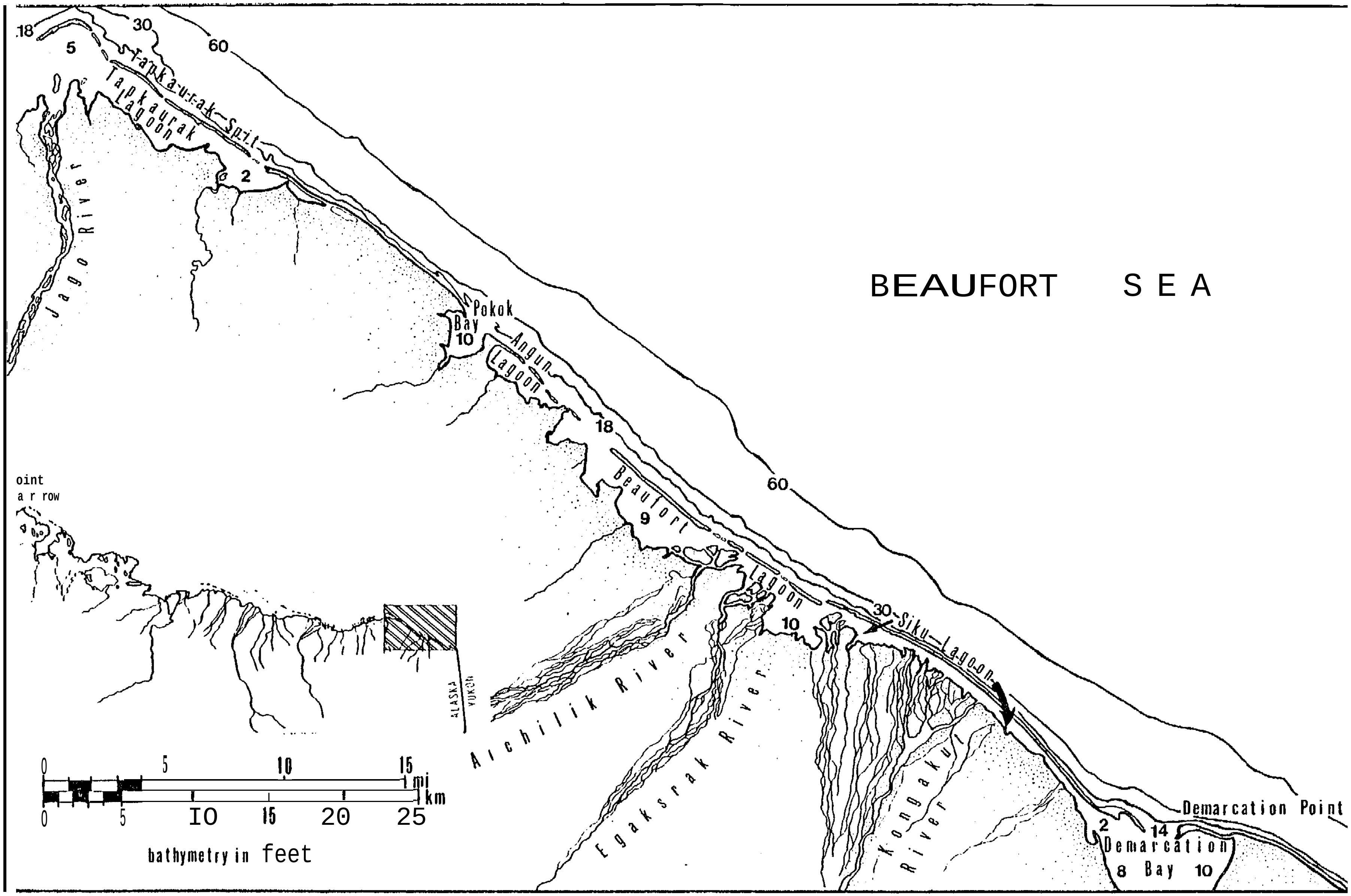


Figure 1-8. Nearshore environment, Canning River to Barter Island, Beaufort Sea coast, Alaska.



'igure 1-9. Nearshore environment, Tapkaurak Lagoon to Demarcation Point, Beaufort Sea coast, Alaska.

areas in the Beaufort Sea is not known, but they are known to generally prefer seas with less severe ice conditions than are characteristic of the Beaufort Sea (Lowry et al. 1979a). One might speculate that ice conditions (early break-up??) that annually recur at these places and that are not found elsewhere in the nearshore Beaufort could affect the seals' choice of the sites.

Ringed Seal

Although the ringed seal is primarily an offshore animal, many use landfast ice in the nearshore zone as birthing habitat in spring, and late-spring leads in nearshore ice as haul-out areas for molting (Burns and Harbo 1972; Lowry et al. 1979a,b). Deeper lagoons (e.g. Stefansson Sound) and areas offshore of barrier islands are selected by seals for these purposes; waters less than several meters deep are seldom used at any time. Burns and Harbo (1972) found ringed seals in June in the nearshore zone to be rather uniformly distributed among coastal segments from Barrow to Barter Island, with no apparent preference for any particular longshore segment of this zone. Locally, they were more concentrated along cracks in the nearshore ice.

Common Eider

Common eiders use nearshore areas very sparingly except for nesting and brood-rearing, June to August. They nest almost exclusively on coastal islands (Johnson and Richardson 1981). Divoky (1978) shows that they seldom nest on islands that are not offshore from river deltas. He postulates that these islands are inaccessible to arctic foxes (a major predator on eider eggs and broods) because of river overflow in spring. Most major eider nesting islands in the Beaufort Sea are indeed offshore from major rivers--Colville River (Thetis Island, 38 nests), Kuparuk River (Egg Island, 24 nests), Sagavanirktok River (Cross Island, about 100 nests; Narwal Island, 33 nests), Shaviovik River (Pole Island, about 60 nests) (Divoky 1978) (Figs. 1-5 to 1-7). Smaller numbers of nests are common on islands not off river mouths.

There may be additional factors that regulate eider nesting distribution in the Alaskan Beaufort Sea. For some reason, none nest west of the Colville River, though islands exist there. The largest colonies are on islands relatively far from the mainland (Cross Island, Pole Island). Some islands in immediate proximity to islands with many eider nests have no nests. Johnson and Richardson (1981) report that eiders prefer to nest near or in driftwood or other debris, and that similar islands with no debris have few or no eiders.

A few patterns are clear. Sections of the coast with no islands have no eiders. No eiders nest west of the Colville River; few nest east of Flaxman Island (Divoky 1978) (see Figs. 1-5 to 1-7). Thus the central islands that are relatively far from the coast and/or near deltas of large streams have by far the most nests in the Beaufort Sea. Islands with driftwood generally have more eider nests than islands without debris.

King Eider

Nearshore Beaufort Sea waters are seldom used by king eiders. Most use occurs during spring migration (late May, early June), when some king eiders rest near the mouths of rivers that are flooding and provide the only open water along the coast. During molt migration of males and fall migration of females and young, eiders normally fly directly from tundra nesting areas to sites out of the Beaufort Sea along routes outside coastal waters. In spring, summer and fall, many migrants pass relatively near land at Barrow in the western Beaufort, but few stop.

Oldsquaw

Oldsquaw, the most common species of waterfowl in the Beaufort Sea, uses the coastal zone for feeding and molting. During their spring migration oldsquaws, like king eiders, sometimes rest (and may feed briefly) in recently-thawed coastal waters near river mouths before moving on to tundra nesting areas. From mid-July to mid-August males and some non-breeding females congregate in coastal lagoons and bays to molt and feed. During freeze-up in late September, females and broods of the year move from tundra areas to lagoons and bays to feed before their migration to wintering areas.

Patterns of use of nearshore areas by oldsquaws during molt and migration have been well documented (Johnson and Richardson 1981, Richardson and Johnson 1982b). These birds are seldom found in offshore areas, and in nearshore waters they strongly prefer semi-enclosed lagoons and bays to coastal waters open to the sea. Oldsquaw densities at these times do not seem to vary greatly among the various protected nearshore areas, but the wider *lagoons,* because of their greater surface areas per longshore distance, host more birds (see Johnson, this volume). There is a notable scarcity of oldsquaws in large, turbid, unprotected areas such as Harrison Bay (Divoky in prep.).

Why oldsquaws seek protected coastal areas is not certain, for there is no evidence that their food is not just as abundant in shallow, unprotected sites (see Griffiths and Dillinger 1981). (Variability in food supplies among coastal habitats will be discussed later.) Johnson and Richardson (1981) and Johnson (1982) postulated that they seek protection from wind and waves that barrier islands, spits and points of land offer.

Black Brant

Black brant migrate over the nearshore environment and feed along its margins in salt marshes or other low-lying vegetated sites. Similarly to eiders and oldsquaws, they may stop briefly at flooded river mouths during their spring migration in late May and early June, but their main use of coastal habitats is during nesting (early to mid-summer), following molting (early August), and in fall migration (late August, early September). Because the main breeding concentrations of brant on the Alaskan Arctic Slope are in deltas of large rivers, it is only at the seaward margins of the deltas that they commonly feed in nearshore environments during nesting and brood-rearing (June-August) (King 1970). In early August a unique phenomenon occurs in coastal bays, lagoons and salt marshes in the Cape Halkett-Smith Bay area--huge flocks of brant (15-20 thousand total) from inland molting areas northeast of Teshekpuk Lake move to these sites to feed (Derksenet al. 1979). Then in late August and early September, fall migrants from nesting areas in northern Alaska and Canada move westward along the coastal lagoons and bays, stopping in salt marshes and other vegetated sites by the sea to feed (Kiera 1979). Both the post-molting flocks and fall migrants apparently avoid coastal areas west of Dease Inlet near Barrow (Pitelka 1974).

Why brant use varies among coastal sites is relatively clear. From June to August, they restrict themselves mostly to vicinities of river deltas because deltas are where spring migrants find open water and, later, where most brant nest. In early August the Cape Halkett-Smith Bay area is heavily used by post-molters because the only large inland molting area is nearby. (Why they molt where they do is speculative.) In late August and early September they stop mainly where salt marshes and other low-lying coastal vegetation communities exist--stream deltas, gently sloping lagoon margins and similar areas not fronted by coastal bluffs are all likely to attract brant. They bypass the area west of Dease Inlet because their traditional path of migration goes overland from Dease Inlet to the Chukchi Sea.

Canada Goose

Beaufort Sea coastal waters are used primarily by non-breeding Canada geese that move to the coast after molting in the Teshekpuk Lake area where brant molt (see above) (Derksen et al. 1979). In late July and early August, about 15,000 Canada geese move from this inland molting region to stream deltas, breached lakes, and other coastal. wetlands in the Cape Halkett-Smith Bay area, where they feed for a few weeks before moving south. Why they feed here and not elsewhere along the coast is reasonably clear--it is the nearest coastal region to their traditional molting area. Why they select the Teshekpuk Lake area to molt is not known (Derksen et al. 1982).

Phalaropes

Both red and red-necked phalaropes move from tundra nesting areas to the Beaufort Sea coast to feed in late summer and early fall. Along most stretches of coast, only the young of the year use the coastal zone; post-nesting adults fly directly from nesting sites to more southerly regions (Johnson and Richardson 1981). In coastal areas near Barrow, however, post-nesting adult male red phalaropes may feed in the coastal zone briefly in July if nearshore ice melts early (Connors and Risebrough 1978).

More red phalaropes use the western Beaufort, and more red-necked phalaropes use the eastern Beaufort, but their times and patterns of use of the respective sections of the coast are similar. The first flocks move to coastal waters in early to mid-August; the last birds have usually departed south by mid-September (Connors and Risebrough 1978; Johnson and Richardson 1981, Johnson, this volume).

Phalaropes feed from the water's surface, usually' within several meters of the water's edge. Where barrier islands exist, they seem to prefer feeding along islands (both oceanside and lagoonside) in preference to feeding along mainland shores. Because of the additional shoreline habitat offered where spits or barrier islands skirt the coast, phalaropes probably use lagoon areas more heavily than areas with open coasts (Connors in prep.). In general they appear to use the western and central Beaufort areas more heavily than they do the eastern Beaufort (Johnson, this volume).

Why phalarope use is heavier in the western Beaufort, and why red phalaropes are more common in the west and red-necked phalaropes more common in the east apparently relates to distributions of nesting populations. The Arctic Coastal Plain, which is the phalaropes' main breeding habitat in Arctic Alaska, is much broader in the west than it is in the east, fledging more young phalaropes per unit distance of coastline. Thus it is reasonable that western coasts are more heavily used. Further, the red phalarope is the most abundant nester in higher latitudes in western Arctic Alaska and the red-necked phalarope is a more numerous nester in lower latitudes in eastern Arctic Alaska and the north slope of Canada. The ratio of the two species at various coastal locations in late summer reflects their relative nesting numbers in adjacent inland habitats.

Other Shorebirds

Similarly to phalaropes, most other species of shorebird that use the Beaufort Sea coast do so as post-nesters, and use the coast solely to feed in late summer and early fall prior to southward migration (Connors and Risebrough 1978, Johnson and Richardson 1981). Shorebirds other than phalaropes are shoreline foragers, seeking *prey* on land near the water's edge. Ten to 20 species regularly use the coastal zone in August and September (Connors et al. 1979). Among the various species there are differences in coastal habitat types used for foraging.

Because different species frequently prefer different types of coastal habitat for foraging, and because each species nests in varying abundances inland from each coastal segment, each segment receives somewhat different levels of use by different combinations of species (Connors in prep.). However, there are areas of general concentrated use, where several foraging habitats are abundant and where prevailing wind and current conditions act *to* concentrate shorebird prey. Typically river deltas, points of land extending into the sea, bays, and island groups are areas where shorebirds concentrate (Connors in prep.) (Figs. 1-3 to 1-9).

Glaucous Gull and Arctic Tern

Both these species are common in most locations along the Alaskan Beaufort Sea coast in summer (Johnson et al. 1975). They use coastal areas for feeding and for nesting. Both prefer barrier islands for nesting, though neither nests exclusively there.

Divoky (1978) found more gull nests on islands between the Colville River and Camden Bay than elsewhere in the Alaskan Beaufort (Figs. 1-5 to 1-8). He observed that most gulls nested on islands seaward of river deltas (large rivers discharge into this area) for presumably the same reasons that common eiders nest on islands rendered inaccessible to arctic foxes by early summer river overflow. It is notable that both glaucous gulls and common eiders nest most commonly along the same stretch of coastal. barrier islands.

Arctic terns, on the other hand, nest in greatest densities near Barrow* Of 84 tern nests found by Divoky (1978), 58 were on Cooper Island in the Plover Islands (see Fig. 1-3). Divoky believed that the terns were attracted to Cooper Island because the large accumulation of lumber on the island offered nest sites protected from wind. Hawksley (1957) believed that available nearby food resources were also important in determining where arctic terns nested, but no comparisons of food availability in relation to tern abundance in the Beaufort Sea have been made.

Neither gulls nor terns appear to be as selective of coastal areas for foraging as they are of nesting areas. They are common at most coastal sites and at least the gulls appear to increase in abundance as summer progresses (Johnson and Richardson 1981). Divoky and Good (1979) suggest that populations of foraging gulls might be greater at coastal areas providing refuse (such as near oil camps) than elsewhere, and that in recent years the coastal population has increased because of garbage availability,

Other Bird Species

The Plover Islands-Elson Lagoon area near Barrow (Fig. 1-3) is commonly used, at various times during the fall, by black-legged kittiwakes, Sabine's gulls, Ross' gulls, black guillemots, and sometimes thick-billed murres (Divoky and Good 1979, Divoky in prep.). None of these except black guillemots nest there (Divoky and Good 1979). The reason most of these birds frequent this area (and not other areas of the Beaufort Sea) may relate to enhanced food availability caused by the Bering Sea intrusion in coastal waters there. [Although this intrusion may reach all the way to the eastern Alaskan Beaufort, only near Barrow does it commonly affect nearshore waters (see Aagaard 1981).] In the deeper nearshore waters, Divoky (in prep.) has observed birds in patchy feeding concentrations that seem to be correlated with locations of convergence between Bering Sea and Beaufort Sea waters. He believes this converging' of waters somehow increases prey abundance in the region. Convergent fronts are knownto be favorite feeding places of predators, probably because planktonic prey is concentrated there (Pingree et al. 7974) .

Black guillemots as nesters have recently spread into the western Beaufort Sea from farther south. Normally nesting on talus slopes, they nest here in driftwood and man-made debris on the Plover Islands (Fig. 1-3). Guillemots are rare in the central and eastern Alaskan Beaufort. Their relative abundance in the western Beaufort is probably promoted by the occurrence of man-made nest sites there (Divoky 1978) and by the proximity of larger guillemot populations to the southwest.

Arctic Cisco

The arctic cisco uses coastal Beaufort Sea waters extensively for feeding in summer and to a much lesser extent for overwintering. From June to September it is common in essentially all very shallow, nearshore environments from Barrow to Demarcation Point (Craig 1983). In winter it is restricted to delta areas of large rivers, in Alaska primarily the Colville River (Fig. 1-5). It breeds in large freshwater streams; the Alaskan Beaufort stock may breed in the Mackenzie River (Gallaway et al. 1983).

There is no evidence that coastal use by arctic cisco in summer varies appreciably among different segments of the coastline (Craig 1983; Griffiths, this volume) or among coastal habitat types (e.g. lagoon, bay, open coast) (Schmidt et al. 1983). However, indications are that they prefer to feed where the water is warm and shallow (Craig and Haldorson 1981, Fechhelm et al. 1982, Craig 1983), which suggests that more extensive and preferred foraging habitat exists where waters are shallow and warm for relatively long distances seaward (e.g. wide bays and lagoons).

Arctic cisco diets are similar among most coastal segments (Griffiths, this volume). Whether foods available to arctic cisco vary among coastal habitats will be discussed later.

Arctic Char

Arctic char use the Beaufort Sea waters exclusively for feeding (June through September). During this time they are common in the nearshore Beaufort Sea from Barrow to Canada (Craig 1983). They breed mostly in mountain streams of the Arctic Coastal Plain east of the Colville River (Figs. 1-6 to 1-9).

Their distribution in nearshore waters resembles closely that of arctic cisco in that they show a preference for shallow coastal waters that are warmer and less saline than waters in offshore areas and use a wide range of coastal habitats. But they are likely to range somewhat farther seaward than arctic cisco (see Craig and Haldorson 1981, Craig 1983, Tarbox and Moulton 1980).

Although levels of use of coastal habitats by adult char do not seem to vary greatly among coastal sites (Craig 1983, Schmidt et al. 1983), for some unknown reason smaller individuals seem more commonly represented in capture efforts near the Sagavanirktok River Delta (Fig. 1-6) (Griffith% this volume) than they are in lagoon systems away from river deltas. The Sagavanirktok River is known as a major char spawning and overwintering stream; perhaps this has some bearing. Foods eaten by char have been generally similar at all coastal sites; more detailed discussions of food webs will come later.

Least Cisco and Broad and Lake (Humpback) Whitefish

These species generally resemble arctic char and arctic cisco in that they use warm, shallow coastal waters for foraging in summer, and breed and overwinter in freshwater habitats. (The whitefishes in particular seldom venture into marine waters.) But there is one major difference--these species do not range as far from their natal streams as do char and arctic cisco, and their distribution along the Beaufort Sea coast is accordingly restricted (Craig 1983).

All these fish breed and overwinter in Alaska mainly *in* the Colville River and in Arctic Coastal Plain streams and associated lakes to the west of the Colville (Figs. 1-3 to 1-5). They also breed and overwinter in the Mackenzie River in Canada. They are uncommon in, or absent from, mountain stream types between the Colville and the Mackenzie (Craig 1983, Griffiths, this volume).

Most individuals of these species travel less than 100 km (60 mi) or so from the streams of their origin (Craig 1983). Thus very few utilize coastal habitats between about the Sagavanirktok River in Alaska and the

Canadian border (see Griffiths, this volume). There is no indication that these eastern Beaufort Sea nearshore environments are unsuitable for use by these species; they are simply beyond the summer foraging range of most individuals.

Boreal Smelt

Little is known of the distribution of this anadromous fish in the Beaufort Sea. It has not been found to be common except at one place in the nearshore in summer or winter. It has been found in abundance in Harrison Bay in winter (Fig. 1-5), where it is presumably overwintering prior to a spring spawning run into the Colville River (Craig and Haldorson 1981). Perhaps its scarcity in other locations is caused by the absence of natal streams emptying into the Beaufort Sea.

Arctic Cod

The arctic cod is a marine species that sporadically occurs in the nearshore environment, particularly in late summer and fall (Craig et al. 1982). At these times cod have been known to move shoreward elsewhere (Andriyashev 1954). Some may spawn in the outer reaches of the nearshore zone (Craig and Haldorson 1981), but the majority of spawning probably occurs offshore (Craig et al. 1982). They use the nearshore zone mainly for foraging.

Occurrence of arctic cod in nearshore areas appears to be irregular among years as well as in space (Craig and Haldorson 1981, Craig et al. 1982). Reports of cod in nearshore waters are too few and subjective to demonstrate that cod have definite patterns of preference among coastal types. But they are more commonly reported in lagoons and bays relatively open to the sea (see Craig and Haldorson 1981, Bendock 1979) than in more closed lagoons (Griffiths, this volume). One might expect that a typically pelagic fish like cod would use lagoons simply as an extension of the sea, and thus would enter closed lagoons less frequently than open lagoons.

Fourhorn Sculpin and Arctic Flounder

These two bottom-dwelling marine species are common residents of bay and lagoon habitats of the Alaskan Beaufort Sea. Although both presumably move to deeper waters to some extent in winter as ice forms on nearshore shallows, some sculpin (and perhaps flounder) inhabit deeper bays and lagoons year-round. Both species are relatively sedentary (Craig and Haldorson 1981; Craig 1983; Griffiths, this volume).

Griffiths (this volume) found arctic flounder more abundant in Beaufort Lagoon in the eastern Beaufort than did Craig and Haldorson (1981), Bendock (1979), Griffiths and Gallaway (1982), or Griffiths et al. (1982) in central Beaufort Sea areas (Griffiths, this volume). No fishing efforts have been made in the western Beaufort with gear types suitable for evaluating abundance of these species.

Fourhorn sculpin appeared about equally abundant in an eastern Beaufort Sea lagoon (Griffiths, this volume) as in several central Beaufort Sea areas. However, Craig and Haldorson (1981) reported catches per unit effort of sculpin in Simpson Lagoon in 1978 about five times those of Griffiths (this volume) in the eastern Beaufort and of other studies in the central Beaufort. No reasons for these differences in catches are apparent.

Food Webs

As we have seen, studies conducted prior to this program have showed vertebrates in several areas of the nearshore zone of the Beaufort Sea to eat mainly mysids and amphipods, and to a lesser extent marine zooplankton, isopods and fish. Diets of vertebrates in Angun and Beaufort lagoons were not greatly different from those of the same species in the central Beaufort Sea nearshore zone (Griffiths, this volume; Johnson, this volume).

Figure 1-10 compares diets of abundant vertebrates in an open lagoon (Simpson Lagoon) with diets of the same vertebrates in the closed lagoons of this study. In general, mysids and amphipods were the main foods of vertebrates in both lagoon systems, though fish (mainly Cottidae=sculpins)

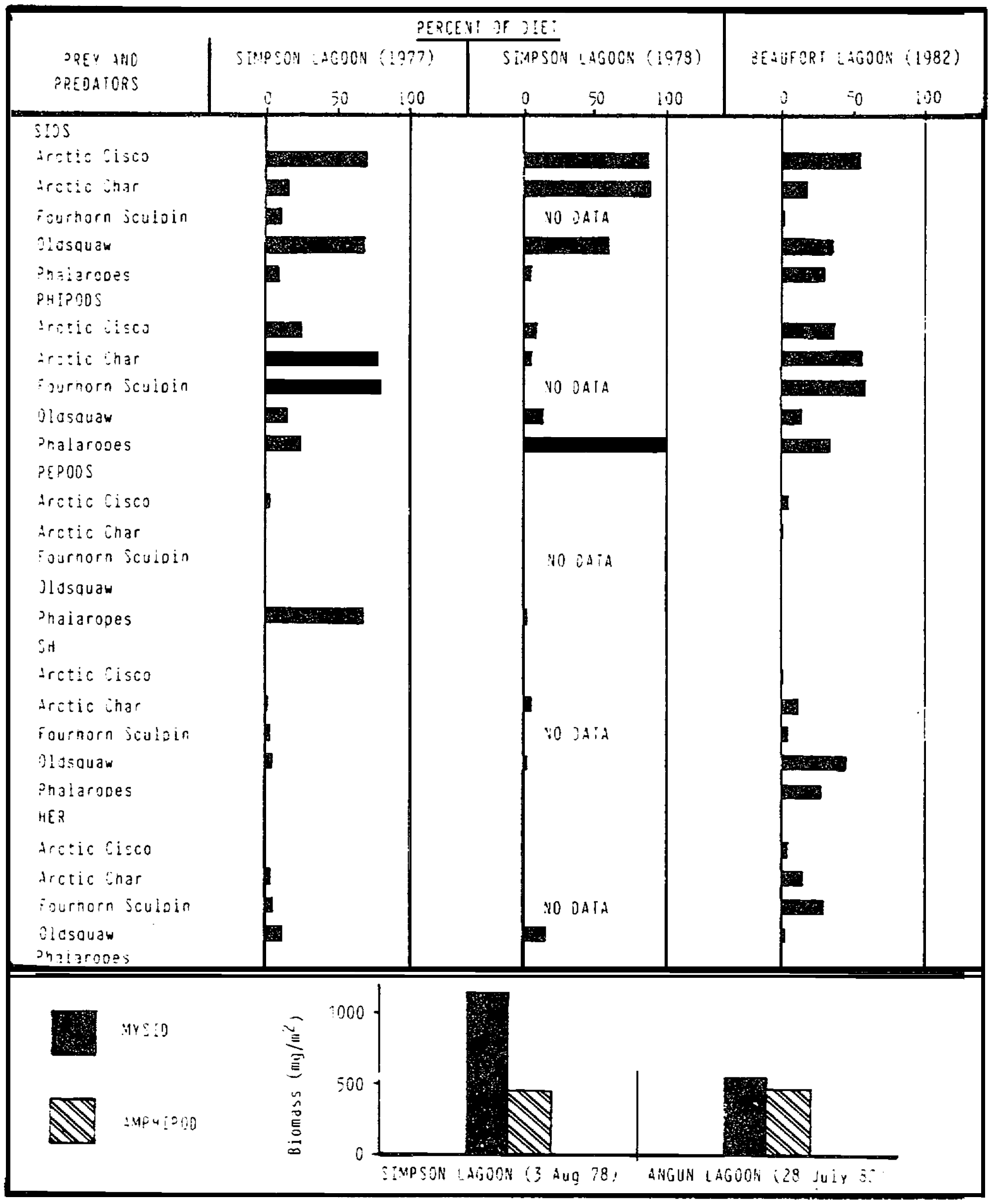


Figure 1-10. Percent composition of identifiable prey items in predator diets in two lagoons on the Alaskan Beaufort Sea coast (TOP), and mid-summer estimates of biomasses (wet weight) of mysids and amphipods in the two lagoons (BOTTOM). (From Griffiths and Dillinger 1981; Johnson and Richardson 1981; Griffiths, this volume; Jewett and Feder, this volume; and Johnson, this volume.)

appear to be somewhat more important to birds in Angun and Beaufort lagoons than they were in Simpson Lagoon.

Invertebrates

The relative proportions of mysids and amphipods in vertebrate diets appear to reflect in most cases the relative abundances of these invertebrates in the environment. Figure 1-11 shows vertebrate diets in Simpson Lagoon and Beaufort Lagoon compared to measured invertebrate biomass in each lagoon. The measured biomass of mysids in Simpson Lagoon in 1978 was about 2.5 times the biomass of amphipods, and correspondingly more important in vertebrate diets. The biomass of mysids in Angun Lagoon in 1982 was about the same as that of amphipods, and mysids were generally less important in vertebrate diets in Angun Lagoon than they were in Simpson Lagoon.

One discrepancy in this pattern is that phalaropes did not select between mysids and amphipods according to the measured relative abundances of these invertebrates. However, phalaropes feed along lagoon edges, and not in benthic environments where the invertebrates normally live and where they were sampled. Moreover, food available to phalaropes depends on how winds and currents selectively deliver food to the coastal fringe as well as on the relative abundance of food types there available to be transported. That these patterns of delivery can be highly variable is suggested by the great variability in phalarope diets, both between years and between places (see Fig. 1-10).

Figure 1-11 implies that relative to amphipods, mysids are more abundant in open lagoons than in closed lagoons--this pattern appears in epibenthic samples taken by scientists as well as in diets of vertebrates. Whether mysids would always be more abundant in open lagoons than in closed lagoons is an important issue related to the utility of lagoons to vertebrates. Figure 1-12 compares biomass estimates of mysids and amphipods for an additional year (1982) in Simpson Lagoon to those of Simpson Lagoon in 1978 and those of Beaufort Lagoon in 1982. The relatively great abundance of mysids appears in both years in Simpson Lagoon, though the total biomass of both amphipods and mysids is different between years. The 1982 sample size in Simpson Lagoon was small, however

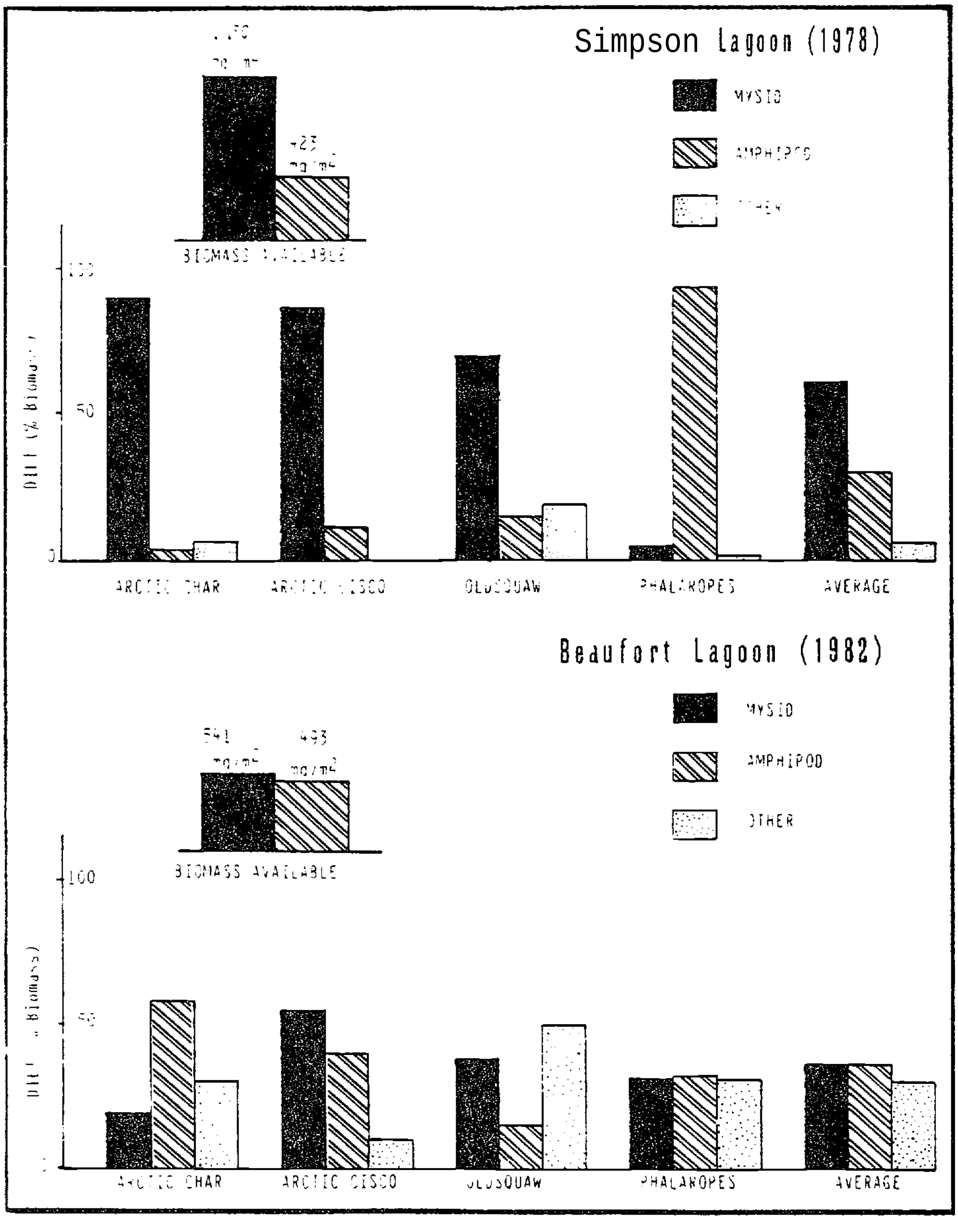


Figure 1-11. Percent biomass of mysids, amphipods, and other items (mainly copepods and fish) in diets of consumers in two coastal lagoons, Beaufort Sea, Alaska. Biomass available in benthic environments as estimated by drop-net sampling is shown . Data from Griffiths and Dillinger (1981); Johnson and Richardson 1981; Griffiths, this volume; Jewett and Feder, this volume; and Johnson, this volume.

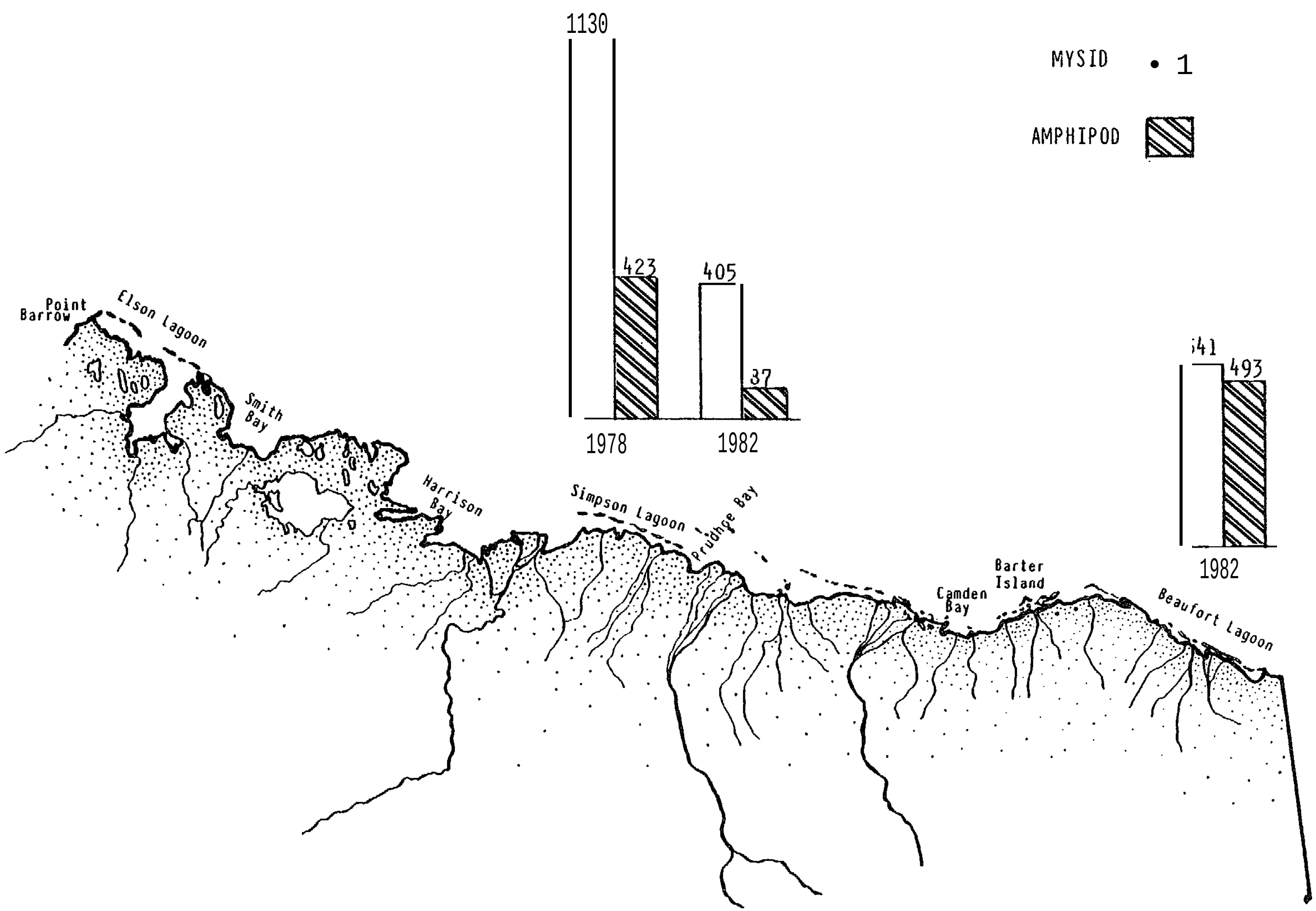


Figure 1-12. Biomass estimates (mg wet wt/m^2) of mysids and amphipoda in Simpson Lagoon (3 August 1978 and 4 August 1982) and Beaufort (Angun) Lagoon (28 July 1982). *Mysis litoralis* and *M. relicts* comprised essentially all the mysid biomass in all cases. Among amphipods, *Onisimus* spp. dominated in Simpson Lagoon and *Gammarus setosus* dominated in Angun Lagoon. Data from Gifttiths and Dillinger (1981) and Jewett and Feder, this volume,

[see Appendix C in Jewett and Feder (this volume)], and, because there is great spatial variability in invertebrate abundance, the data should be interpreted with caution.

As shown by Hachmeister and Vinelli (this volume) and as we shall summarize later, the rates of water exchange between relatively closed lagoons and the sea, compared with those between open lagoons and the sea, are low. This further supports the notion that open lagoons may have more mysids than amphipods [Amphipods, especially Gammarus setosa, the dominant one in Beaufort Lagoon, are more likely to be permanent residents of lagoons than are mysids, which appear to need replenishing each spring from an adjacent reservoir in the deeper waters of the shelf (Griffiths and Dillinger 1981).] The immigration responsible for this annual replenishment is suspected to be current-assisted (Griffiths and Dillinger 1981), thus mysids should move more rapidly into open lagoons than into closed lagoons.

The shorebird component of lagoon consumers, as noted earlier, depend on the delivery of organisms to shorelines. Although no data exist to show any logical patterns of use between lagoon types, it appears that marine plankton, on which shorebirds along the Beaufort Sea frequently feed (Connors in prep.), would be less likely to reach shores of closed lagoons than shores of open lagoons.

Primary Production and Carbon Sources

Schell (this volume) found primary productivity in Angun Lagoon to be substantially lower than that reported for Simpson Lagoon on the central Beaufort coast. Based on samples analyzed, he estimated the annual primary production in Angun Lagoonto be about 1.6 g C/m^2, or about one-fourth that of Simpson Lagoon (5-7 g C/m^2). Cautioning that the great spatial and temporal variability expected in primary productivity measurements make his data and the between-lagoon comparisons inconclusive, he nevertheless gives possible reasons for the observed differences. He suggests that the lower expected rate of water exchange between Angun Lagoon and the sea beyond, coupled with water outside Angun Lagoon that is possibly less nutrient-rich than that outside Simpson

Lagoon, are potential reasons for lower production levels inside the lagoon.

Schell (this volume) likewise sought to determine carbon sources for food webs in Angun and Beaufort lagoons. He compared natural abundances of ^{13}C and ^{14}C in source materials (peat, terrestrial. vegetation, marine algae) with the abundances found in vertebrates at the top of the food web, following techniques of Schell (1983).

Schell's results were interesting. Arctic cisco (an anadromous fish) from Beaufort Lagoon had body carbon derived about half from marine modern (i.e. phytoplankton) production and about half from terrestrially-fixed carbon (of which two-thirds was "modern" carbon and one-third was "old", or peat, carbon). Further, arctic flounder, a marine fish resident in the nearshore environment (lagoons and outside lagoons), showed body carbon to have been derived only one-sixth from marine primary production, over half from terrestrial modern production, and over one-fourth from peat. These results suggest that Beaufort Lagoon vertebrates have land-based production (including peat) as a major source of carbon (i.e. a major portion of the prey of these vertebrates is feeding on *detritus* from land). In contrast, in Simpson Lagoon in the central Beaufort, Schell et al. (1982) reported both anadromous fish and marine fish to have almost entirely marine carbon sources.

The differences in carbon sources between arctic ciscoes in Simpson Lagoon and those in Beaufort Lagoon appear reasonable, considering that (1) arctic cisco diets in Beaufort Lagoon had much greater proportions of amphipods than did those in Simpson Lagoon and amphipods (especially *Gammarus setosus*, the dominant one in Beaufort Lagoon) are probably better adapted to utilizing peat and other terrestrial detritus than are mysids (Schneider 1980), (2) relatively low water exchange rates between Beaufort Lagoon and the sea (Hachmeister and Vinelli, this volume) should reduce marine-produced phytoplankton input and enhance terrestrial carbon retention, and (3) *in situ* plankton production is relatively low (Schell, this volume).

But to confound this explanation, an arctic char from Beaufort Lagoon had body carbon that showed to be 100% marine modern, and most char in Beaufort Lagoon had a higher proportion of amphipods in their diets than did arctic cisco. There are at least two possible explanations for this apparent contradiction, as follows:

1. Sample sizes of cisco and char analyzed for body carbon content were too small to show realistic trends (only two arctic cisco and one arctic char were analyzed). Perhaps the one arctic char analyzed did not reflect the diets of char whose stomach contents were analyzed (n=50; Griffiths, this volume). Maybe it had instead fed largely on organisms in the marine environment (arctic cod? mysids?) before it moved into the lagoon to be captured and sacrified. Observations from other studies (Gallaway pers. comm.) show that individual arctic char the size of the one analyzed may feed extensively on small cod in the Beaufort Sea nearshore zone.

2* The body carbon of fishes that were analyzed reflected partly the diets of fish previous to their occupancy of Beaufort Lagoon. It appears to take a few months for the body carbon of rapidly-feeding fish to be completely replaced by new carbon (Schell 1981) and presumably much longer for replacement of carbon in fish feeding at much slower rates (see Schell et al. 1982).

Arctic cisco caught in late summer in Simpson Lagoon and analyzed for carbon signature (Schell et al. 1982), had most likely been in the nearshore Beaufort Sea environment for two to three months prior to their capture (see Craig and Haldorson 1981). These fish had rapid rates of food ingestion (Craig and Haldorson 1981) and their carbon would be expected to reflect their diets in Simpson Lagoon or other coastal waters in the area. Moreover, many arctic cisco in the central Beaufort Sea appear to spend most of the winter on marine-derived food webs in the Colville River Delta (Schell pers. comm.).

On the other hand, arctic cisco in Beaufort Lagoon might have overwintered in the Mackenzie River Delta (see

Gallaway et al. 1983) and might have come as recently as a few weeks before their capture from overwintering sites (see Bond 1982). These Mackenzie River Delta overwintering areas exhibit freshwater or brackish water characteristics throughout winter and at least some fish there eat different organisms [e.g. polychaetes, that perhaps feed on terrestrial detritus (Bond 1982)] than they do in other Beaufort Sea coastal zones.

To further this second line of reasoning, arctic char may not consume enough food in freshwater habitats where *they* spend the winter to appreciably alter their body carbon signature over winter. D. Schell (pers. comm.) reports that a char caught in the upper Sagavanirktok River in winter showed marine modern body carbon composition. McCart (1980) looked at data from over 2000 stomachs of char caught in fresh water. *Seventy-nine* percent of the stomachs were empty and most of the remainder contained small amounts of food. He believed that most char do not feed appreciably in fresh water.

Despite this second line of reasoning, it appears that at least some fishes in Beaufort Lagoon (i.e. the arctic flounder, which is relatively sedentary and which was found to contain high levels of terrestrially-derived carbon) must live partly from a terrestrial carbon based food web. Whether arctic cisco or arctic char are nourished appreciably by terrestrial carbon in Beaufort Lagoon remains unclear.

Two young of the *year* oldsquaw ducks collected in Beaufort Lagoon were also analyzed for body carbon composition (Schell, this volume). One was completely terrestrially-derived; the other was nearly half marine modern. These results are not surprising because young oldsquaws eat 100% terrestrial-based foods until they move to lagoons in mid- to late summer, at which time they switch to *a* lagoon-based food web (Schell et al. 1982). Depending on when they arrive at the coast, what they eat there and where, their body carbon from mid- to late summer might have any combination of marine and terrestrial carbon.

Physical Features and Processes

As we have seen, the principal physical phenomena affecting biota in the nearshore zone are wind, water quality, water mediated transport, landform morphology, and ice dynamics. There is extensive interaction among these--wind and landform morphology exert great control over water quality and transport, ice dampens the effects of wind on water movement in winter, and ice formation and movement affect water quality. Some physical features and processes are more important than others. For example, water movement and transport, and ice formation and thaw have relatively great direct effects on nearshore biota; wind and the morphology of landforms probably have less important direct effects (but important indirect effects). For lagoon organisms two of the most important habitat features are water quality in summer and water-borne transport between the lagoon and sea. Both are controlled by the rate and nature of water exchange between lagoon and sea.

Hachmeister and Vinelli (this volume) and Schell (this volume) demonstrate several biologically important aspects of lagoon-marine exchanges in summer:

1. Angun Lagoon and Pokok Bay (and certainly other relatively closed lagoons) have much more limited rates of exchange with the sea than do open lagoons such as Simpson Lagoon in the central Beaufort Sea. On the average Simpson Lagoon waters might be exchanged once every 3-4 days (Matthews 1979); Angun Lagoon waters (especially those farthest from entrances) turn over more slowly--on the estimated order of 8-10 days (Schell, this volume) or much longer (Hachmeister and Vinelli, this volume).

2. Exchange between Angun Lagoon and the sea is driven mainly by changes in sea level caused by diurnal tides and wind-driven events. These sea level changes cause water to flow

into or out of' the lagoon as the adjacent sea rises or falls. Wind-driven exchange appears to dominate in terms of amounts of water exchanged, because sea level changes caused by tides are relatively small (Hachmeister and Vinelli, this volume).

3* Exchange rates in open lagoons are much faster than those in closed lagoons, primarily because open lagoons have open ends, such that wind-driven water flows directly through the lagoons regardless of sea level change. Thus water in open lagoons tends to have qualities more nearly similar to the adjacent sea. Water quality in closed lagoons is more affected in summer by inputs they receive from land and by warming effects of the sun.

4. Exchange patterns at Angun Lagoon entrance show net seaward transport at the surface and net lagoonward transport near the bottom (Hachmeister and Vinelli, this volume). Westerly winds generally force surface waters onshore and into the lagoon; a warming of lagoon waters occurs during such events. Easterly winds drive the warm, less dense surface waters seaward and transport colder, saline water landward and eventually into the lagoon at the bottom, lowering lagoon water temperatures. This kind of exchange pattern has been hypothesized to occur in Simpson Lagoon and other coastal localities (Truett 1981a); Hachmeister and Vinelli's data suggest that this surface-to-bottom pattern of exchange should occur in summer at all coastal locations, only that the rates of exchange would be slower in closed types of lagoons.

5. Upwelling normally occurs on the outer shelf beyond the nearshore zone (Aagaard 1981; Hachmeister and Vinelli, this volume). There may be nearshore effects of upwelling, but the connections between upwelling events offshore and water exchange in the nearshore zone have not been demonstrated by

this study. Neither has evidence been presented so far that shows whether upwelling should have greater effects along particular segments of the coastline.

Schell (this volume) has discussed winter aspects of lagoon-marine exchanges and cross-shelf transport. He shows that, as ice forms on lagoons and other shallow nearshore waters in winter, solutes excluded from the ice increase the density of the underlying water. This dense water flows downslope (across the shelf), carrying with it nutrients (nitrates) from the nearshore zone, and probably eventually reaching the deep ocean beyond the shelf break. Less saline seawater moves landward beneath the ice to replace the dense water (Matthews 1981a,b). The dense water and its nutrients are thus lost to the nearshore zone, unless upwelling as described by Aagaard (1981) and Hachmeister and Vinelli (this volume) reintroduces it in summer.

In theory, loss of this high-salinity water from closed lagoons would be less rapid than that from open lagoons, which have broader exits to the sea. The movement of the dense water downslope would certainly be hindered by longshore sills or bars. But different exchange rates in winter between lagoon and sea among the different lagoon types have not been demonstrated.

The characteristics of ice dynamics have not been addressed by new research in this study. Based on other studies (reviewed earlier in this chapter), it appears that the dynamics of ice formation and melt, and the associated physical and biological processes, are generally similar in most places along the coastline. The pattern may be different locally. Ice forms slightly earlier in fall in protected lagoon and bay waters. Inputs of water masses from outside (Bering Sea intrusion near Barrow, discharge of streams in late spring) cause early ice-melt in spring. As noted above, perhaps shallow lagoons relatively closed to the sea become more saline in late winter and spring as brine is excluded from the overlying ice than do deeper and more open lagoons.

Biological implications of the differences in physical features and processes among lagoon types are several. Major biological consequences of these differences are as follows:

1. Closed lagoons may be physically more attractive to anadromous fishes, and perhaps to epibenthic invertebrates in late summer than are open lagoons, because water temperatures tend to be higher. Lagoon depths, freshwater inputs to lagoons, and water temperatures of the sea outside lagoons being equal, closed lagoons should be usually warmer than open lagoons because their rates of water exchange with the sea are slower. Freshwater inputs and insolation add heat to lagoons in summer; exchange with deeper shelf waters removes heat. Some of the anadromous fishes (Fechhelm et al. 1982), and probably some of the epibenthic invertebrates (see Truett 1981b) prefer the highest temperatures that exist in nearshore environments in the Beaufort Sea, which are probably found in areas relatively closed to exchange with the sea.

Data to show conclusively that closed lagoons become warmer than open lagoons in summer do not exist, though temperatures have been measured in both. Unmeasured variables other than the degree of lagoon closure that affect temperature have been too many. But measurements taken in the Simpson Lagoon (open lagoon) area compared with those taken in Angun Lagoon (closed lagoon) suggest temperature differences between lagoon and ocean to be greater at Angun Lagoon. In early August 1978, bottom water temperatures inside Simpson Lagoon averaged about 1°C warmer than those at a station about 2 km seaward of the lagoon (Griffiths and Dillinger 1981). In late July and early August 1982 bottom water temperatures inside Angun Lagoon averaged 4-5°C warmer than those about 2 km seaward of the lagoon (Jewett and Feder, this volume), and about 4°C warmer than seawater entering the lagoon during flood tides (Hachmeister and Vinelli, this volume). Moreover, elongate closed lagoons such as Angun and Beaufort should have "dead" regions of very slow water turnover (see Hachmeister and Vinelli, this volume) where water temperatures in late summer remain considerably above those of mean lagoon temperatures. Few parts of open lagoons would normally have such low-turnover areas.

2. Important epibenthic materials and organisms (e.g. sinking phytoplankton cells, mysids) are probably transported to and retained in lagoons (both open and closed types) in summer. Because of the net landward transport that occurs at the bottom in nearshore waters and into lagoons (Hachmeister and Vinelli, this volume), and the relatively "quiet" epibenthic environments in lagoons as opposed to outside lagoons, all lagoons probably act as sinks in summer for bouyant epibenthic materials. The evidence supporting this contention has been reviewed by Truett (1981a); information lending additional support to the idea is presented in Hachmeister and Vinelli (this volume).

39 Marine organisms and food web materials annually depleted in lagoons and replenished later by transport (e.g. marine detritus, phosphorus, mysids) are likely to be less abundant' in closed lagoons than in open lagoons. Comparisons between this study and studies made in Simpson Lagoon help support this hypothesis. Mid-summer ratios of mysids (which normally leave shallow lagoons in winter and re-enter them in spring) to amphipods (many of which overwinter in lagoons) appear to be lower in Angun Lagoon than in Simpson Lagoon (cf Jewett and Feder, this volume; Griffiths and Dillinger 1981). Rates of primary productivity are lower in Angun Lagoon than in Simpson Lagoon, possibly reflecting lower nutrient (phosphorus) input rates from the sea (Schell, this volume). More of the food web in Angun Lagoon appears based on terrigenous carbon, possibly indicating that marine carbon inputs are lower than in Simpson Lagoon (Schell, this volume). None of these supporting indications is conclusive because of the expected high annual and spatial variability in data.

Most of the vertebrates found in coastal Beaufort Sea waters use these areas for feeding (and molting in the case of oldsquaws and ringed seals) or simply as pathways of movement between summer and winter habitats. There are a few exceptions--some ringed seals use deeper nearshore areas as birthing habitat in spring; common eiders, glaucous gulls and arctic terns nest on barrier islands in the area, and fourhorn sculpin and arctic flounder apparently breed in nearshore waters. But for the great majority of individual animals, including the most economically and visually prominent ones, the area is simply foraging habitat.

A large proportion of the vertebrate species and their major prey groups are relatively uniformly distributed among major longshore segments (eastern, central, western) of the nearshore environment, but others occupy specific segments of coastal waters (Fig. 1-13). Ringed seals, oldsquaws, shorebirds (as a group), arctic char, arctic cisco, arctic cod, arctic flounder, and fourhorn sculpin show generally few differences in abundance among major east-west parts of the nearshore zone. The crustacean prey base (mainly mysids and amphipods) of these vertebrates likewise appears abundant throughout the nearshore zone. Other vertebrates--spotted seals, common eiders, brant, Canada goose, the gulls and alcids, least cisco, broad and lake whitefishes, and boreal smelt--show marked differences in abundance among coastal regions.

The primary factors that regulate the distribution of animals using the nearshore zone appear to be (1) physical habitat features within the nearshore environment and (2) the proximity of locations where animals breed, molt, or overwinter outside the nearshore environment (Table l-l). Differences in food availability among the segments of the nearshore zone appear to not influence vertebrate distribution.

Animals (and their prey) are frequently not uniformly distributed within coastal segments, even though they may be more or less equally abundant among major segments of the coast. Here again, the factors that cause this uneven distribution appear to be (1) physical phenomena--ice dynamics, emergent landform configuration, water temperature and salinity--or (2) phenomena originating outside the Beaufort Sea--river discharge, breeding and overwintering sites of biota--rather than food

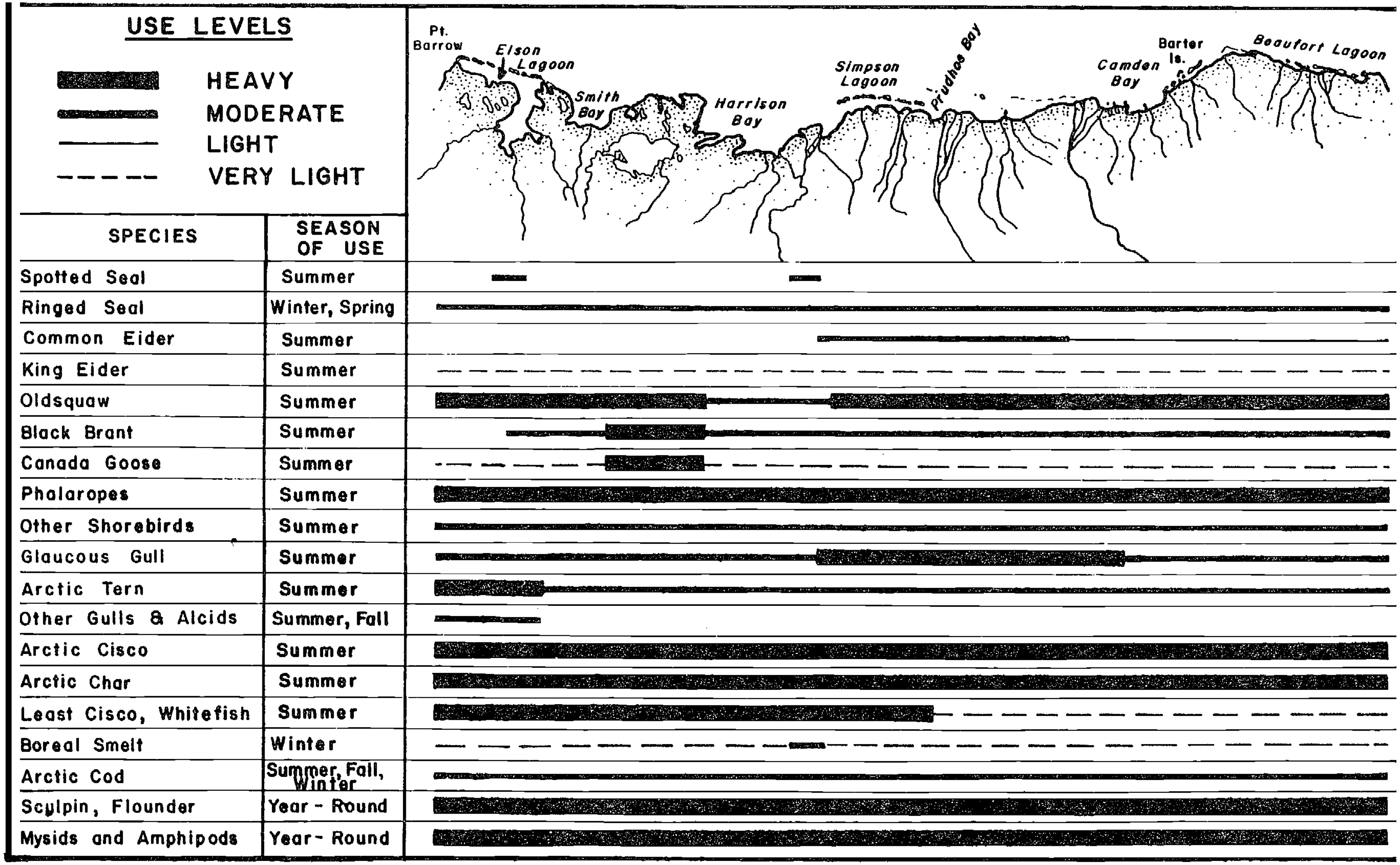


Figure 1-13. General levels of use of longshore segments of the Alaskan Beaufort Sea nearshore zone by important faunal species and groups.

Table 1-1. Factors that influence animal distributions in or use of the Alaskan Beaufort Sea nearshore area.

Animal	Water Depth	Emergent Landform (Configuration, Surface Quality)	Water Temperature and Salinity	Water Inputs From Adjacent Seas, Rivers	Nearshore Ice Dynamics	Breeding/Molting Distribution Elsewhere	Food Abundance
Bowhead whale	X		X	X	X	X	X
Spotted seal	X				X	X	
Ringed seal					X		
Common eider		X		X	X		
King eider					X		
Oldsquaw	X		X		X		
Black brant		X			X	X	X
Canada goose						X	X
Phalaropes		X			X	X	
Other shorebirds		X				X	
Glaucous gull		X		X			
Arctic tern		X					
Other gulls & alcids		X		X		X	?
Arctic cisco			X				
Arctic char			X				
Least cisco & whitefishes			X			X	
Boreal smelt						X	
Arctic cod		?	?				
Sculpin & flounder			?				
Mysids	X	X	X				
Amphipods	X		X				

supply within the nearshore zone (see Table 1-1). For example, oldsquaws congregate in parts of lagoons or bays protected from wind by spits or barrier islands; common eiders and glaucous gulls prefer to nest on islands influenced by river discharge in early summer; anadromous fishes congregate in the very shallow (warmest) waters within lagoons and bays.

We conclude that food for vertebrates is probably always available in the nearshore zone in excess of the needs of the vertebrates, despite the relatively low productivity of the Beaufort Sea in comparison to other seas. Physical features or processes that occur in the Beaufort Sea, or phenomena beyond the Beaufort Sea, generally prevent the vertebrates from using a large proportion of the available food supply. Thus, although the nearshore zone is used by the animals that occur there primarily for foraging, factors other than food regulate how many animals use the area and where the use is concentrated.

CHARACTERIZATION AND COMPARISON OF VULNERABILITIES

The preceding sections have described the lagoons, bays and other shallow waters of the Alaskan Beaufort Sea nearshore zone and the uses of these areas by vertebrates and their food web components. As we have seen, there are obvious physical differences among longshore segments of the coast. Many coastal areas are partly separated from the sea by chains of barrier islands or spits of land; others are open to the sea. Some coastal areas receive discharges from large rivers; other areas have no appreciable stream inflows. Bays and lagoons are shallow, normally a maximum of a few meters deep, but shelf waters fronting open coasts, or beyond islands and spits of land deepen relatively rapidly as one proceeds seaward. We have seen also that some, but not all, of these differences affect how animals use the nearshore zone.

The purposes of this last section are to (1) characterize these shallow coastal environments, using descriptive criteria to which vertebrates and their food web components appear to respond, and (2) based on that characterization, compare levels of vulnerability of the various areas to adverse impact from oil and gas development. We define vulnerability to mean <u>the susceptibility of sites to perturbations that adversely affect biota</u>. Vulnerability differs from 'sensitivity".

Sensitivity has been previously used in the Beaufort Sea to describe where and when animal populations congregate for some important life function and thus might be vulnerable. Vulnerability refers to the likelihood that oil and gas development will in fact cause adverse population-level effects. Thus vulnerability of an area depends on (1) whether animals use the area, and (2) whether adverse effects to animals will occur because of development.

Coastal Characterization

In this section, the Alaskan Beaufort Sea nearshore zone is characterized in terms of eight physical and biological variables (see Table 1-1) that affect biota or the impacts of OCS development on biota. For each variable we discuss its range of variability among longshore segments of the coast, how biota responds to this variability, and what this implies about relative vulnerabilities among coastal segments.

Bathymetry

Maximum depths of coastal lagoons and bays usually range from about 2.5 m (8 ft) to about 4 m (13 ft) (Figs. 1-3 to 1-9). There are several shallower areas and one deeper area. The shallower sites are usually depositional environments fronting river deltas (Gwydyr Bay, Fig. 1-6; neashore Harrison Bay, Fig. 1-5). The only lagoon appreciably deeper over larger areas than 4 m is Stefansson Sound (Figs. 1-6 and 1-7), the widest lagoon along the coast.

Ranges of normal maximum depth among lagoons are sufficiently small that one would expect there to be few depth-related differences in biological use. Among most lagoons none attributable to depth have been reported. But sites shallower than 2 m, and the one deeper area (Stefansson Sound) exhibit some differences in biological use. The shallow sites have a depauperate infauna and a highly seasonal epifauna (because waters freeze to the bottom in winter); they also exhibit decreased levels of vertebrate use. In winter all vertebrates are excluded; in summer oldsquaw use appears relatively low in some (Gwydyr Bay) (Johnson, this volume). The deep lagoon, Stefansson Sound, contains a benthic boulder field with a biological assemblage that is unique in the Beaufort Sea. Also in contrast with other lagoons, it appears to have a consistently higher level of use by arctic cod (particularly in winter), and a lower level of use by anadromous fishes. In essence it is more ocean-like, partly because of its depth, and its fauna is correspondingly more nearly marine.

Among most lagoons, vulnerability of the biota to OCS activities as a consequence of depth would not seem to vary. But because shallow areas have low levels of biological use, and because Stefansson Sound (partly because of its depth) has different biological assemblages, the consequences of activities in these places would be different than they would in most bays and lagoons.

Emergent Landforms

Emergent landforms (islands, spits, mainland shores) are important because of their location and configuration in relation to nearshore waters and because of the quality (substrate type, presence of driftwood and debris, etc.) of their surfaces.

Configuration. Landform configuration is highly variable from place to place. Barrier islands or spits skirt Elson Lagoon (Fig. 1--3), Simpson Lagoon (Fig. 1-6), Stefansson Sound (Figs. 1-6 and 1-7), lagoons near Barter Island (Figs. 1-8 and 1-9), and Beaufort and Siku lagoons (Fig. 1-9); other parts of the coast are relatively open to the sea. Islands distant from the coast make wide lagoons (Stefansson Sound); those near land bound narrow lagoons (Beaufort and Siku lagoons). Some bays are relatively isolated from the ocean because of landform configuration (Admiralty Bay, Fig. 1-3); others are open to the sea (Harrison Bay, Fig. 1-5).

Variability in landform configuration causes great variability in vertebrate use from, place to place. Common eiders, oldsquaw ducks, most shorebirds, glaucous gulls, arctic terns and guillemots are attracted to barrier islands and spits, or to lagoon areas sheltered by islands and spits (Table 1), to feed, molt, or nest. Coasts without islands or spits are used less commonly or not at all by these birds.

Anadromous fishes are probably more abundant in coastal areas that have lagoons or bays than they are elsewhere, because warm water in such areas extends farther seaward, providing more foraging habitat per longshore distance. (The density of these fish may be just as great along open coasts, but the width of shelf used there is probably much narrower.) The habitat preferences of the marine fourhorn sculpin and arctic flounder suggest that they also would be more abundant in segments of coastal waters bounded by islands and spits.

Because densities of some birds (i.e. oldsquaws) and some fishes are similar among most lagoons, the width of lagoons influence how many birds and fish use them. That is, the wider the lagoons are (i.e. the farther the islands are from land), the more oldsquaws, anadromous fish, and marine fish., they support. But in lagoons as wide as Stefansson Sound (Figs. 1-6 and 1-7), use levels per surface area by oldsquaws and anadromous fishes appear to diminish (see Johnson, this volume), such that the numbers of the vertebrates per longshore distance may not be greater than in lagoons of moderate width.

The vulnerability of biota to development activities should vary greatly from place to place as a consequence of landform configuration. Animals that use barrier islands (eiders, gulls, terns, shorebirds) are vulnerable because islands are lucrative sites for drilling or staging activities related to development, and these animals have few alternative sites to use. The vulnerability of animals that use coastal waters relates mainly to oil spills or other contaminants that might affect oldsquaws, fishes and food webs. Bays or lagoons with a few small entrances would seem to make animals in those coastal areas less vulnerable than animals in open lagoon areas, if one reasons as follows. If oil is spilled outside closed lagoons, it could be easily prevented from entering lagoons, thus protecting areas of vertebrate use. If oil is spilled inside a closed lagoon, it could be easily contained, preventing it from reaching other lagoons and bays in the area. In open lagoons, however, oil could not be readily prevented from either entering or leaving.

Surface Quality. Surface quality of emergent landforms varies greatly among places. Presence or absence of driftwood or debris appears to be the most important quality to animals that use islands. Some islands in the Western Beaufort (Cooper Island, Fig. 1-3) are littered with lumber. Some islands near river mouths (Thetis Island, Fig. 1-5) are littered with driftwood. Most islands have relatively small amounts of litter.

Whether litter is present appears important to birds. For example, terns on Cooper Island and common eiders on Thetis Island nest in or near debris; these birds are scarce or absent from islands with no litter. Presence of debris appears to be affected by the proximity of islands to human settlements or to mouths of large rivers that drain timbered inland areas.

Vulnerability of islands in terms of the birds that use them appears high. OCS development is attracted to islands. If development occurs in summer, it may disturb birds. When sites of development are abandoned, they are typically left clean (i.e. without debris), which may have adverse impacts on birds that prefer debris in which to nest.

Water Temperature and Salinity

Water temperature and salinity in summer vary appreciably from place to place in the nearshore zone. Much of the variability is caused by differences in configuration of coastal landforms superimposed on differences in amounts of freshwater discharged from land into the nearshore environment. Landform configuration affects temperature of nearshore shallows by moderating the rate of water exchange between the warm shallows and the colder, saline waters farther offshore. The more ‘closed” lagoons and bays exchange more slowly and remain warmer on average than more open systems. River discharge raises temperature and lowers salinity in areas near river deltas.

Temperature (as opposed to salinity) in summer appears to be the main water quality factor to which anadromous fishes respond. Because fish prefer warm water, closed lagoons and waters fronting river deltas should be most attractive to them. Small individuals of some anadromous fishes may indeed exhibit preferences for these kinds of sites (see Griffiths, this volume). Arctic flounder had higher young:adult ratios in Angun and Beaufort lagoons than in Simpson Lagoon. Small arctic cisco and small arctic char were present in greater proportions than adults directly off the Sagavanirktok River Delta than in several locations in lagoons.

No preference patterns that appeared related to mean temperatures of coastal lagoons or bays appear in adult anadromous fish. Note, however, that waters very near shores (mainland or lagoonsides of islands) is always relatively warm in the open-water season (see Griffiths, this volume) and appear to attract anadromous fish.

By altering the configuration of emergent landforms (building solid-fill causeways, etc.), industry may alter temperature regimes in the nearshore environment. This temperature change may have the potential for altering habitat use by small fish, but seems less likely to affect large fish. Waters in closed lagoons or fronting deltas of large rivers may be more vulnerable to biological effect via temperature alteration because small fish may congregate there in summer.

Winds and Water Circulation Patterns

Patterns of wind speed, wind direction and the effects of wind on coastal water movement are not in themselves expected to vary among coastal locations (Kozo, this volume). The major variable that alters the effect of wind on biota and on water movement patterns is configuration of emergent landforms. Because landforms are different from place to place, wind effects on biota and on water movement and exchange patterns are different among coastal locations. These differences may cause local differences in four things that affect biota--water temperature (discussed above), transport of food web components (epibenthos) into nearshore waters, trajectories of pollutants (oil) in nearshore waters, and direct effects of wind on biota.

Existing evidence suggests, as discussed earlier, that nearshore bays and lagoons relatively closed to the sea tend to receive less biomass of mysids and other marine-derived invertebrates in summer than do open lagoons. Transport of invertebrates into these areas is probably slower than it is into open lagoons and bays. The effect of this on vertebrates is questionable. Food abundance, though variable among years and lagoon types, has not been shown to affect the abundance or well-being of vertebrates, which appear to be flexible in their requirements for prey.

The trajectory and depositional fate of oil in nearshore waters will probably be strongly affected by landform configuration. Closed lagoons would probably be less vulnerable, partly because they are more easily protected by contingency measures, than would open lagoons and bays, as was discussed above.

The ability of oldsquaws to find protection from wind and rough water depends on the existence and configuration of islands, spits, and points of land. The availability of protective landforms certainly varies among parts of the coast.

Thus, although wind and water movement contribute to the vulnerability of coastal habitats, the configuration of landforms really controls how these affect the vulnerability of each part of the coast. The effects of emergent landforms on the vulnerability of coastal biota were discussed above.

Water Inputs from Streams and Oceans

Water inputs at major stream deltas along the coast, and from the Chukchi Sea (Bering Sea water) in the extreme western Beaufort Sea near Barrow, alter the character of the coastal waters in those areas. In early June of each year, stream discharge melts sea ice in front of the Colville, Kuparuk, Sagavanirktok, Canning and smaller rivers before ice melts elsewhere. Waters quickly become fresh or brackish here, and remain warmer and more brackish through summer. In the western Beaufort Sea in summer, an intrusion of Bering Sea water rounds Pt. Barrow, strongly affecting nearshore water quality and perhaps fertility in that area.

Animals respond to these inputs. Portions of oldsquaw, king eider, common eider, black brant, and other waterfowl populations migrating along the coast in spring congregate near river deltas where the water is open. Common eiders and glaucous gulls apparently prefer islands surrounded by this discharge on which to establish nests. Small arctic char and arctic cisco may prefer waters off river mouths in summer. Waterbirds not found elsewhere in the Beaufort Sea congregate near the Bering Sea water intrusion to feed in summer.

Differences in vulnerability related to these inputs occur mainly because some animals that congregate near these inputs are not found elsewhere, and are therefore not vulnerable elsewhere. Thus waters near river deltas are the only places where many birds are vulnerable in early summer. Young of arctic cisco and arctic char may be more abundant there during the open-water season and thus disproportionately vulnerable as an age group. Assemblages of birds unique to the Beaufort Sea are present at Barrow. There seem to be no reasons why animals in these areas of input should be more vulnerable to oil and gas development than they would if they occurred elsewhere.

Ice Dynamics

As noted in the previous chapter, there are few biologically significant differences among coastal regions in ice dynamics and ice characteristics in the nearshore zone. Differences include a wider zone of landfast ice in some sections than in others, more recurring open leads in winter near Pt. Barrow than elsewhere, and earlier breakup near river mouths (discussed above).

Animals that may respond to these differences include spring migrants of waterfowl (discussed above), spotted and ringed seals, and some shorebirds in mid-summer. In some areas where landfast ice is relatively extensive and the water is relatively deep (e.g. Stefansson Sound), there may be more ringed seals per unit distance of coastline than in other areas, but we could find no data to support this. It is possible that spotted seals occupy the Admiralty Bay and Colville Delta areas because these sites are ice-free earlier than many other areas, but this is speculative. The Barrow area has been postulated to be used more by shorebirds in mid-summer because open coastal water sometimes occurs sooner there than elsewhere, but this is likewise speculative.

In summary, there may be differences in use of the nearshore environment caused by differences in ice conditions among areas, but little evidence exists to demonstrate this. Any differences in vulnerability of coastal biota among areas caused by difference in ice dynamics seem speculative at best.

Proximity to Sources of Animal Populations

Proximity of coastal areas to sources of animal populations strongly affect the intensity of use of areas by some species, as noted in the previous chapter. Spotted seals may be common only in the western Beaufort Sea partly because these areas are closer to the seal source (Chukchi and Bering seas). Black brant, Canada geese, red phalaropes and perhaps other shorebirds are more abundant along portions of the western Beaufort coast in late summer, and red-necked phalaropes along the eastern Beaufort coast, simply because population sources of these birds are nearby. Black brant in early summer feed more commonly near river deltas than elsewhere because they nest in higher densities in river deltas. Least cisco and broad and humpback whitefishes distribute themselves along the coast within certain distance limits from freshwater natal and overwintering areas.

The implication of these patterns to vulnerability of the biota is straightforward. Where the animals are more numerous along the coast, greater numbers stand to be affected by development activities in the area. There seems to be no relationship between coastal proximity of populations and vulnerability of coastal. habitats or food webs.

Abundance of Food Web Components

There is no discernible difference in use of coastal waters by vertebrates that can be attributed to differences in food abundance among areas, except in the case of terrestrial grazers (black brant and Canada geese). These two species (in addition to selecting coastal sites near their Cape Halkett molting area) also selectively feed in salt marshes and other low-lying vegetation communities near the coast. These types of areas are, coincidentally, relatively vulnerable to pollution by sea-borne oil, because they are commonly inundated by storm surge.

Summary and Conclusions

The foregoing characterization of coastal environments in the nearshore Beaufort Sea, and evaluation of responses and vulnerabilities of biota as a consequence of spatial differences in characteristics, may be summarized as follows:

1. Some environmental characteristics that influence animal use of the Beaufort Sea coast do not vary enough in amplitude among longshore segments of the coast to cause much difference in animal use among coastal segments. These characteristics include ice dynamics, water depth, water temperature and salinity, and food abundance. Though each may be highly variable on a micro-scale, they usually do not seem to influence how animals distribute themselves among major coastal segments. There may be exceptions, as we have seen--(a) spotted seals and some birds may respond to early ice-free water in the western Beaufort, (b) very deep (Stefansson Sound) and very shallow (Gwydyr Bay) lagoons have different biotic assemblages and use patterns, (c) small fish of some species may congregate in segments where water is warmer, and (d) brant and geese find better food at selected locations.

2. A relatively few environmental characteristics of coastal areas strongly influence how vertebrates distribute their use among the segments of the coast. These are configuration and surface quality of emergent landforms, proximity of coastal areas to sources of animal populations, and water inputs from adjacent streams and seas. The use patterns of all vertebrate species that have a non-uniform longshore distribution are affected by one or more of these three characteristics.

How animals do or do not respond to spatial differences in coastal characteristics implies something about the vulnerabilities of the biota, as follows:

1. Animal distribution and use patterns are most sensitive to changes in three factors--configuration and surface quality of emergent landforms, distribution of animals elsewhere, and water inputs from adjacent streams and seas. The latter two of these three are controlled by conditions elsewhere, and are not likely to be affected by man's activities in nearshore shelf waters. Thus, change in configuration or surface quality of barrier islands, spits, points of land, and other emergent landforms in or adjacent to nearshore waters is one of the few important avenues of vulnerability of biota to OCS development activity.

2. Development-caused changes that do not exceed normal ranges of ice events, water depths and general bathymetric configurations, water temperatures and salinities and vertebrate food abundance are unlikely (in most cases) to cause changes in vertebrate abundance, distribution or use patterns. The fact that there is large spatial variability in most of these characteristics, but not corresponding variations in animal use patterns, implies that vertebrates are extremely resilient to change in these characteristics.

3* Because biota using the nearshore Beaufort Sea appears to be relatively resilient (invulnerable) to most large-scale habitat or food web changes, we believe that the greatest potential for adverse effects on biota of OCS oil and gas activities in the nearshore Alaskan Beaufort Sea is through direct pollution-caused (e.g. resulting from oil spills) mortality or morbidity of animals, or in some cases, pollution-caused losses of food bases. Oil poses the greatest threat to water birds swimming or feeding in nearshore waters in summer (e.g. oldsquaws, phalaropes, gulls, terns). Spilled oil coupled with a storm surge could inundate coastal feeding habitats of geese, brant and shorebirds (e.g. salt marshes, stream deltas and other low-lying coastal wetlands). In comparison, aquatic food-chains and vertebrates that depend on them seem less vulnerable to adverse effects of oil spills.

Comparison of Vulnerabilities

As explained in the Coastal Characterization section above, relative vulnerabilities among longshore segments of the coastal environment depend on (1) the extent to which biota of concern uses a particular coastal segment, (2) the extent to which coastal characteristics that influence biota of concern are expected to be modified by development activities, and (3) the likelihood that accidentally-released pollutants (oil) will harm biota of concern or food sources to which biota have no good options.

A major problem in making objective comparisons of vulnerability among coastal regions is that each region hosts a different array of species, each of which has different levels of vulnerability to different kinds of development activity. Many arbitrary judgments must be made to devise detailed vulnerability scale or index. We do not believe that sufficient information exists to develop a complex rating system that is scientifically defensible.

Thus, instead of trying to develop a complex rating scheme, we will briefly summarize the apparent kinds and levels of vulnerability of four major nearshore habitats--open coasts, open lagoons, closed lagoons, and delta fronts--that appear to differ in which animals use them and in what kinds of development activity will be of most concern. Further, we will summarize which sections of the coast are unique in animal usage because of outside influences, and thus may require special considerations in making OCS leasing decisions.

Open Coasts

Several segments of the Alaskan Beaufort Sea coast are not protected from the open sea by barrier islands or headlands that partially enclose coastal waters. These include, from east to west: (1) east end of Elson Lagoon to east end of Harrison Bay (Figs. 1-3 to 1-5), and (2) short coastal sections in Camden Bay (Fig. 1-8) and east of Tapkaurak Lagoon (Fig. 1-9). By far the longest reaches are in the western Beaufort.

No species distributed widely along the coast show obvious preferences for these open areas, though post-molting black brant and Canada geese use the western area heavily because their inland molting area is nearby. (Goose and brant use of this open-coast area is probably more apparent than real, for we noted earlier that they congregate in the few coastal bays, salt marshes, and river deltas that exist in the region rather than using the waters exposed to the sea.) Anadromous fishes, fourhorn sculpin, arctic flounder and shorebirds occur along open coasts, but probably in fewer numbers than in lagoons and bays. Ringed seals and arctic cod, species essentially marine in habit, may be just as abundant in nearshore shelf' waters here as elsewhere.

The general vulnerability of these open coasts appears to be very low. They are open to seaborne oil spills, but few species that are particularly vulnerable to oil use these waters to any extent. It is difficult to imagine landform modifications that would adversely affect open coasts, except that long seaward-extending causeways might hinder migrations of some species of fish (e.g. the whitefishes). We do' not believe open coastal waters are vulnerable to other kinds of development actions.

Open Lagoons

Open lagoons (areas bounded by barrier islands but having relatively free exchange with the sea and with adjacent nearshore waters) occur mostly in the central Beaufort east of Harrison Bay and west of Camden Bay, and include Simpson Lagoon, Gwydyr Bay, Stefansson Sound (including Prudhoe and Foggy Island bays), and the lagoons and bays landward of Stockton and Maguire islands (Figs. I-6 and 1-7). Elson Lagoon (Fig. 1-3) has a barrier island configuration (and probably exchange patterns) that more nearly resembles the closed lagoons to be discussed below.

The number of vertebrate species common in open lagoons and the number of individual animals using open lagoons are large in comparison to those off open coasts and those in closed lagoons. Islands off open lagoons have higher numbers of common eider and glaucous gull (but not arctic tern) nests than islands off closed lagoons. Open lagoons tend to have more ringed seals, arctic cod and other pelagic species than do closed lagoons (but not necessarily than occur off open coasts). Data suggest that open lagoons host more oldsquaws and anadromous fishes (though not necessarily greater densities) than do closed lagoons or sections of open coasts.

Two additional factors add to the biological richness of open lagoons. First, because open lagoons in summer offer typically wide areas of warm, brackish water in comparison to closed lagoons (which tend to be narrower) and open coasts (where warm coastal waters mix rapidly with colder waters of deeper shelf areas), invertebrates important in food webs have larger areas of warm water where at least some (mysids) grow faster in summer. Invertebrates, like vertebrates, are apparently much more abundant overall (though perhaps not always per unit area) in open lagoons than in other coastal types. Second, at least one of the open lagoons (Stefansson Sound) has sufficient deep water protected from iceaction to have developed a unique benthic biological community (the 'Boulder Patch").

The vulnerability of open lagoons appears to be relatively high. Their islands are particularly vulnerable because they are lucrative sites for OCS development activity that may disrupt nesting activities of common eiders and gulls. Change in emergent landform configurations (e.g. construction of causeways), if extensive, could prevent access by fish to portions of the lagoons, or could cause shoaling that reduces lagoon depths and thereby makes them less attractive to vertebrates as feeding areas. Oil spilled inside an open lagoon might be difficult to contain therein; oil spilled outside an open lagoon might be difficult to keep out. Open lagoons host large numbers of molting oldsquaws, which are particularly vulnerable to oil on water.

Closed Lagoons

Closed lagoons (areas bounded by barrier islands and/or spits of land and having restricted avenues of exchange with adjacent nearshore waters) include Elson Lagoon in the western Beaufort (Fig. 1-3) and a series of lagoons and small bays from Barter Island to Demarcation Point in the eastern Beaufort (Figs. I-8 and 1-9). These (except for Elson Lagoon and the adjoining Dease Inlet) are narrower than the typical open lagoons on the central Beaufort coast.

Closed lagoons appear to be commonly used by fewer vertebrate species and individuals than use open lagoons. But (except for species the ranges of which do not reach the closed lagoons) they seem to be preferred over shallow open-shelf areas by birds, anadromous fishes and some marine fishes. Oldsquaws, shorebirds, arctic Char, arctic cisco, and fourhorn sculpin appear to be approximately as abundant (per unit area) in closed lagoons as they are in open lagoons. (Though some anadromous fishes appear equally abundant along open coasts, it is likely that. the width of the habitat they use there is less than that in either open or closed lagoons.) Arctic flounder may even occur in greater densities in closed lagoons than in other coastal types. Invertebrates that are main prey items for vertebrates may be just as abundant (per unit area) as in open lagoons, but their total abundance (discussed above) may be less.

We suspect that the vulnerability of closed lagoons to OCS oil and gas activities is higher than that of open coasts but lower than that of open lagoons. Usually fewer birds use the spits and islands off closed lagoons (as opposed to those off open lagoons) for nesting. Oil spilled outside closed lagoons (which is probably more likely than oil spilled inside, because of the relatively small areas of closed lagoons) should be easily kept from entering, because of the few and narrow entrances. (Birds are most vulnerable to oil on water; because they remain mostly in lagoons, most would be thereby protected.) One important point is that certain major alterations in emergent landforms (e.g. closing off lagoon entrances) could have larger detrimental effects to fish and birds than the same degree of landform change elsewhere, because of the relatively small entrances of closed lagoons.

River Delta Fronts

Major river deltas and vicinities have unique characteristics that affect their vulnerabilities. Deltas may occur in any of the previous coastal types, and moderate to large ones receive such rivers as Meade River (empties into Dease Inlet, Fig. 1-3), Okpikpuk River (Fig. 1-4), Colville River (Fig. 1-5), Kuparuk and Sagavanirktok rivers (Fig. 1-6), Canning River (Figs. 1-7 and 1-8), Sadlerochet and Hulahula rivers (Fig. 1-8), and Jago and Kongakut rivers (Fig. 1-9). The Colville and the Sagavanirktok rivers have two of the largest deltas.

Unique uses of river deltas are several. Delta fronts are the only places during spring migration of birds along the coast that have open water that attracts birds (mostly waterfowl). Deltas generally have more of the salt marsh and other wetland communities that are attractive to geese, brant, and shorebirds from mid-summer to early fall. Delta front waters appear particularly attractive in summer to young of arctic char, arctic cisco and perhaps other fishes. Spotted seal usage of the coast may be related to river delta influences.

Because the processes that make delta fronts attractive (discharge of warm water, depositional environments that encourage salt marsh communities, etc.) probably would not be greatly affected by OCS development activities, it seems that the main vulnerabilities of these areas would relate to hazards of oil introduction. The most vulnerable component of the delta biota is birds (and perhaps spotted seals in the Colville Delta). Oil in delta front waters during early June would be especially hazardous to migrating waterfowl (though perhaps would be a highly unlikely event). River deltas are typically low-lying and storm surges inundate large portions of them, particularly salt marsh and similar wetlands used extensively by geese, brant and shorebirds. Thus we believe that the vulnerability of the delta front species to oil hazards is relatively high.

Areas Different Because of Outside Influences

Several areas of coastal waters have assemblages of animals that are different by virtue of the proximity of the areas to outside populations of animals or to outside inputs from other seas, as follows:

1. The extreme western Beaufort Sea nearshore zone near Barrow (Fig. 1-3) has a unique assemblage of birds, either because the Bering Sea intrusion there provides a unique food source

or the area is closer to outside populations of typically Chukchi-Bering Sea species than are other parts of the Beaufort Sea, or both.

2. Coastal sites between Smith Bay and western Harrison Bay (Fig. 1-4) receive more intensive use by black brant and Canada geese than do other similar habitats along the coast, because a unique molting assemblage of these birds occurs inland from these sites.

3. Delta fronts of larger rivers receive generally heavier use by black brant in mid-summer than do other coastal sites because brant prefer delta areas in which to nest.

4. Red phalaropes are more abundant in the western Beaufort, and red-necked phalaropes in the east, because their respective nesting abundances are relatively great inland from those sites. (Though not discussed at length in this report, the same phenomenon probably applies to several other bird species that use Beaufort Sea coasts.)

(5) Least ciscos and broad and lake (humpback) whitefishes are present in the western half of the Alaskan Beaufort Sea (Figs. 1-3 to 1-6) but virtually absent from the eastern part because they range only short distances from their natal and overwintering streams, which are all in the west.

The vulnerabilities of the various coastal segments that these populations uniquely occupy are different only by virtue of the animals being present. Because no qualities of the Beaufort Sea nearshore environment *per se* seem to influence where these animals use the coast, there seem to be no other reasons to consider these areas otherwise vulnerable beyond the considerations addressed in the previous parts of this Comparison of Vulnerabilities.

Summary and Conclusions

Factors that influence vulnerabilities of biota to OCS development in the Alaskan Beaufort Sea nearshore zone are too many, and require too many arbitrary value judgments, to justify presenting a precise rating system to compare vulnerabilities among coastal regions. Instead, we describe general levels and types of vulnerability among four major nearshore types--open coasts, open lagoons, closed lagoons, and river delta fronts. For most of the relevant development considerations and vertebrate species, open lagoons appear more vulnerable than closed lagoons, and both lagoon types appear more vulnerable than open coastal waters. In river delta fronts, which may occur on open coasts or in open or closed lagoons, birds are particularly vulnerable to oil spills during spring migration, and their delta feeding habitats are vulnerable to oil introduced by storm surge. Several coastal stretches are used by animals more heavily than are others because of outside influences--animal populations or adjacent seas that are nearby. These stretches are more vulnerable than others only by virtue of the presence of the animals and not because of intrinsic characteristics of the coastal environment.

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