ENVIRONMENTAL CHARACTERIZATION OF THE NORTH ALEUTIAN SHELF NEARSHORE REGION: CHARACTERIZATION, PROCESSES, AND VULNERABILITY TO DEVELOPMENT

by

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EXECUTIVE SUMMARY

1. The North Aleutian Shelf Lease Sale 92 area encompasses all of Bristol Bay, from Unimak Pass northward to offshore Cape Newenham. The nearshore habitat of Bristol Bay is an interface between the rich resources of the southeastern Bering Sea and the rich resources of the river/lake and lagoon/estuarine systems. As such, this nearshore interracial area is extremely important, being heavily utilized for feeding purposes and as critical habitat necessary to many ecologically or commercially important species.

2. The observed high biological utilization of the inshore areas, and subsequent distributions of biota, can be explained by two basic factors, that of food availability and that of suitable habitat.

3. Based upon fragmentary data, it is hypothesized that marine primary productivity accounts for the majority of the organic carbon available to support the inshore food chains, but that overall contributions from rivers and coastal lagoons may be approximately 7-10 percent and about 14 percent respectively, and probably more important locally than indicated by these averages over the entire area. This inshore food web is primarily benthic, in that much of the algal production and detritus is ungrazed by pelagic herbivores and sinks to the bottom.

4. The endemic system thus includes primary productivity (both marine and lagoonal/terrestrial), which is generated within the nearshore zone and which supports most, if not all, of the zooplankton, benthic epifaunal and infaunal, and marine fish productivity of the region. Most or all of the higher trophic level marine mammal and bird species rely on this endemic system for nutritional maintenance to varying degrees. It is also hypothesized that a second, essentially independent, trophic system is operational within the nearshore zone.

This second system, a parallel "import/export" system, seasonal and pulsating in nature, is comprised of the huge runs of anadromous fish, which utilize the area, along with their retinue of predators. The hypothesis in this regard is that these migratory populations of anadromous (and in some cases marine) fish such as salmon, smelt, herring, capelin, and eulachon satisfy most of their energy and growth requirements in other marine or, in the case of juvenile salmon, freshwater environments and "import" this biomass in seasonal pulses into the nearshore zone. Calculations indicate that the carbon available from this import system at the higher trophic levels is at least equivalent to that expected to be derived from the productivity of the first, endemic system. It is conjectured that these seasonal pulses of imported energy resources may be critical

to the maintenance of the particularly high populations of some top predators, especially beluga whales, harbor seals, and perhaps Steller sea lions and marine birds which frequent the area.

5. Critical habitats present in the nearshore, interracial zone, are extremely important to numerous species of both ecological and commercial importance. The distributions of these species in the nearshore zone are often governed by these habitat requirements. Examples include spawning substrate for herring or capelin; haulout or rookery habitats for marine mammals such as walrus, Steller sea lions, or harbor seals; inshore nursery areas for a diverse array of species such as yellowfin sole and crab; and nesting and rookery areas for marine shorebirds.

6. Bristol Bay Basin or Amak Basin, structural depressions of sedimentary material located in the southwestern portion of the proposed lease area and north of the Alaskan Peninsula, are considered to be the most likely sites of petroleum development. Conventional technology is envisioned, both for exploratory drilling (semi-submersibles, drillships, jack-up rigs) and for production platforms (e.g. Cook Inlet structures). Transportation to shore by pipeline and subsequent overland pipeline transport to a port site located on the south coast of the Alaska Peninsula is probable. Statistically, one oil spill of greater than 1,000 barrels but less than 10,000 barrels would be expected during the lifetime of these oil fields, although a small but finite chance exists for a larger spill.

7. Because the area is large compared to the size of an individual spill, because the lifetime of a likely spill as a surface slick is probably limited to 1-2 weeks, and because the transport dynamics are dominated by frequent storm events, mean oceanographic conditions and transport are of limited use when analyzing potential vulnerability. Rather, specific locations and dynamic transport events of 1-14 day time scales will be important.

In, spite of incident specificity (locality, volume, meteorological history), some generalizations and concerns can be summarized regarding vulnerability of inshore biota and habitats to oil spills. The most vulnerable habitats are clearly the enclosed lagoons, which would retain oil for long time periods with associated toxic effects to a wide range of organisms, from primary producers through infauna to higher predators. Eelgrass itself is only moderately sensitive to oil, reflected in measured lower productivity. However, effects on the eelgrass sediment habitat are felt to be indirect but of more long-term importance. The more open inner bays are also of concern, though a lack of data on their utilization and importance currently exists. Though specific localities (such as rookeries) are vulner-

able and are mentioned elsewhere, the sand and gravel habitats in shallow water are generally of concern because oil can be mixed downward by wave action. These habitats are generally utilized by numerous species for spawning areas, as nursery grounds for juveniles, or as feeding areas.

Among the most vulnerable marine mammals will be the sea otter, which is confined to the inshore area and is sensitive to oiling of fur, critical to insulation and buoyancy. Young pups of sea lions and harbor seals could also be vulnerable as they may have not developed protective blubber. Increased air and marine traffic could also be of concern around rookeries or hauling grounds, such as to sea lions on Amak Island, walrus on Round Island, or Harbor seals at Port Moller, Port Heiden or the Cinder River area.

Birds are obviously vulnerable to direct oiling, but may also experience reduced reproductive success through transfer of oil back to nests where eggs are being incubated or by ingestion of oil during preening or feeding. Species which spend a major proportion of time on the water or a large proportion of their life cycle in the area are considered vulnerable, especially if they breed in the area, are highly gregarious, or have low population turnover ratios (one to two eggs/year/breeding pair) , such as alcids do. For example, common murres (one egg/year/breeding pair) have up to 80% of their population frequenting cliff area breeding grounds. Kittiwakes (2 eggs/year/breeding pair) are similar. Among waterfowl, black brant are extremely vulnerable since most of the world's population stages in the area of Izembek Lagoon. Not only would they be vulnerable to losses by direct oiling, but also through effects of oil retained in the lagoon and consequent loss of feeding habitat. Similar factors would affect other waterfowl such as eider and Emperor geese, though populations are not as concentrated. However, over 50% of the world's population of Emperor geese is thought to occur in Nelson Lagoon each fall. Shorebirds would probably be less vulnerable, being affected primarily through their food supplies and perhaps being more adaptable through mobility.

Of fishes, capelin and herring are probably most vulnerable since they spawn on beaches or in shallow water. In fact, all osmerids would be vulnerable as their larvae are known to concentrate close to the surface. Outgoing juvenile salmon are also of concern since they frequent the top 1-2 meters of the water column, and are confined to the nearshore area, at least as far out as Port Moller. As adults, yellowfin sole are not likely to be impacted by a spill. The larvae and juveniles released in shallow water, however, may be influenced. Distributional data are currently not adequate to assess the potential exposure of the larvae and juveniles to an oil spill.

Among the invertebrates of concern are the commercially fished populations of crab and the as yet unutilized populations of clams. High among invertebrates of concern would be king crab because they utilize the nearshore area for both spawning and nursery grounds. Tanner crabs generally are deeper offshore, and thus of much less concern. The population of Alaskan surf clam is, however, restricted to the shallow water along the Alaska Peninsula coast.

8. Large data gaps exist which will hamper management decisions regarding Bristol Bay resources, particularly when oil and gas developments are added to the present problems. Among the most obvious data gaps are a) those concerning fundamental food web relationships based upon endemic and import/export carbon sources and "b) those concerning utilization of nearshore habitats and the ecologic importance of these zones.

The integration of physical and meteorological oceanographic efforts with ecological studies was a unique and successful feature of previous PROBES and OCSEAP studies in the southeastern Bering Sea. This close cooperation should be continued for the needed studies in both the nearshore zone and in the lagoons and inner bays. The major purpose of such physical support studies is to understand the transport systems important to the food webs described above; however, the movement of oil or other potential pollutants in the inshore zone or into lagoons and bays is also of importance.

The North Aleutian Shelf is apparently on a meteological knife-edge with large interannual variability in storm tracks either north of or along the Aleutian Chain/Peninsula associated with large-scale meteorological patterns (Overland and Pease 1982). Nearshore flow is event dominated, with periods of wind-driven counterflow close to shore, probably statistically very significant but variable, and important to larval distribution of inshore spawning species, to upwelling and density structure, to inshore/offshore mixing of detrital organic matter, and to the movements of food organisms and predators.

Future work must emphasize food web relationships. For example, inshore marine primary productivity and that contributed by lagoonal/riverine systems has been estimated from very sparse data. The critical roles of lower level consumers, and even their inshore distributions, are not documented. Zooplankton grazing rates control the relative importance of pelagic and benthic food chains, the latter postulated above to be the most important in the endemic nearshore system. Mysids and euphausiids potentially have very important food web roles, yet they are essentially unsampled in the inshore zone, particularly the inner bays. The importance of detrital material in the nearshore area, .

and infaunal standing stock and production estimates are also topics for which research is needed, so that importance and potential vulnerability of food web links may be understood. Similar conditions exist with regard to good data on higher trophic level consumers, starting with almost nothing on major forage fishes, such as smelts, and proceeding with large data gaps on feeding of key marine mammal and bird species (such as otters, sea lions, harbor seals, and seabirds).

A similar situation exists with regard to utilization of nearshore habitats. From other similar situations, it would be expected that the large lagoonal areas would be extensively utilized as nursery grounds for marine species. Yet, sampling designed to look at such broad utilization has been carried out in only one lagoon (Izembek) and only for 3-4 weeks. An assessment of importance cannot be made from such limited data. The extensive shallow estuarine bays surrounding Bristol Bay have also not been studied as to their real importance as nursery or feeding grounds, though some work has been started on the open Peninsula coast regarding inshore utilization and feeding by otters and crabs. Major study efforts should be placed upon these lagoons and embayments in order to document their suspected, multifaceted importance to Bristol Bay food webs, in addition to their obvious bird habitat importance.

INTRODUCTION

1. Purposes

Early oceanographic and ecological studies in the Bering Sea tended to be in the offshore deeper waters, or focused on specific fishery resources. Later, increased emphasis in the form of large, integrated programs has been given to the southeastern Bering Sea as a result of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), as a result of National Science Foundation studies (IDOE, PROBES), ant! also as a result of continued marine resource related studies by the State of Alaska and by Federal Agencies. Shelf-wide studies in the Bristol Bay region have described the circulation, hydrographic structure, tides, and climatology of the area. Biological studies have defined the utilization of this region by plankton, benthos, fish, birds, and marine mammals. A synthesis report, summarizing and interpreting southeastern Bering Sea data has been issued by the NOAA/OCSEAP program (Hameedi, ed. 1982) for the Saint George Basin area, which extends generally from Unimak Island to the Pribilof Islands. A two volume summary of the oceanography and resources of the eastern Bering Sea shelf was funded by NOAA, Office of Marine Pollution Assessment (Hood and Calder, eds., 1981). This two velure set contains summary and synthesis papers by many active investigators working in the southeastern Bering Sea.

In March of 1982, OCSEAP held a synthesis meeting to assess the status of the scientific knowledge in the North Aleutian Shelf lease area. A synthesis report for this North Aleutian Shelf area is now in rough draft form (L.K. Thorsteinson, cd., 1983 draft). From existing data, participants at this synthesis meeting identified high productivity and extensive utilization of offshore shelf areas, from approximately the 20 meter depth seaward. They were able to characterize in detail the ecological processes involved. Similar high productivity and utilization in the lagoonal systems along the North Aleutian shelf coastline was also reasonably understood in terms of the causative ecological processes, based on previous study results.

Within the nearshore area, however, the workshop participants did not find it possible to define the controlling ecological processes leading to the high biotic utilization known to occur in this area, particularly within five kilometers of the north coast of the Alaska Peninsula. Their difficulties were largely due to a lack of data existing for this nearshore zone, or to the fragmentary nature of these data taken as an incidental part of larger studies. The purposes of this present study, therefore, are to review and interpret the present but limited

available data pertinent to the nearshore zone; to hypothesize controlling ecological processes and test them with available data; and to consider the vulnerability of these communities and processes to oil and gas-related effects. Data needs can then be defined and future studies focused on processes or key species, as suitable.

The specific objectives of this study as defined by NOAA/OCSEAP are therefore as follows:

- Describe the present status of knowledge concerning the biotic communities and organic productivity of the nearshore (0-5 km from the coastline) zone along the entire North Aleutian Basin lease area, (Unimak Pass to Cape Newenham), with particular reference to the area adjacent to Izembek Lagoon.

- Describe the ecological processes which might be causing the observed distributions, densities, and interrelationships.

- Discuss potential vulnerability of this region to impacts from offshore oil and gas development.

- Identify significant data and information needs in order to test the hypothesis that organic enrichment by eelgrass detritus, or other related causes, leads to the observed distributions of biota.

2. Study Area

The study area for this project, shown in Figure 1 , includes the nearshore coastal zone of the North Aleutian Basin lease area. This area extends from Unimak Pass around the shoreline of Bristol Bay to Cape Newenham, and seaward from shore to a distance of five kilometers.

In actual practice, of course, a seaward boundary of five kilometers does not physically exist. Since some processes acting over the entire southeastern Bering Sea shelf affect this nearshore region, we include some review and interpretation of data from these larger areas. However, the focus is on the nearshore zone. Likewise, a natural hydrographic front exists at about the 50 meter depth contour, defining the outer edge of the coastal domain water. This contour generally lies offshore from the five kilometer distance. Processes, habitats, and utilizations within this wider area are also treated, however, in order to better elucidate the ecology of the nearshore area.

3. Potential Development and Conflicts

The continental shelf of the eastern Bering Sea is considered to be one of the most promising potential

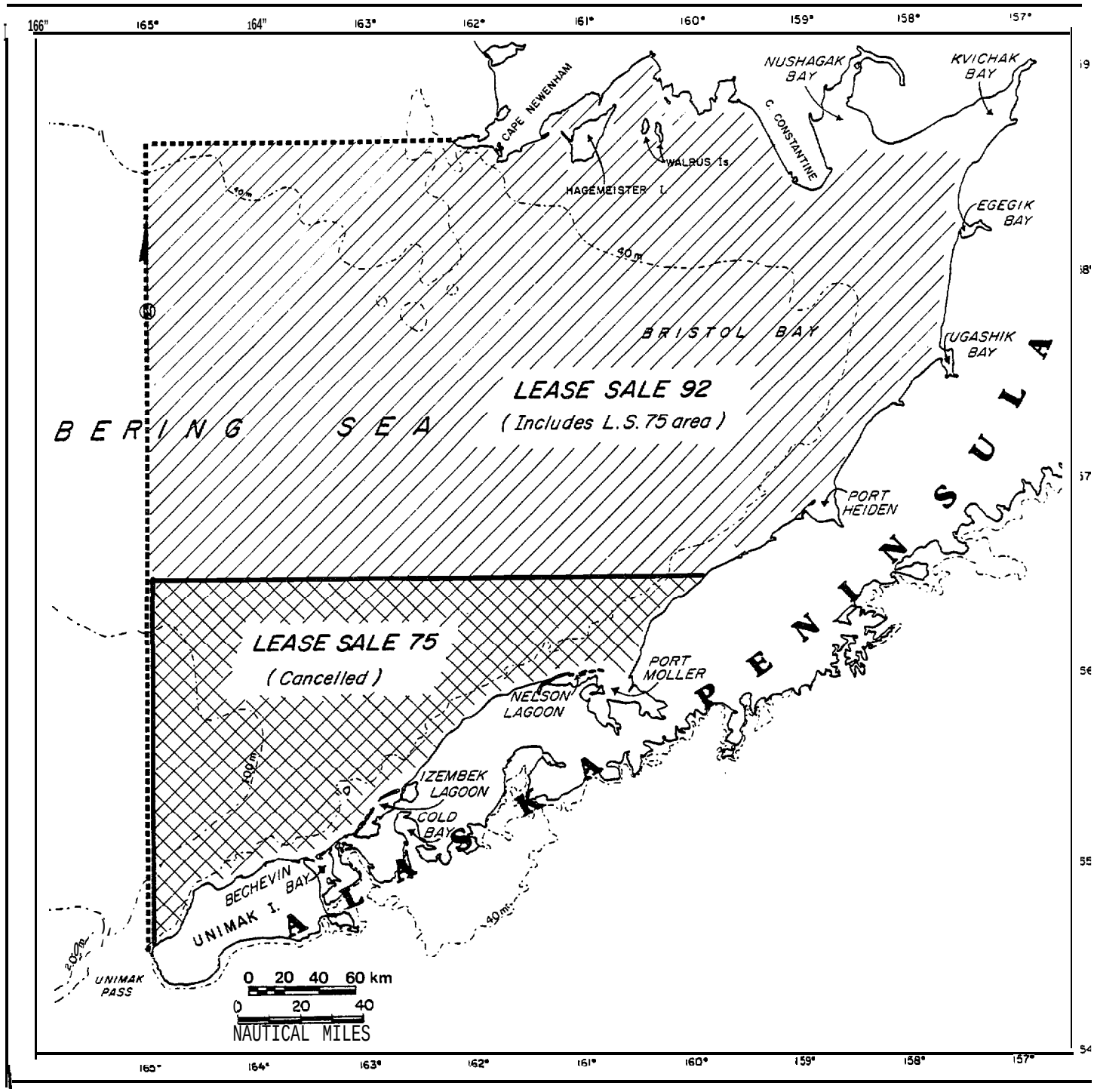


Figure 1. Study area--North Aleutian Shelf nearshore area.

petroleum provinces remaining to be explored off the coast of the United States. The formations which are potential petroleum source rocks occupy a structural depression known as Bristol Basin, Figure 2 (Marlow et al, 1980). This subsidence basin is filled with sedimentary rocks composed of detritus eroded from Alaska mainland mountains and of volcanic debris from the Alaska Peninsula. The maximum thickness of these Cenozoic deposits is poorly known, but may reach eight kilometers in the deepest part of the depression. A large portion of Bristol Basin contains deposits more than three kilometers thick. Offshore strata, considered to have the best potential for petroleum, are flat-lying sandstone, siltstone, and shale which range in age from Eocene (40-60 million years before present) to Holocene (10,000 years to present). These areas of highest interest are shown in Figure 3, designated as the St. George Basin, Amak Basin, and Bristol Bay Basin.

Lease Sale 92 (Figure 1) for the North Aleutian Basin planning unit, consists of all of the Bristol Bay area, and is scheduled for sale April 1985 (July 82 Planning Schedule). Previous lease sales (#51 and #75) scheduled in 1977 and 1983 were cancelled.

Potential conflicts with development of these petroleum resources exist because of the extreme biological productivity of the North Aleutian Shelf-Bristol Bay area. The rich resources existing in this area and the close proximity of lucrative salmon and crab fishing areas, of national wildlife refuges, and of state-owned critical habitats, have made petroleum development very controversial.

4. Approach

Since no new field data are to be obtained for this project, the collection and review of available literature formed the foundation for this study. As identified in the March 1982 synthesis meeting, data within the nearshore zone of the North Aleutian Shelf were known to be deficient. The approach of the present study was to utilize data that did exist and to extrapolate data from adjacent areas where appropriate. The strategy was to concentrate on the basic physical and biological processes controlling the ecology of this nearshore zone, to construct hypotheses concerning these controlling processes? to test these hypotheses with the available data, and to identify data gaps.

Literature of the southeastern Bering Sea is extensive, of course, and may pertain to the nearshore zone only incidently (e.g., one nearshore station on a line extending far offshore) or only by inference. Therefore, discretion was used to include enough of these data for perspective, without repeating unnecessarily the excellent reviews and syntheses that already exist.

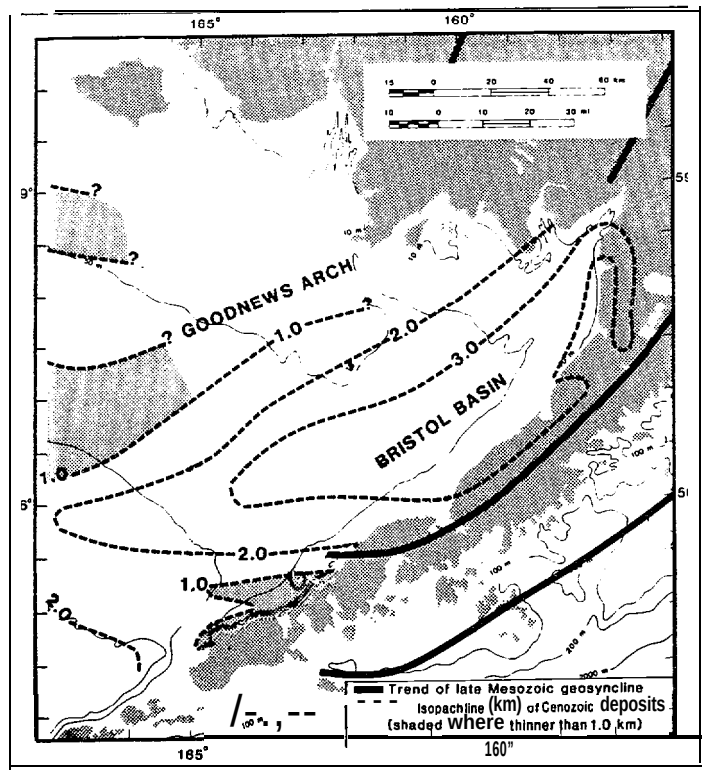


Figure 2. Potential petroleum source rocks, southeastern Bering Sea (Science Application, Inc. , 1981 , adapted from Marlow et al, 1980).

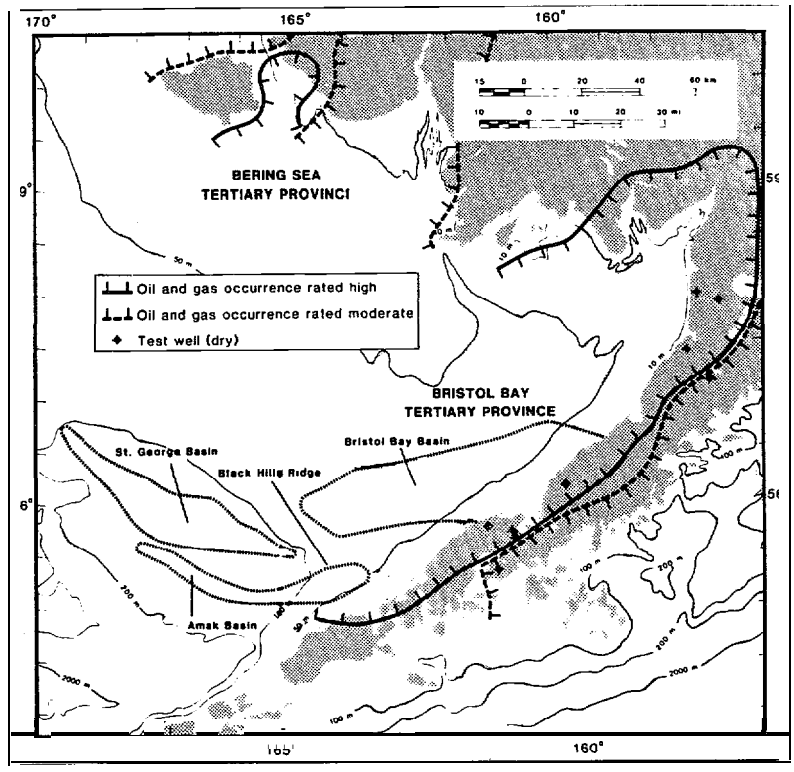


Figure 3. Offshore strata with high potential for petroleum, southeastern Bering Sea (Science Application, Inc., 1981, adapted from Marlow et al, 1980).

NEARSHORE ZONE CHARACTERIZATION

1. Physical, Chemical, and Geological Characterization

a. Physical Oceanography and Meteorology

Oceanographic Structure. Before 1975, oceanographic data for the Bering Sea and Bristol Bay were scattered in space and time and were biased toward the deeper portions, rather than on the continental shelf (Kinder, 1981). By necessity, therefore, most work had concentrated on the mean state of the Bering Sea at large spatial scales, with emphasis on the deep basin. Later work shifted to the continental shelves and to shorter temporal and spatial scales, which allowed variability and oceanographic processes to be better addressed. Building on the earlier data base obtained because of oceanographic concerns of fisheries research, the later larger, multidisciplinary programs such as PROBES (Processes and Resources of the Bering Shelf, funded by the National Science Foundation) and OCSEAP (Outer Continental Shelf Environmental Assessment Program, funded by the Bureau of Land Management) have rapidly added to our knowledge of Bering Sea oceanography, particularly on the continental shelf.

Early data, particularly those of the research organizations of the member countries of the North Pacific Fisheries Commission - Canada, Japan and the United States - were summarized by Dodimead, Favorite, and Hirano (1963), as well as earlier by Favorite and Pederson (1959) and Favorite et al (1961). This review of the entire subarctic Pacific also includes portions of the Bering Sea and a special appendix on Bristol Bay. Subarctic boundaries, salinity structures, surface heating/ cooling, and wind mixing were deduced. Currents and gyres were derived from geostrophic analyses of hydrographic data and wind driven transports from meteorological data. Dodimead et al (1963) utilize a concept of oceanographic domains as areas of consistent structure and oceanographic behavior. Building further on such concepts, Takenouti and Ohtani (1974) reviewed Japanese work. Their domains, representing mean conditions, are shown in Figure 4. In our region of immediate interest, they identify "Coastal Water" nearshore in Bristol Bay with a "Convective Area" further offshore over the shelf, and the "Alaskan Stream" intruding through Unimak Pass and northward along the shelf break. Circulation was identified as being counterclockwise in the Bristol Bay region. Similar circulation for our area of interest was also shown by Arsen'ev (1967) , Figure 5. Summer mean surface salinities of Figure 6 (Favorite, Dodimead and Nasu, 1976) conform to the general circulation over the deep basins, suggest the front overlying the slope, and indicate the large horizontal salinity (density) gradients important to shelf processes.

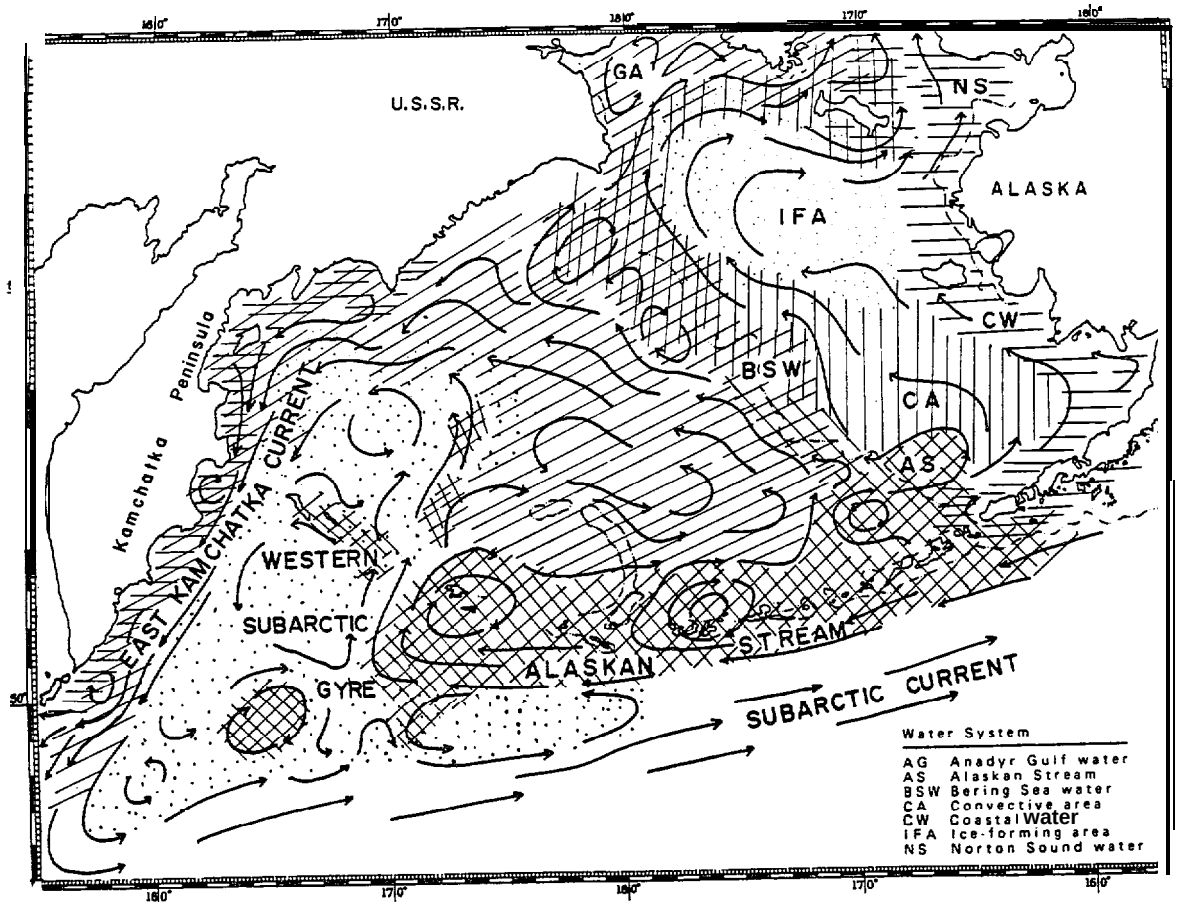


Figure 4. Schematic diagram of circulation and extent of water masses in the Bering Sea and northwestern Pacific Ocean (Takenouti and Ohtani, 1974).

CIRCULATION IN WESTERN BERING SEA

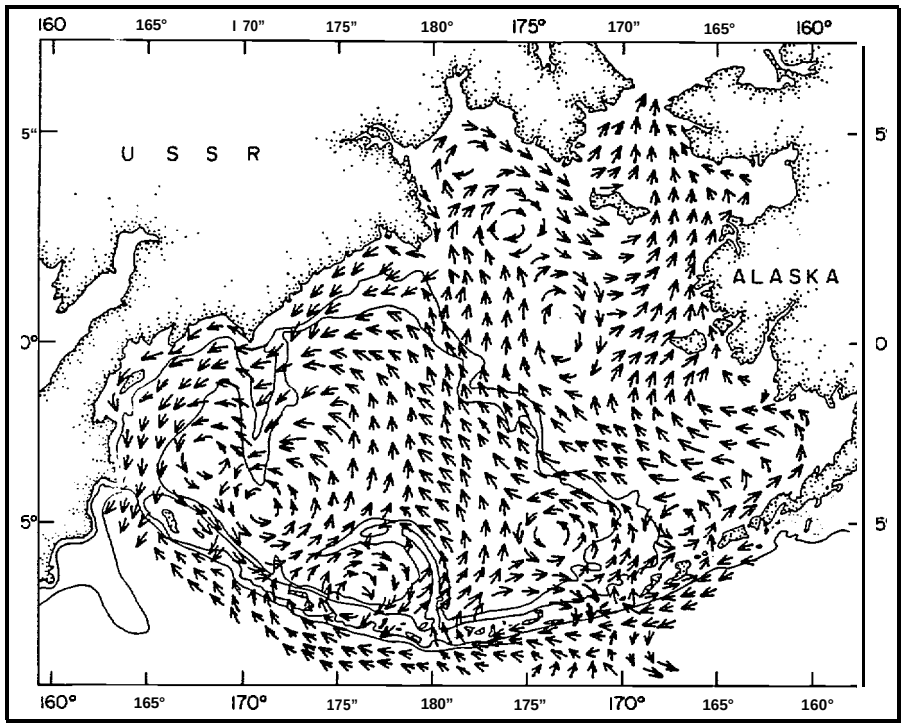


Figure 5. Bering Sea circulation according to Arsen'ev (1967) .

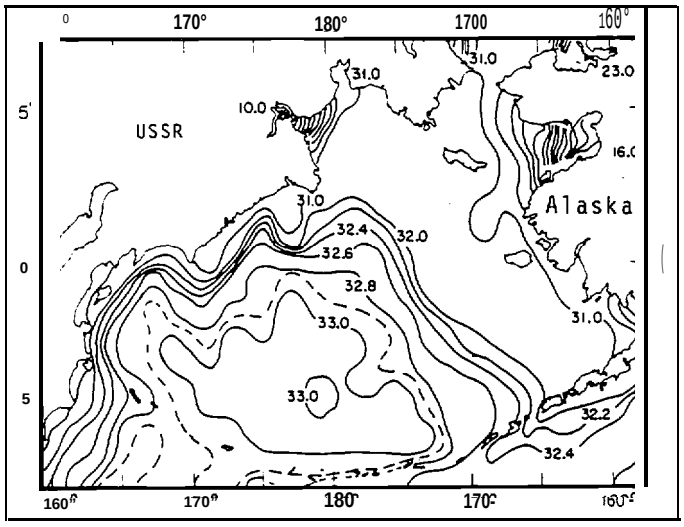


Figure 6. Summer mean surface salinity g/kg (Favorite, Dodimead, and Nasu, 1976) .

Since 1975, extensive hydrographic data and some moored current meter data have become available for the southeastern Bering Sea through the OCSEAP and PROBES programs. Kinder and Schumacher (1981a) have synthesized these hydrographic data. Based upon hydrographic structure, the shelf is divided into distinct domains (Figure 7), coinciding with depth intervals and separated by oceanographic fronts.

The shelf break front (Figure 7), separates the outer shelf domain from the oceanic domain. This latter domain consists of Alaska Stream/Bering Sea waters lying off the continental shelf. The shelf break front is broad (50 km) and diffuse, distinguished by a much higher salinity gradient than is the outer shelf domain.

The outer shelf domain itself exists between the 100 m isobath and the shelf break at about the 170 m contour (Figure 7). This domain exhibits a wind mixed surface layer, a tidally mixed bottom layer, and a 20 to 80 m thick middle layer characterized by low turbulent mixing (Figures 8 and 9). In this domain, horizontal mixing of oceanic Alaska Stream/ Bering Sea water with fresher shelf waters manifests itself as interleaving along isopycnal surfaces in the low turbulence middle layer.

The frontal boundary separating this region from the middle shelf domain occurs at about the 100 m depth contour. This boundary is a generally weak front occurring over approximately a 50 km wide band (Figure 8), distinguished by a steeper salinity gradient (0.01 g/kg/km) than exists in the adjacent domains.

The middle shelf domain may be characterized, in general, as a two layer system during the summer. A wind mixed surface layer is typically 15 to 20 m thick, and a tidally mixed bottom layer is typically 50 m thick. In 70 to 100 m of water, this domain thus exhibits a two-layered hydrographic structure, often with a sharp interface and with corresponding low vertical transfer across the interface (Figure 9). The upper layer is warmer and fresher (e.g. 8° C and 31.5 ppt) than the lower layer (typically 3.5° C and 31.8 ppt). This lower layer is essentially a remnant of surface cooling in the winter. During summer, this layer is insulated from warming by stratification. In winter, however, the structure becomes almost vertically homogeneous due to increased wind mixing, surface cooling (Reed, 1978), and the addition of salt at the surface from the formation of sea ice. In the spring, melting of sea ice and freshwater runoff quickly re-establish the sharp, two-layer system, reinforced by surface warming through the summer.

The inner front, at about the 50-meter contour and approximately 10 km wide (Figure 8), is thus a structural front (Schumacher et al, 1979) dividing domains with

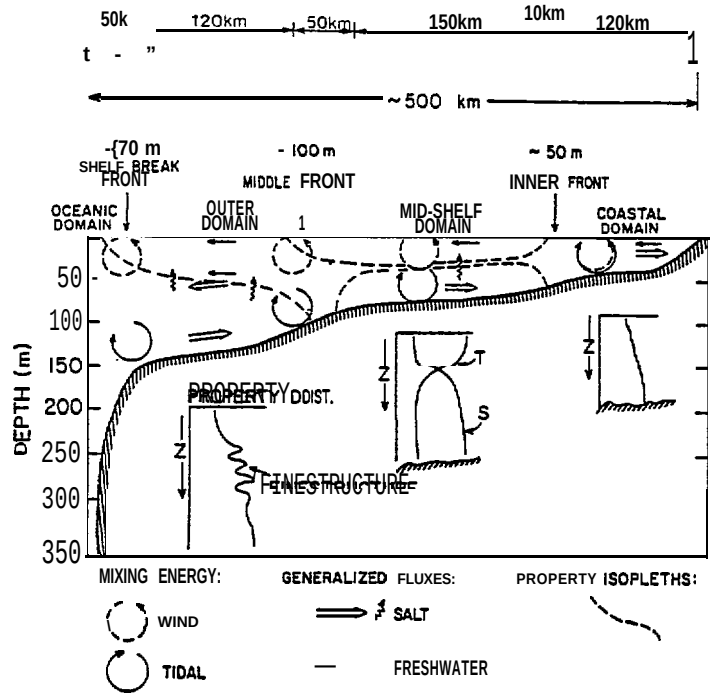


Figure 8. Conceptual advection-diffusion model of the oceanographic structure of water of the continental shelf in the southest Bering Sea (Coachman & Walsh, 1981) .

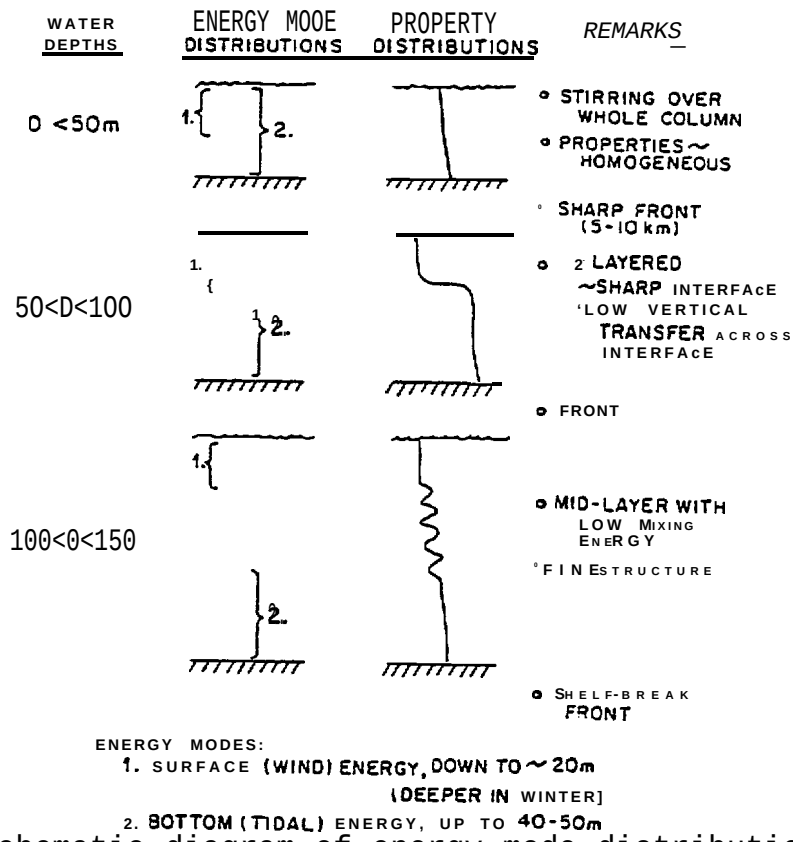


Figure 9. Schematic diagram of energy mode distributions by depth ranges and accompanying water column structure. The inner front, being closely associated with the 50 m depth contour, does not appear in the area of deeper, outer Bristol Bay (Coachman and Charnell, 1979).

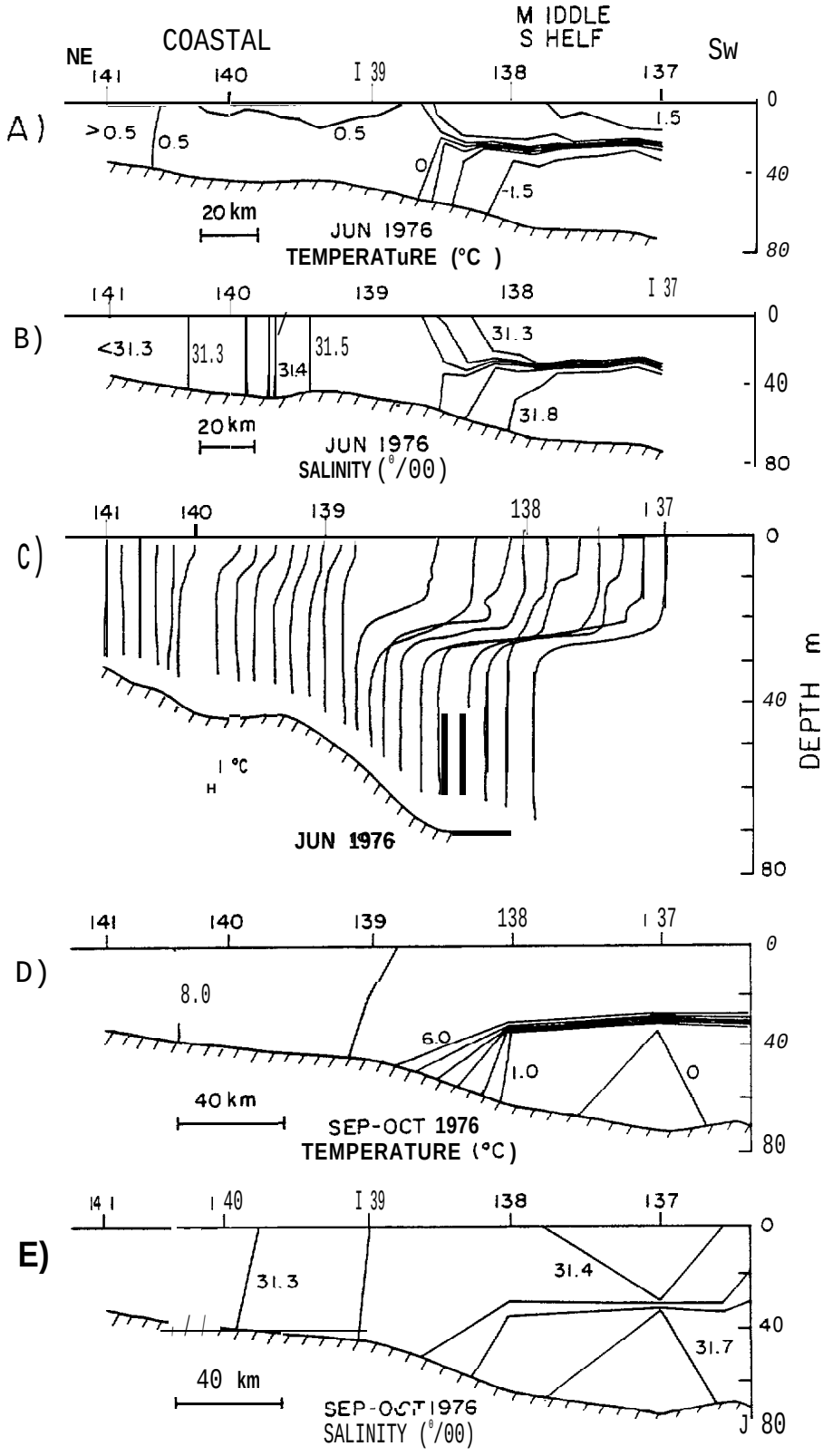


Figure 10. The structural (inner) front separating the coastal and middle domains. This line was between Nunivak Island and the Pribilof Islands. (A, B) Temperature and salinity cross sections, and (C) sequential temperature profiles from June 1976. The sections are based on stations separated by about 10 km. (D, E) The same section based on widely spaced CTD stations in autumn 1976 (Schumacher et al, 1979) .

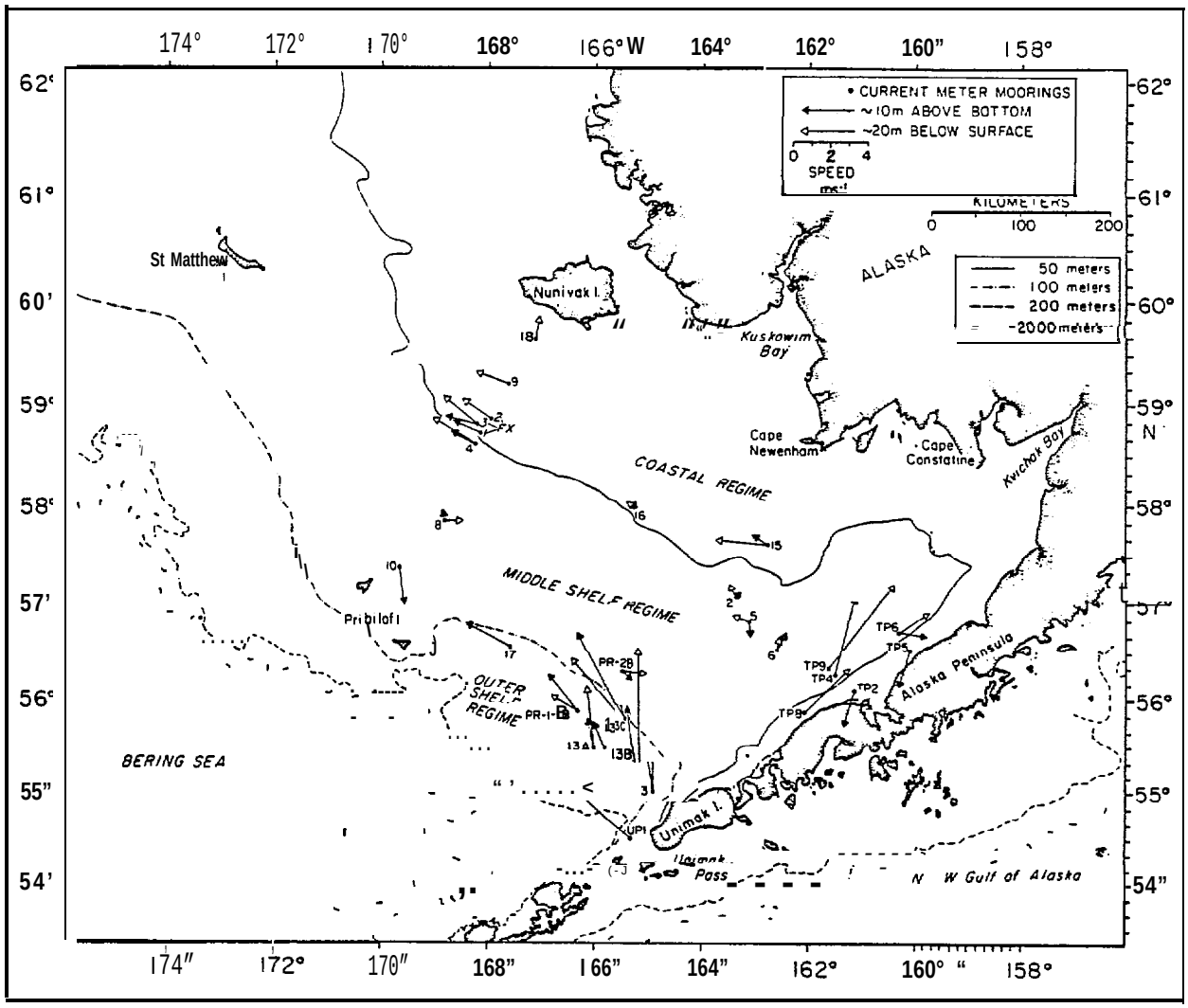


Figure 11. Mean flow based on all records at each mooring site (Schumacher and Kinder, 1983) .

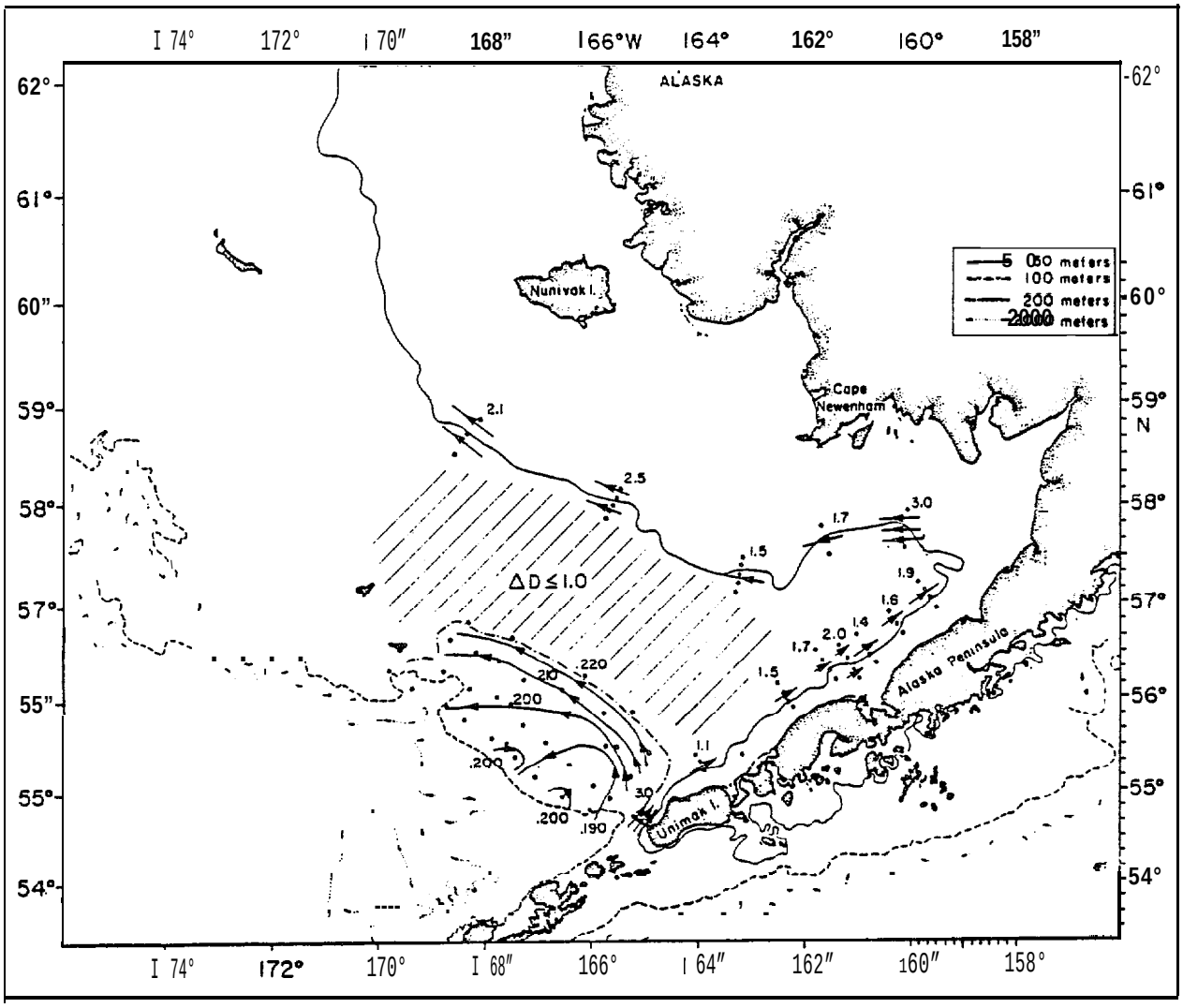


Figure 12. A compilation of hydrographic data from six cruises during summer conditions presented as dynamic height contours (0/80db) for synoptic data from the outer shelf and dynamic height (0/40db) difference along sections occupied various times normal to the inner front. The dots represent CTD station locations and the contour interval is 1 dyn cm. The shaded portion of the middle shelf regime shows that ΔD<1 dyn cm (0/40db) throughout this area for the six cruises (102 stations) (Kinder and Schumacher, 1981a) .

frequencies, about 92%. Kinetic energy at meteorological frequencies was only slightly less than in the coastal regime, but the lack of coastal boundaries precludes coastal Ekman divergence and generation of pressure-induced alongshore current pulses; instead, currents respond to the wind as rotating vectors.

In the coastal domain, the area of most immediate interest, vector mean flow parallel to the 50 m isobath, i.e. along the inner front, was statistically significant. Speeds paralleling this feature were generally between 1 and 6 cm s^{-1}, with the higher values during winter. The coastal current was observed from the vicinity of Unimak Pass, along the Alaska Peninsula to the vicinity of Nunivak Island. Although fluctuating kinetic energy in this regime is dominated by tides (about 94%), significant energy at meteorological frequencies can be clearly distinguished as current pulses. Because vector-mean winds are weak, wind-driven circulation is believed to contribute little directly to the observed mean flow; instead, a combination of baroclinic geostrophic current (Figure 12) and current generated as a result of interaction between tides and shoaling bathymetry are the primary forcing mechanisms. We consider this coastal domain in more detail below.

Characteristics of these general flow regimes are summarized in Table 1 after Schumacher and Kinder (1983). Generalized mean flow regimes are depicted in Figure 13.

Tidal data in the southeast Bering Sea have been reviewed by Pearson, Mofjeld and Tripp (1981). The tidal distribution is unusually complicated but is generally mixed, in places predominantly mixed semidiurnally and in other places, particularly near the coast, mixed predominantly diurnally. Principal tidal constituents are M2, N2, O_1, and K_1. The cotidal charts for the M_2 and K_1 constituents are shown in Figure 14 and the corresponding current ellipses in Figure 15, after Pearson et al, 1981. The M2 current constituent is largest with amplitudes of 15-30 cm/ sec on the open shelf with those of the N2 being approximately 25-40 percent of the M2. The K_1 is the largest diurnal constituent with amplitudes of 10-20 cm/sec on the shelf with the O_1 being about 60-75 percent of these values. Tidal current ellipses in the nearshore areas flatten considerably, showing nearly rectilinear motion near the Alaska Peninsula.

Inshore, tidal heights and currents are amplified in upper Bristol Bay, particularly in the funnel-shaped embayments at the head of Bristol Bay. For example, the mean diurnal tidal range at Kvichak, at the head of Kvichak Bay, is 5.0 m (16.5 ft) and that at Clarks Point in Nushagak Bay is 5.9 m (19.5 ft) with maxima of 7 m (23 ft) (Us. Department of Commerce, 1981a). Corresponding tidal heights

Table 1. Characteristics of southeastern Bering Sea flow regimes (adapted from Schumacher and Kinder, 1983).

	Outer (1 00m-shelfbreak)	Middle (50-100m)	Coastal (Coast-50m)
1. Mean	1-10 cm/sec along isobaths, counter-clockwise (due both to baroclinicity and tide-bathymetry interactions. 1-5 cm\ sec across isobaths, shoreward (due primarily to oceanic forcing).	Not statistically significant except along middle and outer fronts	1-6 cw./sec, counterclockwise (due both to baroclinicity and tide-bathymetry interaction
2. Fluctuating horizontal kinetic energy	81% tidal-remainder equally due to meteorological and oceanic fore ing	92% tidal-remainder primarily meteorological in form of rotating current	94% tidal-remainder primarily meteorological in form of Ekman divergence and associated longshore geostrophic current pulses.*

* See Pearson, Baker, and Schumacher, (1980) .

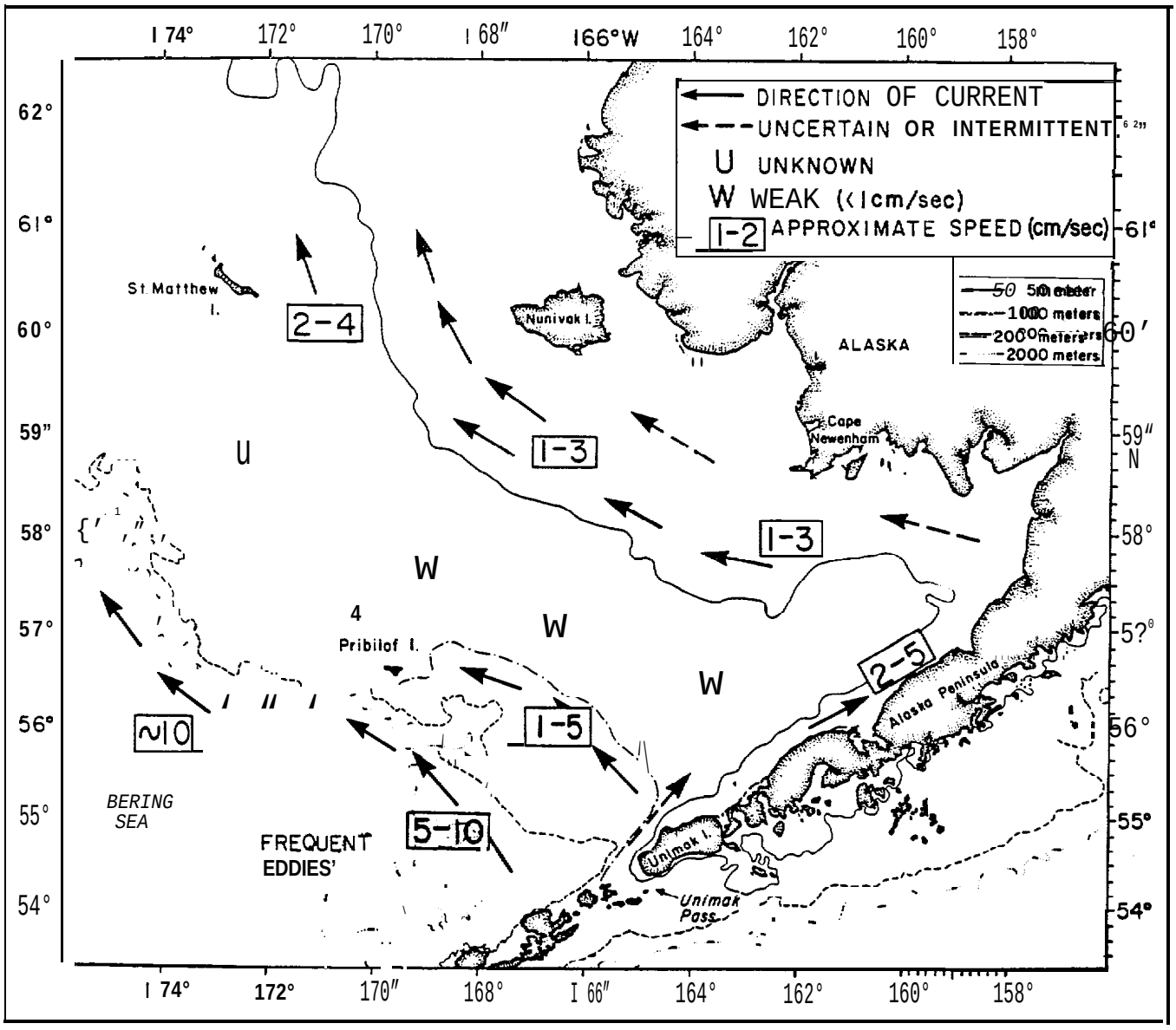


Figure 13. Schematic mean circulation (Kinder and Schumacher, 1981b) .

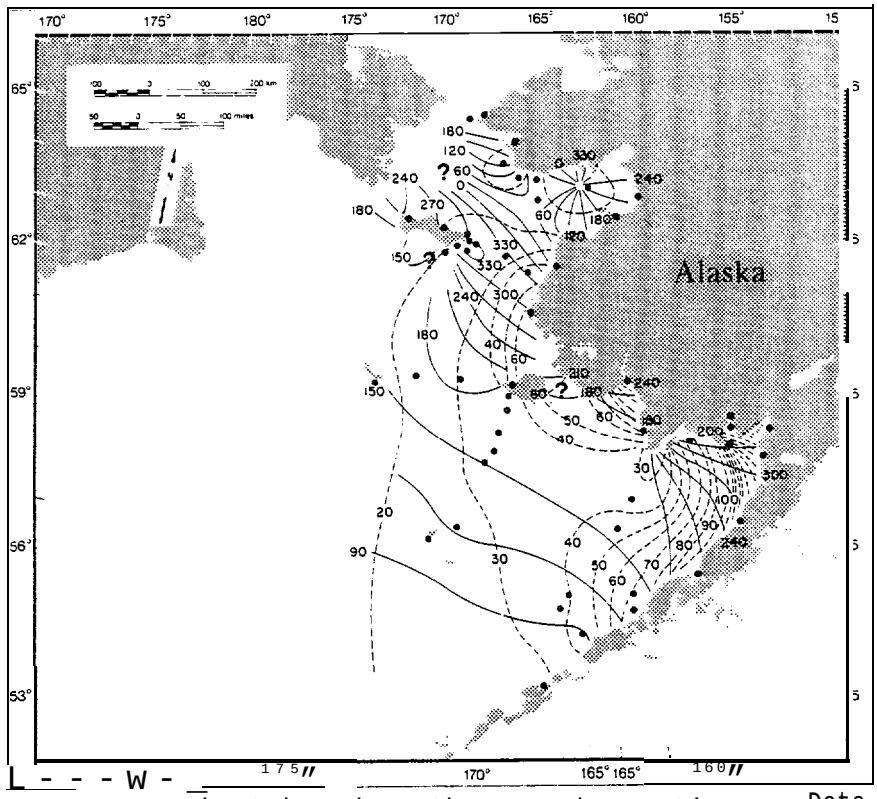


Figure 14a. M_2 cotidal chart based on the new observations. Dots represent locations of stations used in construction of the chart. Solid lines are cophase lines referred to Greenwich. Dashed lines are coamplitude, in centimeters. Areas of major uncertainty are denoted by question marks (Pearson, Mofjeld, and Tripp, 1981) .

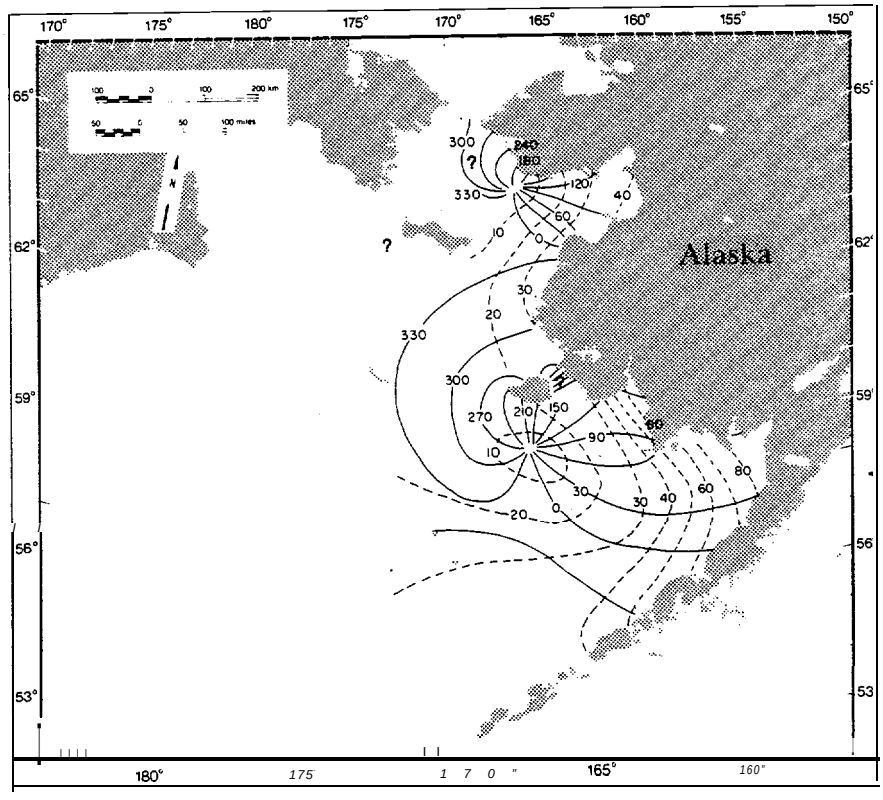


Figure 14b. Same as 14a, but for K_1 (Pearson, Mofjeld, and Tripp, 1981) .

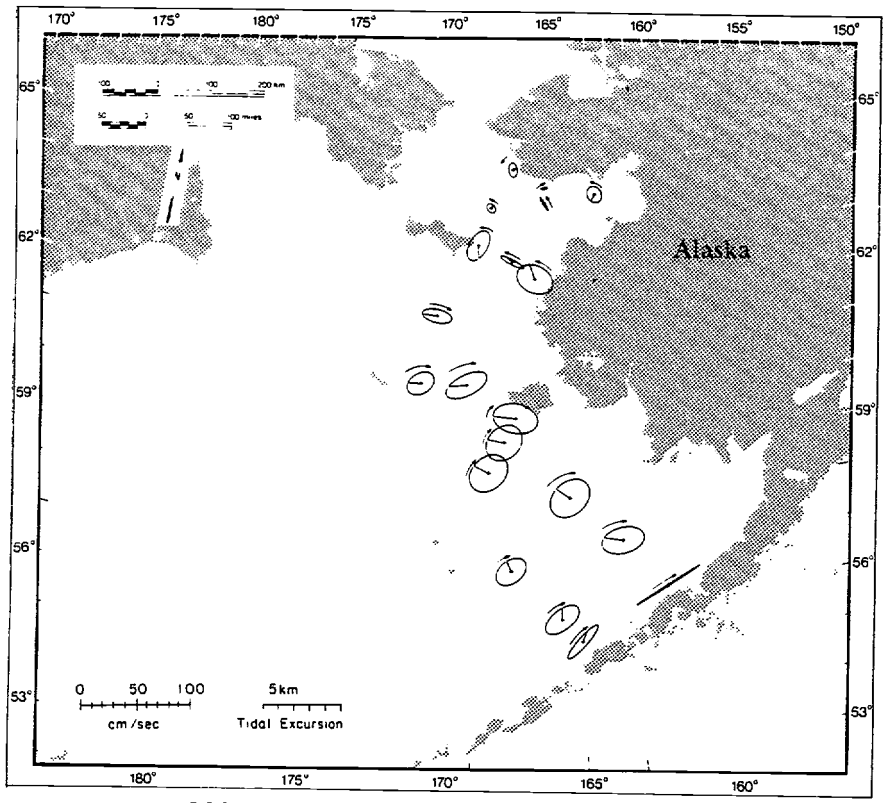


Figure 15a. M_2 current ellipses for stations listed in Table 1. For stations with records from two depths the ellipse for the deeper meter is plotted. Ellipses are centered on station location; line from center indicates constituent current vector when the M_2 Greenwich equilibrium phase angle is 0°. Arrows indicate sense of rotation (Pearson, Mofjeld, and Tripp, 1981) .

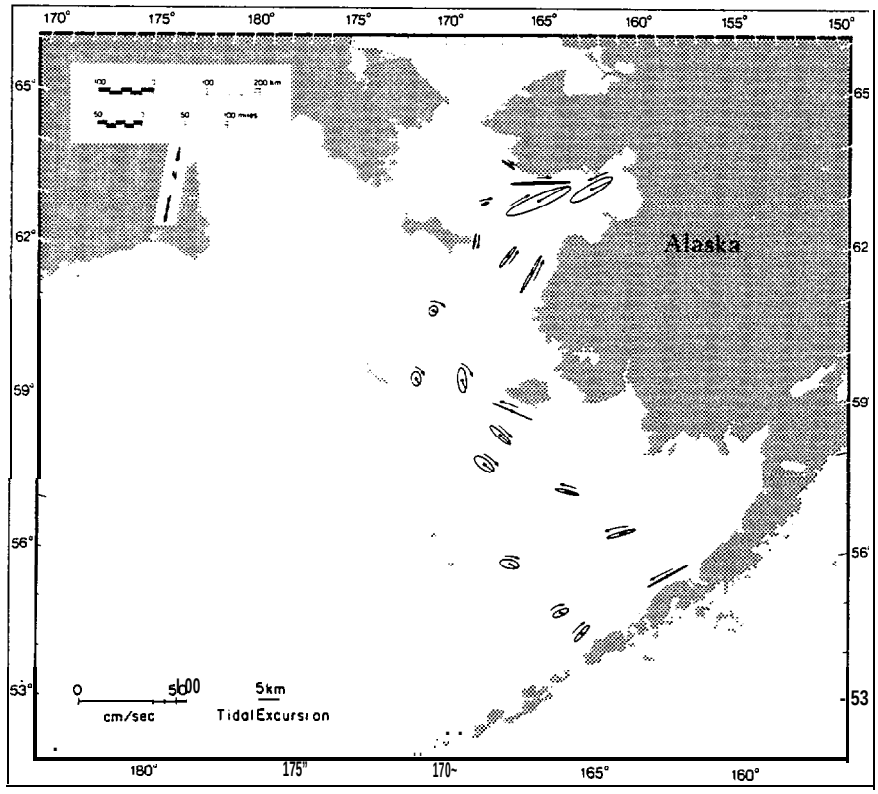


Figure 15b. Same as 15a, but for K_1 (Pearson, Mofjeld, and Tripp, 1981) .

at Izembek Lagoon are much lower, being only 2.3 m, while those at Port Moller and Port Heiden are 3.3 m and 3.7 m respectively. Tidal currents are likewise magnified in these entrances and bays (U.S. Department of Commerce, 1981 b). In Kvichak and Nushagak Bays at the head, tidal currents of 2-3.5 kts (100-175 cm/see) form long, linear shoals aligned parallel to the currents and axes of the bays (10 m high, 4 km apart). Along the Alaska Peninsula, the net littoral drift is to the northeast, apparent by the barrier spits across the lagoonal areas. Tidal currents in the entrances are significantly high, however, being 1-2 kts (50-100 cm/see).

Meteorology. The marine climatology of the Bering Sea has recently been reviewed by Overland (1981). Data have also been summarized in a climatic atlas (Brewer et al, 1977). Arctic, continental, and maritime air masses affect the Bering Sea. In summer, the entire region is normally under the influence of maritime air from the Pacific. Strong flow of air from the north and east brings continental and arctic air to most of the area in January and February, as well as in spring and fall for the northern area. The winter circulation pattern persists for nine months, from September through May, indicated by the predominance of an arctic high-pressure air mass over the northern Bering Sea.

A major result of the general circulation is a region of low pressure normally located in the vicinity of the Aleutian chain, referred to as the Aleutian Low. This statistical low appears on monthly mean pressure charts as a low-pressure cell oriented with the major axis in an east-west direction. Pressures are generally lower along this major axis as the result of the passage of low-pressure centers or storms along preferred tracts.

Indeed, storm events are a characteristic feature of the southeastern Bering Sea. The monthly frequencies of low-pressure systems (Figure 16) in the southern Bering Sea are four to five in winter and three to four in summer. Thus this area may be characterized as an event-dominated system.

In winter, the most frequent airflow is from the northeast, around the northern side of the low-pressure cell present at some location along the Aleutian Chain. In summer, with the movement of lows into the Bering Sea, a more southwesterly mean flow develops over the southern two-thirds of the region. In the Aleutian Chain in winter and during the summer in the southern Bering Sea, frontal activity can be severe as very cold arctic or continental air comes in contact with the warm air from the Pacific Ocean, forming a sharp discontinuity.

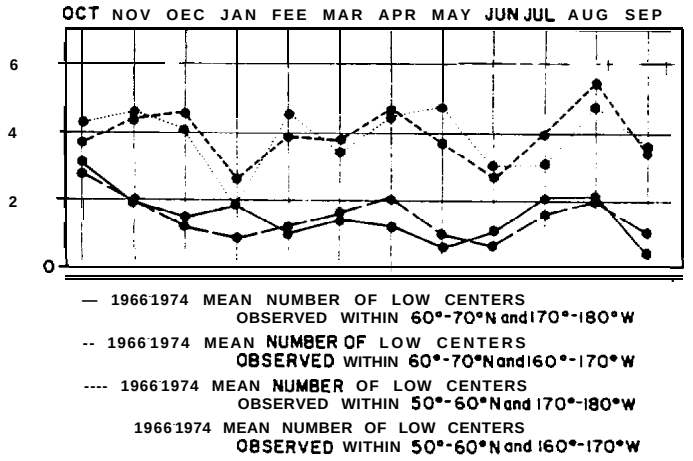


Figure 16. Frequency of low-pressure systems by month for the northern and southern Bering Sea (Overland, 1981) .

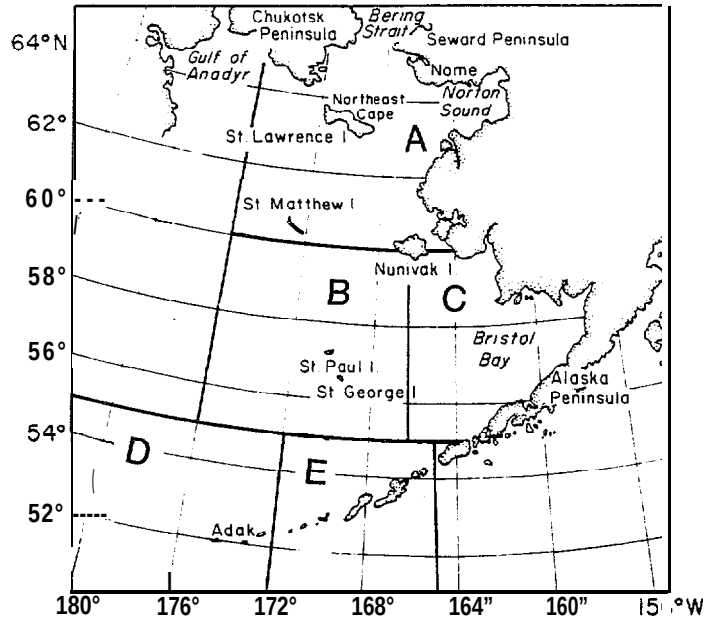


Figure 17a. Location map for -the eastern Bering Sea.

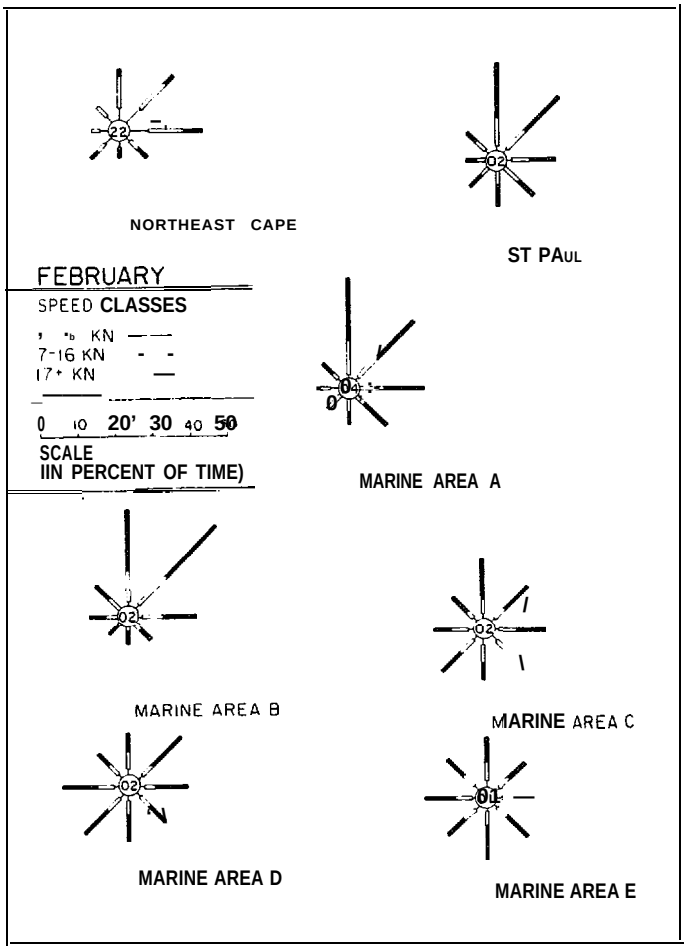


Figure 17b. February wind roses. (Direction from which the wind is blowing.)

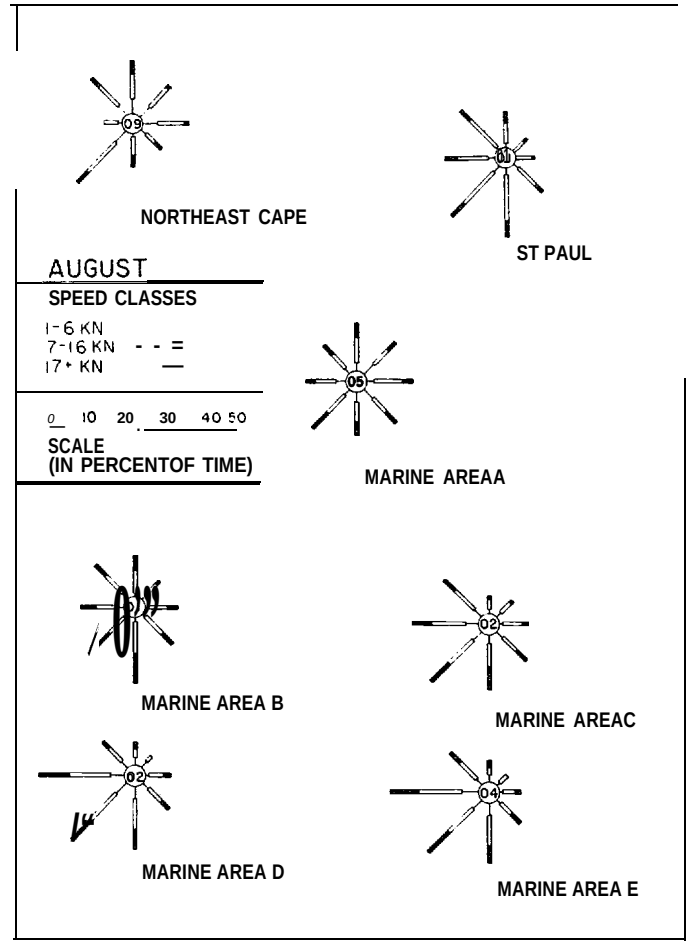


Figure 17c. August wind roses. (Direction from which the wind is blowing.)

Figures 17a, b, and c. Surface winds in the Bering Sea (Overland, 1981) .

Surface winds in the Bering Sea are shown in Figure 17 for February and August. In winter, the northern stations show a high percentage of winds over 17 knots from the north or northeast, while in the Bristol Bay area the winds are fairly uniformly distributed over all directions with moderately large speeds, indicative of a fairly continuous progression of storms through the area. In summer, wind speeds are generally lower, and the Bristol Bay area shows a predominance of south and southwest winds.

Mean precipitation for selected stations is shown in Figure 18. Mean annual total precipitation approximates 62 inches/year at Dutch Harbor, but drops rapidly as one enters Bristol Bay. Corresponding yearly totals are 37 inches/year at Cape Newenham and 13 inches/year at Port Heiden. In February, 70-90 percent of precipitation occurs as snow.

Additional monthly climate variables are shown in Figure 19.

Overland and Pease (1982) and Niebauer (1981) document large interannual variability in ice and oceanographic conditions, apparently related to whether storm tracks curve northward parallel the Aleutian Chain, which in turn, is related to large scale meteorological variations.

Waves . Approximately 3-15 percent of the observed WaVeS, depending on season, exceed 3 to 3.5 meters in height, and may therefore be considered hazardous (Brewer et al, 1977). The frequencies and distributions of these hazardous wave conditions are shown in Figure 20.

Design wave conditions have been calculated (Dames & Moore, 1980) as follows for the area of the north side of the Alaskan Peninsula and for comparable areas.

Area	Water Depths (meters)	Maximum Waves 100-Year (meters)
North Aleutian	15-120	23
St. George	91-152	23
Upper Cook Inlet	9-76	8.5
Norton Sound	15-49	6.1

These values were calculated using fetch lengths, wind durations, measured water depths, and extreme wind speeds reported by Brewer et al, 1977.

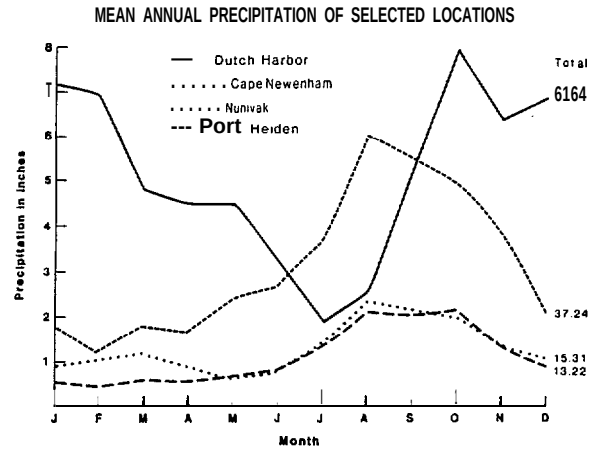
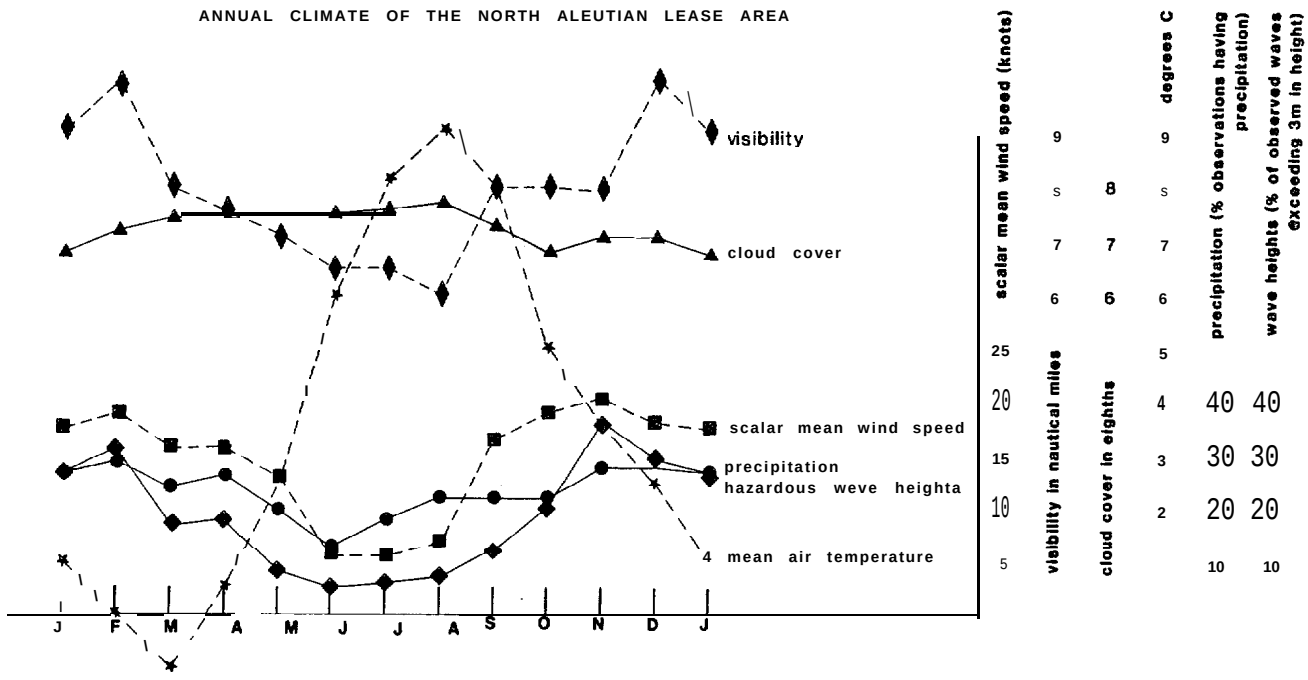


Figure 18. Mean precipitation for selected stations (SAI, 1981).



ANNUAL CLIMATE

Monthly statistics for several climate variables are shown in Fig. 19. Visibility is given in nautical miles. Fifty percent of observations reported visibility less than or equal to the value plotted. Cloud cover is given in eighths (1/8) . Fifty percent of observations reported cloud cover less than the value plotted. Temperatures are shown as a value that 50 percent of observations exceeded.

Figure 19. Climatic variables, North Aleutian Shelf (SAI, 1981; Brewer et al, 1977).

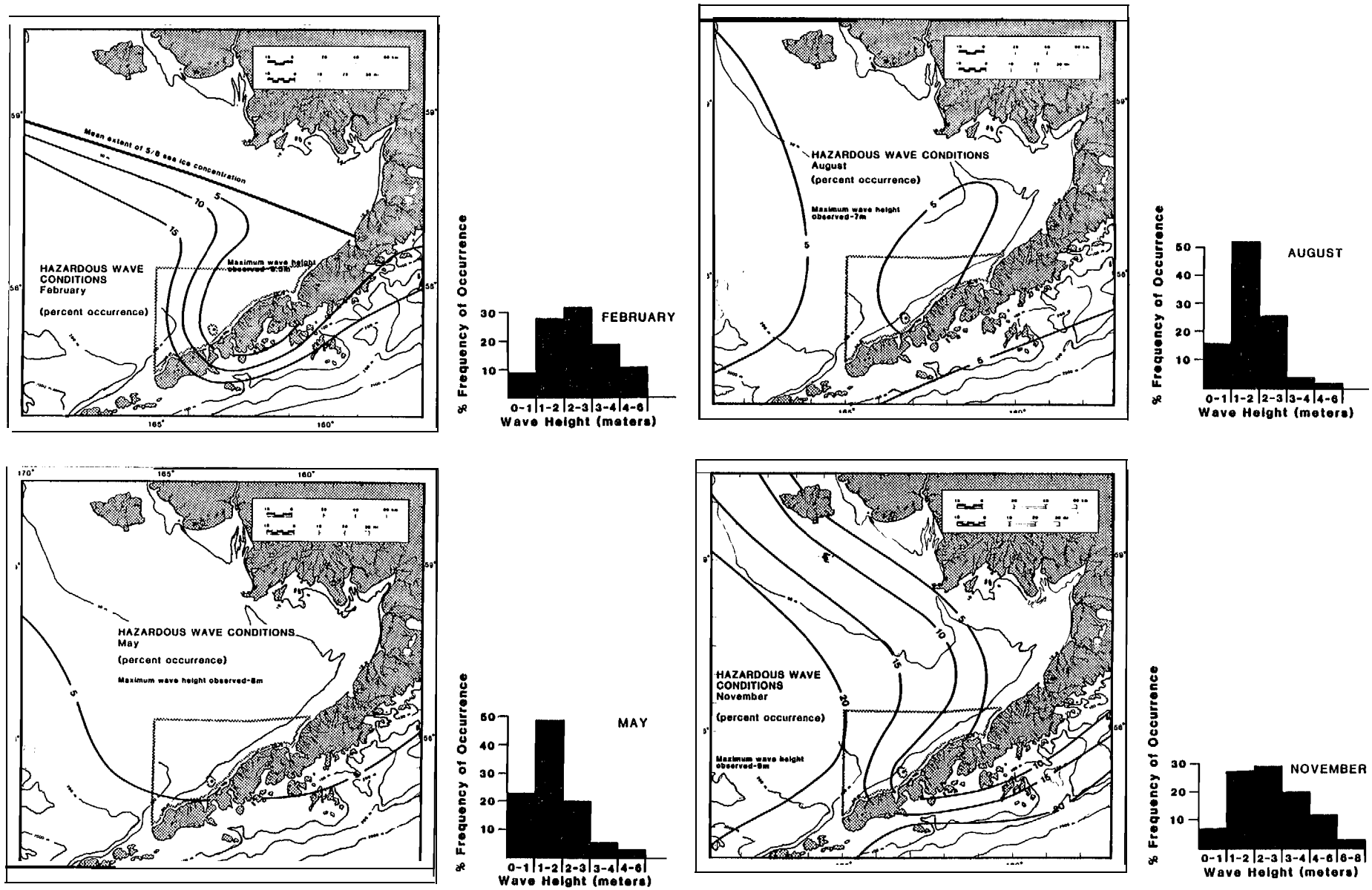


Figure 20. Hazardous wave conditions (SAI, 198 .

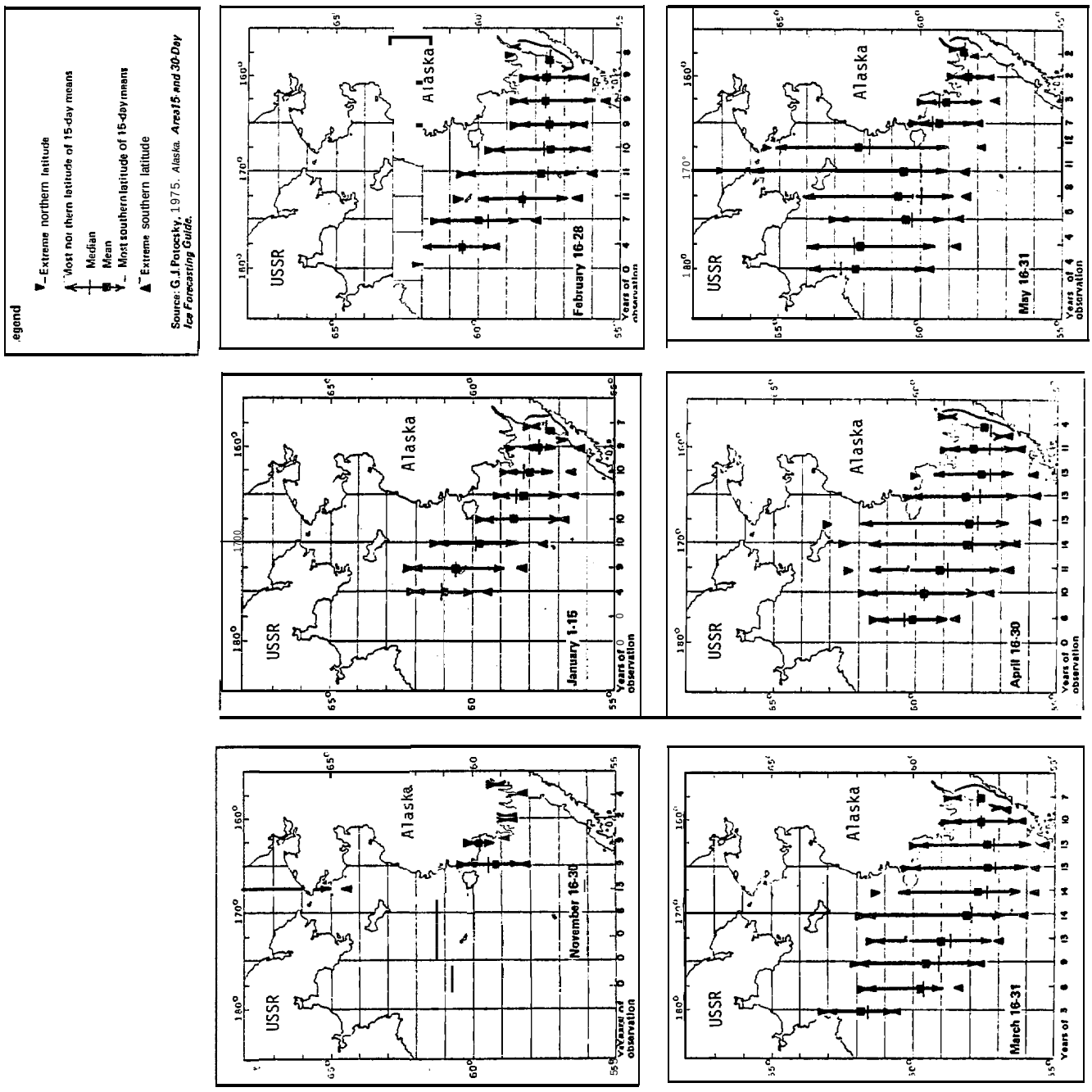


Figure 2.. Sea ice extent in the Bering Sea Brower et al, 1977

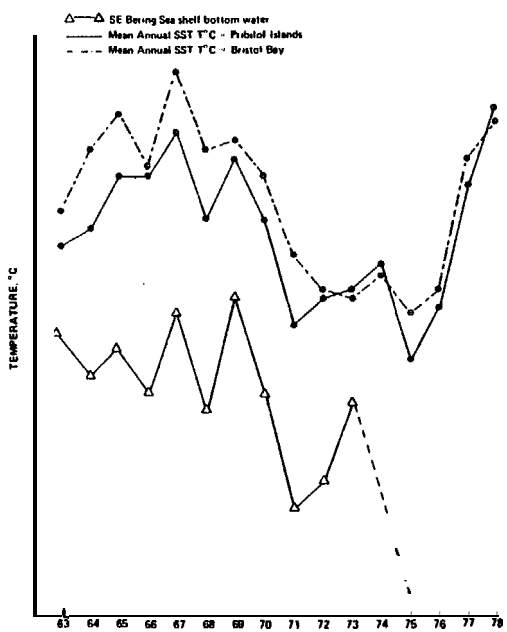
Brewer et al, 1977, calculate more conservative values (larger waves) as follows:

Return Period (years)	Significant Wave Height (meters)
"5	13.0
10	15.0
25	17.5
50	20.0
100	22.5

Ice. The distribution of sea ice in the Bering Sea is seasonal and shows large interannual variability. The mean and extremes of the seasonal ice extent in the Bering Sea are shown in Figure 21 (Brewer et al, 1977). In summer, the entire Bering Sea is free of ice. In early fall, sea ice forms in coastal areas. By early November, sea ice occurs into the southeastern Bering Sea. The maximum extent of sea ice occurs in late March.

Unlike the Arctic Ocean, sea ice in the Bering Sea does not typically form a close pack, and multiyear ice does not exist (McNult, 1981). In October and November, ice forms along the northern coasts. Under the influence of predominantly northeasterly winds, ice formed in the leeward of east-west trending coasts is advected to the south-southwest within the pack, is broken into floes near the ice edae by the effects of wave propagation, and melts at the southerly edge in the warmer waters (McNult, 1981; Muench and Ahlnäs, 1976). Coastal polynyas effective in ice generation thus exist along the southern side of the Seward Peninsula and Saint Lawrence Island, and along the northern coast of Bristol Bay. Martin and Bauer (1981) have described typical ice distribution along a line from open water to the interior zone of the ice to the north. Closest to the open water is the edge zone, characterized by small, heavily rafted and ridged floes about 20 meters in diameter and 2-4 meters thick, typically extending in a 5-10 kilometer band. In the second, or transition zone, floes are also about 20 meters in diameter, but not heavily ridged, being only 0.3-0.6 meter thick. This band is about 5 kilometers wide. In the third zone deeper into the ice, the floes may be several kilometers in diameter but only 0.3 meters thick.

Large interannual variability occurs in sea ice conditions and extent, as well as in Bering Sea surface water temperatures. Niebauer (1981) has analyzed recent fluctuations in ice and sea surface temperatures. Some of his results are illustrated in Figure 22. The period 1973-1979 was shown to be a time of extreme fluctuations, with 1973-1976 characterized by below normal temperatures and above normal ice cover under northerly winds, while 1976-1979 was a period of strong rise in temperatures and retreat of the ice pack under winds with more southerly bias. Overland and Pease (1982) correlated 23 years of storm-track and ice



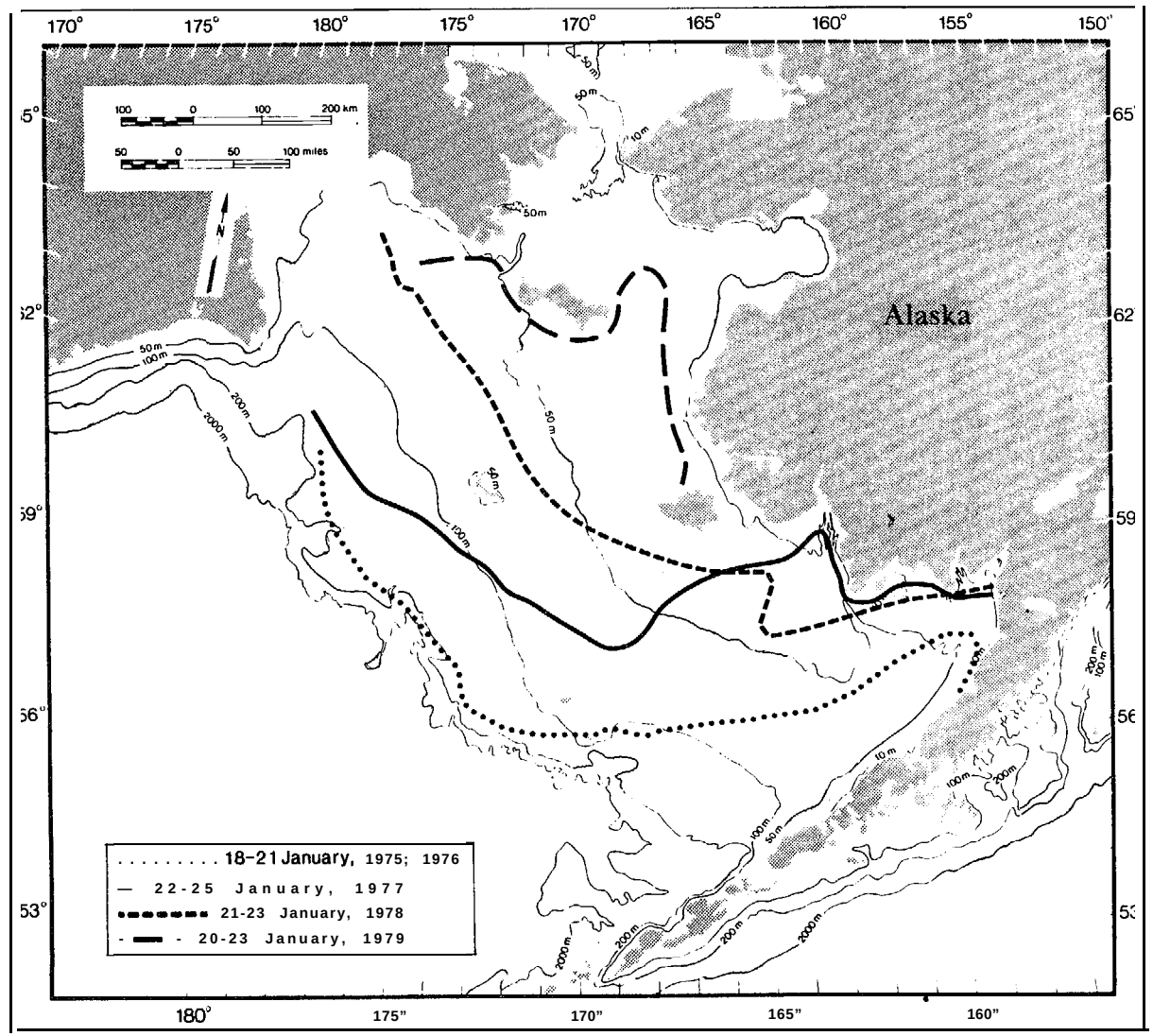


Figure 22. Variability of sea ice extent (Niebauer, 1981) .

cover data and conclude that light ice years are correlated with an increased frequency of storm tracks curving northward along the Siberian coast, compared to those paralleling the Aleutian Chain. They therefore conclude that meteorological steering of cyclones, determined primarily external to the Bering Sea, is the primary factor in determining interannual variability of sea ice extent. Such variability in sea ice has, of course, great influence on the distribution and success of the biota.

Inshore Hydrography and. Currents. The major area of interest for the present study is the inshore zone, within the coastal domain (0-50 meters in depth) defined above by hydrographic structure and flow characteristics. Of Particular interest are the inshore areas within five kilometers of the coast, which apparently exhibit high utilization by marine biota.

Bristol Bay is essentially a large estuary, with major freshwater additions along its nearshore boundaries, from diffuse sources as well as from large rivers. Typical overall salinity/temperature distributions within Bristol Bay, Figures 23 and 24, show this inshore distribution of fresh water, particularly at the head of the Bay (Institute of Marine Science, 1971).

Freshwater input at the head of Bristol Bay from the Kvichak and Nushagak rivers totals 39 km^3/year, which is about equal to the Kuskokwim (35 km^3/year) though smaller than the Yukon (204 km^3/year) further north (U.S. Geological Survey, 1980). Corresponding estimates of total runoff to the north shore of the Alaska Peninsula were made from mean rainfall data (Arctic Environmental Information and Data Center, 1980) and from topographic maps of drainage areas. This runoff to the nearshore area of the north side of the Alaska Peninsula totaled about 20 km^3/year, or about 34 percent of the total freshwater runoff into Bristol Bay.

Straty (1977) has traced nearshore flow Patterns of freshwater from the rivers of the inner Bay using hydrographic stations, drifters, and dye releases. Some of his hydrographic results, summarized in Figure 25, clearly show this freshwater entering the Bay and flowing along the northern side of the Bay. His drifter data, Fiqure 26, also indicate the counterclockwise flow around the inshore perimeter of the Bay.

Sediment plumes visible in available satellite images (Geophysical Institute, University of Alaska, unpublished data summary,1980), Figures 27 and 28, also illustrate the counterclockwise inshore flow.

Schumacher and Moen (1983) and Schumacher et al (1982) have summarized recent data for the inshore region from Unimak Pass and along the north shore of the Alaska Peninsula.

The station patterns and moorings that they discuss are shown in Figure 31 for the Unimak Pass area and in Figures 32 and 33 for the Alaska Peninsula area.

Scatter plots and progressive vector diagrams from the Unimak Pass moorings are shown in Figure 34 and hydrographic results and dynamic topography in Figure 35. Their results show mean flow from the Gulf of Alaska Shelf westward and then northward through Unimak Pass. Reversals (southward flow) occurred eighteen percent of the time in spring and 31 percent in summer, with mean flow into the Bering Sea during spring being three times greater than in summer. Currents in Unimak Pass at periods between three and ten days correlated with bottom pressure differences through the pass, the latter were in turn related to the longshore winds which induced sea level changes along the Gulf of Alaska coast. The westward coastal flow south of the Peninsula consists of relatively fresh water and appears to be a westward extension of the Kenai Current (Schumacher and Reed, 1980) and the coastal jet in the Gulf of Alaska (Royer, 1979; Royer, 1981a; Royer, 1981b), driven by freshwater discharge into the Gulf. The flow through Unimak Pass has a strong baroclinic component.

Hydrographic data (Schumacher and Moen, 1983) taken along the northern shore of the Alaska Peninsula are shown in Figures 36 and 37, while vertical differences in sigma-t are given in Figure 38.

These results show that while the waters over the continental shelf adjacent to the Alaska Peninsula generally adhere to the previously defined hydrographic domains (Kinder and Schumacher, 1981a), complications exist in the coastal domain. For example, while the coastal domain (less than 50 meters) was generally mixed, the addition of freshwater as a line source (particularly between Ports Moller and Heiden) and from the Kvichak River, can result in significant stratification (Figure 38), up to three sigma-t units, even though the water in the coastal domain is shallow and tidal mixing is strong. There was also a suggestion in the data that melting ice could impact the local buoyancy/tidal mixing balance.

In February, the hydrographic data showed the impact of the seasonal variations in the less saline Kenai current water upon coastal water along the Peninsula. This was most apparent in a reduction of mean salinity between Port Moller and Unimak Island between August 1980 and February 1981. This lends support to a previous hypothesis that the Kenai Current contributes to flow around the perimeter of Bristol Bay and northward toward the Bering Strait (Schumacher et al, 1982). Dynamic topography (Figure 39) also is consistent with northeast flow along the Peninsula.

SURFACE TEMPERATURE

CONTOUR INTERVAL 1.0° C

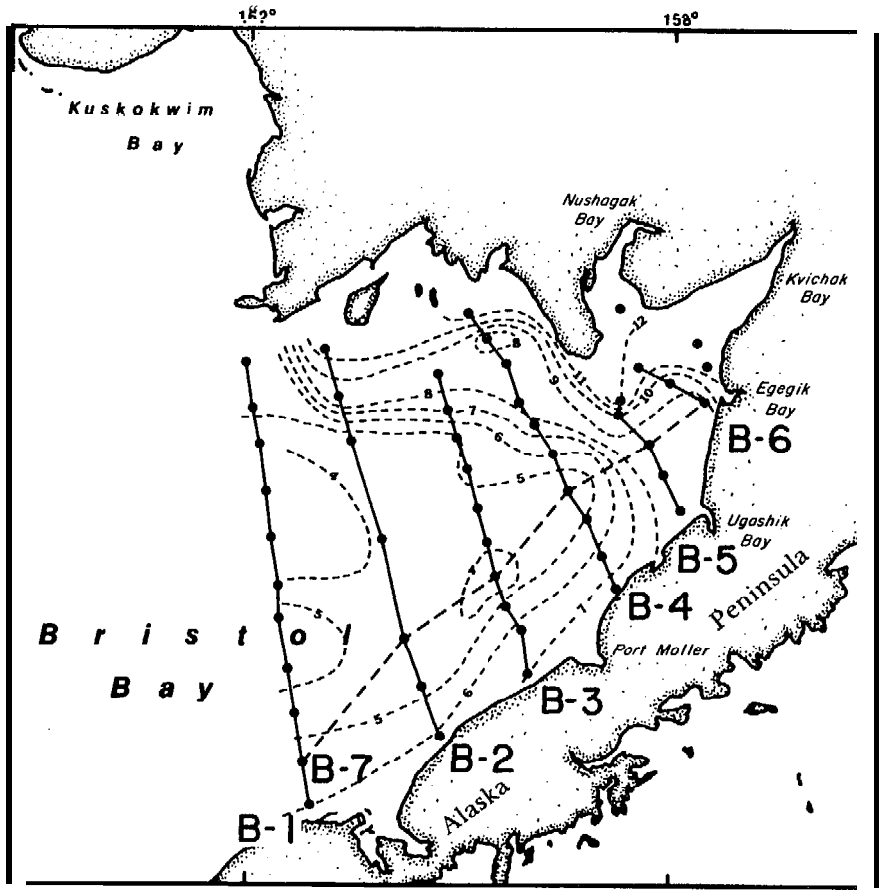


Figure 23. Bristol Bay surface temperature distribution August, 1968 (lMS, 1971).

SURFACE SALINITY

CONTOUR INTERVAL <29.0 = 1.0‰, >29.0 = 0.5‰

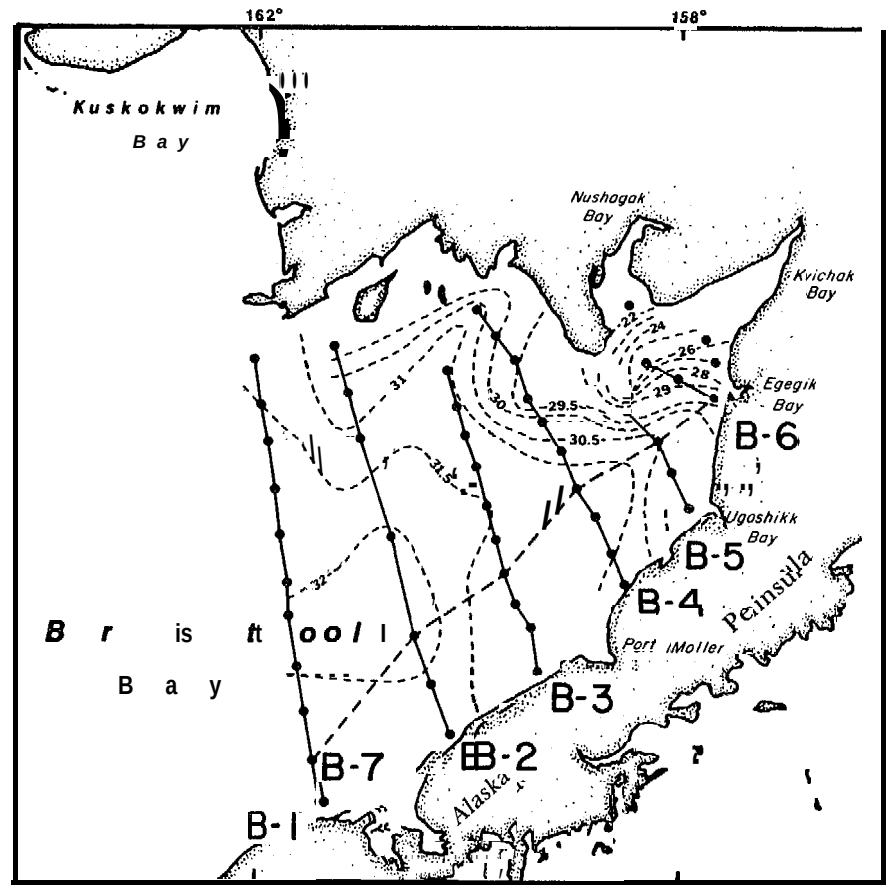


Figure 24. Bristol Bay surface salinity distribution August, 1968 (lMS, 1971).

Station Locations and Section Lines

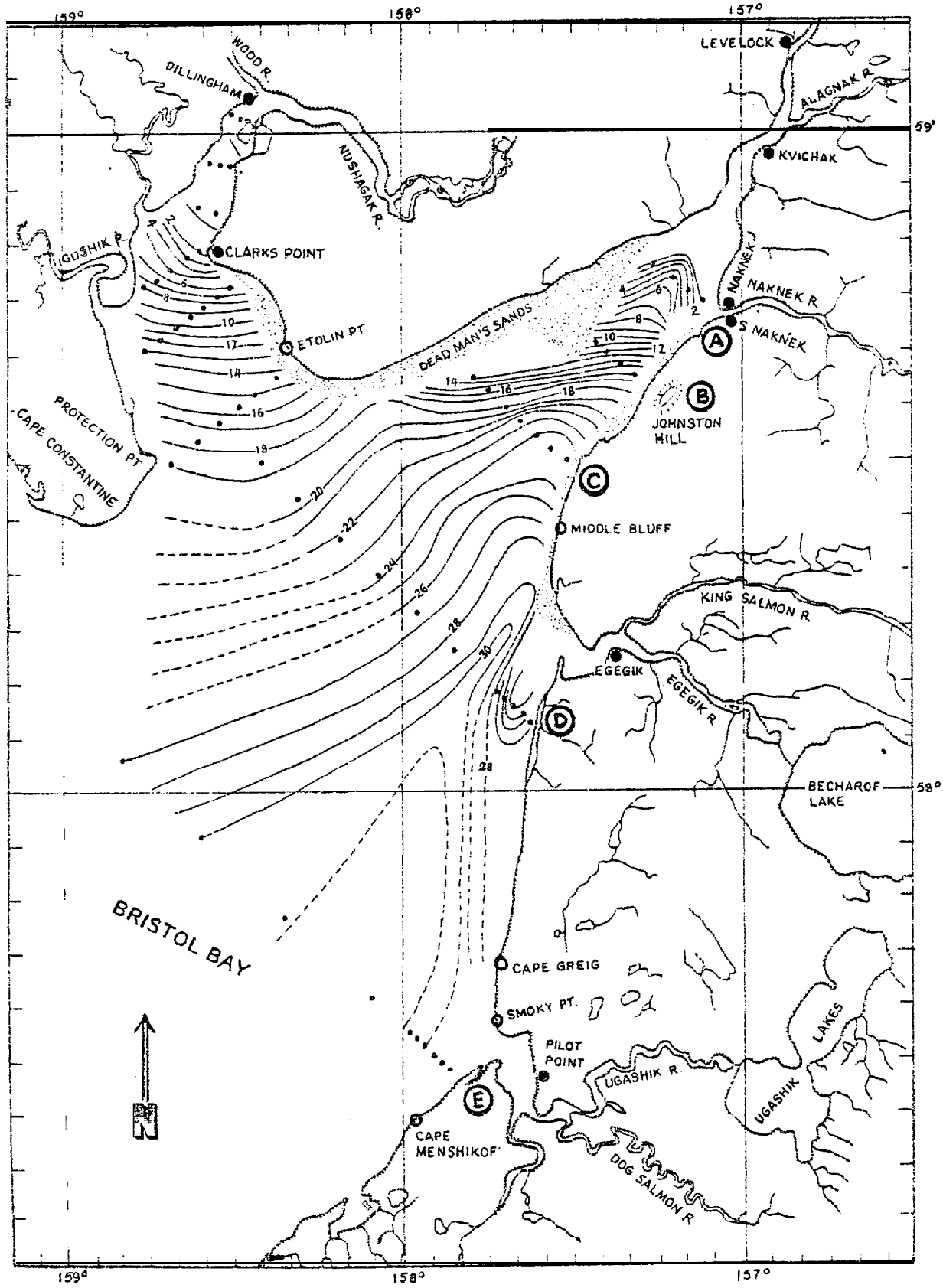


Figure 25. Surf ace salinity (ppt) at low tide, inner Bristol Bay, July and August, 1966 (Straty, 1977).

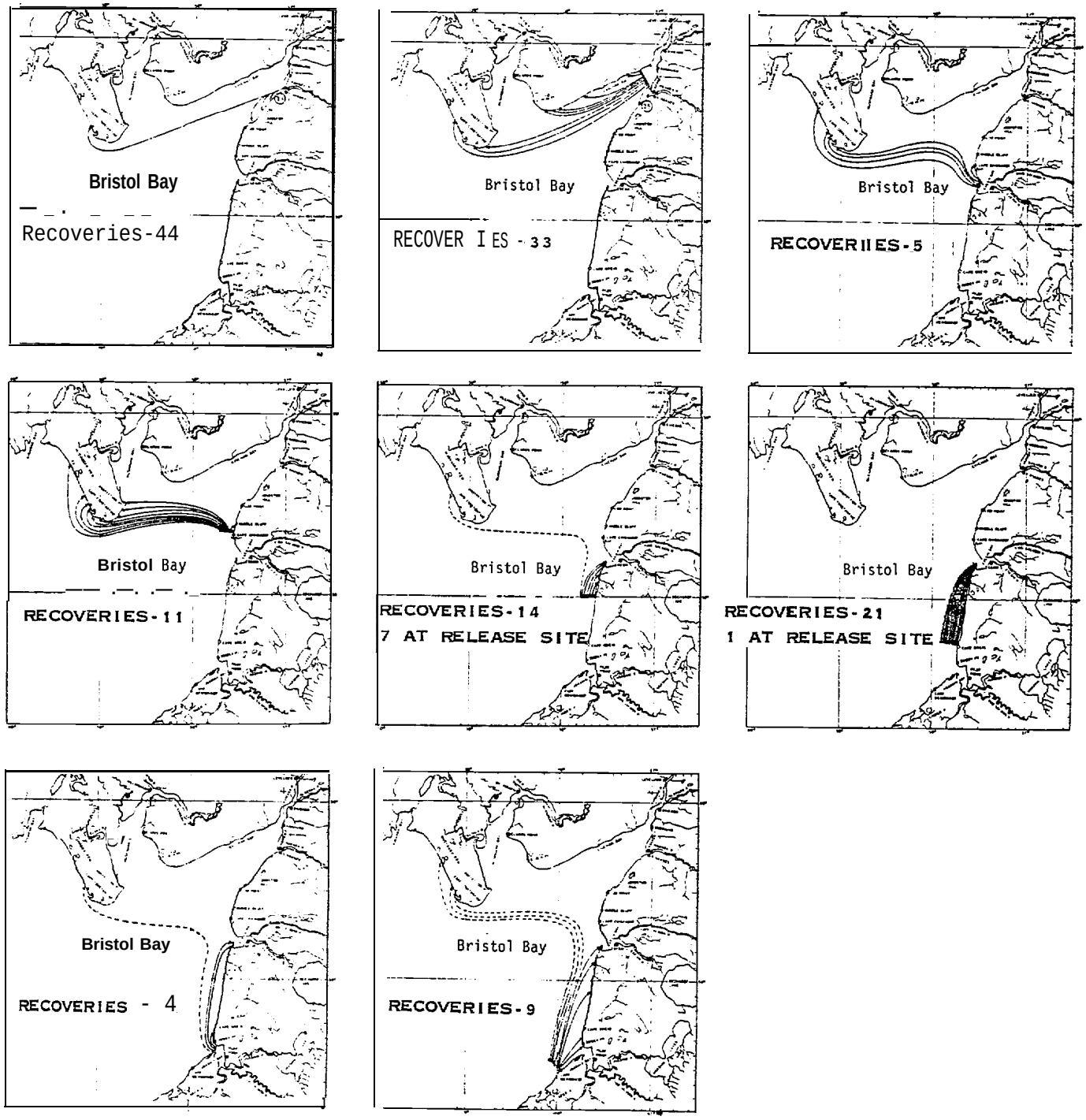


Figure 26. Drifter results, Bristol Bay (Straty, 1977) .

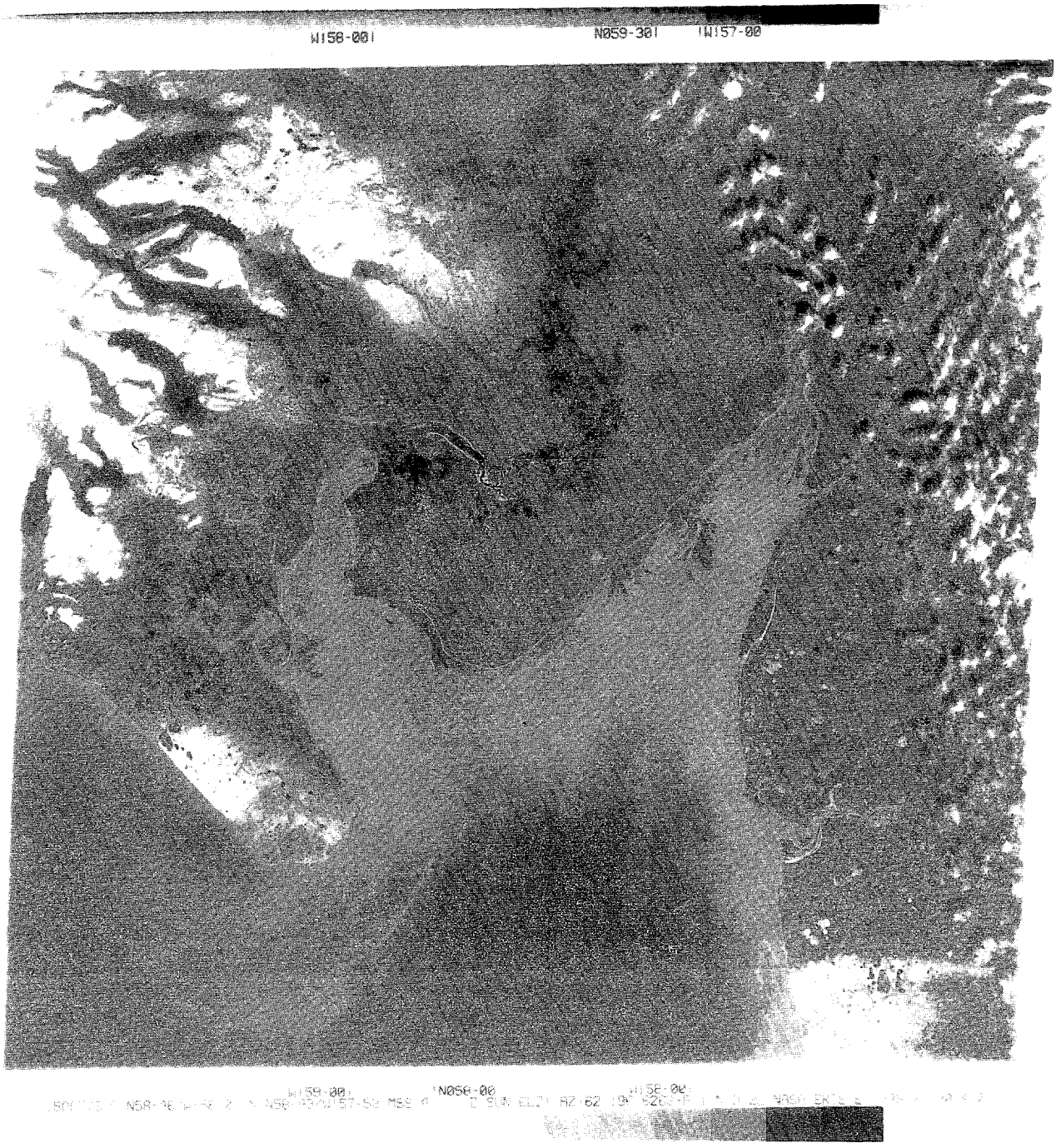


Figure 27. Satellite image, Bristol Bay inshore area, upper Bay (Geophysical Institute, University of Alaska).

Figure 28. Satellite image, Bristol Bay inshore area, Ugashik Bay/Port Heiden area (Geophysical Institute, University of Alaska) .

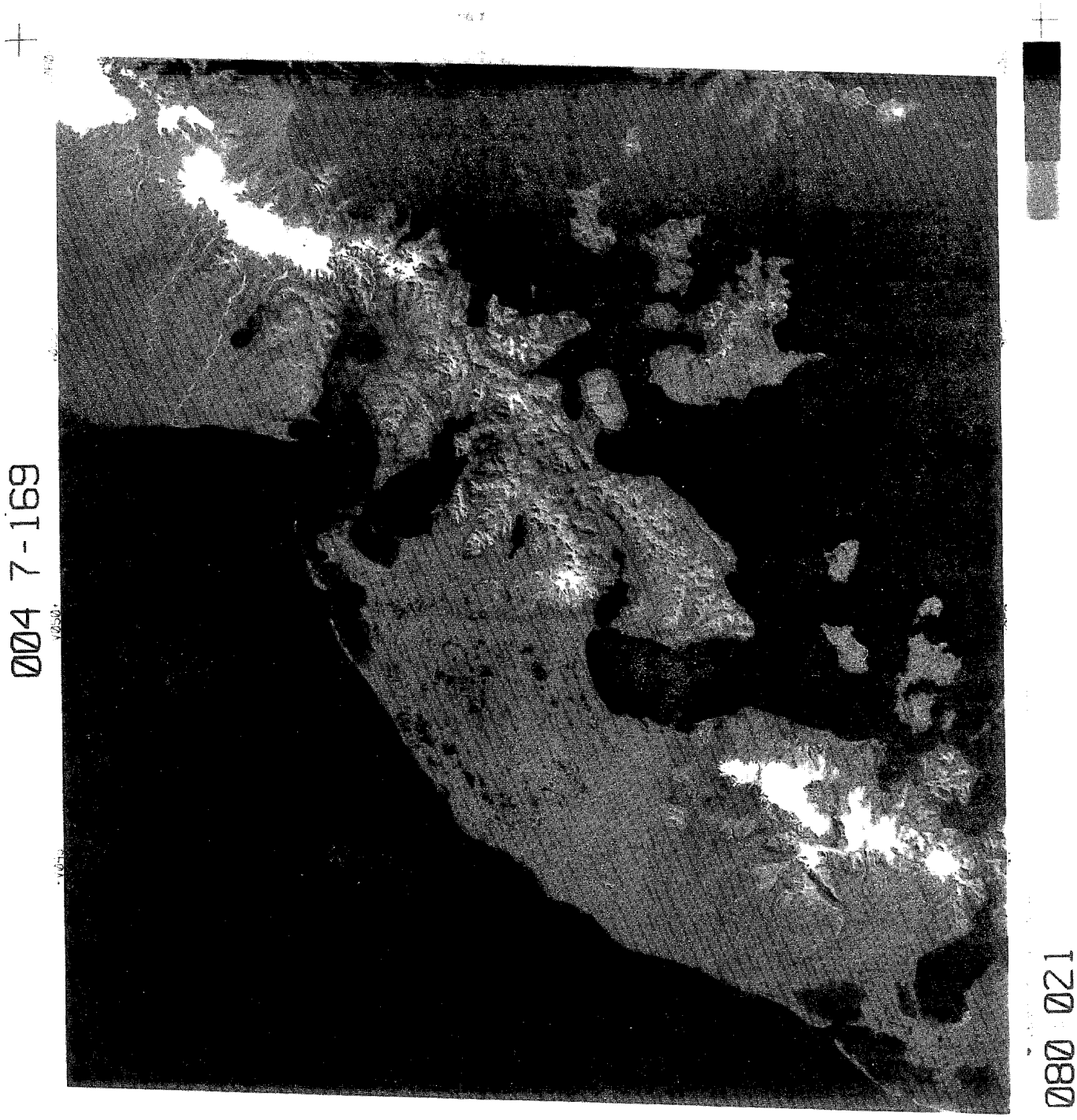


Figure 29. Satellite image, Bristol Bay inshore area, Port Moller area (Geophysical Institute, University of Alaska) .

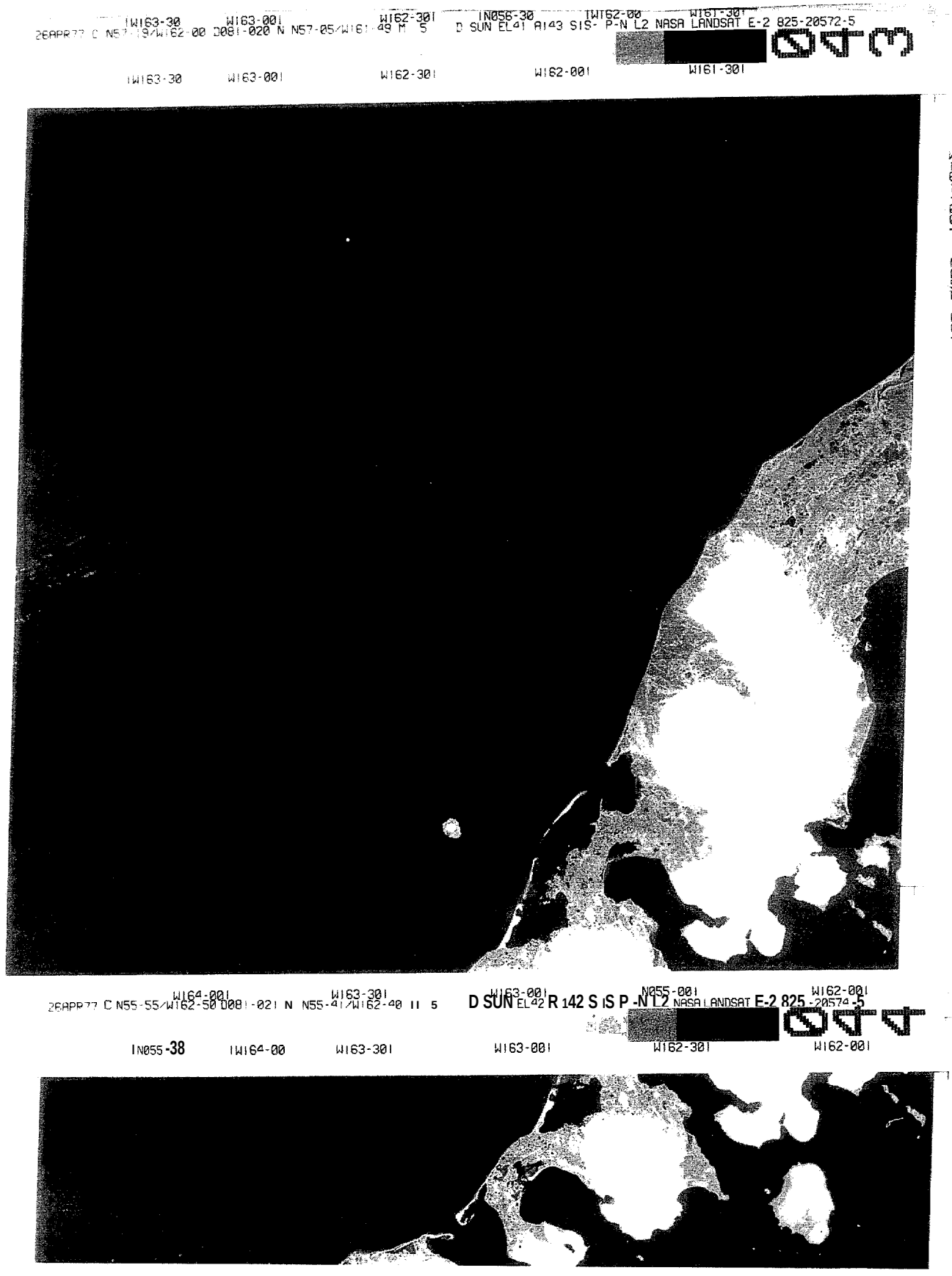


Figure 30. Satellite image, Bristol Bay inshore area, Izembek area (Geophysical Institute, University of Alaska).

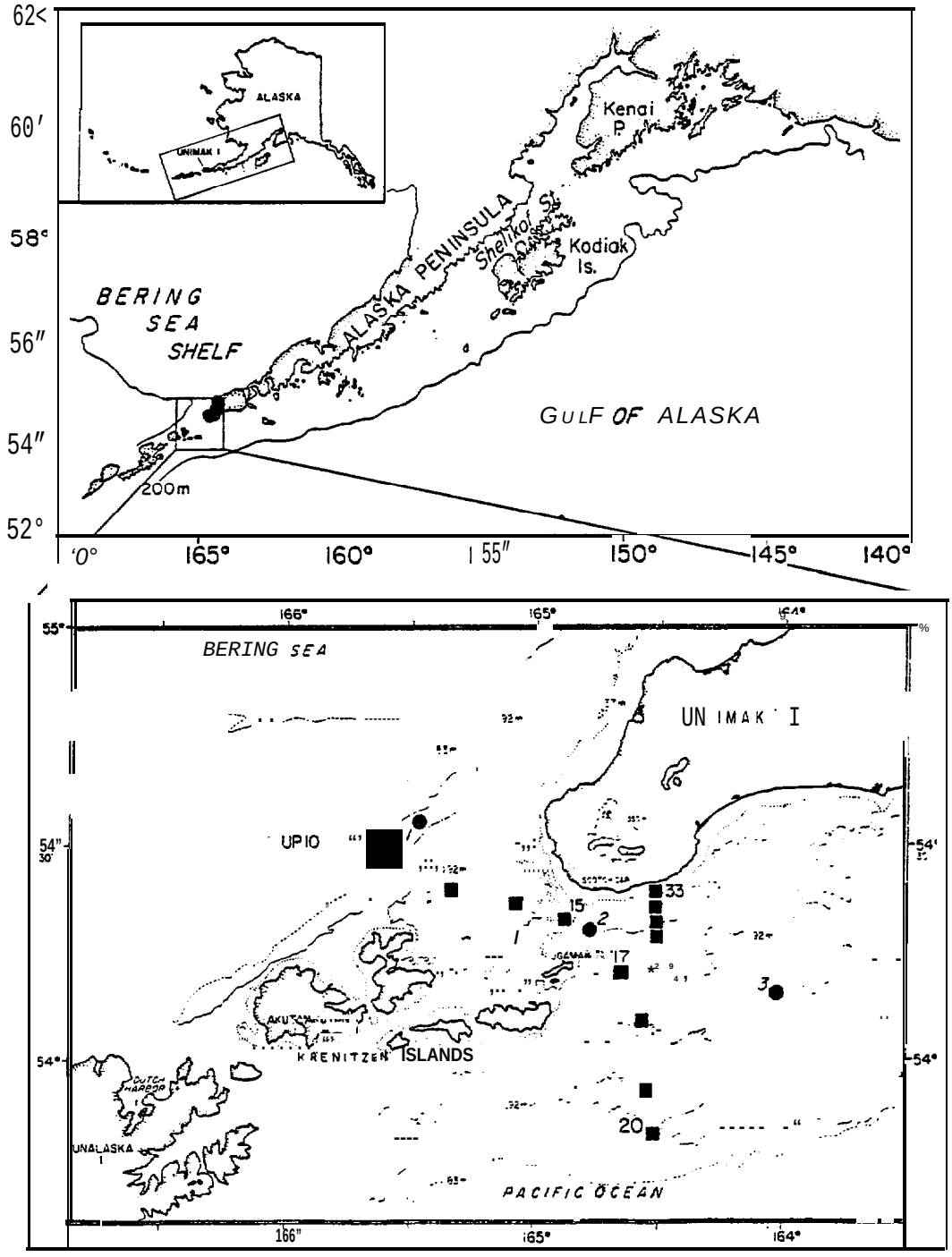


Figure 31. Location of CTD stations, cur rent meters and pressure gauge moorings, Unimak Pass area (Schumacher and Moen, 1983).

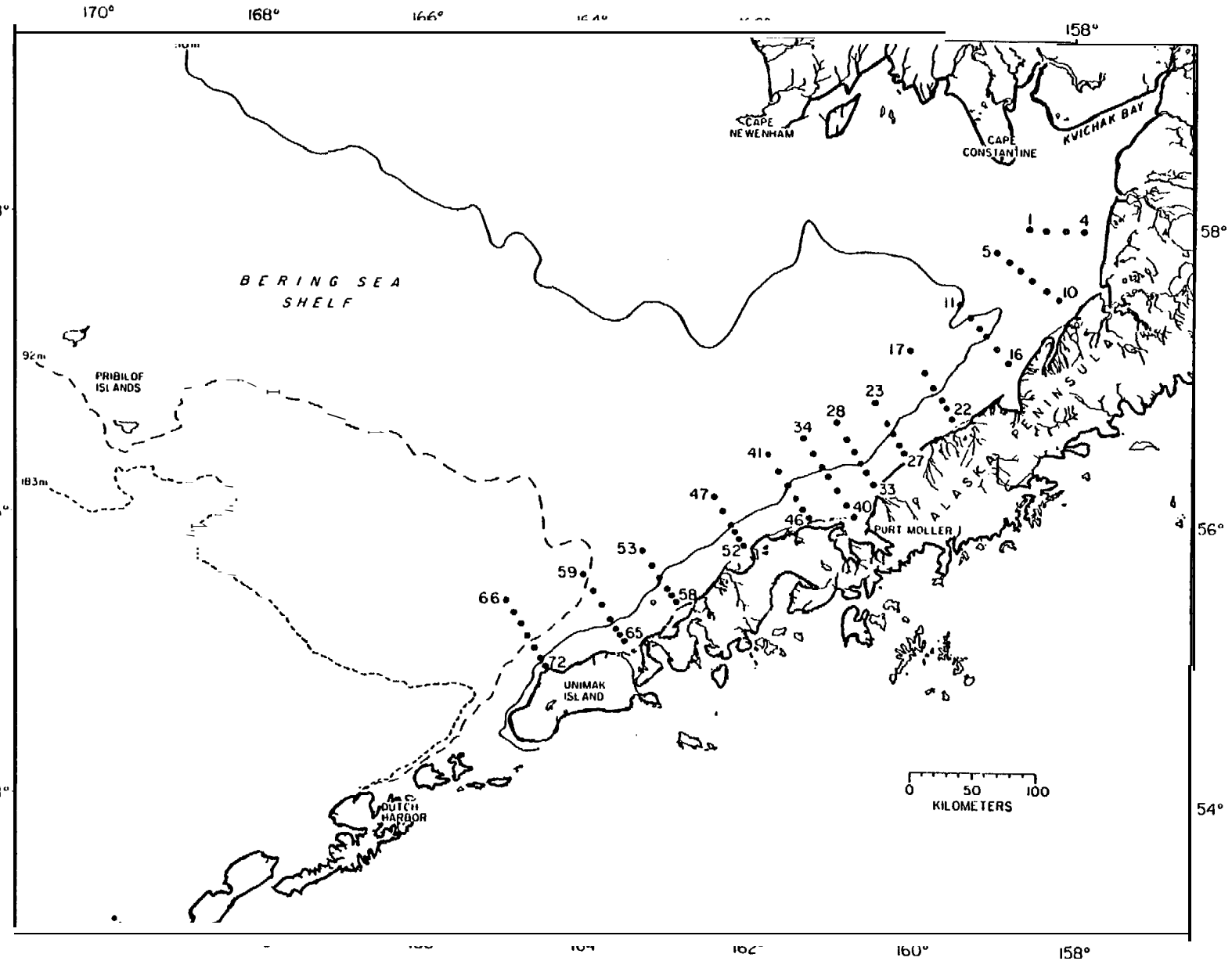


Figure 32. Location of CTD stations (NA 1 to 72) for the North Aleutian Shelf study (Schumacher and Moen, 1983 .

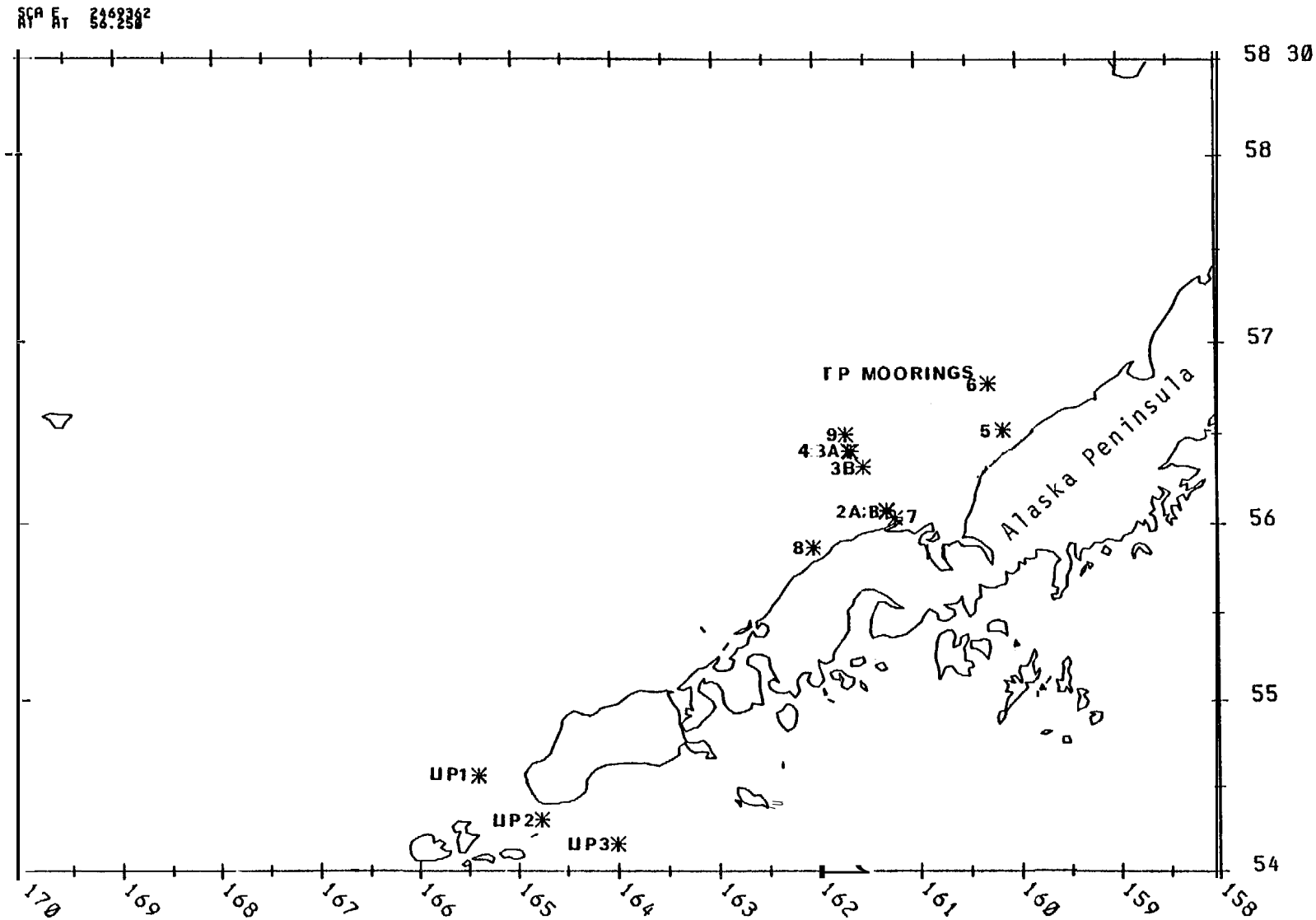


Figure 33. Location o≤ current meter mo ings (Schumacher and Moen, 1983).

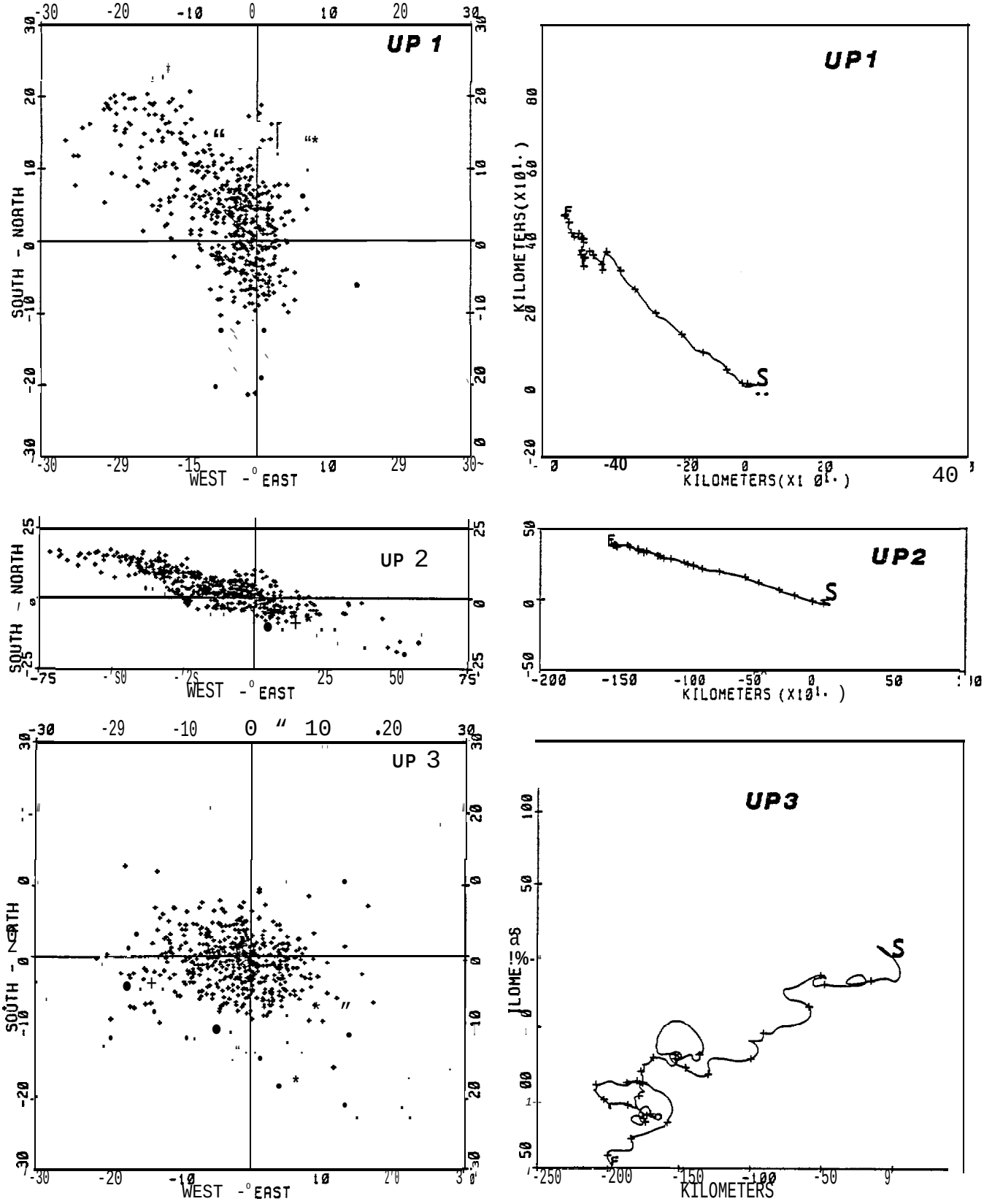


Figure 34. Results from 35 hour filtered current data presented as scatter plots and progressive vector diagrams (S represents the start of the record, and the crosses are at 5-day intervals). Note the different speed and length scales (Schumacher et al, 1982).

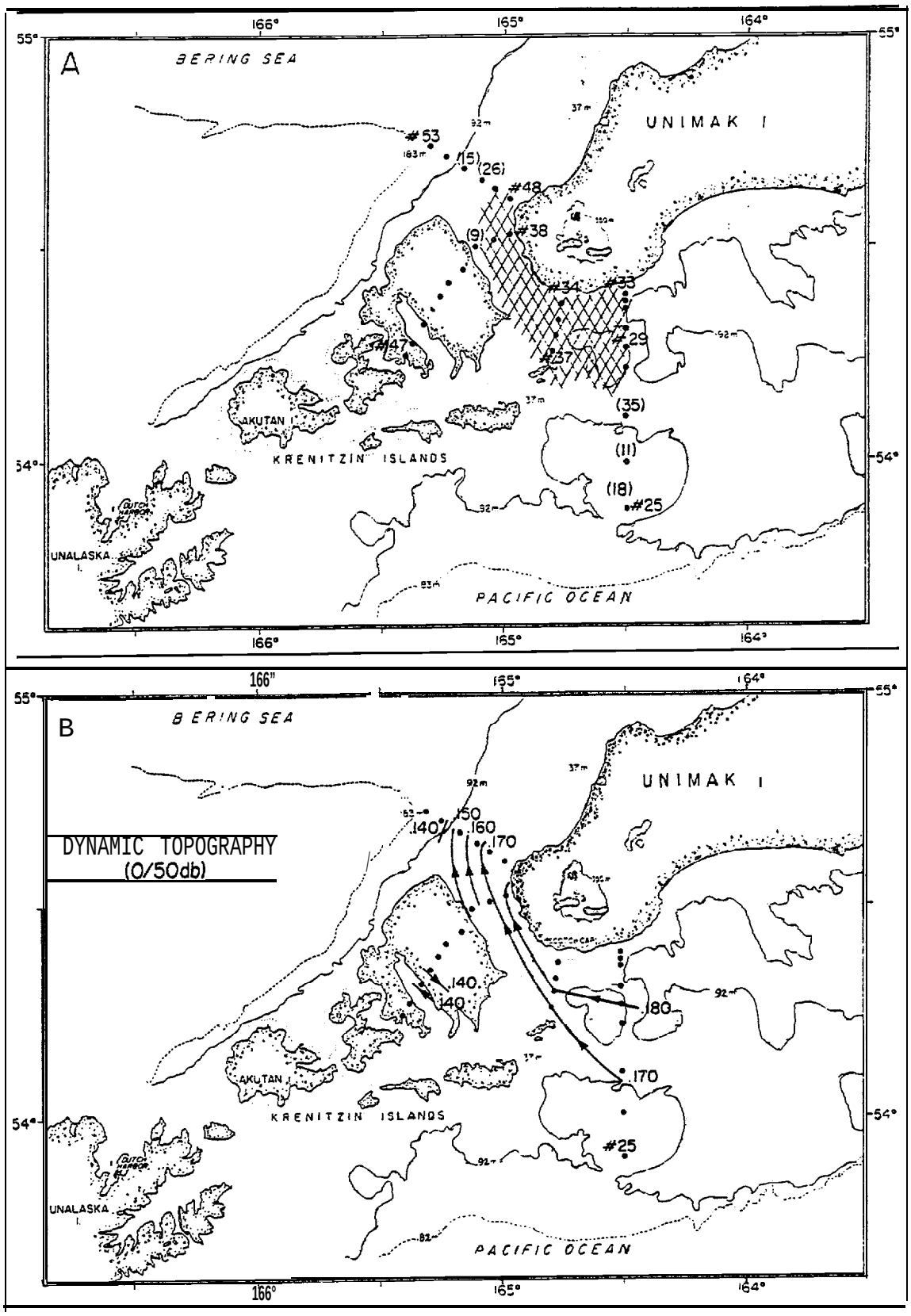


Figure 35. Hydrographic data for September 1981 presented as (a) areal extent of waters with salinity ≥31.75 gin/kg in the upper 50 m (or bottom) where the numbers in parentheses are depths of the low-salinity band for z >50 m and (b) dynamic topography (0/50 d) with a 0.01 dyn m contour interval. CTD station numbers are indicated by the number sign (Schumacher et al, 1982).

Inshore CUrrent records (Schumacher and Moen, 1983) support previous results (Kinder and Schumacher, 1981b; Schumacher and Kinder, 1983), which imply a moderate (2 to 6 cm/s) Eulerian mean flow from the vicinity of Unimak Island, counter-clockwise around Bristol Bay, and thence northwest past Nunivak Island. A mechanism for long-term (on the order of months) flow is the persistent cross-shelf density distribution, which resulted in baroclinic speeds of 1 to 5 cm/s, typically concentrated in a 10- to 20-km-wide band in the vicinity of the 50-m isobath. Scaling of Eulerian tidal residual flow suggested a weak contribution, <1.0 cm/s, except where the tidal current was orthogonal to the 50-m isobath off Port Heiden (Schumacher and Kinder, 1983).

Although wind energy was evident in alongshore current pulses, mean winds during the current observations were weak and toward the west, in opposition to the observed mean flow. Cross-shelf current pulses were also evident, and the observed tendency was for offshore flow in the upper water column.

Substantial vertical shear in currents was also observed. The combination of wind-induced shear and geostrophic baroclinic shear accounted for about one-half the observed values.

Because of the frequency of storms in the area, approximating three to five per month, the effects of such events on the oceanography of the area are of prime importance. Schumacher and Moen (1983) and Pearson, Baker, and Schumacher (1980) describe one such storm event, during which moorings were in place and shipboard hydrographic measurements were made in the nearshore region of the Peninsula. The summer structural front, located in the vicinity of the 50 meter isobath, separated the well-mixed coastal domain from the two-layered middle shelf domain of the southeastern Bering Sea. This system was perturbed in mid-August by a strong storm (winds in excess of 30m see-l) which vertically mixed temperature, salinity and nearshore suspended particulate matter (SPM) throughout the water column. Using CTD and SPM data collected 1, 7, and 14 days after the storm, the subsequent reestablishment of frontal domain characteristics was documented.

The line of CTD stations normal to the Peninsula (Figure 40) was occupied on 19, 24, and 31 August 1980. Temperature, salinity, sigma-t and light attenuation sections are shown in Figures 41, 42, and 43. The time to run a complete line was about six hours. About one day prior to running the first section, the remnants of typhoon Marge passed eastward through the study area. This storm resulted in winds up to 30 ms^{-1} and six to eight meter waves. The turbulence associated with this storm mixed the water column at least 45 km seaward of the coast (Figure 41). Suspended

BOTTOM TEMPERATURE (“C)

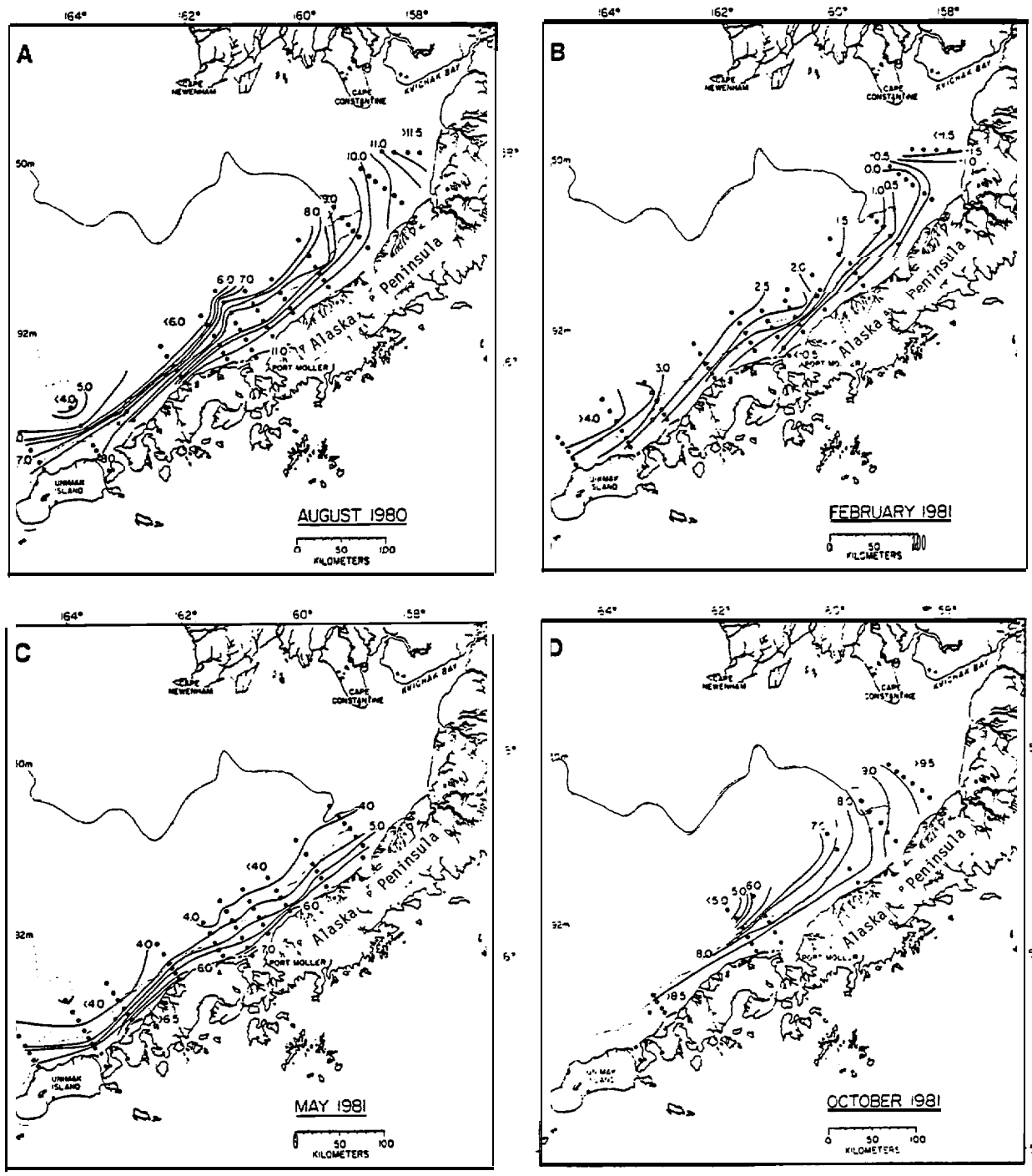


Figure 36. Bottom temperature e (“C) contours (Schumacher and Moen, 1983) .

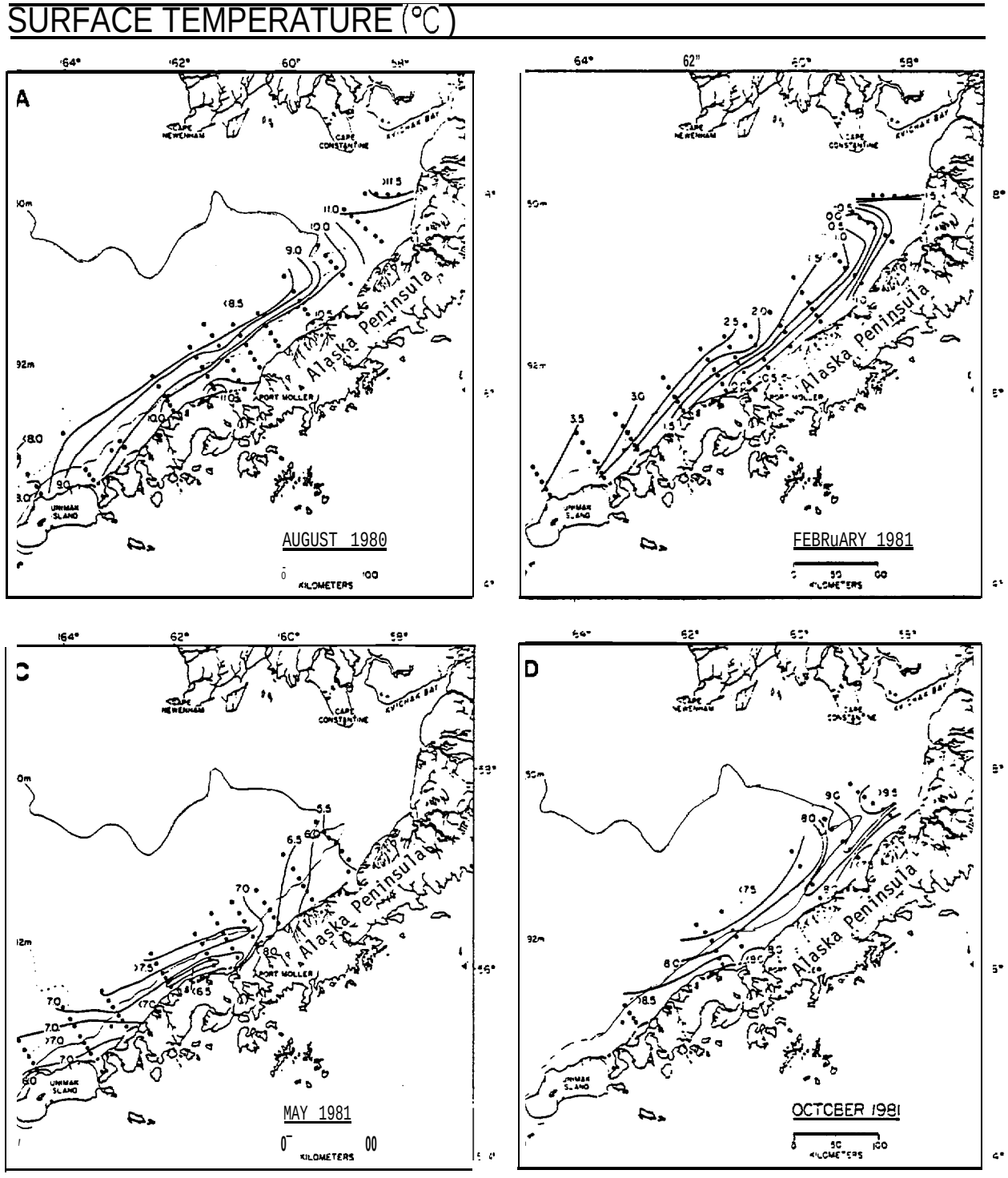


Figure 37. Surf ace temperature ("C) contours (Schumacher and Moen, 1983) .

A SIGMA-T

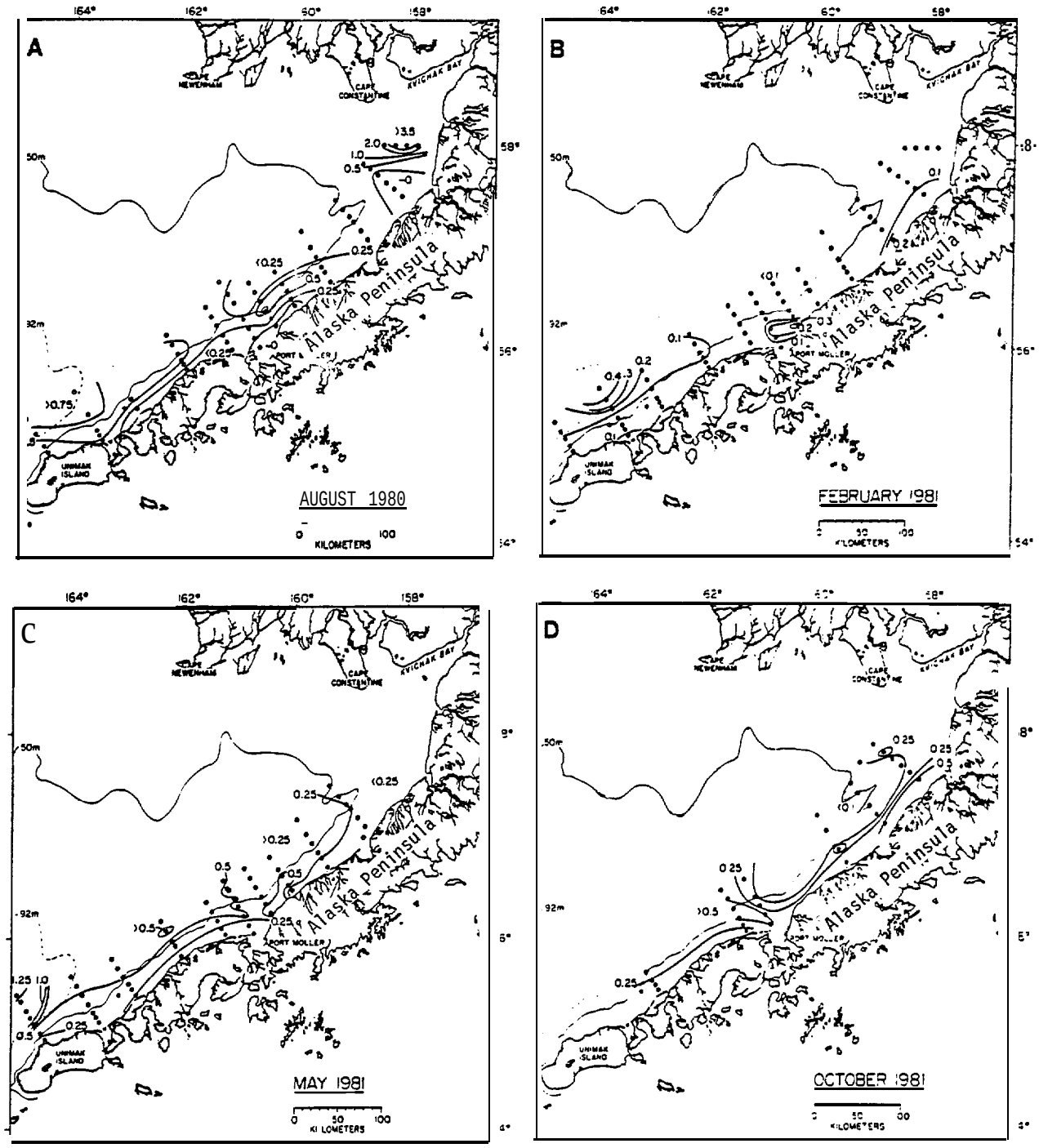


Figure 38. Bottom minus surface sigma-t contours (Schumacher and Moen, 1983).

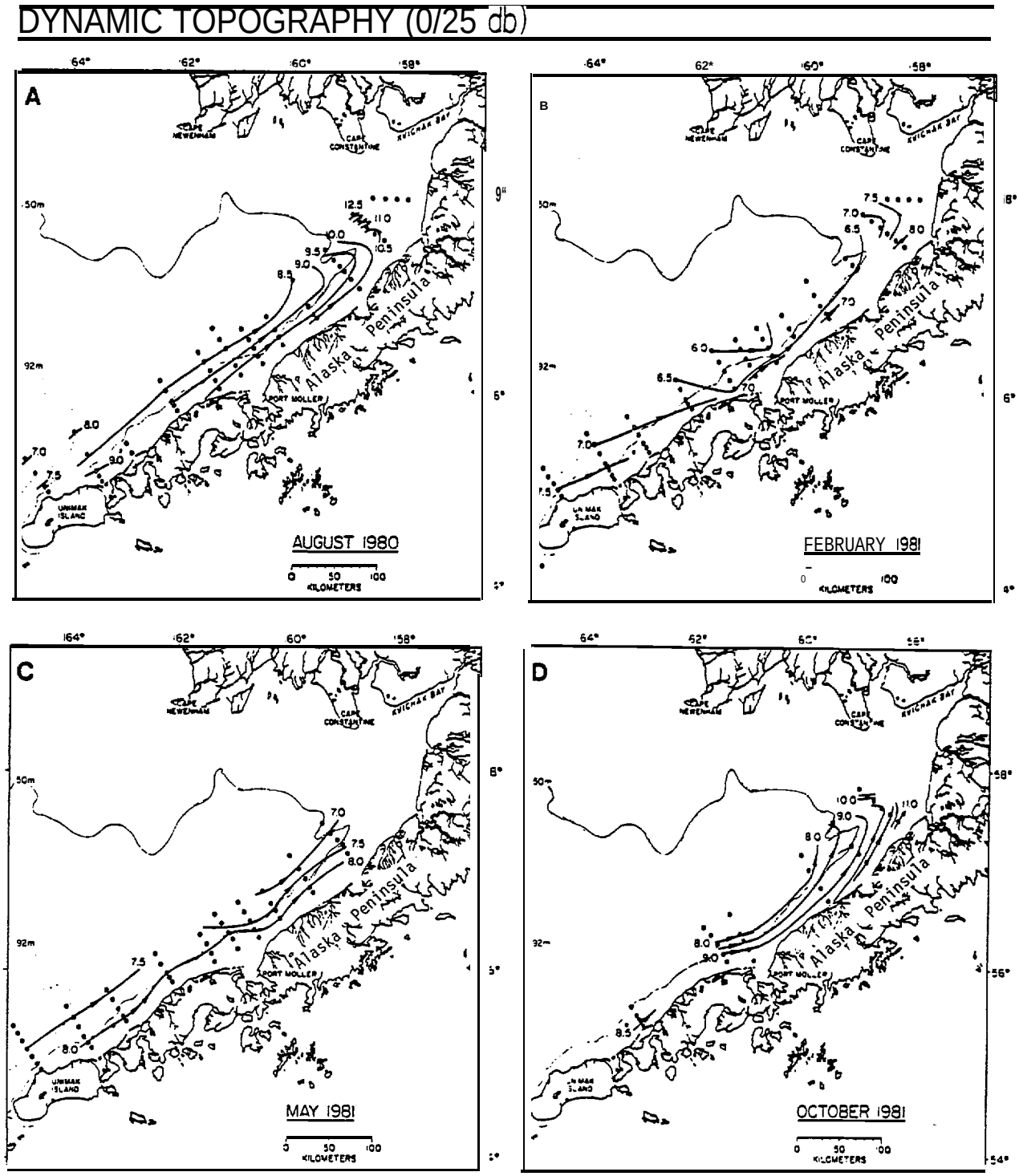


Figure 39. Dynamic topography (0/25 db) (Schumacher and Moen, 1983).

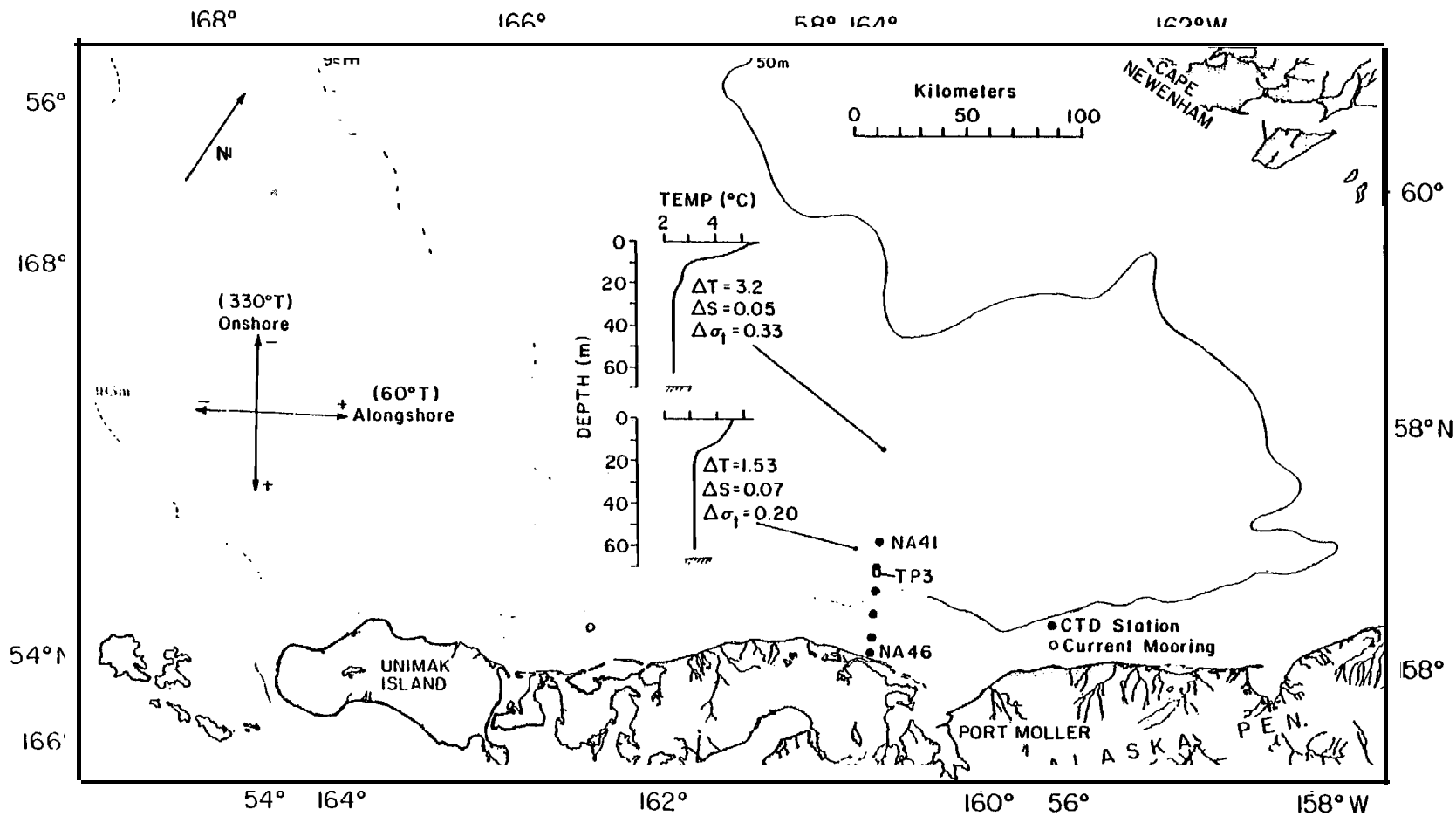


Figure 40. North Aleutian Shelf study area, showing location of hydrographic data section (NA41 to NA46) and mooring TP3A. Also shown are CTD data from 31 May 1980 and axes used for current and wind data (Schumacher and Moen, 1983).

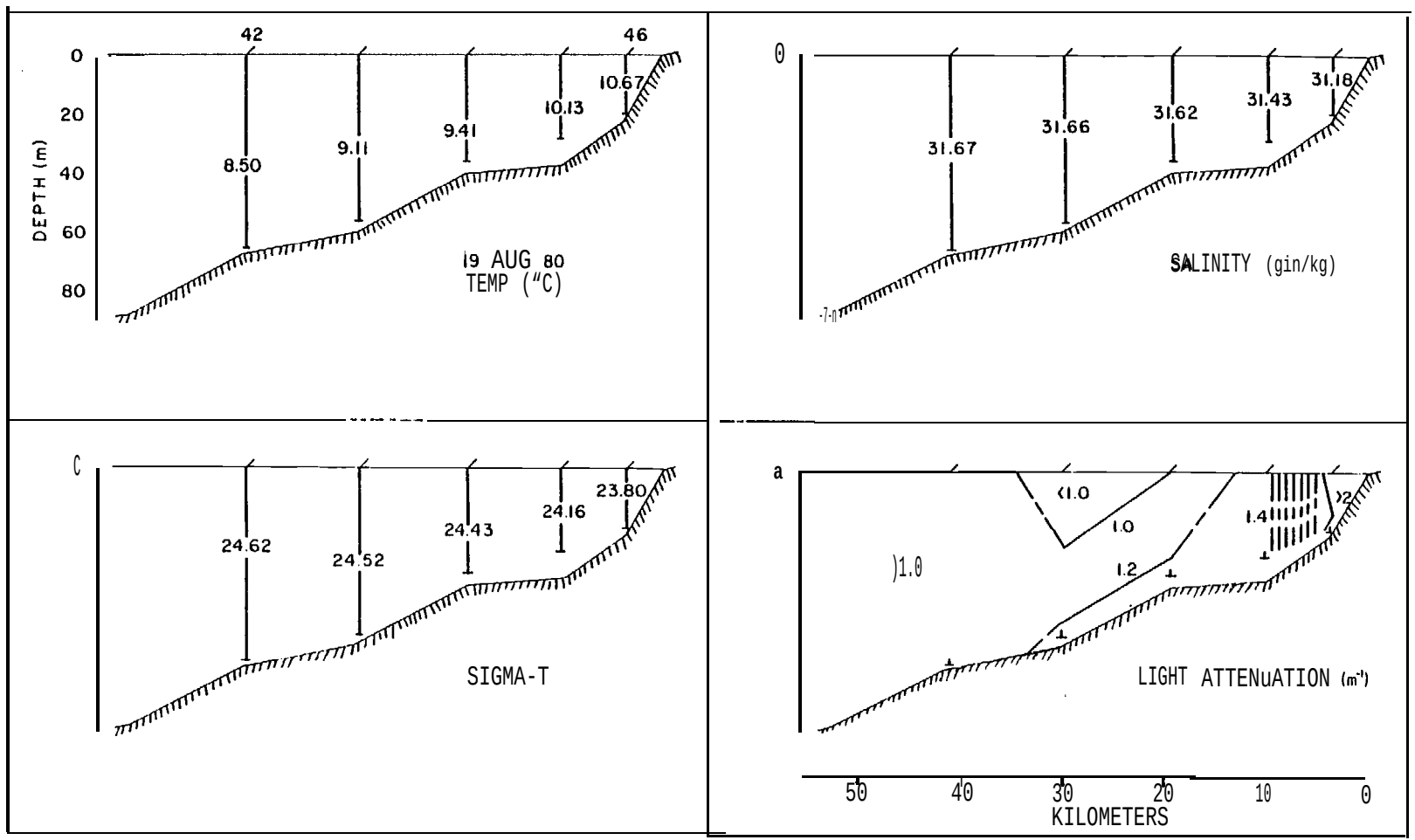


Figure 41. Hydrographic and light attenuation sections from 19 August 1980. Note the location of the 8.5*C isotherm (Schumacher and Moen, 1983).

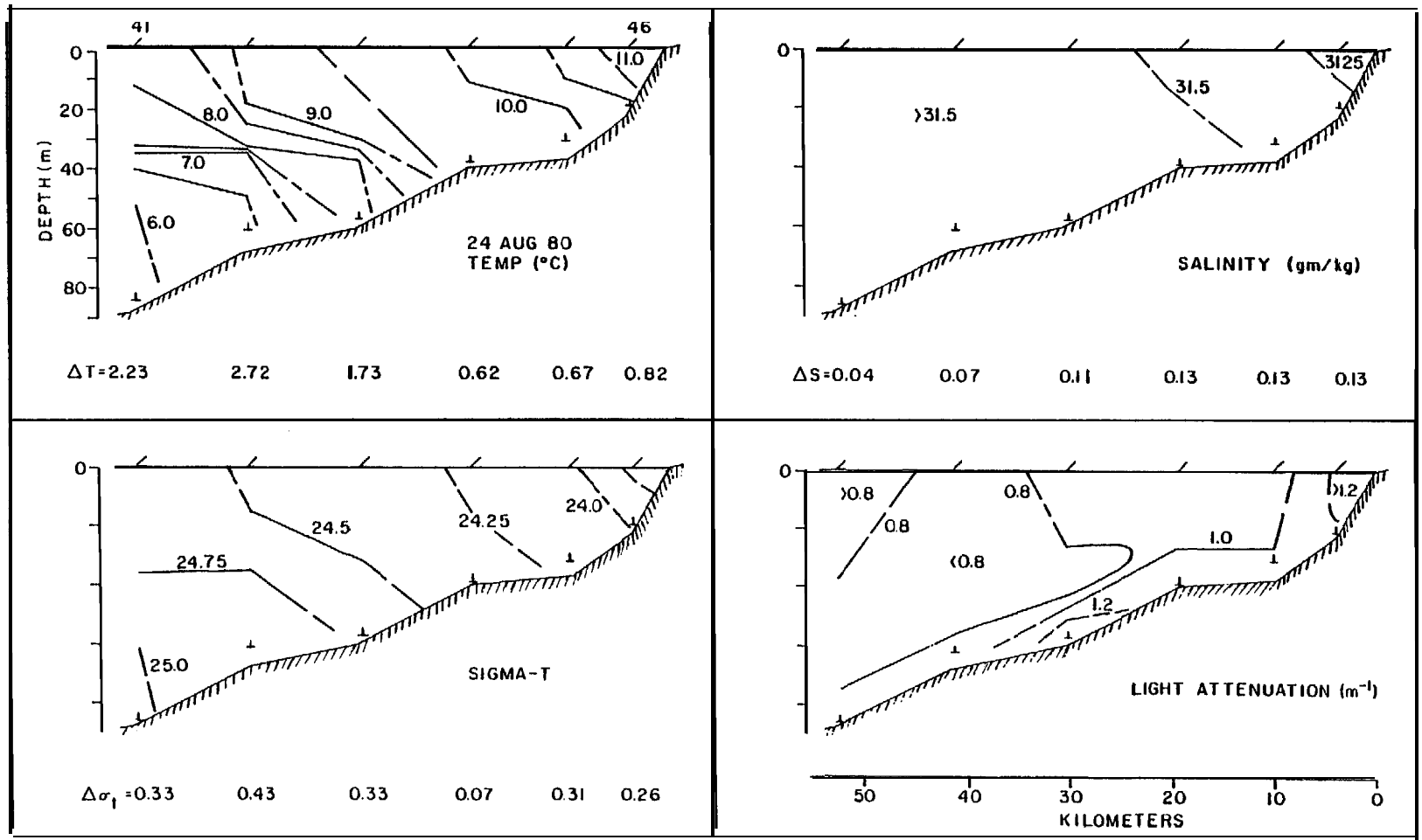


Figure 42. Hydrographic and light attenuation sections from 24 August 1980. Contour intervals are 0.5°C, 0.25 gm kg^{-1}, 0.25 σ_t units and 0.2 m^{-1} for light attenuation. Magnitude of upper minus lowest 1 m average parameter is presented under a given station as a Δ. Note, lowest 1 m average salinity at station 42 was 31.71 gm kg^{-1} (Schumacher and Moen, 1983).

particulate matter was also well mixed within 10 km of the shore, and seaward of station 45, isopleths exhibited weak downward vertical gradients with SPM increasing monotonically.

During the second occupation of this section (Figure 42), the entire shelf region was thermally stratified, with surface minus bottom temp-erature difference (ΔT) from 0.6 to 2.7°C. Colder bottom waters intruded onshore, with a displacement of the 8.5°C-isotherm of about 10 km. A similar change of mixed to stratified structure was observed in isohalines with the strongest stratification (A S=0.13 g kg^{-1}) over the normally mixed coastal domain. These data suggested an onshore deep flux (bottom salinity increased) and an offshore upper flux (upper layer salinities decreased). Light attenuation values indicated a 50 percent reduction in nearshore concentration of SPM, while over the middle shelf domain (>--50 m) a subsurface minimum layer was established.

Hydrographic conditions observed on 31 August (Figure 43) showed a return to more typical stratification distributions; middle shelf waters were stratified with $\Delta\sigma$ t>0.43 and coastal domain waters were vertically well mixed. SPM profiles also indicated mixed conditions in the coastal domain and a minimum layer was clearly established near or below the pycnocline.

Alongshore (v positive toward 60°T) winds are shown in Figure 44. The passage of the storm resulted in maximum alongshore wind speeds of about 25 ins-l. About 3.5 days after the storm's peak speeds, a period of relatively steady alongshore winds existed for about three days with a mean speed of -5.5 ms^{-1}. With the exception of the storm winds and those on 24 August, onshore wind speeds were only about 1 in^{s}-l.

Currents at 5 and 39 meters below the surface are shown in Figure 44, where the alongshore axis is the same as for the wind and the onshore axis is u positive 150°T. Near-surface currents reversed from onshore to offshore concomitant with the wind reversal and this initial offshore pulse lasted for about three days. While near-surface currents were offshore, those at 39 meters were onshore for the same time period. The visual correlation between wind and near-surface currents did not extend to currents at 39 meters depth. The along-shore current appeared to be similar at the two depths. Figure 44 also shows the cube of the near-bottom tidal current which is a measure of tidal dissipation power. Note that it increases significantly over the periods of measurement.

Thus, the destruction and subsequent reestablishment of typical summer middle shelf and coastal domain hydrographic features was related to winds and tides. The initial vertical mixing of the water column resulted from a combination

of wind-wave and current shear turbulence which destroyed vertical structure at least 40 kilometers, or twice the usual distance, from the shore. Longshore winds then reversed and generated an offshore Ekman flux in the near surface waters and a continuity preserving onshore flux at depth. The offshore flux brought warmer, less saline surface water offshore, while the onshore flux at depth provided colder more saline waters; these resulted in stratification across the entire study area. As tidal mixing power increased, coastal domain waters became vertically mixed and middle shelf domain waters returned to a two-layered configuration.

Inshore Ice. Nearshore ice characteristics in the eastern Bering Sea, including the Bristol Bay region have been described by Stringer (1981). Nearshore ice conditions in the Bering Sea differ from those in the Beaufort and Chukchi Seas. Two important factors that are almost totally absent in the Beaufort Sea influence ice behavior in portions of the Bering Sea. These two factors are tides and ice advection. While the Beaufort coast experiences very small tides, tides at many locations on the Bering Sea coast range over several meters. Also, while Beaufort Sea ice is almost always packed against the coast, in many places along the Bering coast the ice is almost continuously being pushed away from shore by winds and currents.

Pack ice in Bristol Bay appears to be greatly influenced by the fact that no barrier exists to keep ice from moving to the southwest, as well as by significant tidal range. These circumstances, combined with the presence in winter of strong offshore winds in the northern part of the bay, results in a general southwestward motion of ice out of Bristol Bay. Normally, this motion is so persistent that LANDSAT and lower-resolution satellite imagery nearly always show open water along the northern side of the bay where ice has been blown offshore. Fast ice is not extensive and is generally found only in highly protected locations.

Due to the nearly constant motion of ice away from the coast and the resulting open water, new ice -is often formed along a broad band running east to west across the northern side of the bay. It is often possible to see the transition from open water to new ice, young ice, and first-year pack ice on a single LANDSAT image. Superimposed on this behavioral pattern is a dynamic process: as the ice moves out of Bristol Bay into a less confined area, it breaks up into large pans with dimensions on the order of 10-20 kilometers. The voids between these pans then freeze. This process of breakup and refreezing may then repeat itself several times. Although the characteristic motion is out of Bristol Bay, occasionally a storm can drive ice onto the coast, including the north shore of the Alaska Peninsula. Nearshore ice conditions in the Bristol Bay region are summarized in Figure 45, adapted from Stringer (1981).

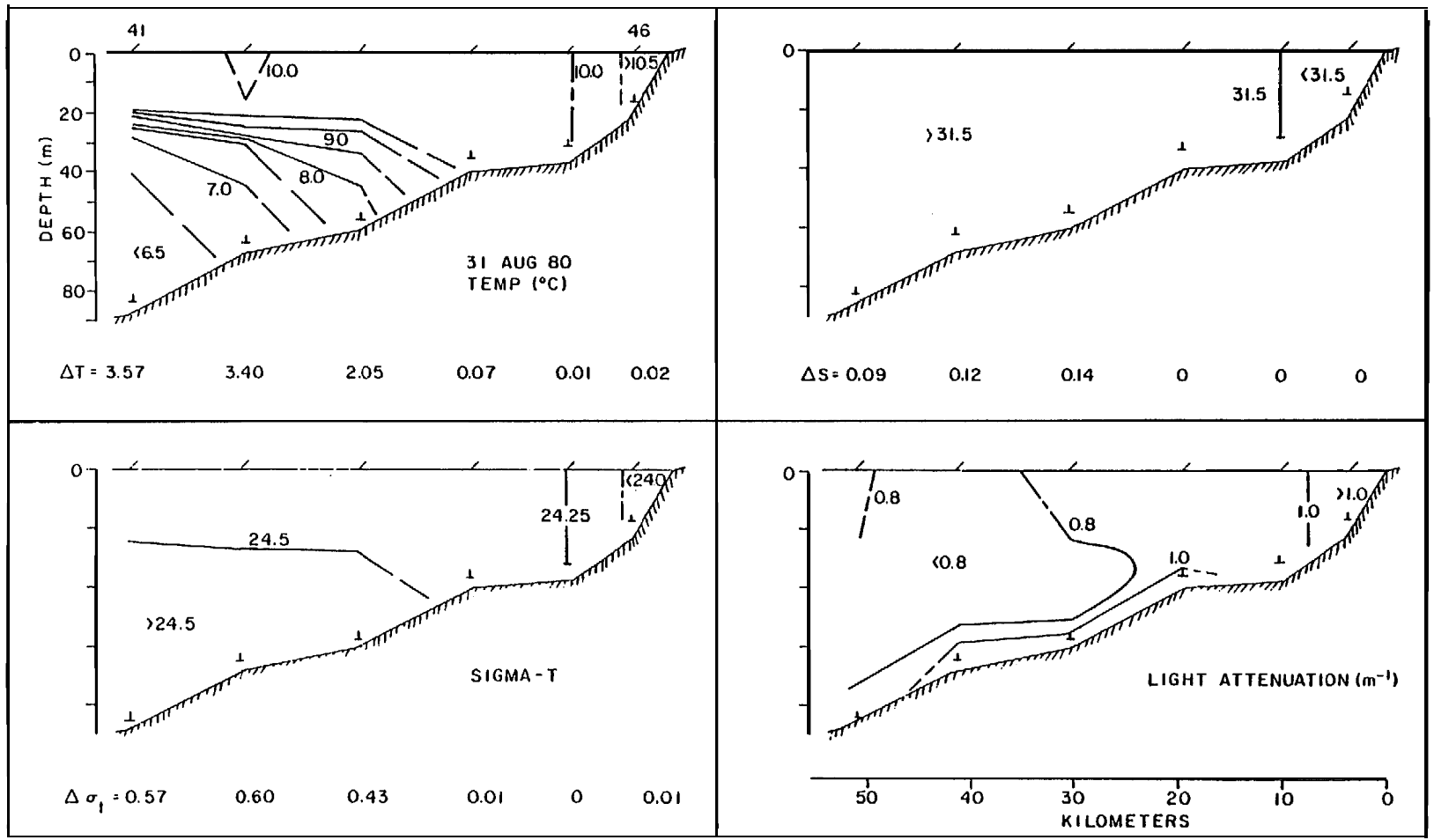


Figure 43. Hydrographic and light attenuation sections from 31 August 1980 (Schumacher and Moen, 1983).

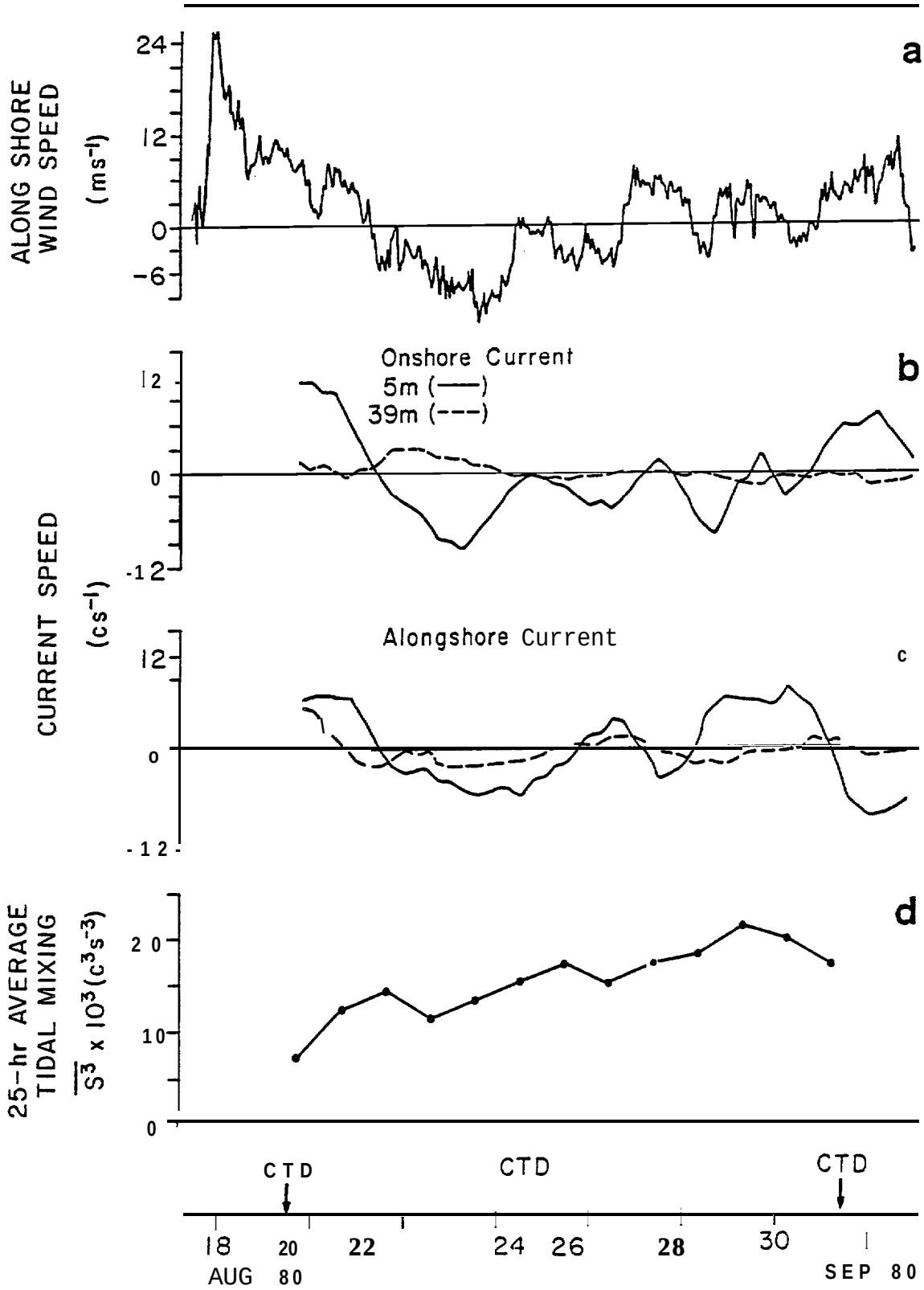


Figure 44. a) AlongShore windspeed, b) onshore current at 5 and 39 m, c) alongshore current at 5. and 39 m, and d) 25-hour average tidal mixing parameter S^{-3} from the 39 m depth current record (Schumacher and Moen, 1983).

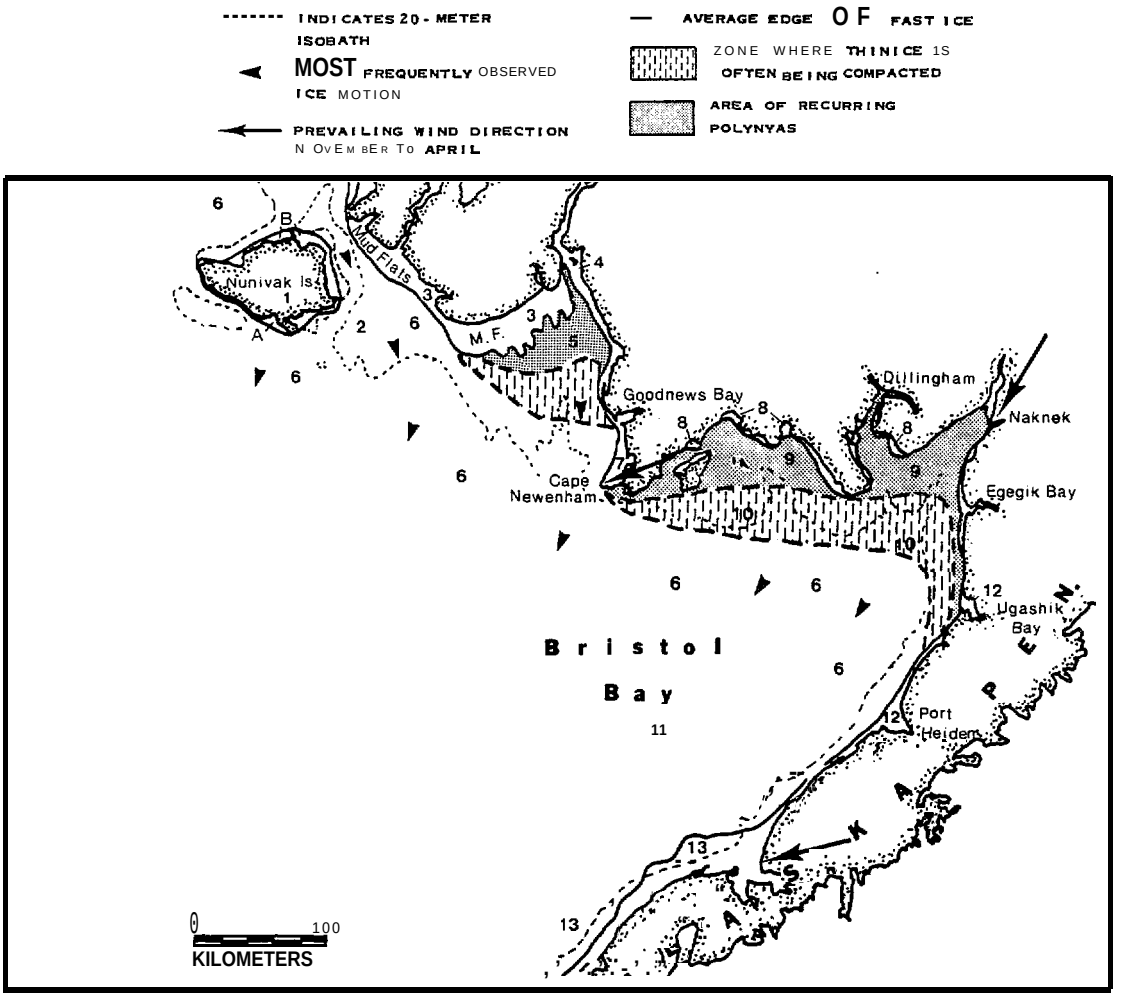
b. Geological and Chemical Setting

Geological Setting. The geology of the Bering Sea has been studied, mainly by Soviet and United States workers, since the middle of the nineteenth century. A thorough review of earlier work with emphasis on the northern and western parts was prepared by Lisitsyn (1966). The greater activity of the post World War II period in marine geology, geomorphology and paleontology was summarized by Hopkins (1967) in "The Bering Land Bridge." Modern geological studies began just after World War II with a series of U.S. Navy Electronics Laboratory cruises, from which data the map of bottom sediments was prepared by Deitz et al (1964). The Cenozoic sedimentary and tectonic history was reviewed by Nelson et al (1974), and the contemporary sediment regimes of the eastern region by Sharma (1974, 1979). Hopkins (1978) and Burrell et al (1981) collected some samples for analysis of geochemical characteristics and sediment/benthic biota relations respectively. The main portion of the samples obtained in the nearshore region (<50m) for sedimentary analysis are shown in Figure 46. Few of these were taken within less than ten meters water depth. Recently, a series of benthic stations were occupied (VTN, 1983e) in the inshore area (10-60m depths) from Unimak Pass to the Port Moller area, Figure 47.

The characterization of the geological processes of the very nearshore region between Unimak Pass and Cape Newenham from existing data will require extrapolation of existing sedimentary data to the shore line and will make use of suspended particulate matter data (Baker, 1981; Baker, 1983), elemental composition of suspended matter (Feely et al, 1981), and other relevant geochemical (Burrell et al, 1981) and physical data (see preceding section).

Geologic History. The abyssal basin of the Bering Sea is thought to be a northern embayment of the Pacific Ocean that became isolated by the development of the Aleutian Ridge prior to late Eocene, but not later than Cretaceus time (Scholl, Greene and Marlow, 1970; Scholl and Buffington, 1970; Scholl et al, 1974). The interaction of oceanic and continental crust was localized at the base of the continental slope of the Bering Sea during most of Mesozoic time. A shift in the subduction to the south, to the present site of the Aleutian trench-arc system, took place at the beginning of the Tertiary period. The southernmost tectonic unit of the southeastern Bering Sea seems to consist of intensively deformed Cretaceus flysch sediments intruded by serpentine. A similar complex is exposed in mainland areas of Alaska and Siberia (Scholl et al, 1974).

Since Tertiary time, the erosional surface represented by the acoustic basement has been flexed upward and downward



1 FAST ICE AROUND NUNIVAK ISLAND IS CONFINED TO WATERS IN SHORE OF THE 20 METER ISOBATH WITH EXCEPTION OF TWO LOCATIONS
A. IN THIS PORTION OF THE SOUTHERN COAST THE 20 METER ISOBATH IS VERY CLOSE TO SHORE YET BECAUSE OF PROTECTION OFFERED IN THIS AREA, FAST ICE EXTENDS FAR SEAWARD
B. IT APPEARS THAT SOUTHWARD ICE IS PILED IN THIS AREA

2 PACK ICE GENERALLY IN SOUTHWARD MOTION THROUGH ETOLIN STRAITS CAN PILE UP ON SHOALS

3 FAST ICE IS LOCATED OVER MUD FLATS IN WATERS NO DEEPER THAN A FEW METERS

4 TIDAL ACTION [RANGE 5 METERS] IS RESPONSIBLE FOR REMOVING ICE FROM THE KUSKOKWIM CHANNEL

5 THIS AREA OFTEN CONTAINS OPEN WATER AND BROKEN ICE WITH ICE RUBBLE PILES FOUND ON SHOALS

6 PACK ICE OFTEN SHOWS SIGNS OF REPEATED BREAKAGE AND FORMATION OF NEWER ICE

7 FAST ICE SHOWS SOME VARIATION IN EXTENT DUE TO OCCASIONAL GROUNDING ON SHOALS AND IS GENERALLY FOUND IN WATERS LESS THAN 6 METERS DEEP

8 FAST ICE ON THE NORTHERN SIDE OF BRISTOL BAY IS CONFINED TO HIGHLY PROTECTED AREAS WITH WATER DEPTHS LESS THAN 4 METERS. TIDAL RANGE IS AS GREAT AS 7 METERS

9 THIS AREA IS OFTEN A POLYNYA OR CONTAINS NEWLY FORMED ICE

10 ICE IN THIS AREA IS OFTEN COMPACTING AND GROWING IN THICKMESS AS IT MOVES SEAWARD

11 ICE WITHIN BRISTOL BAY IS OFTEN COMPOSED OF SEVERAL AGES, FORMED AS OLDER ICE BREAKS INTO PANS AND THE VOIDS FREEZE WITH NEWER ICE

12 FAST ICE ALONG THE EASTERN END OF BRISTOL BAY IS LIMITED TO AN AREA CLOSE TO SHORE BY OFFSHORE WINDS AND CURRENTS

13 DURING YEARS WITH EXTENSIVE BERING SEA ICE, FAST ICE CAN BE FOUND ALONG THIS COAST WINDS TEND TO DRIVE ICE ONTO SHORE ON MARCH 9, 1974 AN EXTENSIVE SHEAR RIDGE WAS OBSERVED HERE

Figure 45. Map summarizing Bering Sea regional nearshore ice characteristics (Adapted from Stringer, 1981).

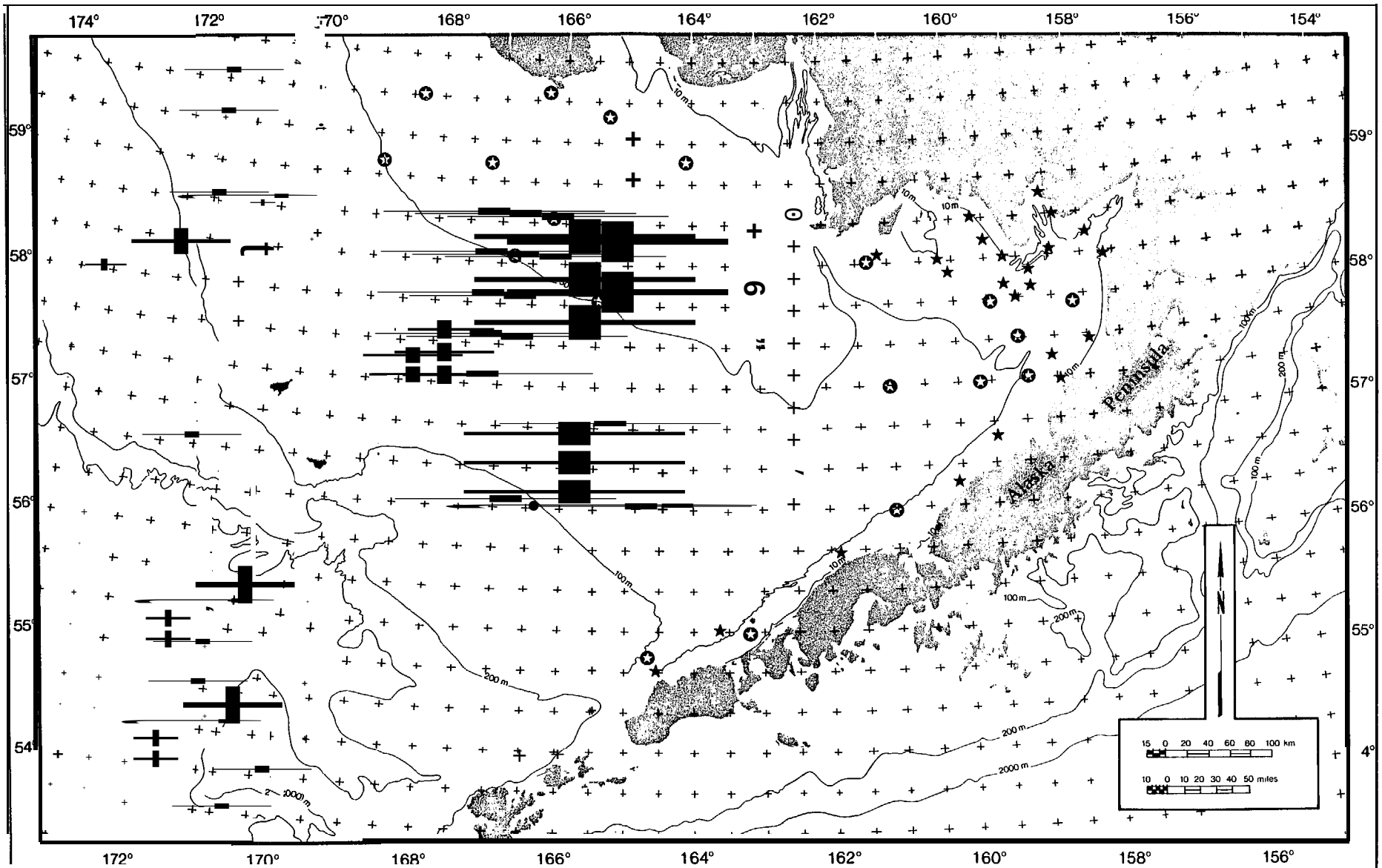
in insular and peninsular areas, where rocks of Paleocene and older age are now exposed, and into sedimentary basins on the continental shelf.

It is possible from available data to postulate the late Mesozoic-early Cenozoic history of the southeast Bering Sea. An episode of volcanism began during Cretaceus time and continued into the Palocene epoch. The Okhotsk volcanic belt extended through the Bering Sea to the Alaska mainland. Soon uplift processes ended the sedimentation and a long period of erosion began throughout Alaska and the continental shelves of the Bering Sea. At the end of the Oligocene time, the north Aleutian shelf was probably a surface of marine and subaerial placations which later warped and formed basins which are now filled with Tertiary sediments of the main layered sequence.

The main layered sequence (MLS) is an acoustic unit that represents greatly deformed sedimentary strata underlying most of the floor of the continental shelf of the Bering Sea. The unit is over 500 meters thick over about two thirds of the shelf area including the North Aleutian Shelf (Nelson et al, 1974). Stratigraphic studies of middle and late Tertiary beds in mainland Alaska [Cook Inlet and Nenana Basins (Wahrhaftig et al, 1969; Kischner and Lyon, 1973)] showed a major change in the drainage patterns in Alaska that must have had pronounced effects on the sedimentary history of the Bering Sea. Central Alaska was drained before Miocene times by tributaries that flowed southward across the present site of the Alaska Range to the area of Cook Inlet and thus to the Gulf of Alaska. The uplift of the Alaskan Range diverted the drainage north to the Yukon River and thus westward to the Bering Sea.

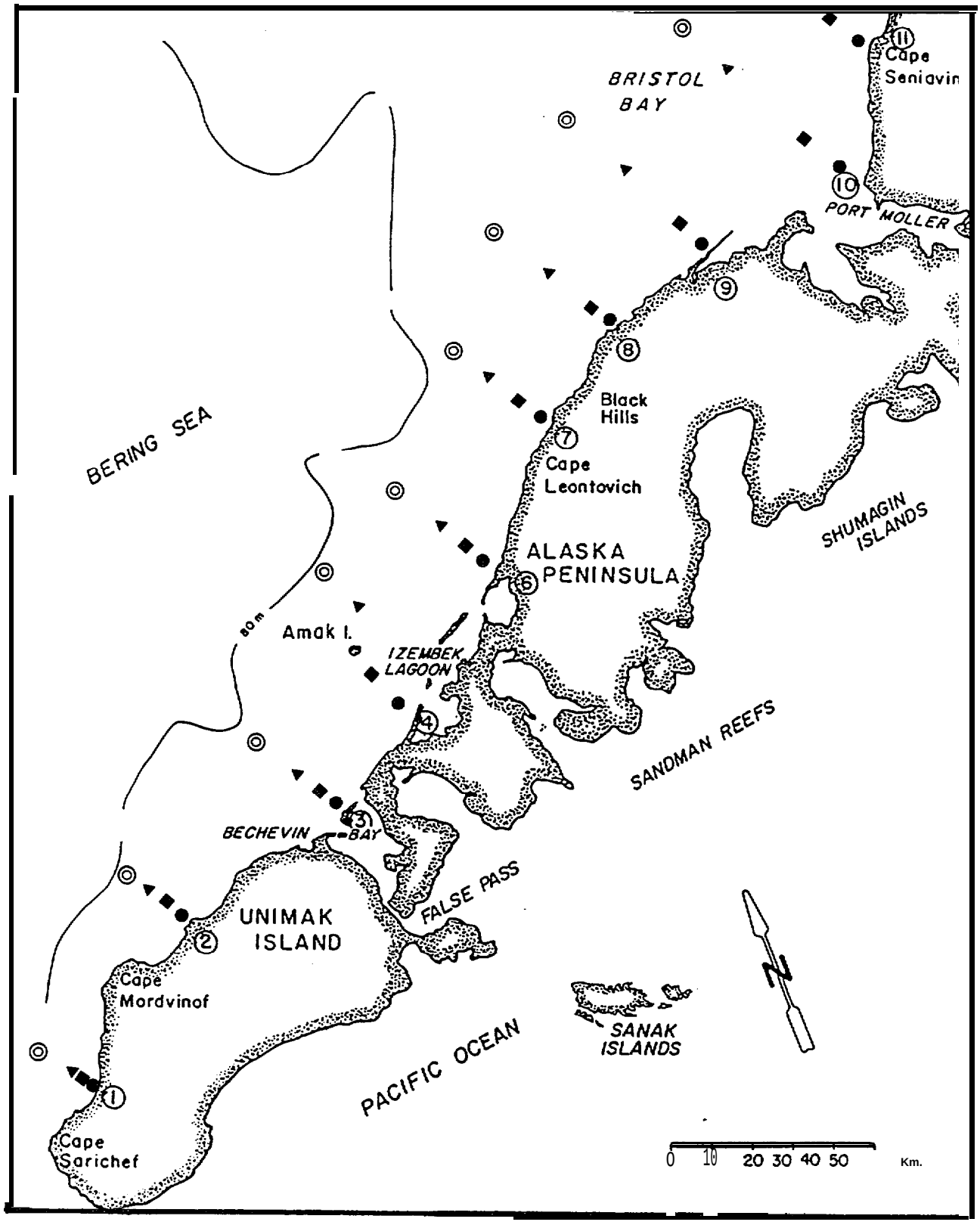
The MLS then began after a prolonged period of denudation through the Eocene into Oligocene time. The erosional detritus from the Bering continental shelf and southwestern Alaska was presumably deposited in the Aleutian and Commander basins. Marine sediments were deposited on the actively subsiding continental margin along the southeast Bering Sea. During late Miocene, the uplift of the Alaska range caused a great increase in the land area shedding sediments to the Bering Sea and probably significantly increased the rates of sedimentation in its offshore basins. Most of the Miocene and Pliocene time was a period of progradational sedimentation at the continental margin; deposition of the MLS built the shelf outward off Bristol Bay.

The MLS is overlain with a complex suite of deposits probably of Quaternary age (Grim and McManus, 1970; Kummer and Creager, 1971). The Quaternary sediments on the continental shelf are rarely thicker than 100 meters and in some places are only a few meters thick. The deep basin is mantled by Quaternary sediments nearly one kilometer thick (Scholl and Creager, 1971).



✪ - Hoskin, Univ. of Alaska Cruise 290, 1978 ★ - Sharma, 971

Figure 46. Nearshore sediment stations 1975-1980.



● - 10m ▲ - 50m

■ - 30m ◎ - 60m

(#) - TRANSECT

Figure 47. Nearshore benthic biota and sediment stat ions, Alaska Peninsula (VTN, 1983e) .

The Pleistocene history of the southeast Bering Sea shelf is characterized by repeated episodes of subaerial exposure, fluvial sedimentation, and massive glacial encroachment associated with deposition. The distribution of glacial deposits in southwestern Alaska indicates that glaciers extended far into Bristol Bay (Coulter et al, 1965). Approximately 16,000 years ago the Kuskokwim River evidently flowed south to central Bristol Bay and then seaward to the abyssal Bering Sea (Hopkins, 1972).

In Holocene time, the erosional and depositional features of the Pleistocene have been marked by sediments on the southeastern Bering Sea shelf. Offshore from mud-filled local embayments along the shoreline, the Holocene deposits form a classic gradational sequence ranging from nearshore coarse sands to muds at the shelf edge (Sharma, 1974).

Contemporary Sedimentation. Based on the limited data available, Sharma (1974) described the distribution of sediments on the southeast Bering Sea shelf as shown in Figure 48. The texture varies from gravel and coarse sand in the nearshore regions to progressively finer sediments offshore.

The nearshore sediments, as shown in Figure 49, are extremely poorly sorted. The grain size modes for the sand fraction obtained by Hopkins (1978) with Van Veen grabs on a 45 mile grid are shown in Figure 50. In these data, a grain size mode of 149 µm was found to coincide roughly with the 25 m contour in eastern Bristol Bay. This investigator also observed that the largest total number of biological individuals occurred at stations having grain size modes of 125-149 µm (fine sand) with smaller numbers occurring in either the finer or coarser sized sediments.

The sediment types described by VTN (1983e) are shown in Figure 51 for the nearshore area north of the Alaska Peninsula and between Port Moller and Unimak Pass. These data, Table 2, resulting from sampling by an unweighed, 0.25 m2 Van Veen grab, show coarse sand in this inshore area, with gravel/sand areas lying around 3-0 meters depth and north of Unimak Island, offshore of the Cape Leontovich/Black Hills region, and offshore Cape Seniavin.

The clay minerals of the southeastern Bering Sea shelf consist of 40-70 percent of an expandable component (Figure 52); 20-50 percent illite (Figure 53); and 30-40 percent chlorite. Kaolinite is generally present in less than 10 percent (Burrell et al, 1981). Nearshore to the Alaska Peninsula the expandable clay exceeds 59 percent of the clay size fraction, while other components contribute only trace amounts. The expandable material represents contributions from bordering volcanic regions whereas other components are presumably introduced by way of the northern and eastern rivers (Naidu and Mowatt, 1977).

The organic carbon content of sediments on the eastern North Aleutian Shelf region has been described by Sharma (1974) as shown in Figure 54. As seen in Figure 46, there are relatively few stations in the nearshore region north of the Alaska Peninsula; however, more intensity was realized in the region of Cape Constantine and Walrus Islands in Togiak Bay. A strong correlation between clay content of the sediments and organic carbon content was found for the southeast Bering Sea Shelf (Figure 55). Concentrations in the range of 0.5 percent were found only off the continental shelf and in an anomalous pocket in Togiak Bay.

Heavy Minerals. There are relatively high concentrations of heavy minerals in sediments along the Alaska Peninsula which can be related to high values in the adjacent beaches. There is 23 percent by weight in the 2.5 - 3.0 size and only eight percent in the 1.5 - 2.0 size range of sediments. The heavy mineral assemblages consist predominantly of hypersthene (green and purplish brown), amphibole (mostly hornblende), and opaques (magnetite and ilmenite). Diopside occurs in minor amounts and traces of garnet, sillimanite, spidote, staurolite, tremolite, sphene, uralite, chlorite and zircon are present. A higher weight percentage of heavy minerals is found near the southern shore than in the center of Bristol Bay. The distribution of heavy minerals in samples analyzed in Bristol Bay is shown in Figure 56.

Heavy metal analyses of surficial sediments on the southeast Bering Sea shelf are very limited (Burrell et al, 1981); however, those data available for iron (Figure 57) and vanadium indicate higher nearshore concentrations in the surficial sediments than is found in deeper water. The mean values observed for heavy metals in surficial sediments along with correlation coefficients are shown in Table 3. These data primarily show a highly significant correlation for structural alumina-silicate elements: Al, Fe, Ca, and CO. More will be said about the heavy metals distribution in sediments, in suspended particulate, and in the water column in the sections on suspended particulate matter and trace metal chemistry.

Suspended Particulate Matter. Several studies have contributed to the understanding of the distribution, composition and flux of suspended particulate matter (SPM) in the nearshore region of the North Aleutian Shelf.

Some SPM data were reported by Sharma (1971, 1974, 1979), Sharma et al (1972) and Burrell et al (1981) for the eastern Bering Sea shelf, but few stations were occupied within the nearshore area of this study. Likewise Loder (1971) and Handa and Tanoue (1981) provided valuable information of the particulate organic matter in the eastern Bering Sea and elsewhere, but not specifically in the region

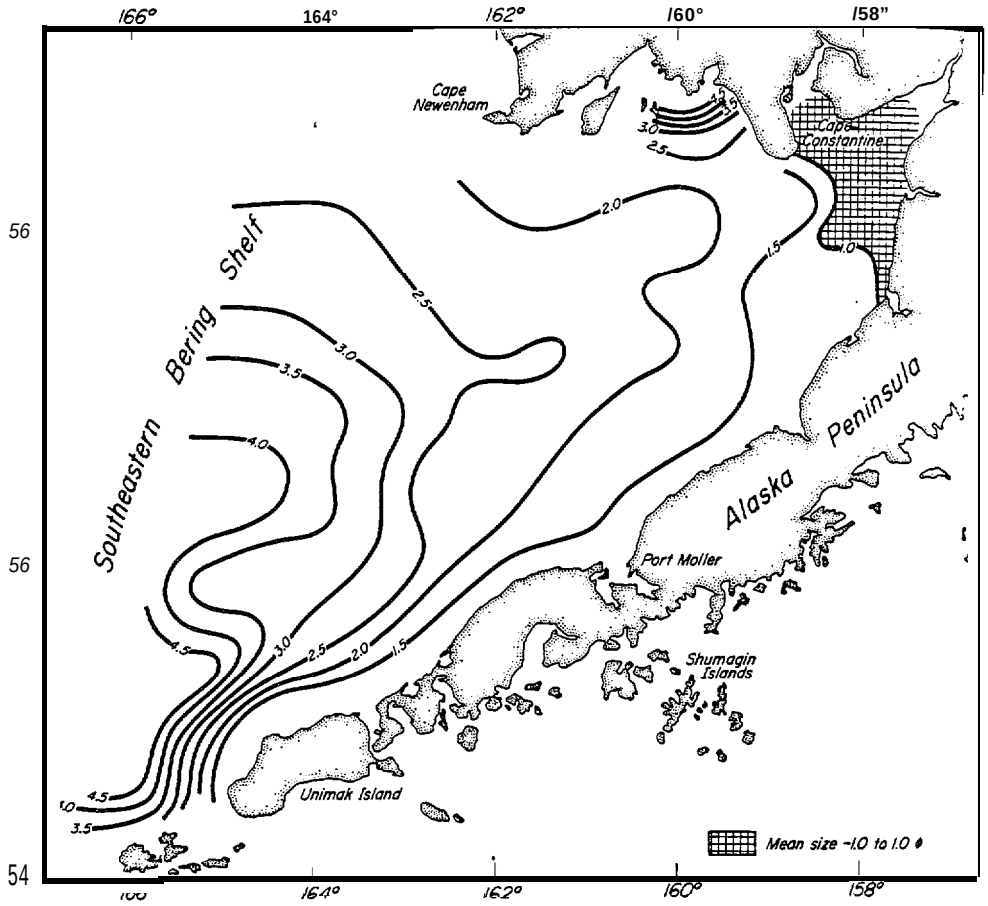


Figure 48. Sediment size distribution (ø) on southeastern Bering Shelf (Sharma, 1974).

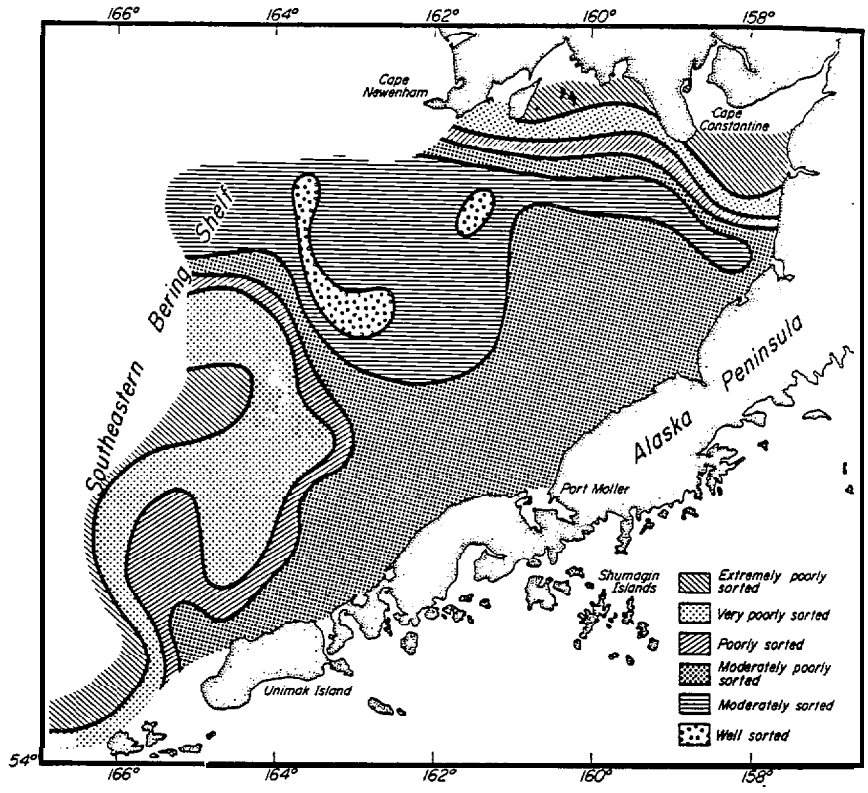
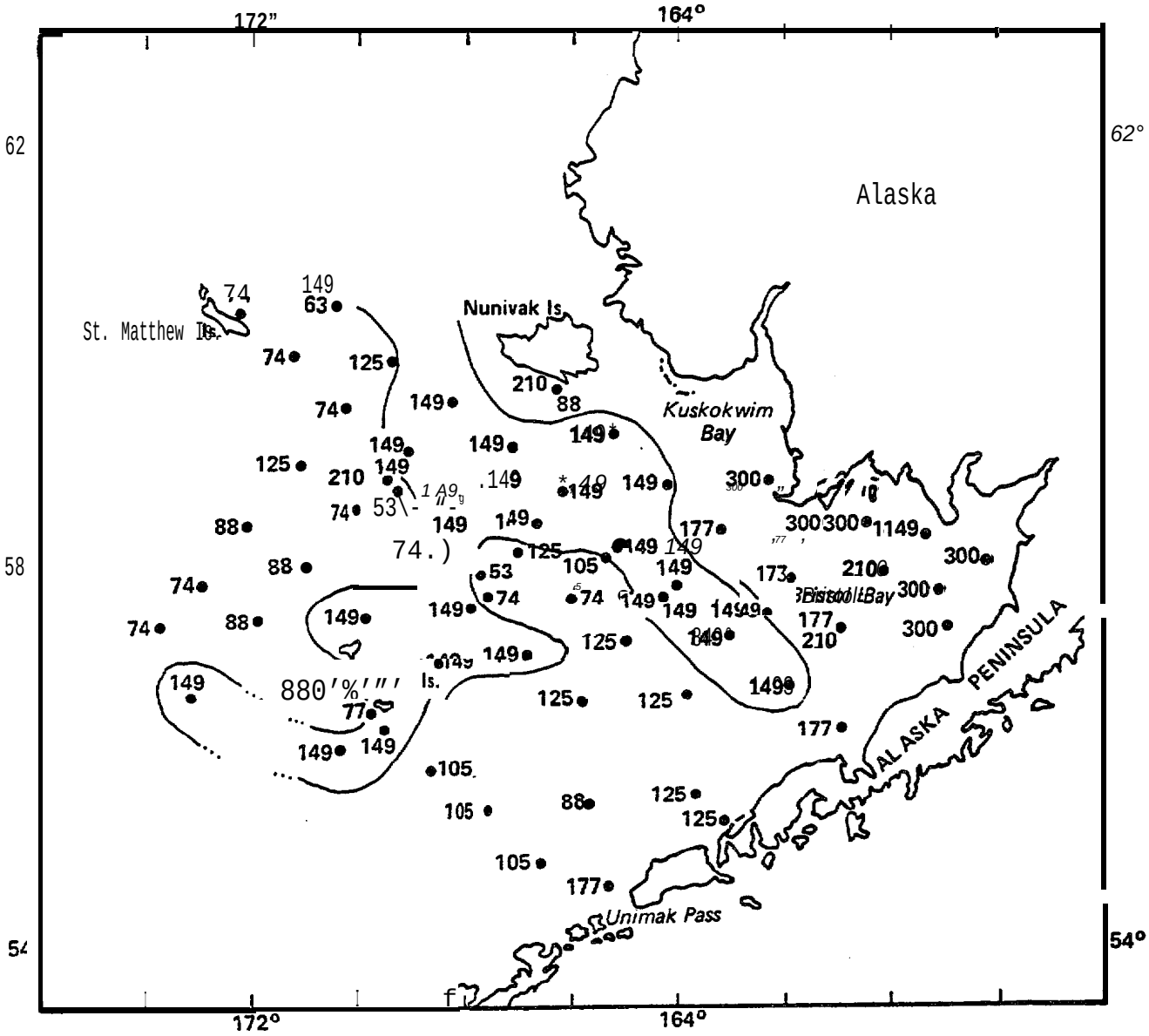
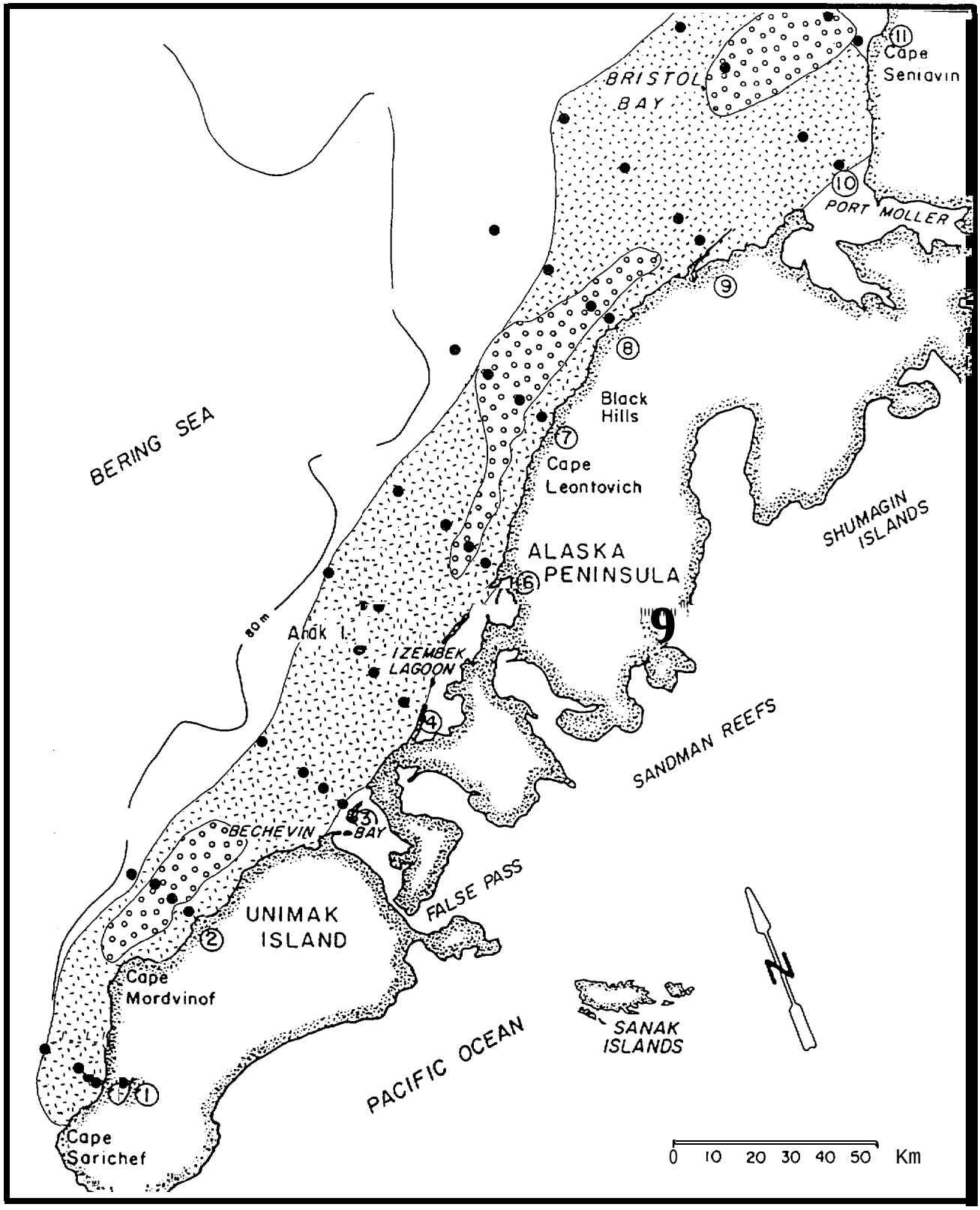


Figure 49. Sediment sorting on southeastern Bering Shelf (Sharma, 1974).



GRAIN SIZE MODES, µm FOR SAND SAMPLES, n =66

Figure 50. Map of grain size modes, µm, for the sand fraction. Number of samples = 66 (Hoskins, 1978) .



● STATION

(#) - TRANSECT

- SAND

SAND AND >1 % GRAVEL

Figure 51. Nearshore sediment types, Alaska Peninsula (VTN, 1983e).

Table 2. Sediment characteristics and benthic communities. (From VTN, 1983e).

Transect	Depth (m)	Month	Infaunal* Community	Gravel (%)	Sand (%)	Silt (%)	Mean Diameter (dg)	Mean (0)	Sorting Index (S_1)
1	30	June		0.6	87.4	12.0	0.15	2.74	1.31
1	50	June		0.7	85.7	13.6	0.14	2.84	1.31
2	10	June	I	0.1	93.6	6.3	0.15	2.74	1.27
2	30	June	11A	36.6	62.7	0.7	2.37	-1.24	3.07
2	30	October	IIA	20.6	78.6	0.8	2.02	-1.01	1.77
2	50	June	11A	6*8	92.9	0.3	1.24	-0.31	1.64
2	60	October	I	0.0	99.2	0.8	O*39	1.36	1.47
3	30	June	IIB	0.1	93.3	6.6	0.15	2.74	1.21
3	50	June	IIB	0.0	94.5	5*5	0.18	2.47	1.29
3	60	October	IIB	0.0	99.3	0.7	0.76	0.40	1.52
4	10	June	I	0.0	97.6	2.4	0.18	2.47	1.28
4	30	August		5.2	94.3	0.5	2.06	-1.04	1.34
4	30	October	I	0.0	95.7	4.3	0.17	2.56	1.36
4	30	June	IIB	0.0	99.3	0.7	0.39	1.36	1.37
4	60	October	IIB	0.0	95.6	4.4	0.17	2.56	1.28
6	10	June		0.2	99.7	0.1	0.21	2.25	1.18
6	30	June	11A	65.9	32.3	1.8	4.91	-2.30	1.98
6	30	October		46.0	53.3	0.7	4.20	-2.07	1.98
6	50	June	IIB	0.0	98.1	1.9	0.19	2.02	1.25
6	50	August		0.0	97.6	2.4	0.23	2.12	1.37
6	60	October	IIB	0.0	97.6	2.4	0.21	2.25	1.26
7	10	June	I	0.0	93.0	7.0	0.14	2.84	1.21
7	30	October	11A	82.4	16.0	1.6	5.65	-2.50	1.56
7	50	June	11A	4.3	95.3	0.4	0,93	0.10	1.90
8	50	June	IIB	0.8	99.0	0.2	0.61	0.71	2.29
9	30	June	I IB	4.5	93.7	1.8	1.11	-0.15	1.88
9	30	June		0.0	98.0	2.0	0.24	2.06	1.23
9	60	October		0.2	99.4	0.4	0.25	2.00	1.26
9	50	June	IIB	0.0	97.2	2.8	0.22	2.18	1.19
10	10	June	I	0.0	97.3	2.7	0.17	2.56	1.28
10	30	June	IIB	0.1	98.0	1.9	0.19	2.40	1.26
10	50	June	IIB	7.0	92.0	1.0	0.77	0.38	2.64
10	60	October		0.0	98.8	1.2	0.21	2.25	1.22
10	60	October		0.0	99.3	0.7	0.21	2.25	1.22
11	10	October	IIB	3.9	95.6	0.4	1.63	-0.70	1.48
11	30	June	11A	8.6	88.3	3.1	1.29	-0.37	1.69
11	30	June		42.1	57.4	0.5	2.53	-1.34	3.37
11	50	June	IIB	0.5	96.6	2.9	0.31	1.69	1.38

-= Not sampled
* =See text for explanation

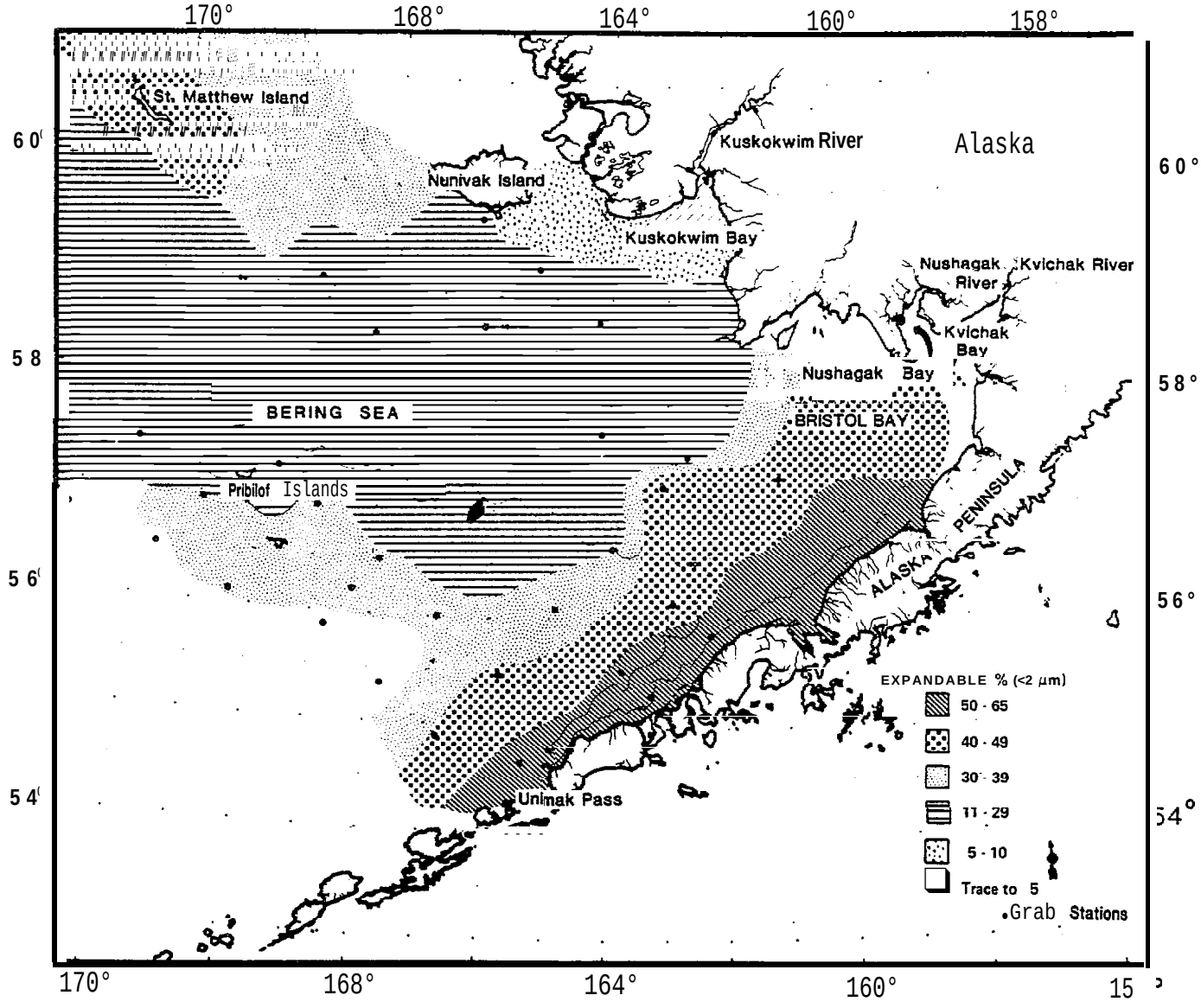


Figure 52. Distribution of expandable mineral component (%) in <2 µm size fraction of southeastern Bering Sea sediments (Burrell et al, 1981) .

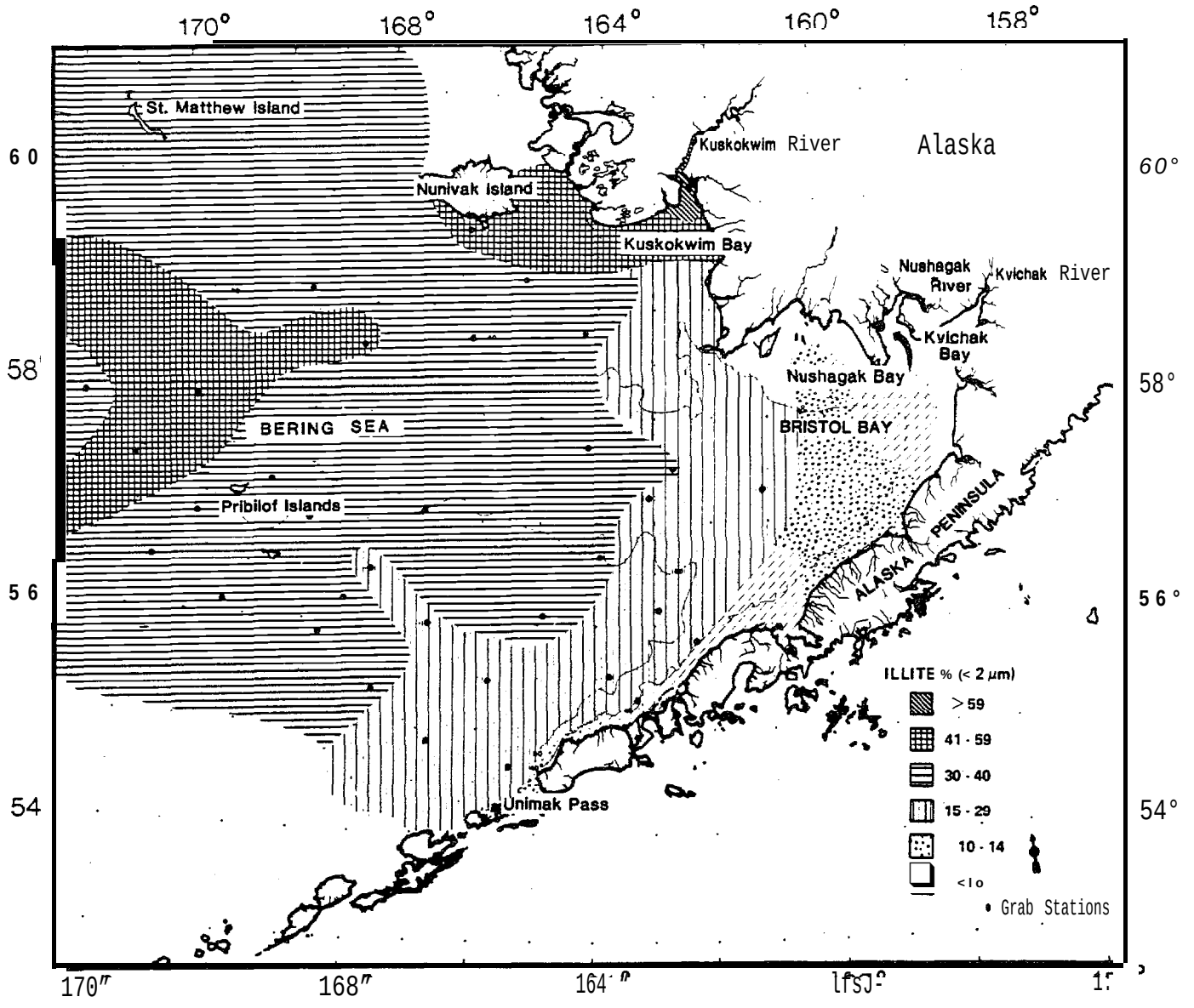


Figure 53. Distribution of illite (%) in <2 um size fraction of surficial sediments of the southeastern Bering Sea (Burrell et al, 1981).

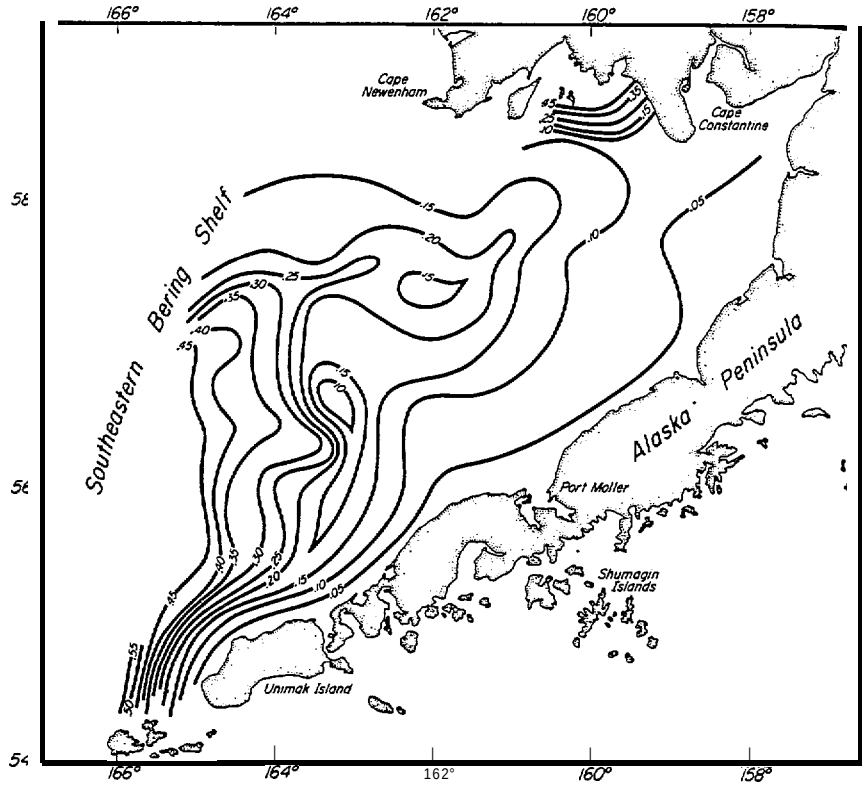


Figure 54. Organic carbon (weight percent) in southeastern Bering Shelf sediments (Sharma, 1974).

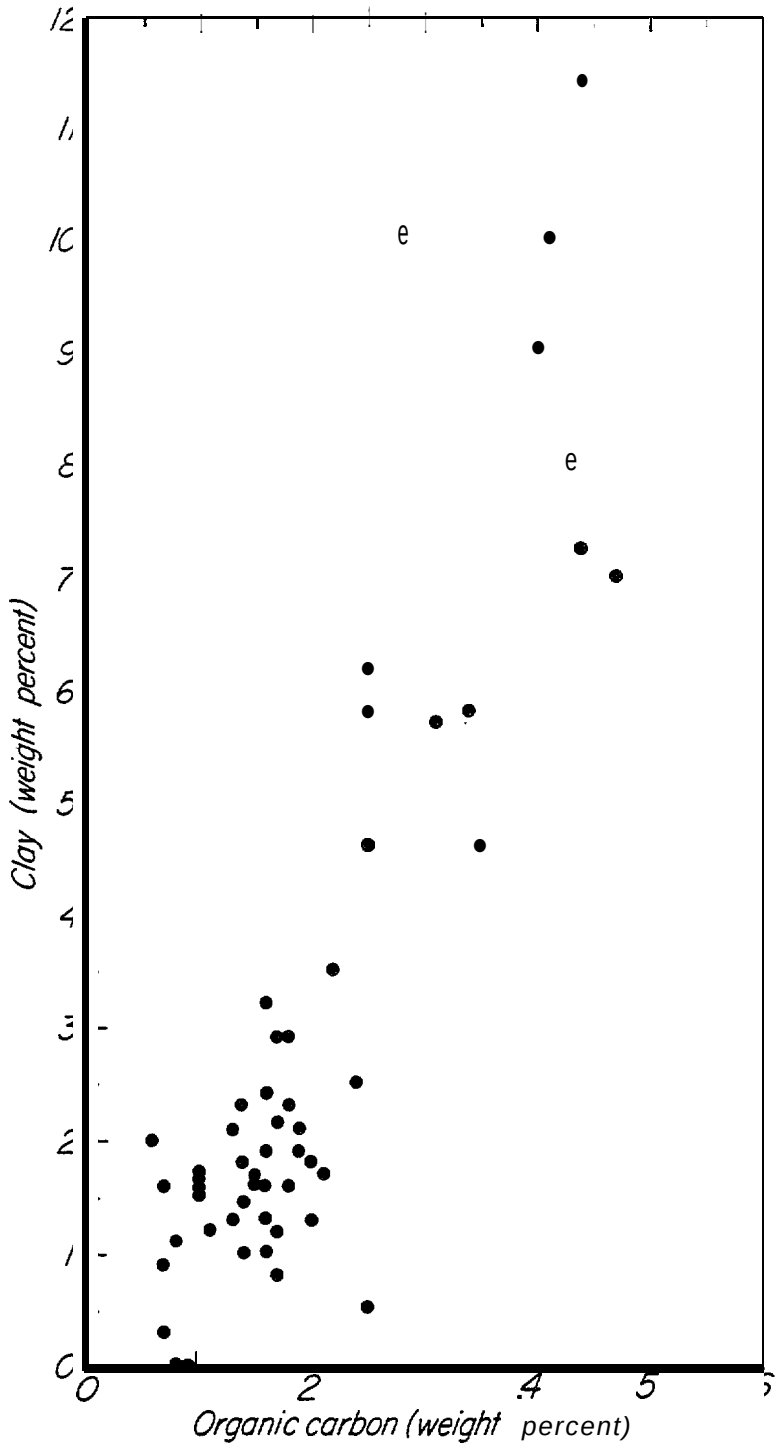


Figure 55. Organic carbon versus clay in sediments from the southeastern Bering Shelf (Sharma, 1974) .

of this study. The most relevant data available are those of Baker (1981, 1983) on the SPM on the North Aleutian Shelf, and Feely et al (1981) who investigated both the SPM and its elemental composition for relevant locations in the study area.

Baker and colleagues (1981, 1983) occupied about 72 stations on twelve transects from very shallow water along the beach to offshore beyond the 50 m contour. The transects began east of Unimak Pass and extended beyond Ugashik Bay. Cruises were completed in August 1980, January 1981, and May 1981.

As an example of his results, the areal maps from Baker (1983) of transmissometer readings (light attenuation) and of salinity are shown in Figures 58 and 59 for the nearshore area north of the Peninsula. The salinity distribution observed in the surface water in August 1980 (little difference at depth in nearshore region), Figure 58, showed a strong source of fresh water from the northeast (presumably the Kvichak River and smaller rivers) and a minor source in Heredeen Bay in Port Moller. There is no evidence of freshwater intrusion from Unimak Pass at this time. A plot of surface attenuation values follows much the same pattern (Figure 58) showing highest concentrations in the northeast corner with a decrease seaward but remaining fairly constant along shore to the southwest in the zone occupied by the well-mixed coastal domain. SPM measurements made at five meters (Figure 59) from the bottom show similar results to the surface values inside the coastal domain, but minimum attenuation values were found at or just seaward of the 50 meter contour. These areal distribution maps for this cruise, and for the January and May 1981 cruises, thus depict a SPM distribution in which particles from point sources along the coast are largely retained in the nearshore zone and dispersed parallel to the coast. The particle concentrations along this coast varied less than 25 percent between seasonal cruises.

Offshore, the gradient of mean particle concentration fell rapidly from shore to about the 50 m isobath, then varied little with increasing water depth. Offshore, the middle and outer domains were typified by a three-layer structure: a high-turbidity surface layer resulting from in-situ phytoplankton growth and offshore advection and diffusion from river-derived particles, a broad middle zone of horizontally and vertically uniform particle concentrations, and a bottom layer of increased turbidity largely from local resuspension of sediments. In the middle domain, this vertical structure can be weakened or destroyed by storms. Attenuation and density sections normal to the coast are shown in Figure 60 for a 6-day period following such a storm, and illustrate reestablishment of vertical structure.

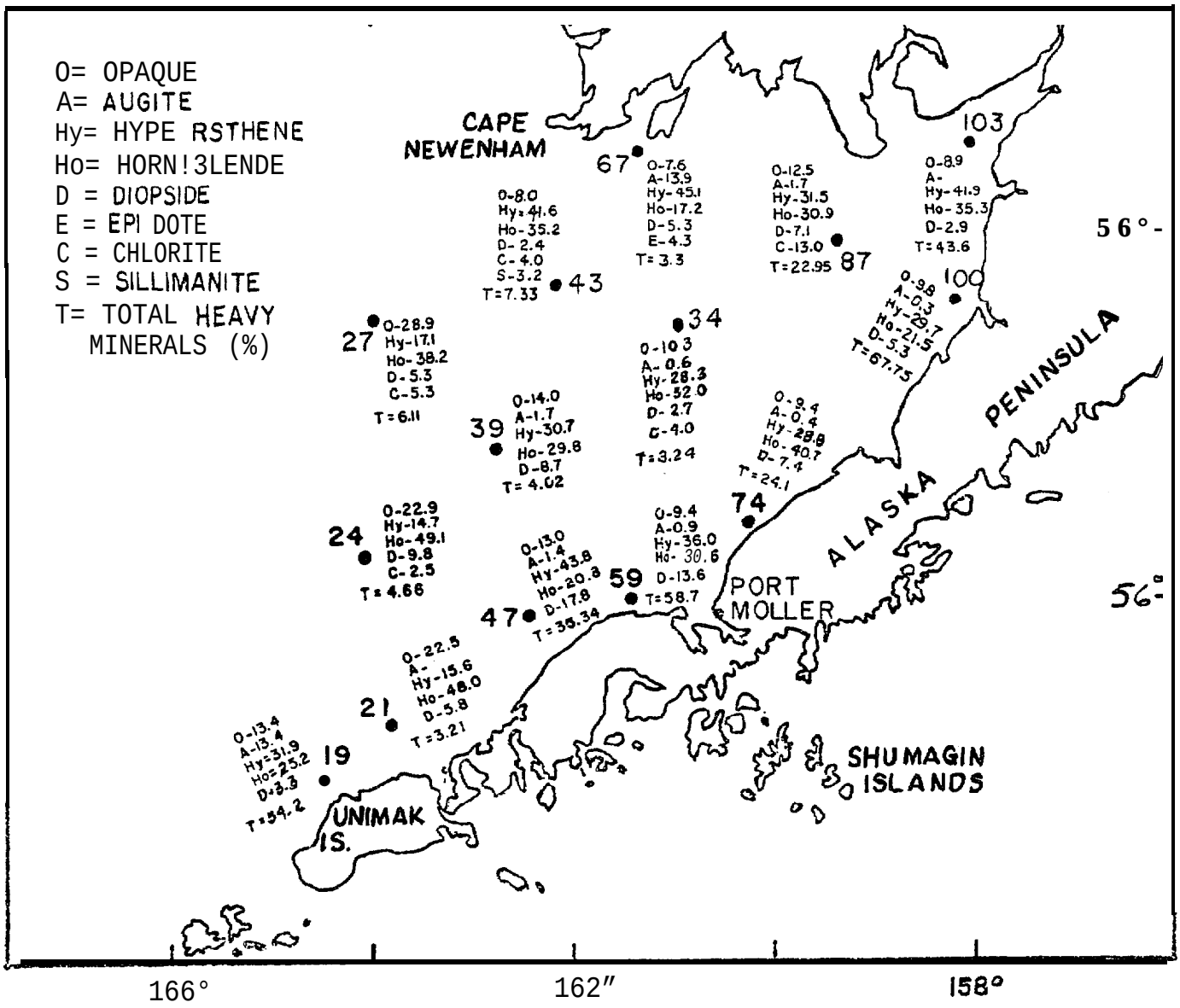


Figure 56. Distribution of total heavy minerals (weight percent) in 0.125 - 0.177 mm size fraction (T), and individual minerals (count percent) in 0.25 - 0.35 mm size fraction (Sharma, 1971).

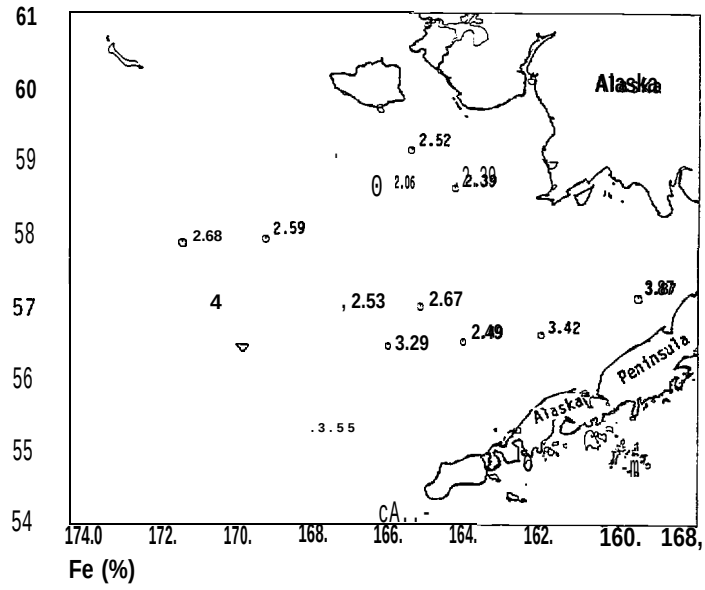


Figure 57. Total iron content (%) of southeastern Bering Sea sediment (Burrell et al, 1981).

Table 3. Mean extractable and total metal concentrations and correlation coefficients of total contents for surficial sediments of the southern Bering Sea. (Burrell et al, 1981.)

Contents			Correlation Coefficients							
Extractable	Total		Al	Ca	Fe	Mn	V	Cr	Co	As
	6.09 ± .96%	Al								
	2.86 ± .9%	Ca	.847							
0.14 .05'7	2.84 ± .55%	Fe	.915	.782						
	494 ± 199ppm	Mn	.733	.361	.715					
	93 ± 17ppm	V	.880	.569	.811	.948				
	64 ± 21ppm	Cr	.570	.774	.648	.337	.435			
	10 ± 2ppm	Co	.863	.738	.950	.629	.745	.596		
	3.6 ± 1.5ppm	As	.466	.338	.713	.642	.582	.534	.707	
	0.6 ± .15ppm	Sb	.500	.544	.658	.495	.474	.679	.706	.661
<2. 5ppm		Ni								
11 ± 6ppm		Zn								

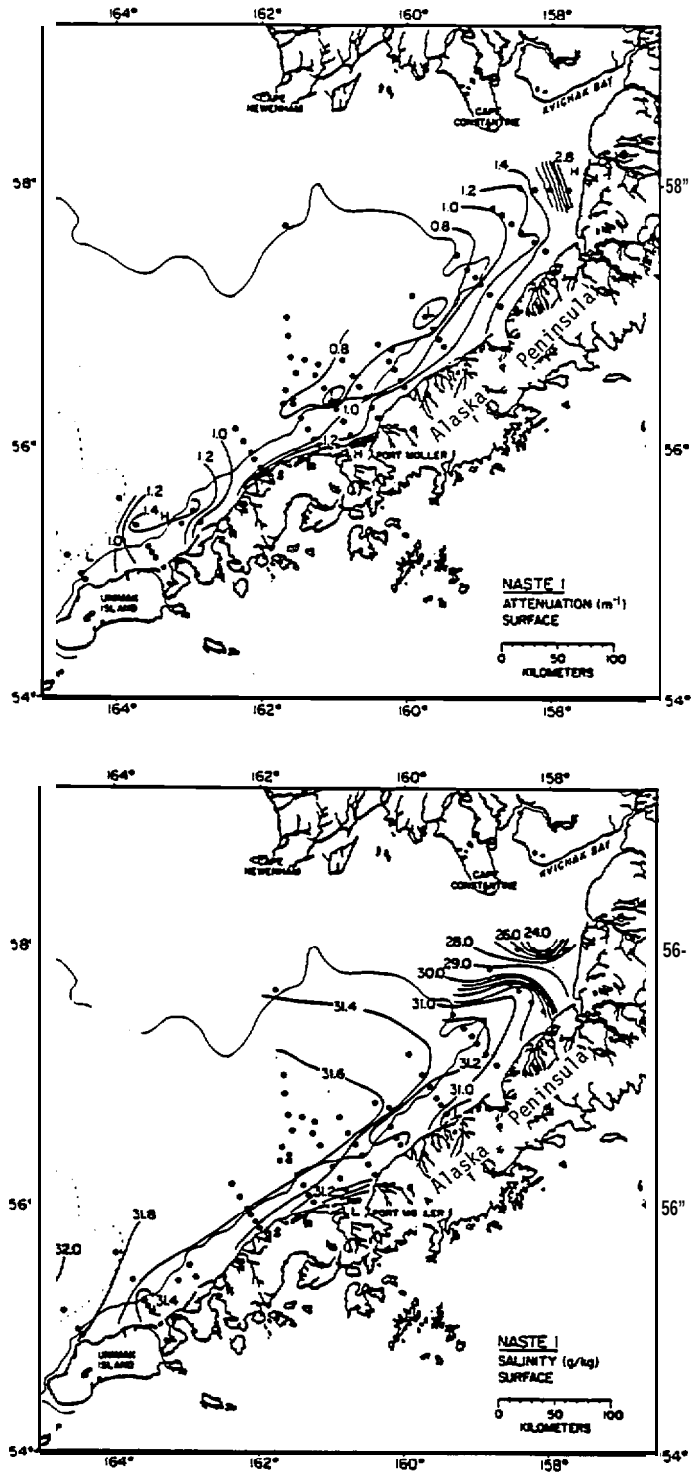


Figure 58. Areal maps of light attenuation (top) and salinity (bottom) at the surface during August 1980. Contour interval is 0.2 m^{-1} for attenuation and 0.2 ppt for salinity (Baker, 1983).

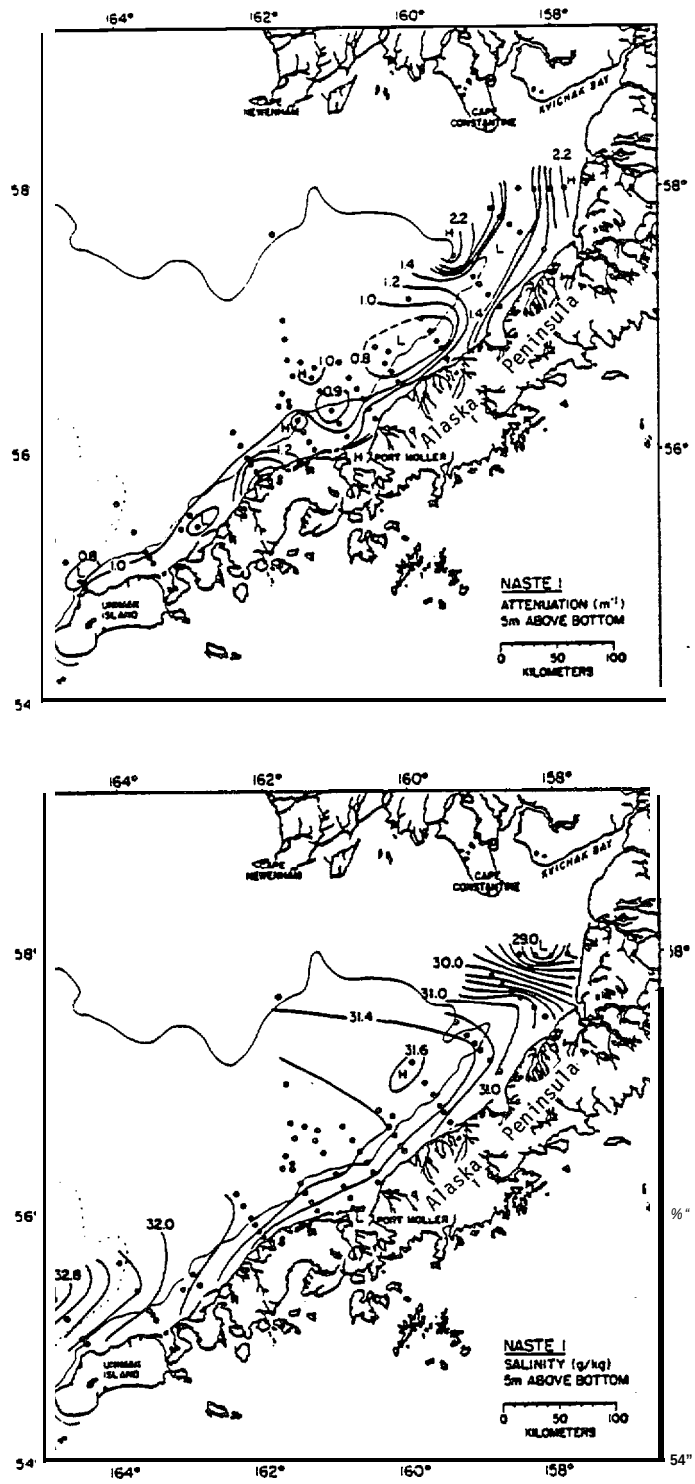


Figure 59. Areal maps of light attenuation (top) and salinity (bottom) at the bottom during August 1980. Contour interval is 0.2 m^{-1} for attenuation and 0.2 ppt for salinity (Baker, 1983).

Attenuation values, as measured by Baker (1983), may be converted to absolute concentration data (mg/l), as measured by Sharma (1972) and Feely et al (1981) by use of their scatter plots which calibrate attenuation values with field determined sediment loads. The concentrations found by Baker are estimated to be about 2.5 mg/l in the head waters of Bristol Bay. Sharma, however, reports concentrations of SPM in the Bay in July 1968 to be between 1.60 mg/l and 12.0 mg/l with lowest values found offshore. He finds the sediment load to be greater at depth with a mean value of between 7.0 and 9.0 mg/l found at 10 to 20 meters in the nearshore area.

Feely et al (1981), who report absolute concentrations for many stations in the study area as well as elemental composition, provide valuable information for purposes of this discussion. Figure 61 shows the distribution of total SPM at five meters above the bottom for all of Bristol Bay. This amount and distribution agrees well with Baker (1983) where the data bases overlap in the nearshore area. The interesting tongue of low SPM water emanating from Unimak Pass and extending to near Port Heiden is noted, but no significance is placed on it at this time. Vertical distribution of SPM for the fall of 1975 (Figure 62) and summer of 1976 (Figure 63) on a cross section from near Cape Newenham to Port Moller shows impressively different patterns, most noteworthy of which is the stratification shown in the shallow water of the nearshore region in the summer of 1976.

The particle size distribution (PSD) patterns in surface and bottom waters are of value in illustrating the differences in the SPM between the coastal and mid-shelf domains. The PSD of surface water and that five meters above the bottom at a section just offshore of Port Moller in the nearshore area is shown in Figure 64. These particle size curves are virtually identical between surface and bottom samples for the inshore stations within the well mixed coastal domain. Surface samples from offshore show lower concentrations than the corresponding bottom samples (or the inshore samples), particularly with respect to coarser-grained particles. Organic matter loading varied from a low of about 25 percent of the SPM for inshore stations in the winter to greater than 50 percent of the SPM for surface samples offshore in the summer.

Composition of Sediments. Elemental composition of the suspended particulate matter transported by the Kuskokwim and Kvichak rivers discharging into northern Bristol Bay is provided by Feely et al (1981) and is presented in Table 4. Comparison of these with the elemental composition of SPM in Bristol Bay, Table 5, reveals that the group I and II samples, all taken from the surface, are derived from river runoff because of the presence of Mg, Al, K and Ti which are associated with terrestrial sources (Feely, 1975). The

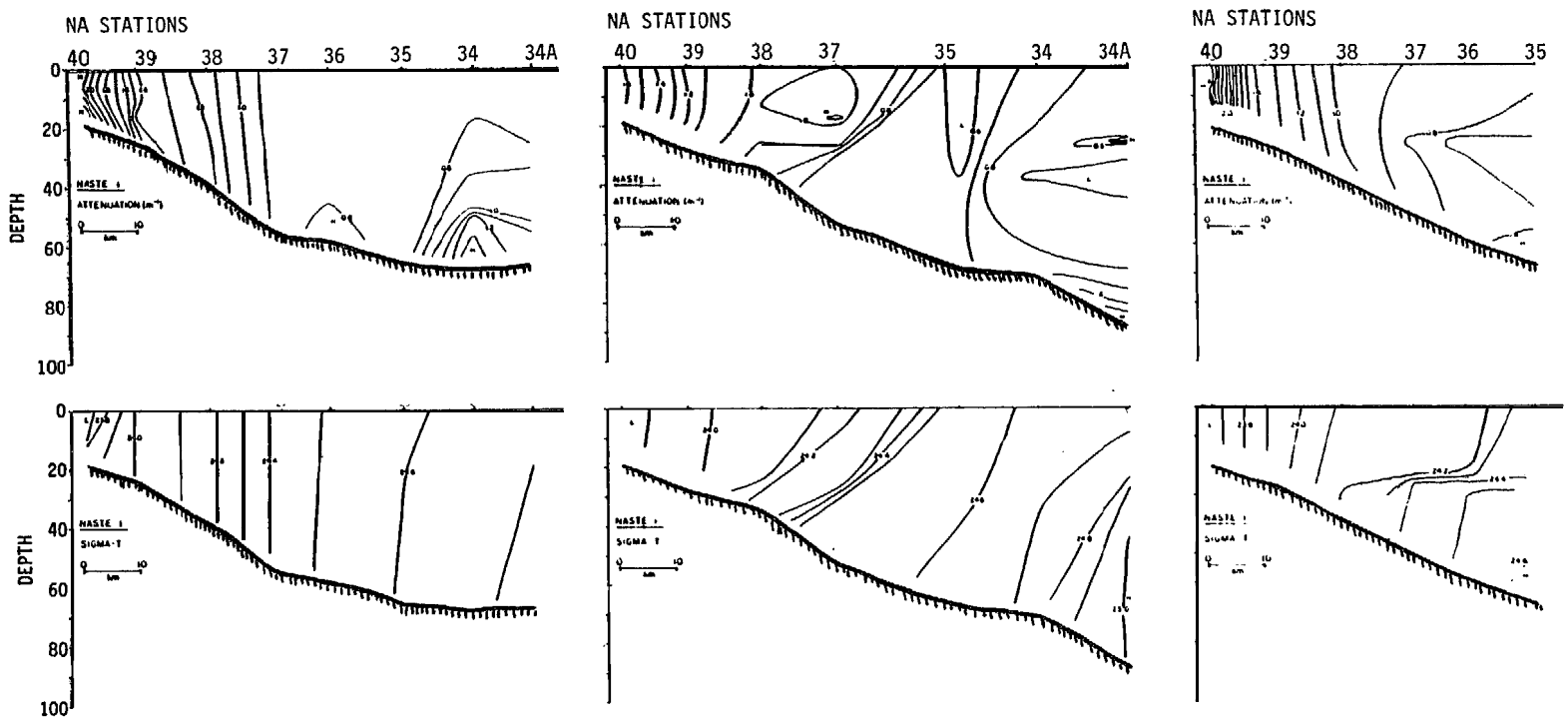


Figure 60. Attenuation (top) and density (bottom) cross-sections for stations NA34-40 normal to coast on August 20 (left), August 24 (middle), and August 31 (right) 1980, following a storm (Baker, 1983).

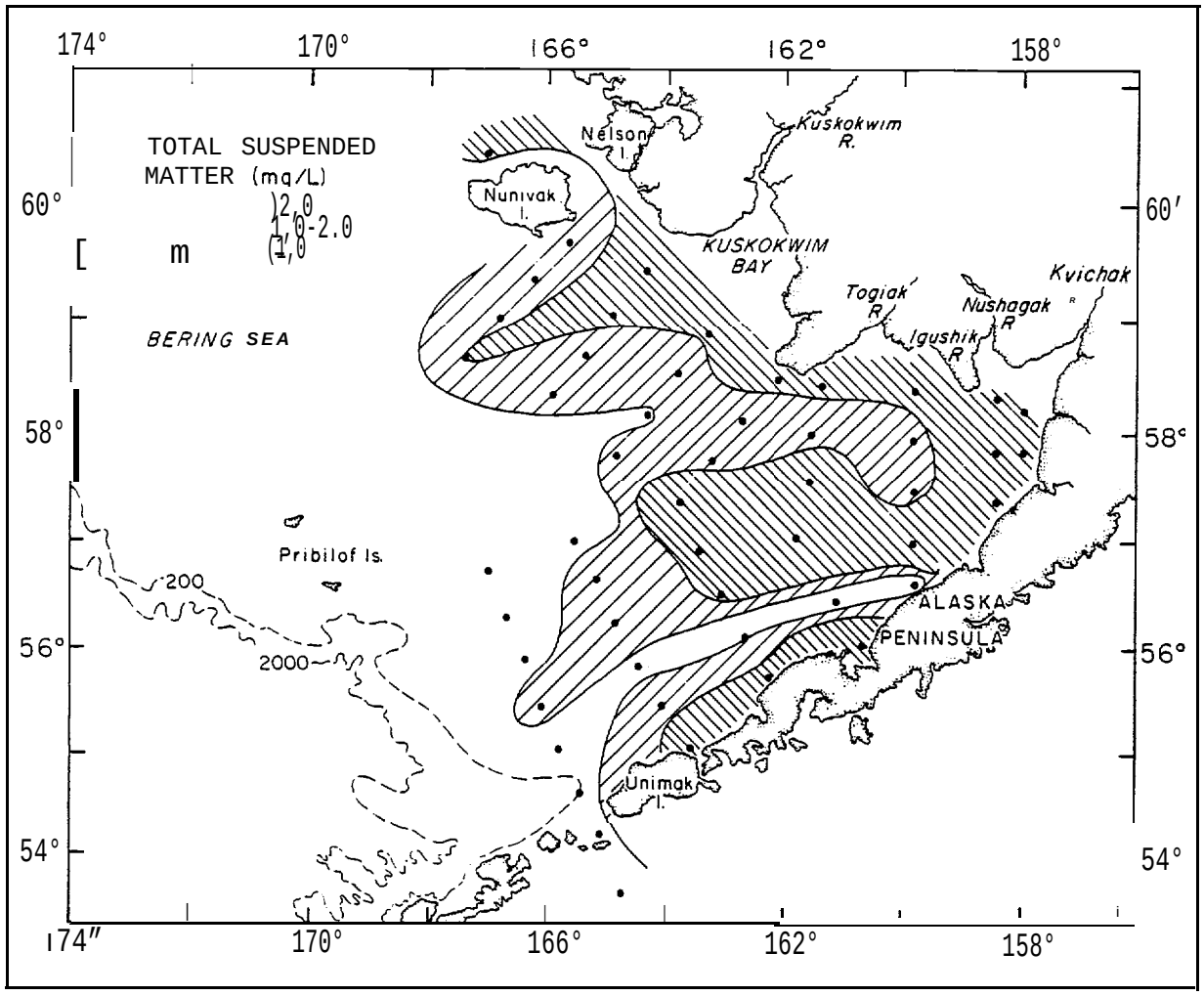


Figure 61. Distribution of total suspended matter 5 meters above the bottom in the southeastern Bering Shelf (Cruise RP-4-MW-76B-VII, 24 June - 9 July 1976) (Feely et al, 1981).

composition of the SPM at five meters above the bottom is likewise of terrestrial origin. The group III stations are significantly depleted in Mg, Al, Si, K, Ca, Ti, Mn and Fe and are enriched in Ni, Cu and Zn. .

Particulate carbon has been widely used as a tracer of particulate organic matter in the ocean (Gordon, 19707 Loder, 1971, and Handa and Tanoue, 1981). Gordon suggests a factor of 1.8 to convert organic carbon, the analytical number usually measured, to particulate organic matter. Considering group III data of Table 5, the average organic carbon in these samples would represent about 65 percent organic matter with a C/N ratio of 7.4. Loder and Hood (1972) have found in a glacial inlet of southeast Alaska that river borne (terrestrial origin) organic matter had a C/N ratio of between 15 and 22 whereas organic matter of marine origin has a range of 5 to 15. If the same ratio applies in Bristol Bay, then it is apparent that not only the organic matter in Group III SPM, but that of other groups as well, (including the five meters from the bottom group) is of marine origin.

In a very comprehensive paper, Handa and Tanoue (1981), have carefully examined the distribution and composition of particulate organic matter in the Bering Sea and adjacent areas. Although near the Pribilof Islands was the closest any samples were taken to the area of immediate interest in this study, many representative eastern Bering Sea shelf samples were examined and help give perspective to the few measurements that have actually been made in the near-shore region of the Aleutian Shelf. The particulate organic carbon as percentage of total particulate matter in samples obtained between the Western Aleutians and Nome, Alaska is shown in Figure 65. Coastal domain values of 10 to 15 percent carbon (18 to 27% organic matter) in the SPM rose to 20 to 30 percent (36 to 54% organic matter) in the middle and outer domain.

The concentrations of particulate organic carbon (POC) found averaged 204+/-178 µg C/l and 31+/-25 particulate organic nitrogen (PON) in the coastal domain to 64+/-44 POC and 7.4+/-4.9 PON in the middle and outer domain. The C/N ratio for shallow water (0-100 meters) was 6.4+/-1.9 and 8.3+/- 4.9 for deeper water (100-500 meters), both falling well within the 5 to 15 range indicated for organic matter of marine origin. Loder (1971) found in the Unimak Pass area an average of 435 275 µg C/l in the euphotic zone dropping to values below 100 µg C/l in samples taken from deeper water in this region. Since both Handa and Tanoue (1981) and Loder (1971) sampled in July or August, well after the normal spring bloom occurs for the area, the high POC values are somewhat unexpected. At this relatively late sampling period, the concentrations of particulate organic carbon and nitrogen in the coastal Bering Sea were found to

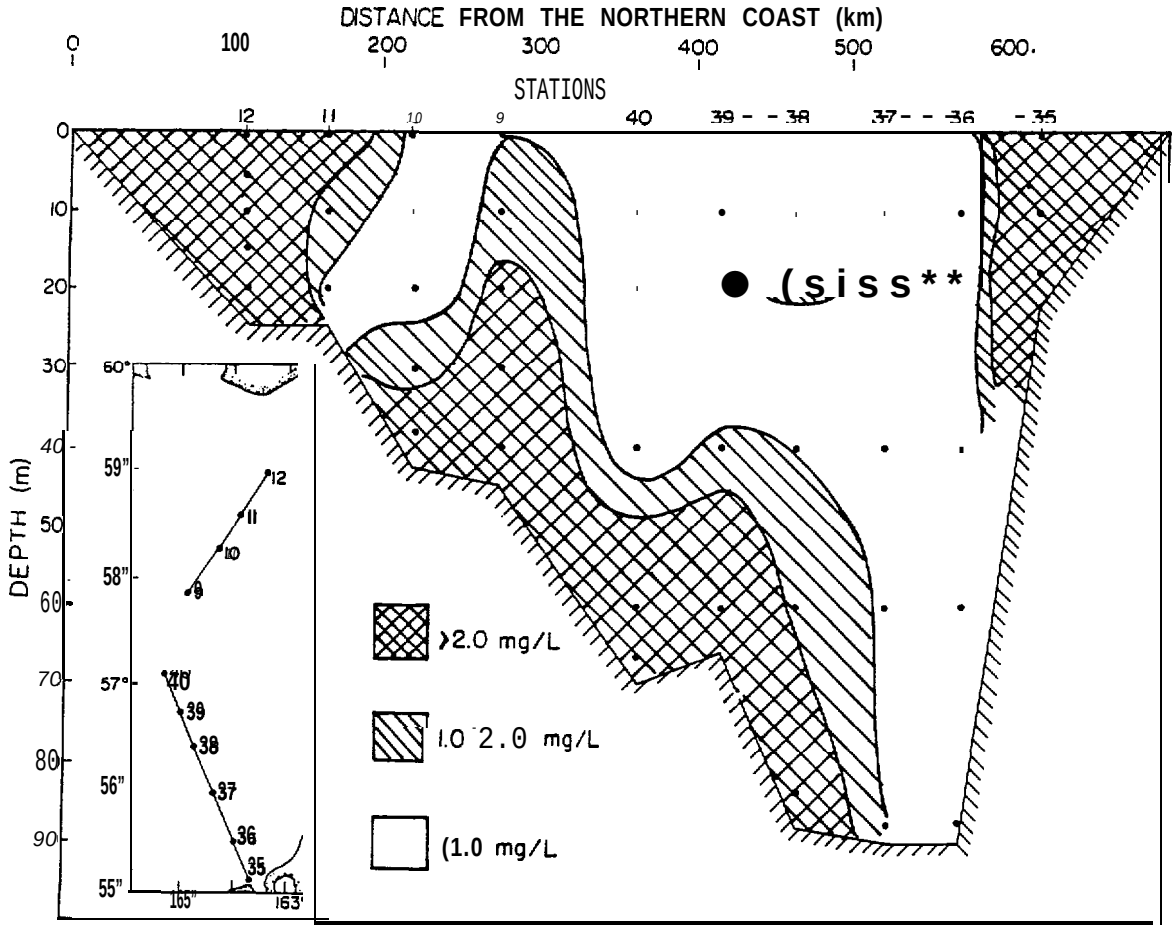


Figure 62. Vertical cross section of the distribution of total suspended matter for stations 9 through 12 and 35 through 40 (Cape Newenham to Port Moller) in the southeastern Bering Shelf (Cruise RP-4-Di-75B-III, 12 September - 5 October 1975) (Feely et al, 1981).

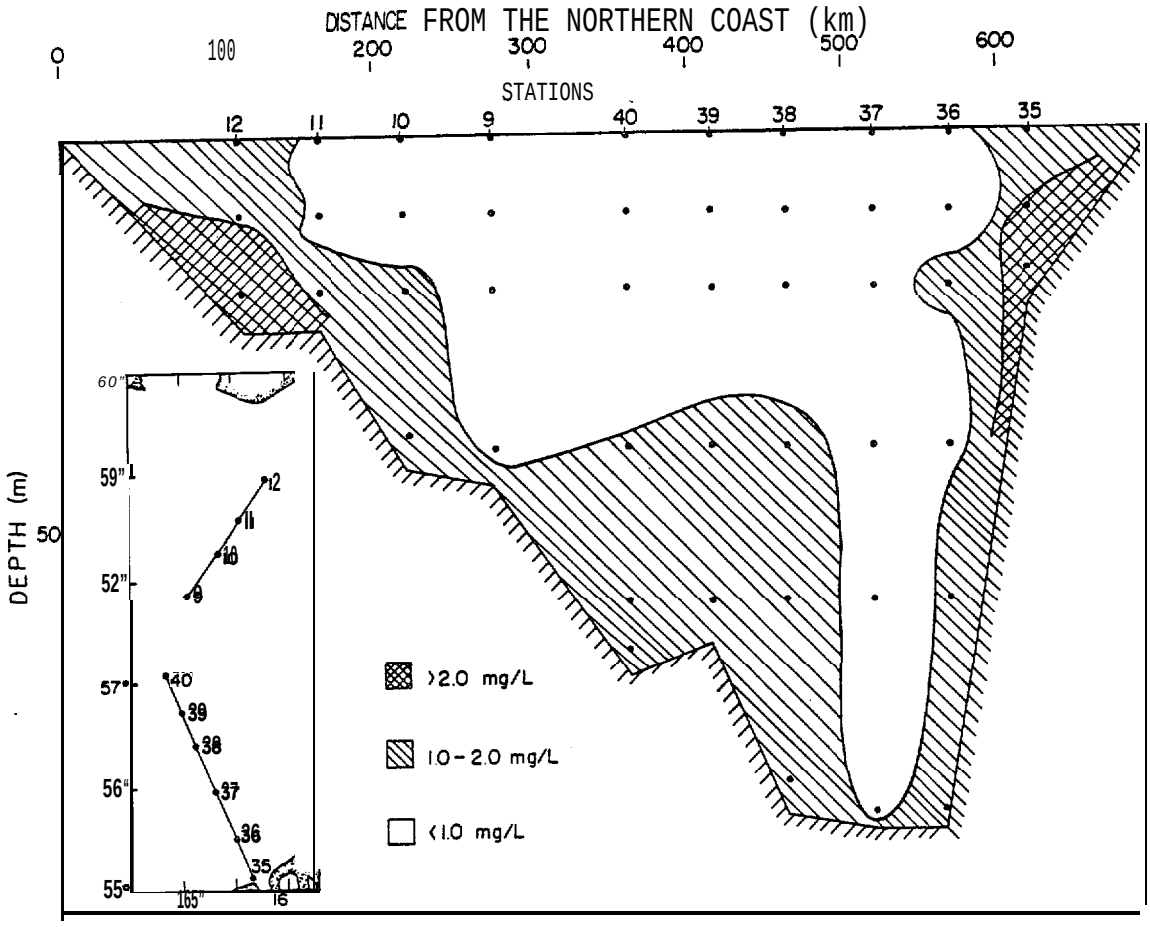


Figure 63. Vertical cross section of the distribution of total suspended matter for stations 9 through 12 and 35 through 40 (Cape Newenham to Port Moller) in the southeastern Bering Shelf (Cruise RP-4-MW-76B-VII, 24 June - 9 JUIY 1976) (Feely et al, 1981).

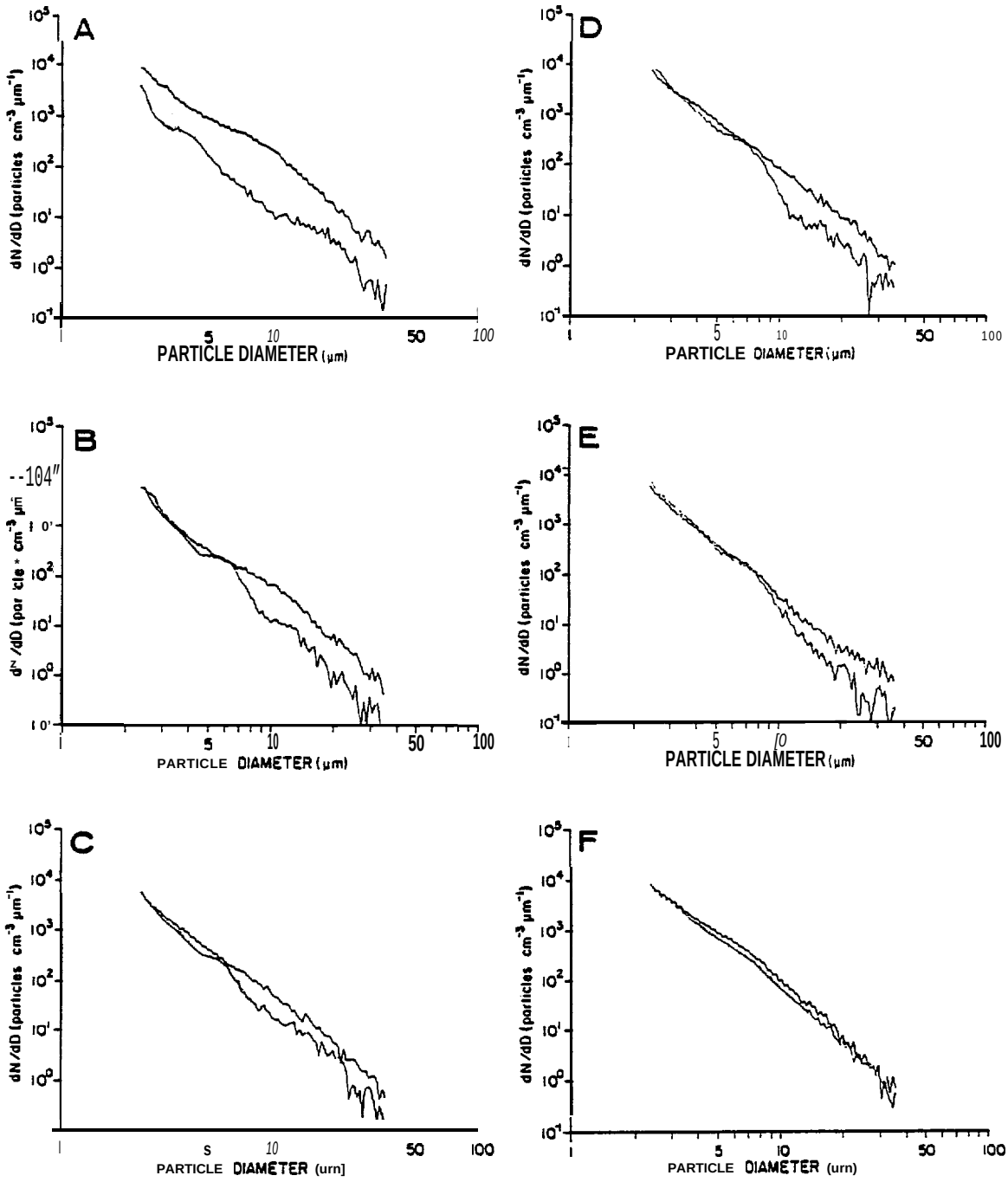


Figure 64. Incremental cumulative curves for particle populations at the surface and bottom at each station (NA34-40 station line) from NASTE 3. A is the outermost station and F is the innermost station (Baker, 1983).

Table 4. Summary of the elemental composition of particulate matter from the major rivers that discharge into the southeastern Bering Shelf. (Surface samples were obtained with a precleaned 4-L polyethylene bottle extended from a helicopter. 12-21 September 1976.) (Feely et al, 1981).

Sample Location	No. of Samples	C wt %	N Wt %	Mg Wt %	Al Wt %	Si Wt %	K Wt %	Ca Wt %	Ti wt %	Cr ppm	Mn ppm	Fe Wt %	Ni ppm	Cu ppm	Zn ppm
Kuskokwim River	9	2.96 ± 2.63	0.38 ± 0.42	2.13 ± 0.39	7.77 ± 0.98	32.13 ± 2.86	1.68 ± 0.16	1.59 ± 0.07	0.56 ± 0.04	105.3 ± 14.9	1498 ± 105	6.57 ± 0.45	69.8 ± 4.8	77.6 ± 7.3	281.4 ± 34.2
Kvichak River	6	2.66 ± 0.15	0.23 ± 0.15	1.24 ± 0.44	4.26 ± 1.07	26.78 ± 10.30	0.81 ± 0.16	0.48 ± 0.13	0.42 ± 0.11	62.2 ± 18.3	941 ± 53	4.36 ± 1.32	36.3 ± 10.9	63.3 ± 8.7	232.1 ± 108.8

Table 5. Summary of the elemental composition of particulate matter from the southeastern Bering Shelf. (Cruise DP-4-D_1-758-III. 12 September - 6 October 1975). Feely et al, 1981.

Sample Description	No. of Samples	c Wt %	N Wt %	Mg Wt %	Al Wt %	Si Wt %	K Wt %	Ca Wt %	Ti Wt %	Cr ppm	Mn ppm	Fe Wt %	Ni ppm	Cu ppm	Zn ppm
Surface (Group I)	24	17.7 ±10.3	2.1 ±1.3	0.86 ±0.14	3.52 ±2.22	25.85 ±5.28	0.51 ±0.17	1.32 ±0.28	0.24 ±0.06	41.2 ±19.3	893 ±285	2.68 ±0.63	24.1	41.9 ±13.9	210.7 ±88.0
Surface (Group II)	4	22.9		1.75 ±0.08	6.11 ±1.32	31.74 ±6.40	0.37 ±0.14	2.66 ±0.89	0.28 ±0.07		1377 ±519	3.15 ±0.35		42.4 ±21.8	353.0 ±127.0
Surface (Group III)	11	35.3 ±19.3	4.8 ±2.7			10.89 ±6.73	0.26 ±0.20	1.14 ±0.50	0.18 ±0.07	60.4 ±32.2	355 ±233	1.92 ±0.66	56.5 ±11.7	64.0 ±31.4	256.0 ±215.0
5 m above the bottom	42	12.2 ±7.6	1.8 ±1.1	1.45 ±0.66	3.92 ±1.27	29.45 ±6.12	0.53 ±0.17	1.64 ±0.65	0.28 ±0.07	50.0 ±20.9	501 ±306	3.16 ±0.82	30.7 ±17.9	54.2 ±47.7	219.6 ±107.6

Group I. Samples containing over 60% of major inorganic elements as oxides at northern stations.

Group II. Samples containing over 60% of major inorganic elements as oxides at southern stations.

Group III. All stations containing less than 60% major inorganic elements.

be remarkably high, only to be compared by high concentrations in the upwelling area of the South Pacific off Equador (Menzel, 1967). [See Handa and Tanoue (1981) for discussion.]

Feely et al (1981) have published results on particulate organic carbon and nitrogen for the specific North Aleutian coastal region as shown in Figure 66 and Figure 67, respectively. These data were taken in September and October, but still show comparably high values (>300 ug C/l and >40 ug N/l) to Handa and Tanoue (1981) and Loder (1971) .

Sediment Transport. The relationship shown between current speed, particle diameter? and sediment erosion transport or deposition developed by Kennett, 1982 (Figure 68) is of value in considerations of the nearshore area north of the Alaska Peninsula in the Bering Sea.

Since the parameters influencing the movement of sediment, i.e. currents and particle diameter, are reasonably well known (previous discussion this section and physical section), it becomes apparent that net sediment transport probably only occurs under the relatively rare conditions of sustained longshore currents. However, erosion and suspension could occur under short term bursts of energy derived from storm waves and unusual tides. A reasonable model directly related to the resuspension phenomenon resulting from energy dissipation in the bottom boundary layer has been developed by Long (1981), Grant and Glenn (in press) and Businger and Arya (1974). This model is shown below:

$$V_t = \frac{K_0 U^* Z}{\phi_m} e^{-Z/N}$$

where V_t is eddy diffusivity, K. is von Karmen's constant (=0.4),"U* is shear velocity, ϕ_m is stratification correction, N is boundary layer thickness and Z is roughness length established by measuring near bottom average velocity profiles.

From this model, it may be seen that since stratification is zero under most conditions in the coastal domain, the eddy diffusivity is largely a function of shear velocity and roughness length. U* is the critical parameter to sediment transport because it includes the interaction between wind (waves), tides (currents) and sediment. It determines the friction felt by the large scale flow field and the eddy diffusivity. As is usual on continental shelves, the mean flow on the nearshore region of north of the Alaska Peninsula is driven by wind and tides. The interaction of this flow against the solid sediment boundary

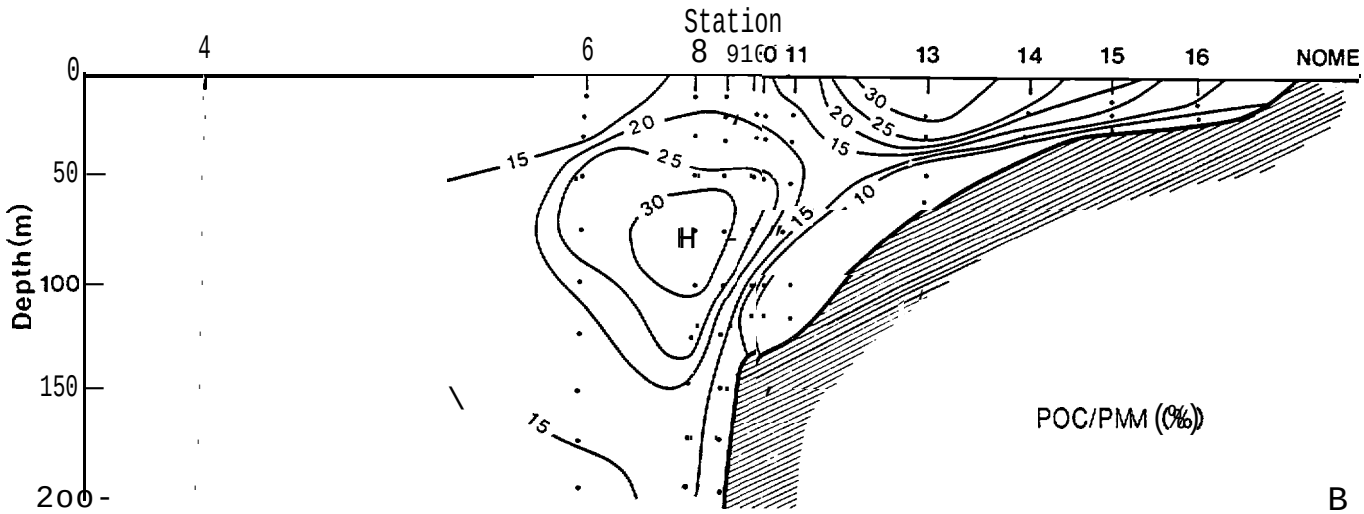


Figure 65. Particulate organic carbon in percentage of total particulate matter in the eastern Bering Sea (Handa and Tanoui, 1981).

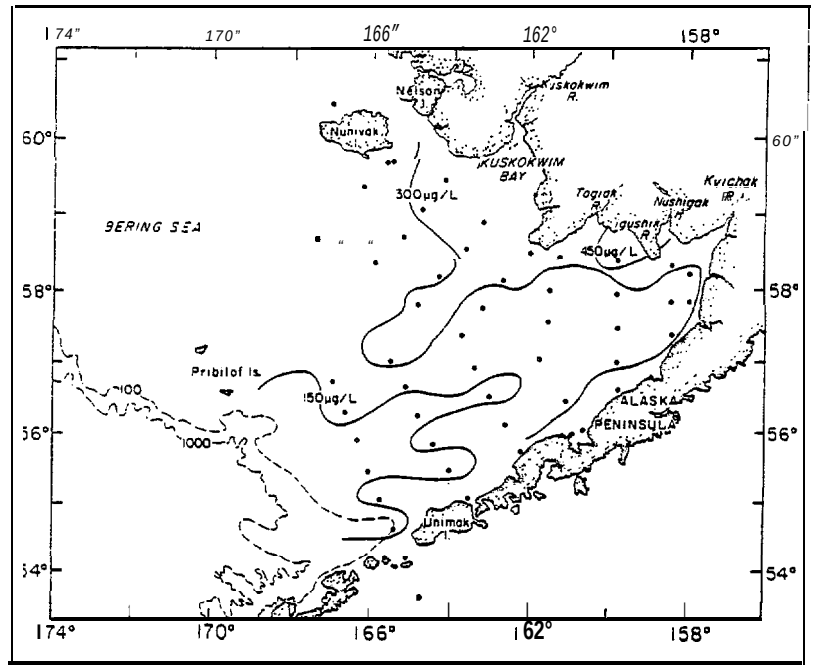


Figure 66. Distribution of total particulate carbon at the surface in the southeastern Bering Shelf (Cruise RP-4-Di-75B-III, 12 September - 5 October 1975) (Feely et al, 1981).

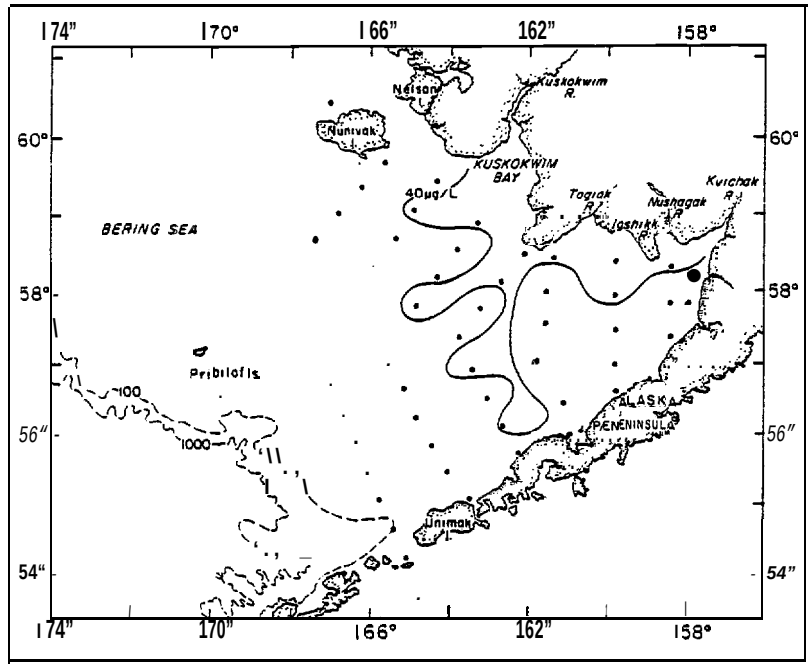


Figure 67. Distribution of total particulate nitrogen at the surface in the southeastern Bering Shelf (Cruise RP-4-Di-75B-III, 12 September - 5 October 1975) (Feely et al, 1981).

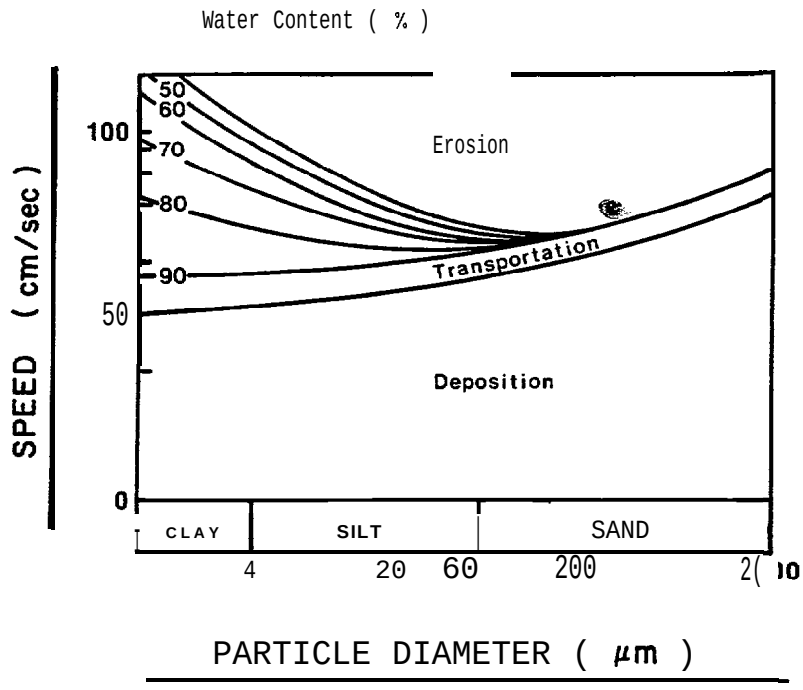


Figure 68. Relationship between current speed, particle diameter, and sediment erosion, transport, or deposition (Kennett, 1982).

leads to a logarithmic relationship to the average velocity profile (Bowden, 1962). The eddy diffusivity generated by the frictional losses from interaction of tidal flow with the bottom then provides the turbulence necessary for the resuspension of sediments and for transport along the boundary layer in the direction of the mean flow.

In addition, the bottom instantaneous stress is associated with wave-caused flow through the non-linear interaction between the steady and oscillatory flow. Above the wave boundary layer region [usually considered the wave length where the energy is about 1/30 of that at the surface (Barber and Tucker, 1962)], the time-mean-stress is enhanced by the wave current interaction above the value for a pure current. This enhancement is established theoretically by Grant and Madsen (1976, 1979) and experimentally in the field by Cacchione and Drake (1982).

Based on measurements of the suspended sediment particulate matter on the North Aleutian Shelf, Baker (1981) has estimated the vertical eddy diffusivity for the region which, based on the above generic discussion, is the most important parameter to measure in consideration of sediment resuspension and transport, particularly in a non-stratified system. To accomplish this, the sediment mass continuity equation was modified to steady state conditions thus eliminating the effect of time. Also, the two horizontal components were eliminated because of their negligible contribution in comparison to the vertical component. This equation then became:

$$K_z = \frac{(\overline{W} - W_s)(Z-A)}{\ln (C_z/C_a)}$$

where K_z is vertical eddy diffusion coefficient, $\overline{W}$ is the advective flow in the vertical direction, W_s is the SPM settling velocity, z is some level above a reference level, A, and C is concentration. K_z can be estimated only if the term $\overline{W}$ - W_s is known. W_s, the settling velocity can be estimated from Stokes equation if it is assumed that the particles are spherical and of known density. This velocity is probably in the range of 10^{-2} to 10^{-4} cm/sec. Vertical advection in the frontal areas and in the coastal domain may be on the order of 10-3 cm/sec.

The settling velocity can be estimated from Stokes equation:

$$W_s = \frac{29\ (\rho_s - \rho)\ r^2}{9\eta}$$

if the particles are assumed to be spherical and their radius (r) and net density $(\rho_s - \rho)$ are known and if the

water viscosity (η) is known. An estimate of the size limits can be obtained from the particle size distribution data in Figure 64, but the in situ density is unknown. Based on reasonable estimates of these parameters, K_z may be estimated for the 5 to 15 meter layer in the coastal domain to be on the order of 150 cm^2/sec. for the data available. A rate of vertical eddy diffusivity of this magnitude would be effective in supporting silt-size particles in suspension and transport along the boundary layer, but probably only under conditions of large waves would coarser materials be eroded and transported. Information available at this time does not permit further treatment of this subject for the nearshore area.

Chemical Processes. Unlike other disciplines of oceanography, chemical studies of the Bering Sea have been undertaken only in the last three decades, largely in the interest of investigating changes resulting from biological activity. Nutrient dynamics has been the main focus, but will be treated in the section related to primary productivity and hypotheses. Considerations of the carbon dioxide system, organic matter (including hydrocarbons), and heavy metals will be considered in this section.

Carbon Dioxide System

The carbon dioxide system, composed of all forms of carbon in the water column and their interaction with the overlying atmosphere and the sediments below, is in constant flux . The degree of flux depends on the trophic level and intensity of biological activity and the physical dynamics of the system. Since parameters within and controlled by the carbon dioxide system, i.e. partial pressure of carbon dioxide gas (pCO_2), alkalinity (A), total carbon dioxide (ΣCO_2) and acidity (pH) are relatively easily and accurately measured, examination of this system as a tool to gain understanding of ecosystem dynamics is becoming increasingly important in studies of the marine environment, particularly on the continental shelves and coastal regions. Partial pressure of C02 measurements in the air and surface water has been extensively measured in the ocean since the International Geophysical Year (Keeling, 1968) to gain understanding of the distribution and rates of exchange of atmospheric C02 and the ocean. These studies have provided analytical techniques and background on carbon dioxide dynamics that have led to methodology for use of this and associated parameters in ecosystem studies (Hood, 1981) that have found particular importance in the Processes and Resources of the Bering Sea Shelf (PROBES) studies completed in 1983 [PROBES Progress Reports (1980, 1981, 1982)1.

Beginning in 1971 (Kelley and Hood, 1971), several studies have been made of the pCO_2 relationships in the

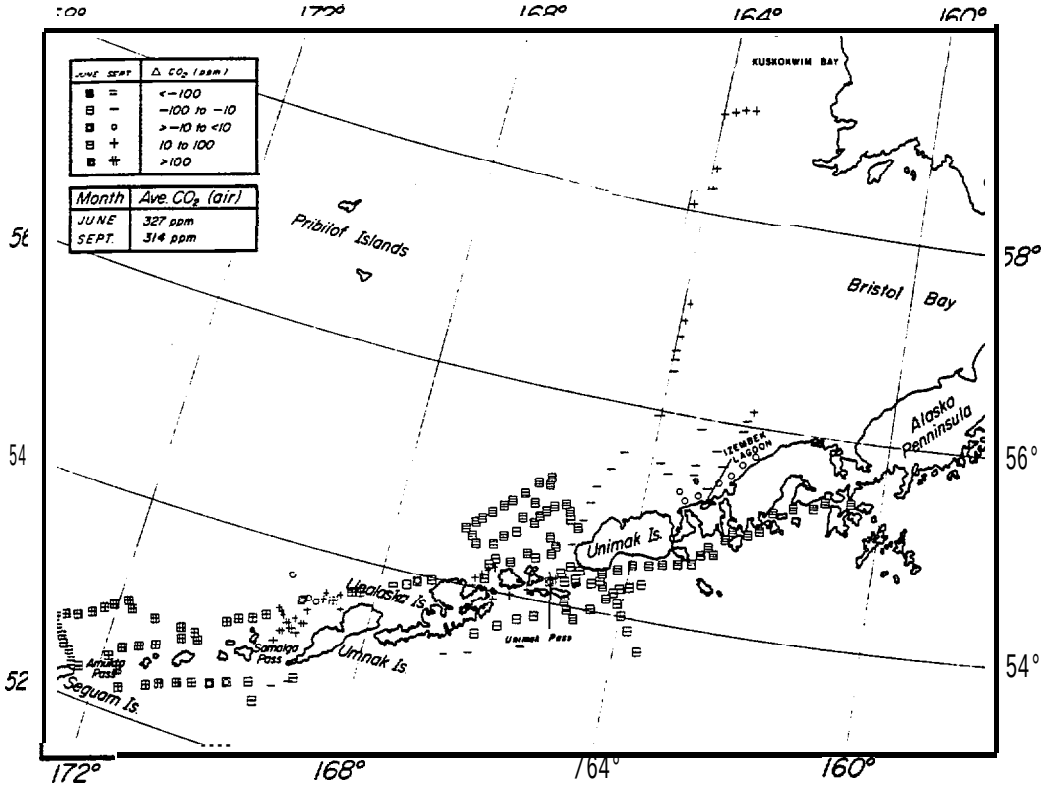


Figure 69. Relative carbon dioxide concentrations between air and surface sea water in the vicinity of the Aleutian Island passes. Cruises of the R V Acona (Kelley et al, 1971).

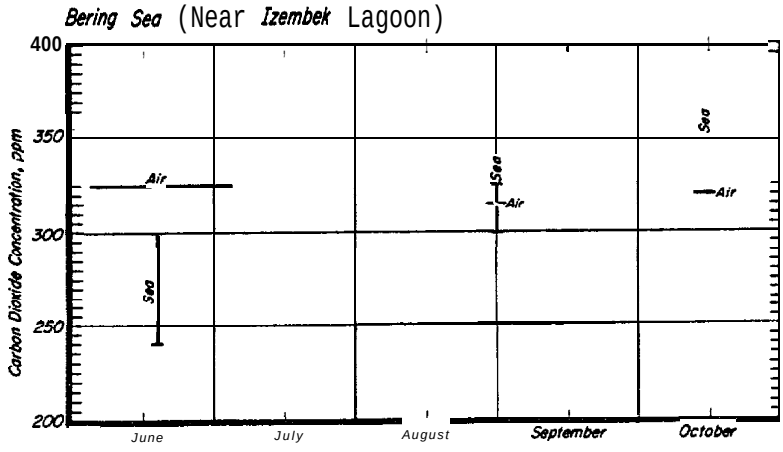


Figure 70. Seasonal (late spring and fall) variation of carbon dioxide in the surface sea water (Kelley et al, 1971).

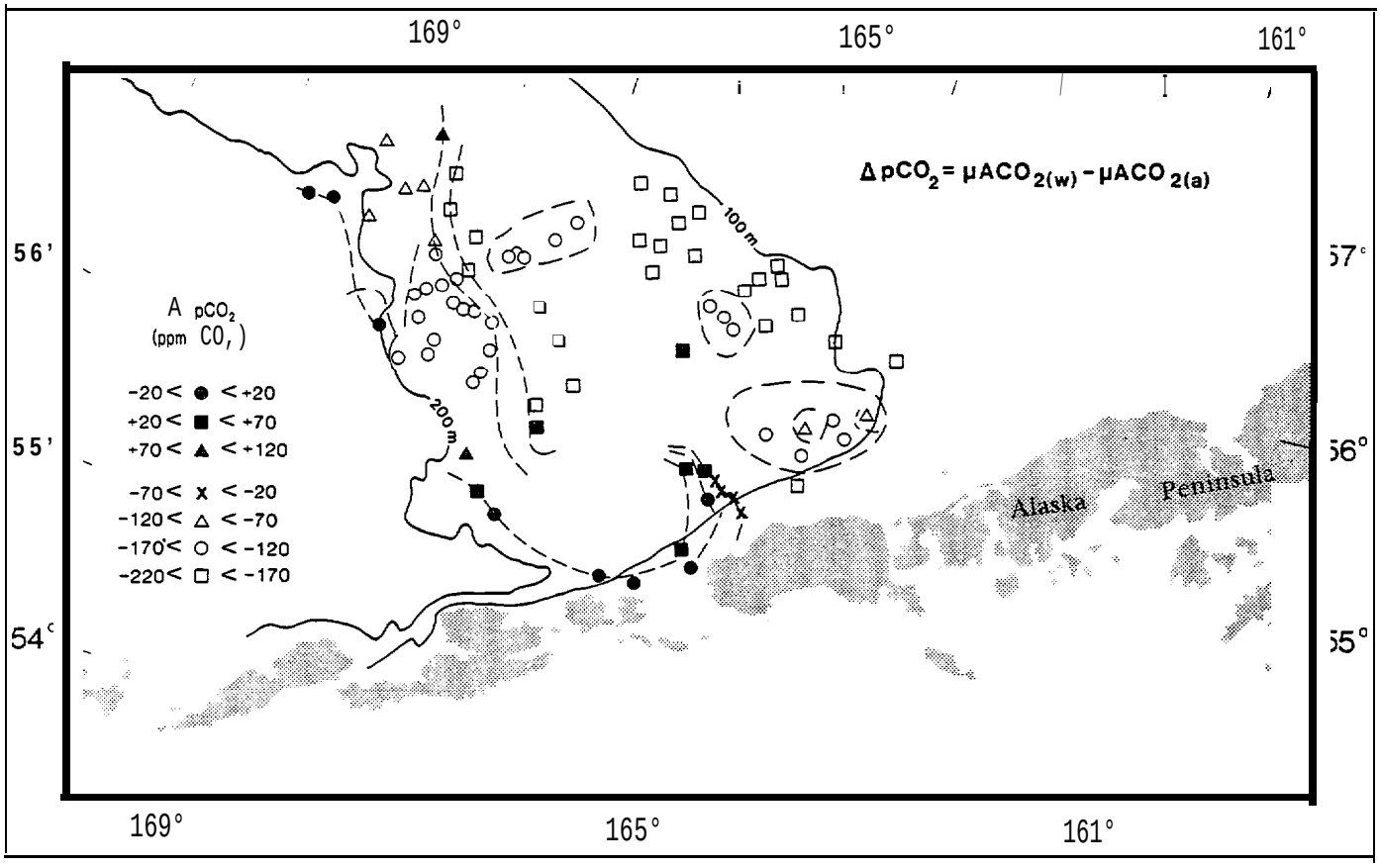


Figure 71. Distribution of pCO_2 in surface water in PROBES study area, May 1976 (Hood, 1981).

Bering Sea, particularly around the Aleutian islands where extensive upwelling occurs. Kelley et al (1971) report on a rather complete seasonal survey of pC02 distribution including data in and nearshore to Izembek Lagoon, as shown in Figures 69 and 70. Figure 69 illustrates only September data for the Izembek Lagoon area which shows near equilibrium values between the atmosphere and surface waters. However, in Figure 70, it is seen that in early June the sea is lower than the air by as much as 90 ppm whereas in October the sea exceeds the air by as much as 30 ppm. No winter data are available for this region. The fluctuations seen here clearly show the effect of the spring bloom in depressing pCO_2. C02, which closely follows pC02 (Codispoti et al, 1982), would also be depressed. This is followed by an increase to near equilibrium in September as a result of respiration and air-sea transfer of carbon dioxide. By October, there is an excess of C02 in the water caused by processes not clearly identified, but probably resulting from. mixing with deeper water which is rich in molecular C02 (Alverez-Borrego et al, 1972).

An extensive survey of carbon dioxide distribution of the eastern Bering Sea Shelf was undertaken in May 1976 (Hood, 1981) as shown in Figure 71. Although the survey did not cover the coastal domain except in Unimak Pass, it does show an increase in differece between air and water at stations eastward of Unimak Pass where pCO_2 in water was found to be near equilibrium or in excess to that of the overlying air. Unpublished data obtained in 1978 (D. Hood, personal communication), given in Table 6, also show PC02 concentrations in the Pass at near equilibrium values with overlying air, but the water was deficient at stations east of the Pass including near Amak Island (about 15 km from the entrance to Izembek Lagoon).

Total carbon dioxide concentrations have not been measured in the nearshore area north of the Gulf of Alaska. Extensive data have, however, been taken in the PROBES study area (Codispoti et al, 1982; Hood and Codispoti, in press). The seasonal changes of total CO_2, pCO_2, and NO_3^- concentrations shown in Figure 72 for station 12 (middle domain) on the PROBES line would, except for timing and intensity, be expected to be similar in the near coastal region.

Organic Matter, Including Hydrocarbons

Organic matter in the world oceans was the subject of several extensive reviews (Hood, 1963, 1966, 1970; Williams, 1969; Wagner, 1969; Riley, 1970; Loder, 1971; Hood and Loder, 1973) over a decade ago, which summarized the work up to that time on the distribution and role of organic matter in the ocean. This subject of investigation was first undertaken in the Bering Sea by Loder (1971) who, along with Feely et al (1981) obtained the only data specifically in

TABLE 6

Partial pressure of C02 in air and water near Unimak Pass in summer of 1978. Acona cruise 261.5, June 17-24, 1978. (Unpublished data, D.W. Hood, personal communication).

Station	Location	Water depth (m)	pC02 (a) ppm	$pCO_{2(w)}$ ppm
1 18/6/78	L 54° 18.3'N; Long. 165° 27.5'W	110	334.3	235.4
2 18/6/78	L 54″ 34.3'N; Long . 165″ 0'W	68	332.2	313.6
3 18/6/78	L 54° 43.9'N Long 164° 59.5'W	66	333.2	334.0
4 18/6/78	L 54° 28.8′N Long. 165° 36.1'W	84	334.0	312.5
5 22/6/78	L 54° 27.0'N Long. 165° 39.5′w	135	338.0	245.0
6	Amak Island		332.0	261.2
7 23/6/78	L 55° 23.3′N Long. 163° 47.2'W	76	334.0	250.0
8 23/6/78	L 55″ 21.4'N Long 164° 4.5'W	76	334.0	250.3
9	L 55° 15.5'N Long. 164° 17.8'W	88	332.0	337.0
10	L 55° 9.3'N Lena 164° 31.8'W	85	333.0	325.0
11	L 55″ 2.2'N Long. 164″ 44.8'W	80	335.0	332.0

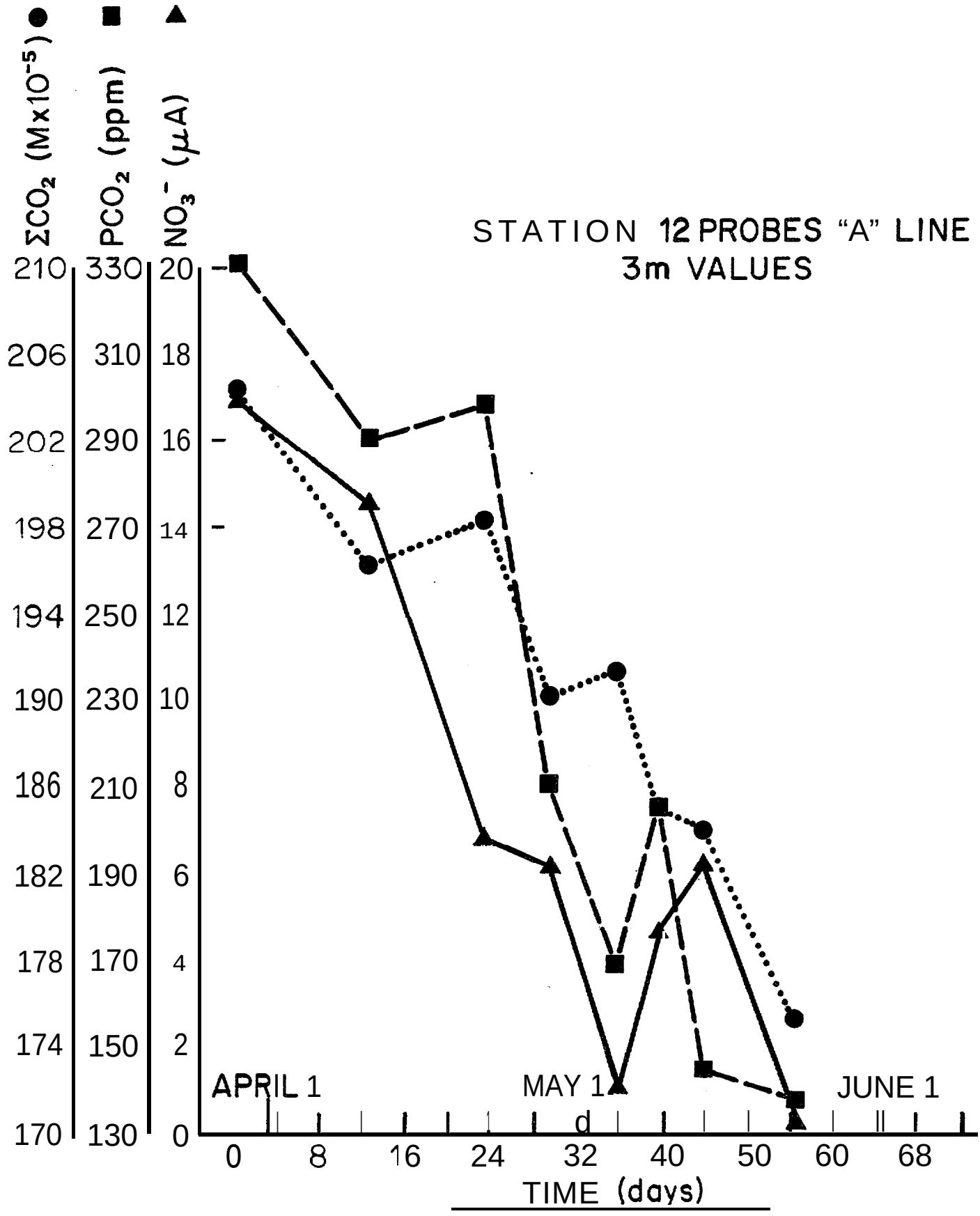


Figure 72. Surface concentration of ΣCO_2, pCO_2 and NO_3^- with time at station 12 (PROBES A line in spring of 1980).

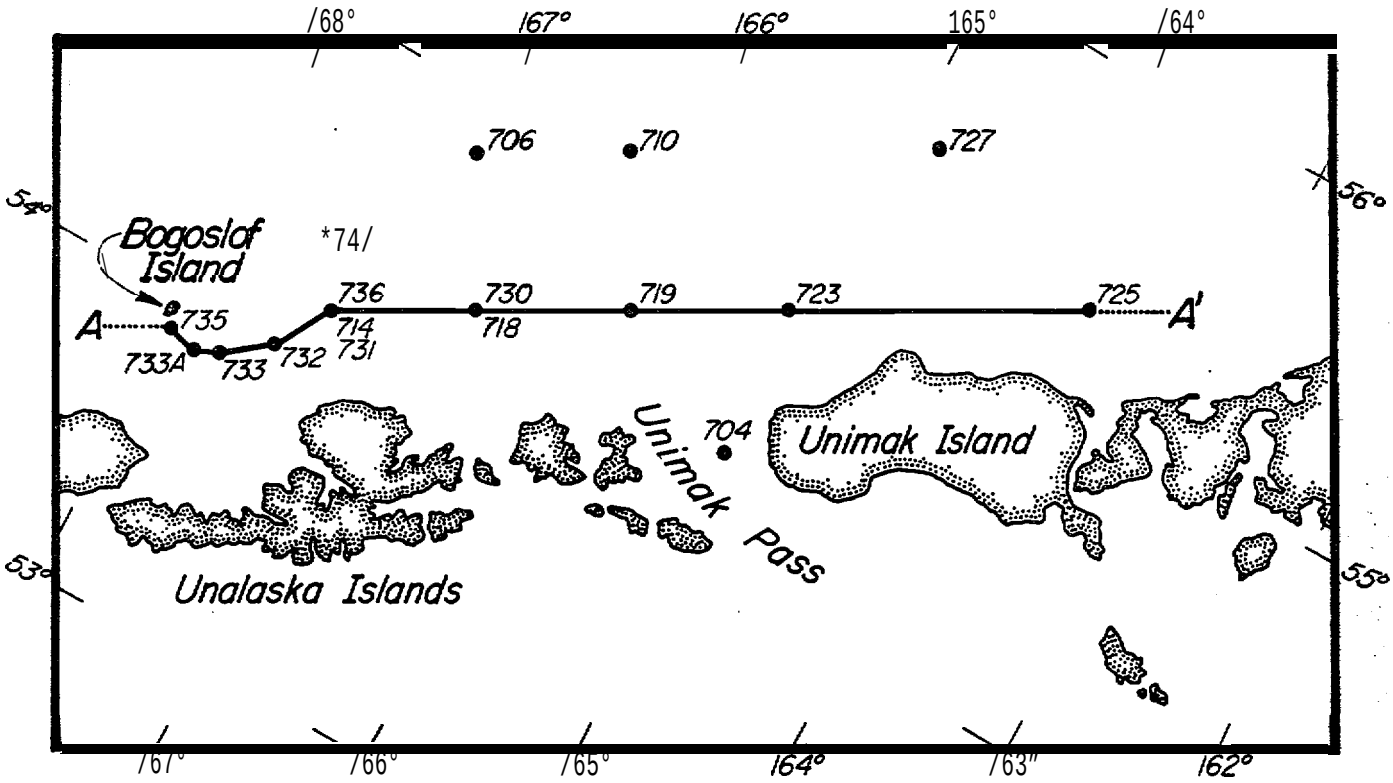


Figure 73. Station locations for samples taken north of Unimak Pass in the southeastern Bering Sea during R V Acona cruise 027, 26 July - 8 August 1966 (Loder, 1971).

TABLE 7

Dissolved and particulate organic carbon concentrations in Unimak Pass area of the southeast Bering Sea in July and August 1966 (Loder, 1971).

Station	Depth (m)	% light penetration	DOC MgC/l	Poc ugC/l
704	0		1.65	234
	10		1.15	164
	20		1.10	148
	30		1.10	129
	50			96
719	0	100	1.00	297
	3	50	1.30	419
	7	25	1.35	389
	12	10	1.00	283
	27	1	1.25	216
	50		1.30	98
	100		1.10	51
723	0	100	1.45	381
	3	50	1.00	303
	5	25	1.45	343
	10	10	1.60	343
	23	1	1.30	220
	50		1.45	135
	100		1.10	
725	0	100	1.85	731
	2	50	1.00	747
	4	25	1.15	731
	7	10	1.10	746
	16	1	1.70	751
	50		1.50	104
727	0	100	1.10	221
	3	50	1.90	185
	8	25	1.40	180
	17	10	1.15	197
	37	1	0.70	58
	40		0.60	55
730	0	100	1.10	811
	3	50	1.05	468
	15	1	1.20	749

the nearshore region north of the Alaska Peninsula. The work until 1974 was summarized by Hood and Reeburgh (1974) and the only contribution since that time is that of Handa and Tanoue (1981) which presents extensive data from cruises of the Hakuho Maru in 1975 and 1978 which occupied stations on the eastern Bering Sea shelf, but none in the study area.

The location of stations occupied by Loder (1971) are shown in Figure 73. The data obtained in the study area are given in Table 7.

In the surface waters, the dissolved organic carbon (DOC) was uniformly between 1.0 and 2.0 mgC/l with a tendency for lower values (0.75-1.50 mg/l) in deeper waters. Particulate organic carbon (POC) was generally high in the nearshore region north and east of the Pass, probably indicative of high productivity in this region even as late as August. Low pCO_2 values (Figure 69) were also found in this region indicating that high rates of primary productivity had recently occurred. Loder (1971) found a high correlation between POC concentrations and absorbance of light in the water column. This would indicate that in this region the major light absorbing agent is particulate organic carbon and also that the particle size distribution of this material is uniform. If skewness in size of particles occurred between stations, light absorbance would change for a given weight of material because of the dominance of smaller materials in light absorbance (Beardsley et al, 1970).

Loder's results agree favorably with those of Handa and Tanoue (1981) who sampled on the shelf north of the Pribilof Islands. Handa and Tanoue found 150 to 900 µg C/l south of St. Matthew Island and DOC concentrations between 0.8 and 1.0 mg/l. The C/N ratios for continental shelf particulate matter was between 6.3 and 9.6 for the 17 samples analyzed with an average value of 8.3+/-4.9.

Handa and Tanoue (1981) have reported the only data on the composition of the particulate organic matter in the Bering Sea. It is expected that the organic matter in the study area is of similar composition to that in other similar coastal regions, thus it is appropriate to briefly review these results. A composite of four stations of the 1978 cruise of the Hakuho Maru within the coastal zone off Nome, Alaska was analyzed for monosaccharides. This area is under the influence of the Yukon River and should be similar ecologically to the region west of the Kvichak River. The analysis gave the following data in molar %: rhamnose-3.01 , fucose-3.33, ribose-trace, arabinose-5.68, xylose-2.80, mannose-14.5, galactose-5.39, and glucose-65.3 to give a total carbohydrate concentration of 32.1 µg C/l or 13.5% of the total organic carbon. They found these data not to be significantly different than that from samples

in the northwestern Pacific Ocean. This comparison gives some credence to limited generalities concerning the composition of particulate organic matter on the continental shelves at least in northern latitudes. Detailed analysis of the carbohydrate composition of marine diatoms conducted by Handa (1969) and Hang and Myklestad (1976) found that cell wall carbohydrates, which are soluble in alkali, consist mainly of mannose with lesser concentrations of fucose, glucose, galactose, rhamnose, xylose and arabinose. The water extractable polysaccharides consisted of 90 percent glucose. These data indicate that the high proportion of mannose found in Bering Sea particulate organic samples must be due to cell wall polysaccharides of diatoms, which are the main primary producers on the Bering Sea shelf (PROBES progress reports 1978-1981) .

Amino acids were determined in several particulate samples on the eastern shelf of the Bering Sea. Serine, glycine and alanine were found to be dominant in all samples from all depths, whereas aspartic and glutamic acids dominated below the euphotic zone (50m). At two stations in the coastal domain near Nunivak Island, total amino acid concentrations between 100-150 µg/l were found, which compares with values found on other continental shelves (104-156 µg/l). In general, the ratio of particulate amino acid carbon to POC (PAC to POC) and particulate amino acid nitrogen to PON (PAN to PON) at the Bering Sea stations were found with ranges of 24.6-31.3 and 47.3-62.0, respectively. These ratios are indicative of marine photosyntheis. At the two coastal stations, lower ratios were obtained indicative of contamination by terrigenous materials.

The distribution and concentration of hydrocarbons in the surficial sediments of the continental shelf of the eastern Bering Sea have been carefully examined by Venkatesan et al (1981). Of the thirty two samples collected in the Bristol Bay area, four were in the coastal domain, one was eelgrass and one was sediment obtained within the eelgrass environment of Izembek Lagoon. The location of the samples is shown in Figure 74. The results of analysis are shown in Table 8.

The results show that total hydrocarbon content follows the same trend as organic carbon (see Figure 55) with low concentrations of total hydrocarbons in coarse-grained sediments and higher values in fine-grained sediments near the shelf edge. The organic sulfur content of these sediments is low (0.01-0.13 percent) as compared to other marine sediments (Didyk et al, 1978) and indicates relatively oxidizing conditions within the sediments. The hydrocarbon to organic carbon (HC/OC) ratio of the nearshore sediment samples varied between 0.0002 and 0.005, which is the range reported for unpolluted sediments (Palacas et al, 1976). The total N-alkanes to organic carbon ratio is less than

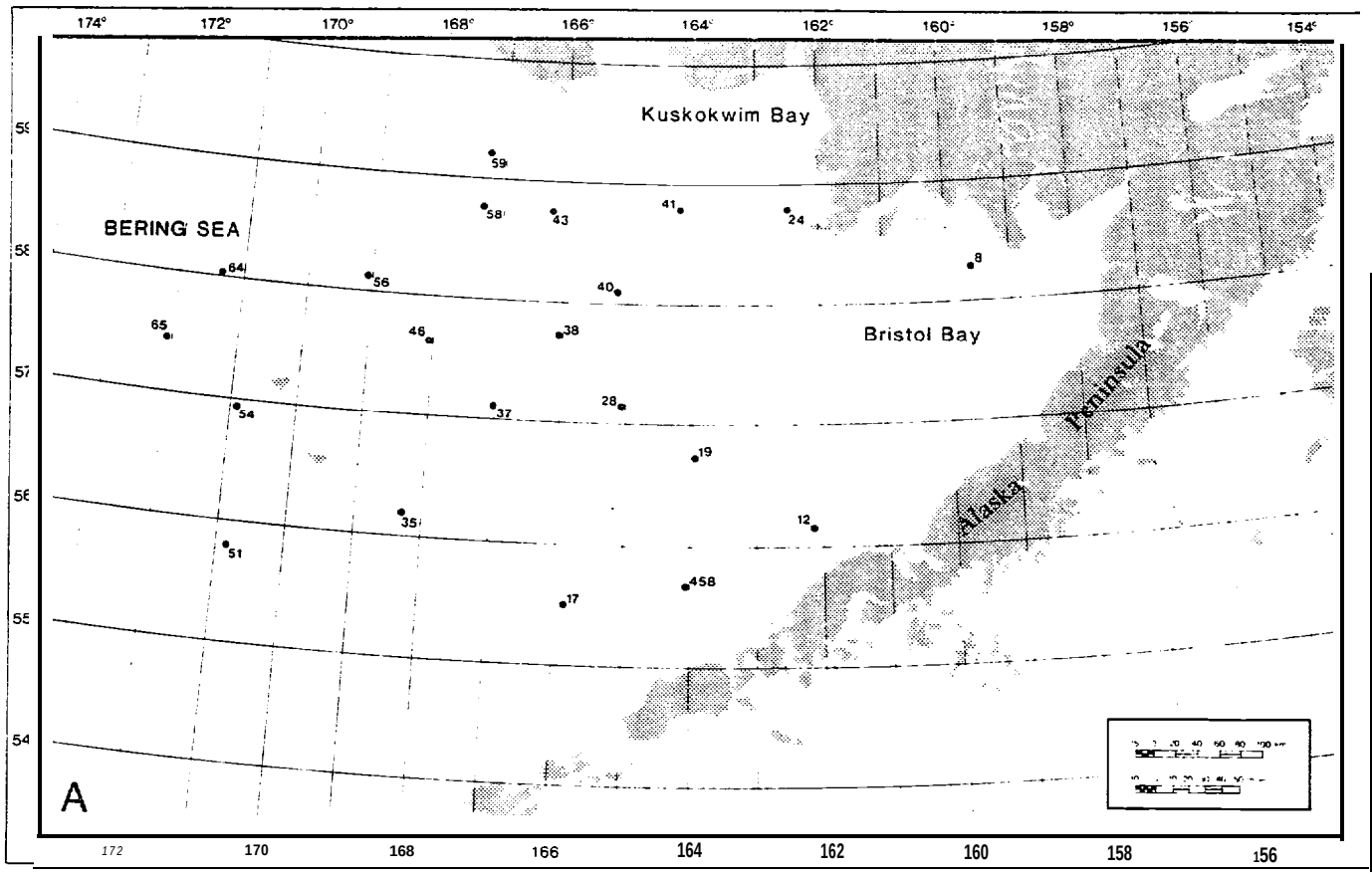


Figure 74. Location of southeastern Bering Sea stations for hydrocarbon analysis (Venkatesan et al, 1981).

Table 8. Gravimetric and gas chromatographic data of southeastern Bering Sea sediment samples (Venkatesan et al, 1981) .

Station number *	Aliphatic fraction (1.19/9)	Aromatic fraction (µ g/g)	n-alkanes (µg/g)	Organic carbon (%)	HC/OC x 10^4	n-alkanes/Oc x 10^4	Pr/Ph	odd/Even
8	5.7	2.8	0.56	0.23	36.9	2.4	2.70	2.99
12	3.4	1.4	0.33	0.14	34.3	2.3	3.32	1.75
17	13.0	5.2	1.09	0.76	23.9	1.4	3.97	3.43
19	7.4	4.5	2.57	0.39	30.5	6.6	5.81	3.17
24	6.1	5.4	0.66	0.33	34.8	2.0	3.39	2.96
28	8.7	4.1	2.93	0.59	21.7	5.0	10.20	4.09
35	180.1	60.8	n.r.	0.41	587.6	n.r.	n.r.	n.r.
37	5.8	4.0	0.76	0.41	23.9	1.8	1.76	3.28
38	4.9	10.6	1.64	0.66	23.5	2.5	5.18	4.41
40	1.9	2.6	0.61	0.32	14.1	1.9	3.37	3.41
41	1 . 4	0.5	0.41	0.37	5.1	1.1	n.d.	3.80
43	2.4	2.7	0.52	0.30	17.0	1.8	2.26	3.08
46	4.3	7.5	0.74	0,42	28.1	1.8	17.90	3.59
51	2.8	0.6	0.77	n.d.	25.4	n.d.	3.49	2.56
54	7.4	9.9	2.10	0.68	25.4	3.1	8.80	2.57
56	10.6	8.5	0.75	0.47	40.6	1.6	2.93	3.78
58	3.8	2.8	0.28	0.31	21.3	0.9	4.80	3.33
59	6.4	6.2	1.55	0.27	46.7	5.7	1.74	2.85
64	12.3	9.8	1.79	0.77	28.7	2.3	2.27	2.75
65	6.9	9.6	1.60	0.67	24.6	2.3	16.43	3.77
45B	3.9	4.9	0.78	0.76	11.6	1.0	3.78	1.96

* Bulk samples of the upper 0-10 cm of surface sediment
Aliphatic = eluted by hexane
Aromatic = eluted by benzene and then cleaned by TCL procedure to remove methyl esters
HC = total hydrocarbons, sum of aliphatic and aromatic fractions in g/g dry sediment
n-alkanes = resolved by gas chromatography
Pr = Pristane
Ph = Phytane
Odd/Even = Summed from C_{15} to C34
n.r. = not resolved
n.d. = not determined

0.0007 for all samples, which is much lower than found in areas where unweathered oil is found in the sediments.

Gas chromatographic analysis revealed that allochthonous lipids are the predominant source of hydrocarbons" in shelf sediments. These lipids are characterized by high molecular weight (C25 - C_{31}) N-alkanes derived from terrestrial sources, probably spruce-alder woodlands. of the Tiaga forest drainage basins. It is surprising to find them distributed throughout the shelf sediments since the waters of the Kuskokwim River are swept north into Norton Sound by the coastal surface currents. The ubiquitous presence of these predominately odd-numbered carbon, high molecular weight compounds cannot be easily explained but may be related to the relative rates of utilization of low molecular weight hydrocarbons by microorganisms since there is no apparent continuing source of these compounds.

The homologous series of isoprenoids is not found in the shelf samples. Pristane is much more abundant than phytane. Pr/Ph ratios ranging from 2 to 18 (Table 8) suggests the isoprenoids are derived from biogenic materials of the marine environment rather than from petroleum (Farrington et al, 1977; Venkatesan et al, 1980)..

Two of the stations taken in the nearshore region north of the Alaska Peninsula (8, 12) showed higher concentrations of the <C24 N-alkane hydrocarbons which could be of marine origin and consist of residues from primary production (Han and Calvin, 1969) and from microbiologically altered algal detritus (Johnson and Calder, 1973; Cranwell, 1976; Hatcher et al, 1977).

Eelgrass, which is the dominant plant in the vast lagoonal region of the northern Alaska Peninsula, was analyzed for hydrocarbon composition by Venkatesan et al (1981) in order to compare eelgrass with the sediments on which it grows as well "as the sediments of the shelf area. As shown in Figure 75, the hexane extractable fraction of eelgrass consists of a simple mixture of C_{15}, C_{17} and C_{19} N-alkanes with only small amounts of hydrocarbons beyond N-C_{25}. The sediment in the lagoon has a hydrocarbon distribution which cannot be correlated with the allochthonous hydrocarbon distributions found on the shelf. The analysis indicates a mixture of C_{17} to C_{31} odd numbered N-alkanes with predominant alkanes N-C_{21} and C23 which is probably a result of microbial degradation of eelgrass detritus (Johnson and Calder, 1973). This differs from shelf sediment hydrocarbons which predominate in C_{25}-C_{31} odd numbered N-alkanes. The authors therefore conclude that the coastal lagoons do not serve as a source of hydrocarbons in the shelf sediments.

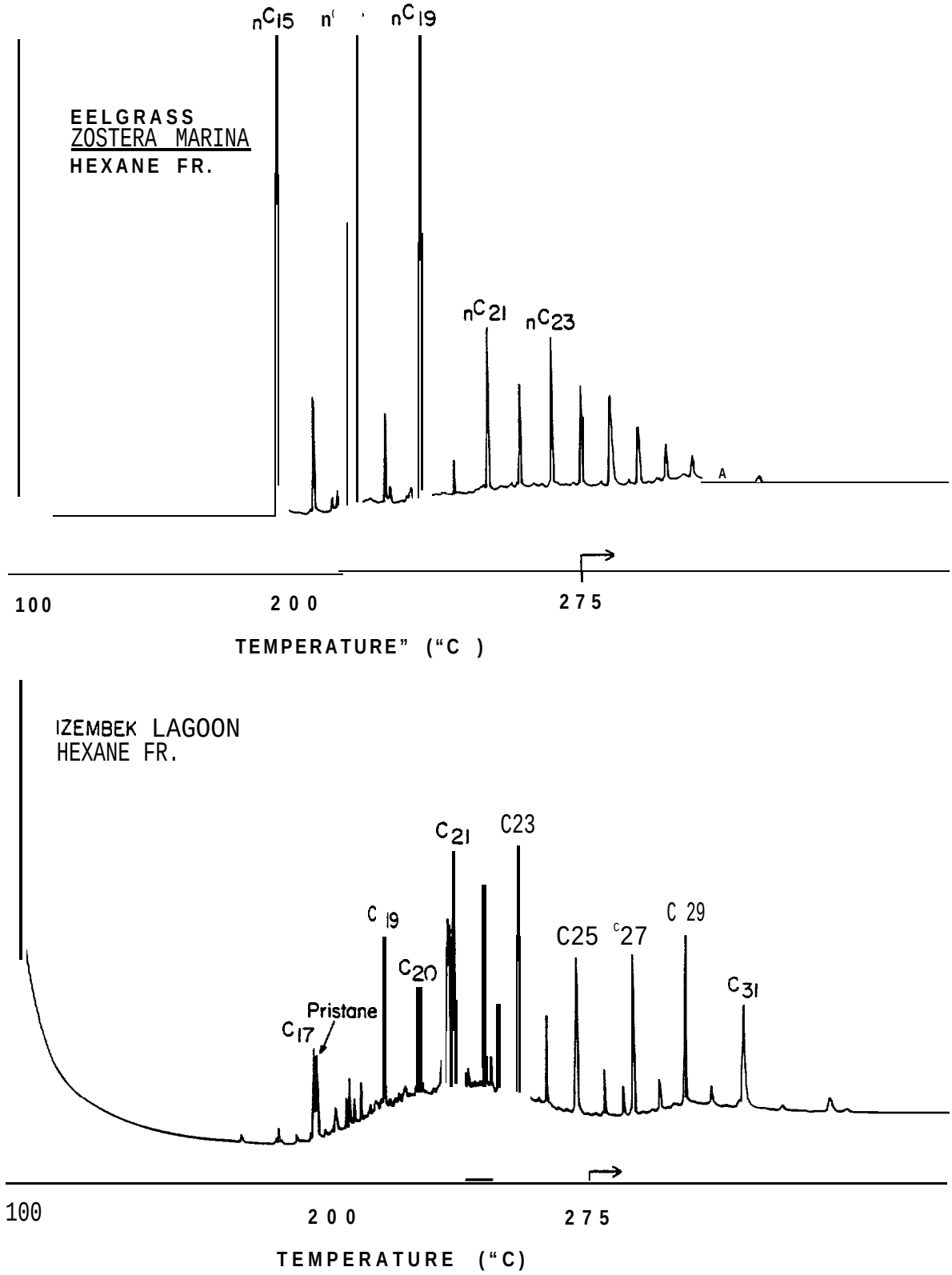


Figure 75. Gas chromatograms of hexane fractions extracted from eelgrass (Zostera marina) leaves and sediments from Izembek Lagoon. Numbers 15-31 refer to carbon-chain length of n-alkanes (Venkatesan et al, 1981) .

Isotopic analysis of the humus material isolated from the sediments on the Bering Sea shelf and in Izembek Lagoon (Stuermer et al, 1978; McConnaughey and McRoy, 1979; Gearing et al, 1976) shows that shelf sediments are heavier ($\delta^{13}C$ of -21.3 ppt) than terrestrial humic acids (^{13}C of -26 to -30 pt) and lighter than the humic acid from Izembek Lagoon ($\delta^{13}C$ of -18 ppt) and eelgrass ($\delta^{13}C$ of - 10.3 ppt). The POC in the lagoon ranges from $\delta^{13}C$ = -19.9 to -17.0 ppt and POC collected at the mouth of the lagoon from -22.1 to -17.3 ppt. It then appears that the humic acid of the lagoon is derived from biodegradation of a mixture of eelgrass, plankton ($\delta^{13}C$ - 24.4%) and detritus. It is also reasonable that, although the hydrocarbons characteristic of the lagoon are not found on the shelf, the more resistant humic substances derived from eelgrass could be mixed with terrestrial material to form the humic materials of the shelf environment.

Shaw and Smith (1981) examined the hydrocarbon content of 34 samples of plankton, fish, marine birds, and marine mammal tissues collected on the Bering Sea shelf. Seal, Phoca vitulina largha, caught in the study area were probably feeding within the coastal domain of Bristol Bay. These animals showed a hydrocarbon distribution including the compound pristane, which appeared to have its origin in the marine pelagic system of the region. Worthy of note is the significance of missing hydrocarbons from the animal organisms examined. The hydrocarbons associated with higher terrigenous plants, commonly found in the sediments, were not observed. Their absence indicates that at least in the spring, terrigenous hydrocarbon sources are minor compared to marine sources. Fossil hydrocarbons were not observed in any samples, indicating that neither natural petroleum seepage nor pollution is resulting in the significant accumulation noted in the above work of petroleum type hydrocarbons in marine animals of the area.

The low molecular weight (LMW) alkanes (C_1 to C4 homologs) are found in crude oil and natural gas (Clark and Brown, 1977) and as such they have been investigated in Bristol Bay to determine the presence of petroleum or thermogenic gas in these waters (Cline, 1981). Methane is by far the most abundant. Besides its presence in petroleum, it is produced through fermentation of simple organic compounds or in hydrogen reduction of CO_2 by anaerobic microorganisms (McCarty, 1964; Reeburgh and Heggie, 1977); and may be produced in oxic marine waters by organisms living in anoxic microenvironment (Scranton and Brewer, 1977). The origin of C2 - C4 compounds also may be biogenic (Smith and Cook, 1974) or photochemical (Wilson et al, 1970). But despite their origin, they are found enriched in ocean surface water (Swimmerton and Lamontague, 1974).

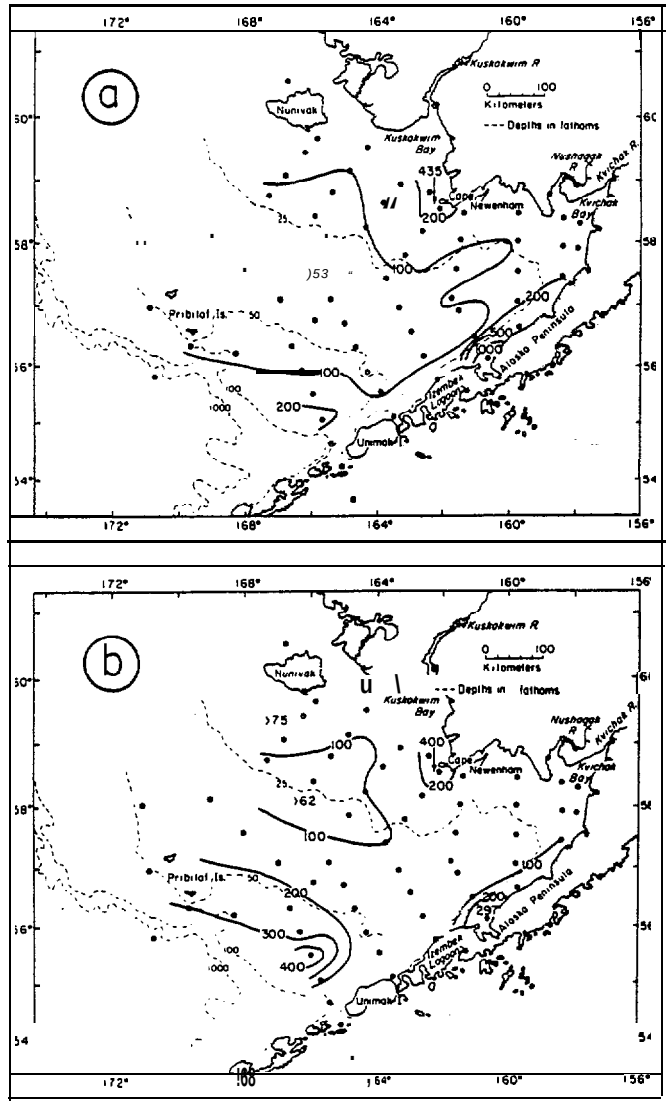


Figure 76. Surface (a) and near-bottom (b) distribution of dissolved methane (nl/l, STP) in July 1976. Near-bottom samples were taken within 5 m of the bottom (Cline, 1981).

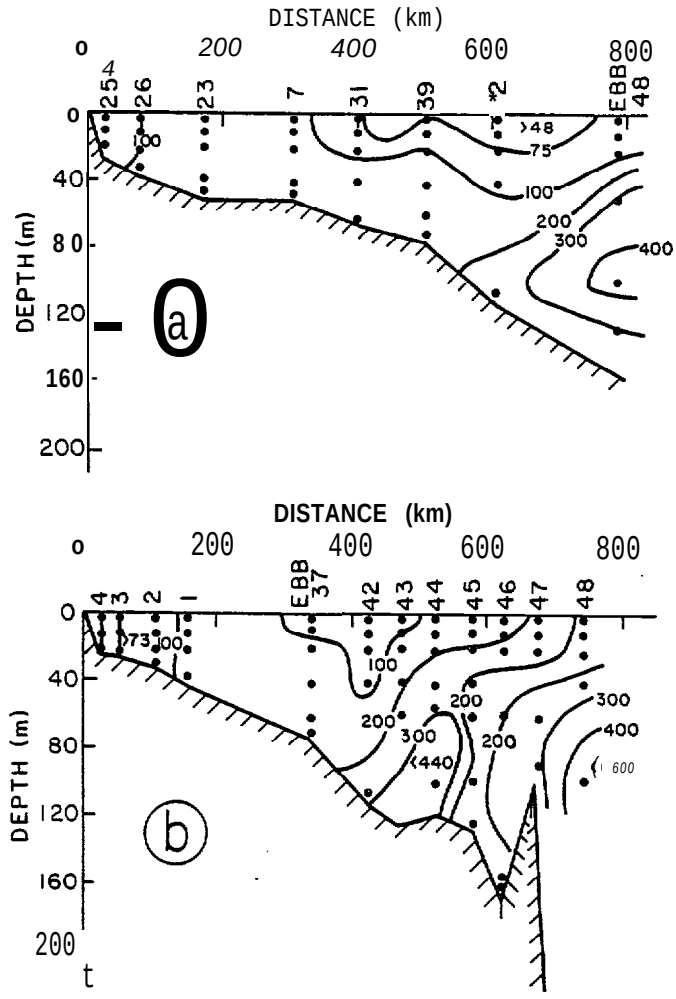


Figure 77. (a) Vertical distribution of dissolved methane (nl/l, STP) along Section II in Bristol Bay. (b) Vertical distribution of dissolved methane (nl/l, STP) along Section I terminating in Unimak Pass. Observations were made in July 1976 (Cline, 1981).

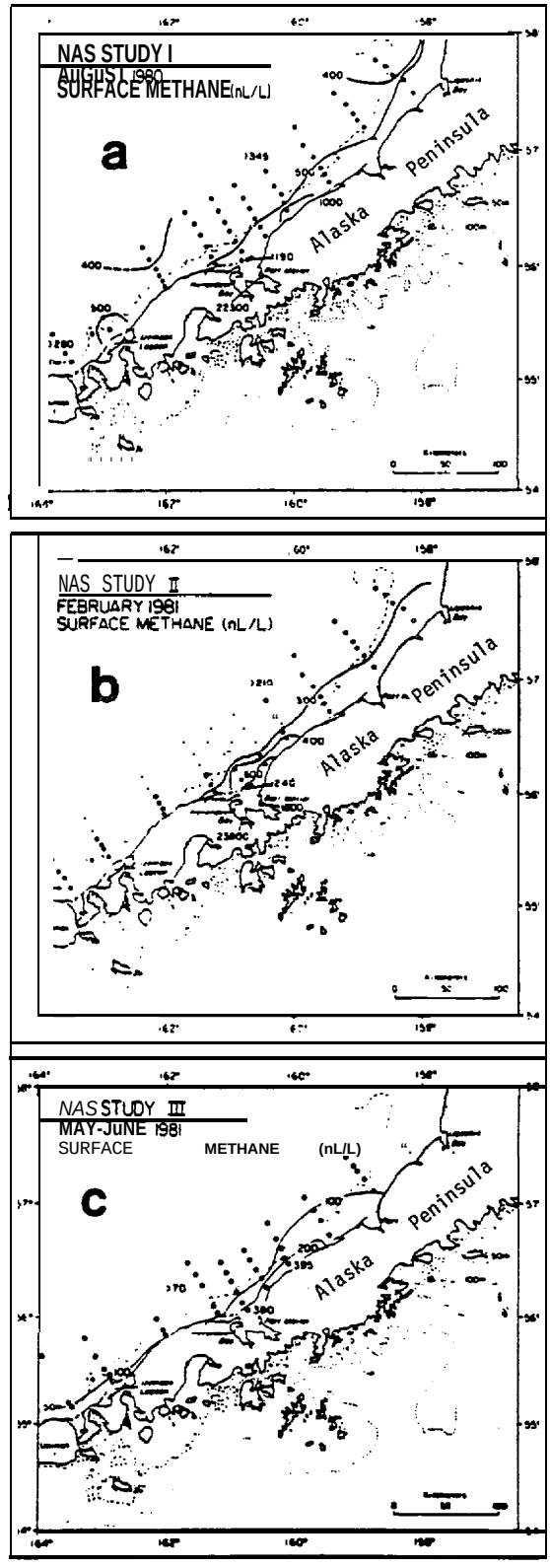


Figure 78. The distribution of methane at the surface along the NAS in (a) August 1980, (b) February 1981, and (c) May 1981. Concentrations are in nl/l (STP) (Cline et al, 1982).

The distribution of methane in Bristol Bay is shown in Figure 76 as reported by Cline (1981). From these data, it is seen that there is a strong source of methane in St. George's Basin just north of Unimak Pass, a strong source in Port Moller and a source near Cape Newenham. In Figure 77, the vertical distribution observed in section (a) originates in Kvichak Bay and ends near St. George Island, and in section (b) originates near Nunivak Island and ends south of Unimak Pass. Methane is vertically homogeneous in the coastal domain, but shows vertical structure in the middle and outer domain. The surface waters in the middle shelf are approximately saturated with respect to air [53+/-3 ml/1 (Yamamoto et al, 1976)1, but close to local sources and in the coastal region, methane in surface waters is severalfold supersaturated.

An intensive study of the rich methane plume near Port Moller was undertaken by Cline et al (1982) with the specific purpose of establishing a point source tracer for use in circulation and diffusion advection model studies to assist in establishing current velocities and estimating the magnitude of horizontal and vertical mixing processes for the coastal domain in the area north of the Alaska Peninsula. The distribution in this section in August 1980 and February and May 1981 is shown in Figure 78. The concentrations in August are several-fold hiaher than in May, probably due to a lag in methane generation after the spring bloom. February concentrations are intermediate. Irrespective of the concentrations, there appears to be little tendency for methane to penetrate the inner frontal zone usually occurring at about 40 meters depth. The evidence for a slow moving coastal current is clear here, in that for each case studied, the concentration gradient and thus the diffusive plume moves north-eastward along the north coast of the Alaska Peninsula.

A simple advection-diffusion model was used and resulted in predicted mean velocities along the shelf (less than 50 meters depth) of 3-6 cm/s, in agreement with current meter results quoted earlier. These mean values represent a mean velocity estimate over a scale length of the tracer, which is about two months.

Removal of methane from the aerobic waters of the coastal zone occurs from two known processes: diffusion through the air-sea interface and microbial decomposition. Air-sea exchange rates were estimated from parameters shown in Table 9. The methodology is based on Broeker and Peng (1982) who have estimated the effect of wind velocity on film thickness Z in the diffusion rate equation. It is expected that the resulting exchange rates are correct within +/- 50 percent. Microbial decomposition has been studied by Griffiths et al (1982) in the environment of the southeast Bering Sea. The authors obtained the data shown

in Table 10, showing a consistently greater rate of oxidation in bottom than in surface waters and a rate of oxidation dependent on methane concentration in the water, location, and time of the year (temperature). Also, it was found that rarely was methane incorporated into cellular material, but appeared as carbon dioxide. It was found that the most rapid oxidation rates in the water column were only seven percent of that found in the underlying sediments.

The results of analysis for LMW hydrocarbons in the southeast Bering Sea shelf are shown in Table 1 1. It was found that the C_{2+} fraction showed seasonal variability regulated by biological processes, presumably microorganismal. As is true elsewhere in Alaska coastal waters, the alkenes are more abundant than the alkanes of the same carbon number. The relatively low concentrations of LMW hydrocarbons, a relatively high ratio of C_1/C_2+C_3 of 30 to 500 and a $C_2/C_{2:1}$ ratio of less than one, all suggest a biological source and indicate the absence of significant quantities of petroleum derived hydrocarbons in this region.

Metal Concentrations

Heavy metal concentrations in the water column have been the subject of limited investigations on the southeast Bering Sea shelf. The most notable effort was that of Barsdate et al (1974) who examined in detail the contribution of the eelgrass beds of Izembek Lagoon to the elemental composition of lagoon and nearshore coastal waters. Based on an estimated production of 5 x 105 mt/yr of eelgrass and an elemental analysis of the eelgrass, the amount of various trace elements incorporated on an annual basis was computed. The results of this evaluation are shown in Table 12. The effect of this incorporation on the chemistry of the sea water is evident in the variation of the concentration of some elements between the lagoon and nearby Bering Sea. In the case of phosphorus, which has been examined extensively in Izembek Lagoon (McRoy et al, 1972a), the eelgrass plants remove 62.4 $mgP/m^2/day$ from the sediments, leading to an export of 3 mt of P/day to the coastal water (495 mt/yr calculated on seasonal output basis). This flow may be seen in the Bering Sea as a plume of phosphorus rich water (Figure 79).

Dissolved inorganic nitrogen (NH_4^+, NO_3^-, NO_2^-) concentrations have also been estimated to have a net export of 96 mt per year, much less than that for phosphorus. There is also evidence for the export of dissolved organic carbon (2 x 104 mt/yr) and silica (2.1 x 103 mt/yr).

Some elements from the Bering Sea waters are extracted by Izembek Lagoon. Most notable were copper and lead as

Table 9. A Summary of parameters used to estimate the air-sea exchange rate (R) of methane along the NAS coastal zone. The model is

$$R = - \frac{D}{h \cdot \Delta z}(c) = -K_{a/s}(C)$$

Date month/yr	Wind Speed m/s	Temp. 'c	D cm^2/s	Az m	h μm	'a/s . . s^{-1}
Aug 80	6	10.7	1.12X10-5	40	70	4.0X10-7
Feb 81	9.5	0.0	0.68X10-5	40	20	8.5×10^{-7}
May 81	7.5	6.5	0.96×10^{-5}	40	50	4.8×10^{-7}

From Cline et al, (1982).

Table 10. Seasonal changes in in-situ methane oxidation rates and turnover times in water samples

Cruise	Area sampled	Methane oxidation rate (nl/liter per day)			Turnover time (days/10^2)			No. tested
		Mean	SD	Range	Mean	SD	Range	
Aug	NAS	3	2	0.8-7.8	0.6	0.7	0.12-3.3	29
	SGB	4	9	0.3-37	0.8	0.7	0.05-2.8	25
Jan	NAS	1	3	0.04-7.4	2	2	0.3-7.2	11
	SGB	1	2	0.02-7.9	3	3	0.1-12	17
May	NAS	0.4	0.5	0.02-1.6	1	1	0.1-10	17
	SGB	2	4	0.1-18	0.6	0.8	0.05-4.5	39
	PM″	16	12	2.4-49	0.3	0.2	0.02-1.0	15

PM″, Port Moller
From Griffiths et al, (1982).

Table 11. Average surface (a) and near-bottom (b) concentrations (nl/l, STP) of methane, ethane, ethene, propane, and propene for various water depth intervals (Cline, 1981).

CRUISE	DOMAIN		METHANE Mean	METHANE Range	ETHANE Mean	ETHANE Range	ETHENE Mean	ETHENE Range	PROPANE Mean	PROPANE Range	PROPENE[1] Mean	PROPENE[1] Range
	Coastal	a	64	45-94	-	-	0.9	0.3-17	-	-	0*5	0.2-11
	(<50 m)	b	59	45-98	-	-	1.0	0.7-1.8	-	-	0.4	0.1-0.6
Sept.-Ott.,	Middle Shelf	a	60	42-83	-	-	0.8	0.3-1.6	-	-	0.4	0.1-1.4
1975	(50-100 m)	b	99	65-163	-	-	1.7	1.2-2.7	-	-	0.6	0.3-1.3
	Outer Shelf	a	76	40-200	-	-	0.5	0.2-0.8	-	-	0.3	0.3-0.4
	(100-200 m)	b	380	100-615	-	-	.1.1	0.7-1.6	-	-	0.3	0.2-0.4
	Coastal	a	112	74-153	0.9	0.6-1.5	3.8	3.0-4.7	0.4	0.3-0.6	1.4	1.0-2.5
	(<50 m)	b	114	73-153	1.0	0.5-2.5	3.4	2.3-4.4	0.4	0.2-0.6	102	0.7-1.6
June-July,	Middle Shelf	a	85	52-134	0.6	0.3-1.5	2.9	1.9-4.7	0.3	0.2-0.6	1.1	0.6-1.7
1976	(50-100 m)	b	115	62-165	1.3	0.5-2.5	2.2	1.1-4.0	0.5	0.3-0.6	0.5	0.2-1.0
	Outer Shelf	a	140	53-276	1.1	0.4-2.1	2.3	1.8-2.8	0.4	0.2-0.7	0.7	0.5-1.1
	(100-200 m)	b	269	164-440	0.9	0.6-1.1	1.2	0.8-1.8	0.3	0.2-0.4	0.3	0.1-0.9

[1]Due to analytical difficulties encountered during the Sept.-Ott. 1975 cruise, concentrations of ethene and propene include ethane and propane respectively.

Table 12. Amounts of various elements annually incorporated in eelgrass in Izembek Lagoon, based 'n 'ry weight concentrations from the literature (annual eelgrass production = 4.6 x 10^5 mt/yr dry wt). (Barsdate et al, 1974).

Element	Concentration in eelgrass (ppm)	Annual elemental incorporation (metric tons)
Carbon	385,000[b]	177,100
	360,000[f]	166,000
Nitrogen	30,450[a]	14,010
	16,000[f]	7,400
Phosphorus	2,860[a]	1,316
	3,600[f]	1,660
Chlorine	43,680[a]	20,093
Potassium	22,640[a]	10,414
Calcium	20,010[a]	9,205
Sodium	19,590[a]	9,011
Magnesium	7,380[a]	3,395
Sulfur	7,300[a]	3,358
Manganese	1,825[a]	840
Silicon	840[a]	386
Aluminum	500[c]	230
Boron	310[a]	143
Iron	245[a]	113
Iodine	203[a]	93
Zinc	27[d]	13
Bromine	9.59[a]	4.41
Copper	7.50[a]	3.45
Barium	7.2	3.3
Fluorine	3.61[a]	1.66
Molybdenum	3.12[a]	1.44
Lead	<1[f]	<0.5
Nickel	0.4[b]	0.2
Cobalt	0.3[b]	0.1
Cadmium	0.23[b]	0.10
Rubidium	0.14	0.064
Berylium	0.12[e]	0.055

shown in Figure 80. These elements were found to be five to tenfold more abundant in waters of the coastal domain some distance from the entrance to the lagoon than in the lagoon waters itself.

Data on heavy metals are not available for other coastal lagoons or nearshore areas in this region, but because of the dynamics of the system it would be expected that they are actively interacting between sediments, water column and the biota.

2. Biological Process Characterization

a. Primary Producers and Carbon Sources

Oceanographic studies of the southeastern Bering Sea have defined the shelf as three domains--outer, middle and coastal--divided by distinct, oceanographic fronts (Kinder and Schumacher, 1981). The 5 km nearshore zone of the North Aleutian Shelf occurs within the coastal domain that is defined by a front located approximately over the 40-50 meter isobath. In this zone there are three main sources of organic carbon to the food webs: phytoplankton, macrophytes, and detritus.

Phytoplankton Production. Measurements of primary productivity of the southeastern Bering Sea are numerous for the middle and outer shelf but are very limited for the coastal domain and, with the exception of Izembek Lagoon, there are few stations within the 0-5 km zone. Furthermore, since there has been no concerted effort to study the seasonal cycle in the coastal domain, we can only extrapolate from what is known in the adjacent domains. As in other shelf regions, the determinant of phytoplankton primary production, once sufficient light is available in the spring, is the nutrient supply, primarily inorganic nitrogen. The water column in the coastal domain, unlike that of the middle and outer domains, consists of a single layer, mixed in this shallow water by the overlapping tidal energy from the bottom and the wind energy from the top (Coachman et al, 1980). This oceanographic condition probably results in a single spring bloom that is dependent on the nitrate available at the end of winter. Hence the disappearance of nitrate can be used to calculate the magnitude of the spring bloom. In the middle and outer shelf domains, this has been calculated as about 100g C/m^2 for the period of late April through May (Sambrotto, 1983). This estimate has been verified by direct carbon uptake experiments. In the coastal domain the spring bloom may begin earlier than in the outer shelf due to warming of the shallow water, but the total production will still be determined by the ambient

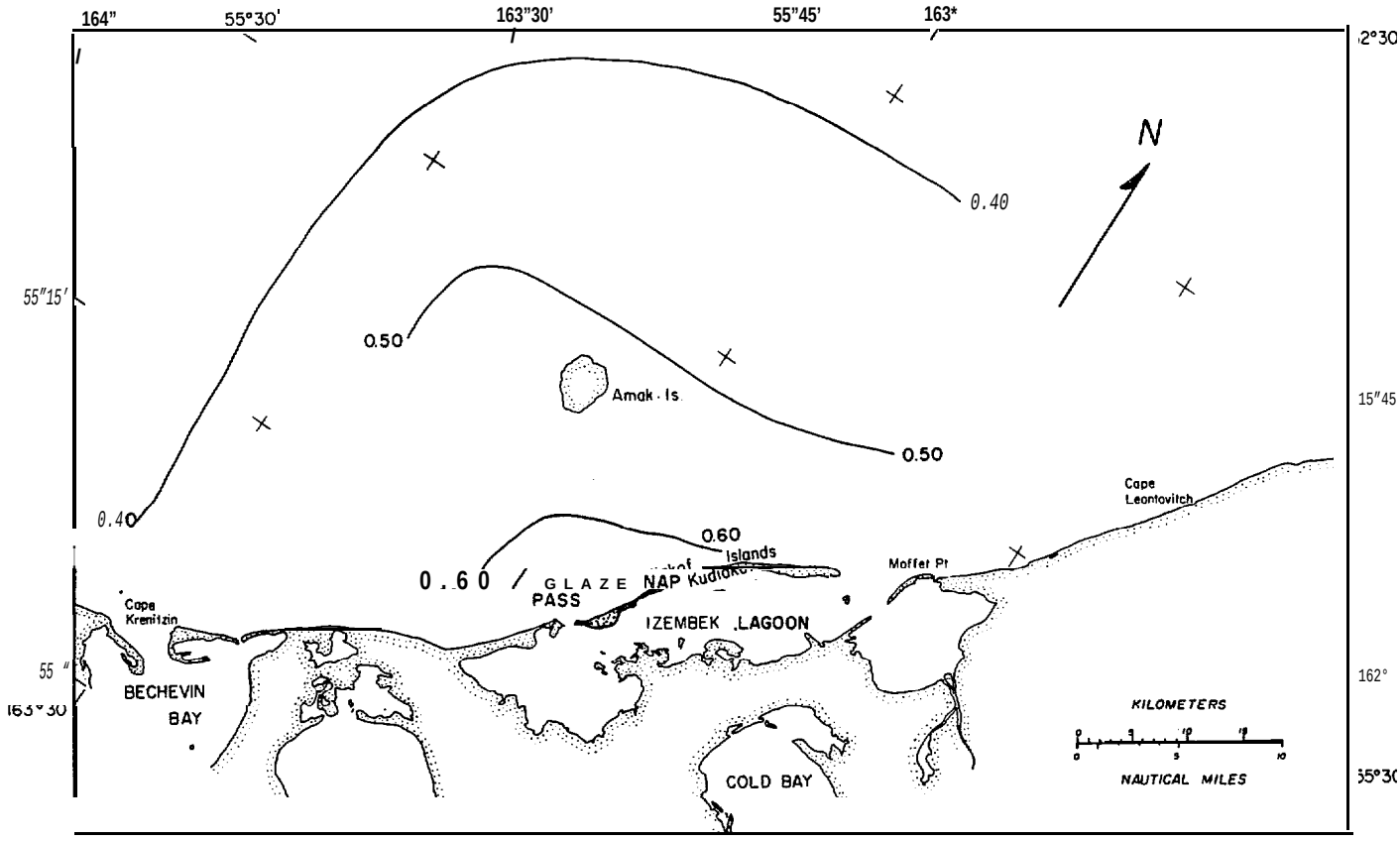


Figure 79. Dissolved reactive phosphorus distribution (µg-atoms P liter) in the Bering Sea adjacent to Izembek Lagoon June 1968 (R V Acona cruise 066) (Barsdate et al, 1974) .

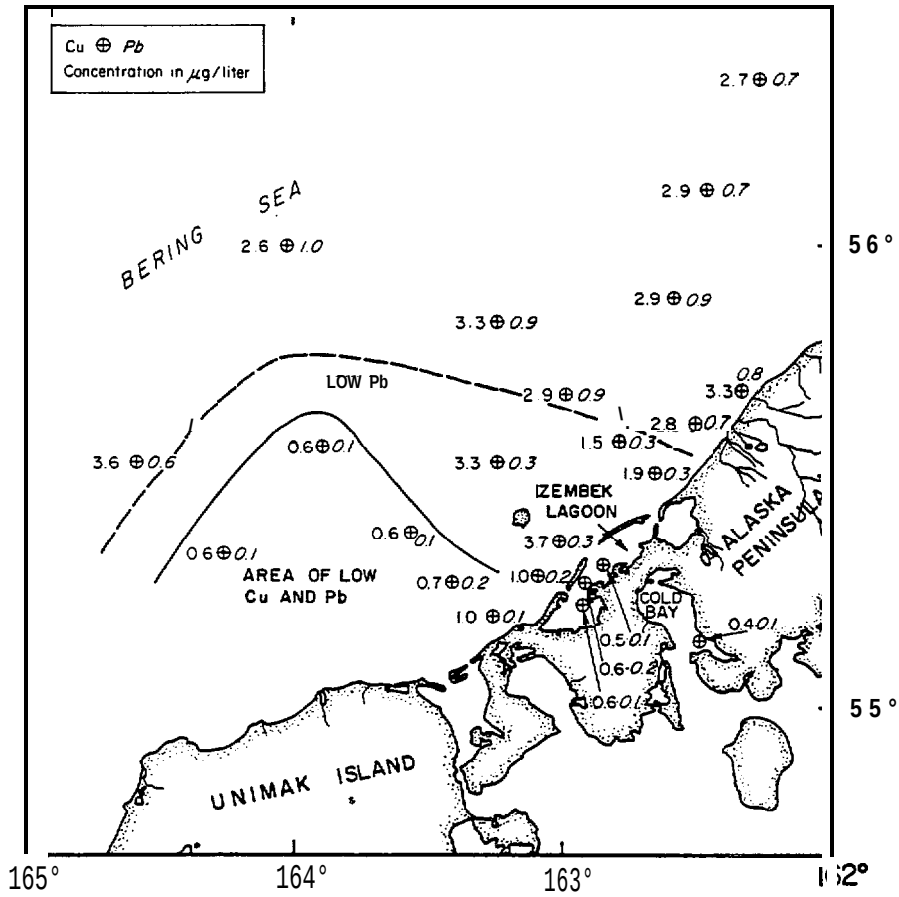


Figure 80. Surface distribution of copper and lead in the Izembek Lagoon sampling grid. September 1970 (R V Acona cruise 103) (Barsdate et al, 1974).

nitrogen content and hence should be similar for the period. The nitrogen content in early spring is about 15 μM (PROBES data) and using an average water column depth of 30 meters, the net production would be $6.3 gN/m^2$ of organic nitrogen and with a C/N ratio of 15:1 (J. Goering, personal communication), the production for the period would be about $95 g/m^2$. The spring bloom occurs over approximately 45 days so the average daily production is about 2g $C/m^2/day$.

Modifications to this pattern will exist if nutrients are supplied from other sources such as from rivers and lagoons, from advection, or from diffusive resupply across the inner front. Runoff can also reduce productivity by increasing turbidity, thus reducing the depth of the euphotic zone. Existing data indicate post-bloom, summer production rates of about 0.24g $C/m^2/day$ from the nearshore waters by Unimak Island (McRoy et al, 1972b). Seaward of this area primary production was considerably higher, probably due to upwelling in Unimak Pass, but the data suggest that this has little or no effect on the coastal domain (i.e. inshore of the 50 m isobath). Apparently, the coastal domain has a single spring bloom of phytoplankton production followed by low, nutrient limited production through the summer and fall.

Macrophyte Production. Eelgrass, *Zostera marina*, is the major marine macrophyte on this coast. This seagrass forms dense, extensive meadows in the protected bays and lagoons of the region (McRoy, 1970). Izembek Lagoon is the only area that has been studied, but presumably the work from this area is representative of the entire region. This lagoon contains the most extensive stands of seagrasses in Alaska and is a major feature of the coast.

The average biomass of eelgrass in Izembek Lagoon is 1kg dry/m^2 (380g C/m^2) with a range of 0.06-1.8 kg dry/m^2 (McRoy and McMillan, 1977). Productivity values range from 3 to 4 g $C/m^2/day$. In Izembek Lagoon, eelgrass is estimated to cover some 68% of the total area (116 km2) and the total standing stock is on the order of 1 x 105 mt dry weight. The total eelgrass production in the lagoon is estimated to be about 5 x 105 mt dry (or 2x105 mt C) per year (Barsdate et al, 1974). A significant proportion, perhaps as much as 75 percent, of this Production is exported to the adjacent sea from the lagoon as particulate and dissolved organic matter. Although most of the bays and lagoons on this coast contain eelgrass, other than for Izembek Lagoon there are no quantitative measurements of either the areal extent of the populations or of their productivity.

An associated component of primary production in eelgrass beds is production by epiphytic and benthic algae. The surface area of the leaves can be as high as 24 times

the bottom area (Dennison, 1979) and this provides an extensive habitat, not unlike a coral reef, for epibiota. There are no direct measurements of epiphytic production in Izembek lagoon but work elsewhere indicates that rates can be as high as 20 percent that of the eelgrass (McRoy and McMillan, 1977). There are no measurements of benthic algal production in the eelgrass beds, but the biomass averages about 2g dry/m^2 and the total standing stock is about 230 mt (McRoy, 1970).

Detritus. The coastal domain of the shelf receives particulate organic matter from the adjacent land margin. The nature of this material is eelgrass detritus from the bays and lagoons and terrestrial detritus from the rivers and marshes. These carbon sources, with the exception of eelgrass from Izembek Lagoon, have not been studied. However, it is likely that there are two major seasonal peaks of the addition of this material. One is expected to coincide with the seasonal maximum in runoff occurring in June and the other is the result of the annual sloughing of eelgrass leaves which occurs in September. Izembek Lagoon has been estimated to annually contribute as much as 1.5 x 105 mt C to the coastal domain (Barsdate et al, 1974). Data on the organic carbon content of the many small streams along the Alaska Peninsula are non-existent, but the few measurements from the rivers in Bristol Bay indicate a particulate concentration of 0.1-0.8g C/m^3 and 2.5 to 4.9g C/m^3 as dissolved carbon (U.S. Geological Survey, 1980). The average runoff along the Alaska Peninsula into the Bering Sea is estimated to be 2 x 10^{10} m^3/yr (P. Kinney, personal communication) whereas that from inner Bristol Bay is estimated to average about 4 x 10^{10} m^3/yr (U.S. Geological Survey, 1980). These freshwater sources could contribute about 1.1 x 10^5 mt C/yr for the Alaska Peninsula (i.e. the North Aleutian Shelf) and about 2.3 x 105 mt C\yr for inner Bristol Bay.

b. Secondary and Higher Producers

Although there are voluminous accounts on invertebrates and marine fishes from the southeastern Bering Sea, there is a paucity of information on these two groups within the 0-5 km nearshore zone. Since recent investigations (PROBES) have delineated the 40-50 meter depth contour as the ecological boundary between the coastal and middle domains, the following characterization of invertebrates and marine fishes of the nearshore zone focuses on accounts from within the 50 meter depth zone.

Invertebrates. Invertebrates fall into three broad categories: 1) zooplankton - those invertebrates which live all or part of their lives within the water column (larval

fishes are also included in this category); 2) in fauna - those invertebrate organisms that live beneath the surface of the ocean floor; and 3) epifauna - those invertebrate organisms that live on the surface of the sea floor.

ZooPlankton

Our knowledge of the species composition, distribution, abundance and biomass of pelagic invertebrate fauna within the nearshore zone of the North Aleutian Basin is limited.

Zooplankton distribution and abundance data can only be inferred from the limited. amount of inshore data available from the broad coastal region near Cape Newenham and Hagermeister Island that was part of the PROBES study area. Virtually no information is presently available on the zooplankton populations along the narrow coastal domain of the Alaska Peninsula or near the large freshwater inputs within Bristol Bay. Data regarding the distribution of mysids in this region is particularly lacking.

The PROBES studies found that two zooplankton groups are consistently present in hydrographically-defined domains in the nearshore (<50 m) regions of the eastern Bering Sea (Cooney, 1981). Middle-shelf and coastal communities are dominated by the small copepods Acartia longiremis, Pseudocalanus spp., and Oithona similis, supplemented by lesser numbers of Calanus glacialis and C. marshallae. The amphipods Parathemisto libellula, the chaetognath Saaitta elegans, and the euphausiid Thysanoessa raschii are the other abundant species. The second nearshore group is associated with the brackish coastal lagoons and estuaries and is dominated by the copepods Acartia clausi, Pseudocalanus spp., Centropages adominalis, Eurytemora pacifica, E. herdmani, and Tortanus discaudatus and the cladocerans Podon and Evadne(Cooney, 1981). Most of the other zooplankton data address the larvae of commerically important decapod crustaceans collected beyond the 50 meter depth zone (e.g. Armstrong et al, 1981, 1982). Zooplankton samples have recently been collected within the nearshore zone, however, thes-e samples were collected specifically for red king crab larvae (VTN Oregon, 1983a,b,c), and it is doubtful if other zooplankters will be included in a final report.

Infauna

Haflinger (1978, 1981) examined the infaunal community of the southeastern Bering Sea and, through station clustering, found a split between the inshore and mid-shelf stations indicating an abrupt faunal transition at the general depth of 50 meters. This boundary coincides with a frontal zone at the transition from coa-stal to mid-shelf water domains. Infaunal biomass was higher nearshore than

in mid-shelf waters and other parts of the southeastern Bering Sea. Most feeding types in this area were predators, scavengers, and deposit feeders. Highest standina stock values were evident at localized areas adjacent to the coast of the Alaska Peninsula and in Bristol Bay. Infaunal wet-weight values exceed 675 g/m^2 near Izembek Lagoon and Port Heiden. Feder and Jewett (1981) also reported high infaunal biomass (exceeding 200 g/m^2 wet-weight) along the 50 meter isobath from Amak Island to upper Bristol Bay. High productivity in localized nearshore communities may depend on detritus of terrestrial origin i.e., from Izembek Lagoon and coastal rivers (i.e., Kvichak, Ugashik, and King Salmon). Relatively low standing stock values were found in northern Bristol Bay, presumably because this region is heavily used by benthic-feeding fishes in the summer months (i.e., yellowfin sole) (Stoker, 1981). Infaunal species typical of nearshore areas were the polychaetes Ophelia limacina and Spiophanes bombyx, the amphipods Corophium crassicorne and Haustorius eous, the clams Spisula polynyma and Tellina lutes, and the sand dollar Echinarachnius parma (Haflinger, 1981).

Four species of bivalves dominate the nearshore zone. A 1977 exploratory survey of subtidal clam resources in the southeastern Bering Sea revealed extensive concentrations of Alaska surf clams (Spisula polynyma) along the north coast of the Alaska Peninsula (Hughes and Bourne, 1981). An area of 6,800 km2 between Port Moller and Ugashik Bay had an estimated exploitable biomass of 329,000 +/- 52,000 mt and potential annual yield of 17,800 mt of whole clams. Highest densities were found at depths of 30-32 meters. Other dominant clam species reported within the 50 meter zone in the southeastern Bering Sea are Macoma cal carea, Tellina lutes, and Cyclocardia crebricostata (McDonald et al, 1981; Hughes et al, 1977). However, of these three, only Tellina lutes occurred in high numbers (more than 72 i nd iv iduals/m^2).

Preliminary results of a more recent survey (VTN Oregon, 1983e) of the infaunal communities of the inshore are-as of the Alaska Peninsula, between Cape Sarichef and Cape Seniavin, indicate the presence of three different community types separated primarily on the basis of depth and sediment type. A shallow, sand-bottom community is composed of the bivalve Siliqua patula along with the polychaetes Capitella capitatta, Magelona sacculata, Nephtys longosetosa, Scoloplos armigera and Travisia pupa. This community was a subset of a deeper water sand bottom community which was dominated by the sand dollar Dendraster. In addition, the polychaetes Ophelia limacina, Spio nr. filicornis and Spiophanes bombyx were important in this community. The deep-sand-gravel community was comprised of many of the ephemeral species of the nearshore sand communities, including Scoloplos armiger and Spiophanes bombyx as

well as the polychaetes Owenia fusiformes, Eteone longs, Glycera capitata, Megacrenella columbiana and Polygordius sp.

Epifauna

Trawling surveys for epifauna in the southeastern Bering Sea in 1975-76 revea-led that the lowest biomass values (1.9 g/m^2) came from waters between 20 and 40 meters (Jewett and Feder, 1981). Although 36 stations were sampled at this depth, only 10 stations were sampled between Unimak Pass and Cape Newenham. The 20-40 meter depth stratum was dominated (biomass) by echinoderms, particularly the sea star Asterias amurensis. Mollusks and arthropods accounted for most of the species within this area. Asterias accounted for 84.4 percent of the total biomass at the 20-40 meter stratum. The average density of Asterias at this stratum was 158 individuals/km; the average density of 18 dominant epifaunal species combined at this stratum was 174 individuals/km. The unidentified seastar that dominated the biomass of trawl catches within the area in question in the summers of 1979-82 (NW&AFC, 1979-82) was also presumably Asterias amurensis. Epifauna data collected within 50 meter waters along the North Aleutian Shelf in 1982 were dominated by a clam (Astarte sp.), hermit crabs, starfish (presumably Asterias amurensis), and a sand dollar (Echinarachnius parma) (Armstrong et al, 1982).

Among 15 biomass-dominating gastropod species occurring within the southeastern Bering Sea, only five occur within the 50 meter contour between Unimak Pass and Cape Newenham (Macintosh and Somerton, 1981) . Of these five species, only Neptunea ventricosa occurs throughout this zone.

Benthic trawling surveys in the southeastern Bering Sea have revealed that 'red king crab (Paralithodes camtschatics), Tanner crab (Chionoecetes bairdi) and Korean hair crab (Erimacrus isenbeckii) all occur within the 50 meter zone (Pereyra et al, 1976; Jewett and Feder, 1981; Otto et al, 1981). In late winter and early spring, adult male red king crab apparently migrate from deeper, offshore areas to join females in shallow water for breeding. Larval hatching occurs prior to breeding. Larval occurrence within the Black Hills - Port Moller area has identified this area as a major red king crab spawning and breeding ground (Takeuchi, 1962; Haynes, 1974; VTN Oregon, 1983a,b,c; Armstrong, et al, 1982). As the season progresses, the center of larval abundance moves northwestward with the prevailing currents along the Alaska Peninsula, toward the head of Bristol Bay, where metamorphosis and settlement occurs (Haynes, 1974; VTN Oregon, 1983a,b,c). Juveniles have only been found in nearshore rocky areas where dense substrate cover is present (e.g., colonial tube-forming polychaetes) . This typifies the substrate preference of early post-larval red king crab elsewhere. Recent data showing a scarcity of

adult ovigerous females, 1 aryae, and juveniles point to a depressed commercial fishery in the southeastern Bering Sea in the immediate future (VTN Oregon, 1983a,b,c; R. Otto, personal communication, 1983). In fact, the Alaska Department of Fish and Game has recently completely closed this fishery to commercial utilization.

Although small concentrations of large male and female Tanner crab occur along the Alaska Peninsula from Unimak Pass to Port Moller, greatest densities occur beyond the 50 meter zone (Jewett and Feder, 1981). A distinct pocket of small male Korean hair crab occurs just north of the Alaska Peninsula adjacent to Izembek Lagoon (Otto et al, 1981). Recently, large populations of Telemsus sp. (horse-crab, or locally known as Bristol Bay hair crab) have been reported in test fishina carried out in the northern part of Bristol Bay in the region of Togiak Bay and Round Island (Dames and Moore, 1983). This crab should not be confused due to its local name with the Korean hair crab (Erimacrus isenbeckii). An average of 7.5 crabs/pot at a size of 0.4 lb/crab were obtained in this area in 3-14 fathoms of water with about 21 hours soak time.

Marine Fishes. The dominant marine fishes, in terms of biomass and density, in the nearshore region of the southeastern Bering Sea are Pacific herring, capelin, and yellowfin sole. Sandlance may also be important in this inshore zone, but sufficient data does not exist at this time.

Pacific Herring (Clupea harengus pallasi)

Abundance of herring in the eastern Bering Sea appears to have increased since 1978 in all major coastal areas. Total spawning biomass is estimated to have ranged from 187,210 to 334,723 mt in 1978, and from 258,079 to 637,583 mt in 1979, an indicated 27% increase at the lower range (Wespestad and Barton, 1981). Studies have shown that Bristol Bay contains the largest assemblage of spawning herring within the entire State of Alaska. In 1981, about 144,000 mt of herring arrived to spawn within Bristol Bay (Fried and Skrade, 1982). Herring usually spawn in areas where the shoreline morphology includes cliffs or bluffs with large jagged outcroppings; where beaches occur in such areas, they are usually intertidal only. Spawning substrates consist primarily of rocks covered with rockweed kelp (Fucus sp.). However, almost any substrate (e.g., Laminaria sp., bare rocks, gillnets) are used under conditions of dense spawning. In northern Bristol Bay, most spawning is confined to the intertidal zone down to depths of five meters. Herring also spawn in shallow bays, beaches or slough areas where eelgrass (Zoestera sp.), and roots of rye-grass (Elymus sp.) and sedges (Carex sp.) are exposed at low tide. The main spawning areas between Ugashik Bay and Cape Newenham are in Metervik Bay and along

the coast west to the village of Togiak (Barton et al, 1977; Wespestad and Barton, 1981). The majority of herring fishing by local residents in this area is for commercial purposes, although most- fishermen retain a limited amount for subsistence needs. The primary onshore herring spawning areas between Ugashik Bay and Unimak Island are Herendeen Bay, Port Moller Bay, Port Heiden and, to a lesser extent, the north coast of Unimak Island (Barton et al, 1977); Wespestad and Barton, 1981).

Capelin (Mallotus villosus)

In 1976, capelin was the most geographically widespread forage fish species encountered in the eastern Bering Sea and constituted the second most abundant species (next to herring) captured at onshore stations between Ugashik Bay and Unimak Island (Barton et al, 1977). Capelin typically spawn along clean, fine gravel beaches. Barton et al (1977) and Baxter (1976) reported that the" only spawning areas that capelin have been observed to utilize between Ugashik Bay and Cape Newenham occur in Togiak Bay, north of Hagemeister Strait, and around Hagemeister Island. They also were observed washed up on the beaches from Cape Krenitzen north to Smoky Point at Ugashik Bay.

Yellowfin sole (Limanda aspera)

Yellowfin sole is by far the species which most dominates the biomass of marine fishes within the nearshore zone of the North Aleutian Basin (Bakkala, 1981a). Perhaps in response to the easing of fishing pressure, fish populations have, since the mid-1970's, steadily approached and perhaps exceeded pristine stock levels. Current biomass estimates for this species are in the two to four million mt range, making it the most common flatfish found on the shelf of the eastern Bering Sea, second only to Alaska pollock in biomass (Bakkala, 1981a; McRoy and Haflinger, 1983). Yellowfin sole migrate seasonally from outer continental shelf and slope waters (>100 m) occupied in winter and early spring to inner shelf waters (15-75 m), where spawning occurs in summer (Bakkala, 1981a). The timing of spring inshore migrations is not well-defined although they have been observed starting from late April to mid-May over the three-year period 1959-61. Ice-induced delays to spring migrations are probably infrequent and of relatively short duration. Unlike the adults, the young remain in shallow nearshore nursery areas throughout their first few years of life. They begin to disperse to more offshore waters at three to five years of age.

Anadromous Fish. Included in this category are salmon and boreal smelt.

Salmon

Historically, the sockeye salmon run of inner Bristol Bay has supported the most important salmon fishery in North America (Stern et al, 1976). Though all five species of Alaskan salmon are taken commercially in the Bristol Bay region (sockeye, pink, chum, coho, and chinook) , the sockeye (red) comprises an average of 86 percent of the total catch at inner Bristol Bay, and 60 percent of that along the remainder of the Alaska Peninsula Bering Sea coast. About 90 percent of the average total run is associated with five river systems (Nushagak, Kvichak-Naknek, Egegik, Ugashik, and Togiak) which empty into inner Bristol Bay (Stern et al, 1976).

The average annual catch for the region, including all five species, is about 12 million fish, ranging to as high as 32.5 million. Of this average annual total of 12 million, 10 million are sockeye.

The average total run for the period 1955-1974 was estimated at 19.6 million fish for the St. George Basin area, 18.3 million of which spawn in inner Bristol Bay. Of the average total of 19.6 million, 16.4 million are estimated to be sockeye, of which 15.7 million return to the rivers of inner Bristol Bay (Stern et al, 1976).

Runs of returning salmon fluctuate widely from year to year, ranging (all species) from an estimated 2.4 million in 1973 to 62.3 million in 1980 (Thorsteinson and Thorsteinson, 1983).

The escapement of juvenile salmon into Bristol Bay is estimated to average 582.5 million smelt, 313.3 million of which are sockeye. About 461.6 million smelt outmigrate from inner Bristol Bay each year, including 299.5 million sockeye (Stern et al, 1976).

Sockeye smelt begin their seaward outmigration from the spawning lakes about the middle of May, with dates varying according to temperature, ice, and climatic conditions (Straty and Jaenicke, 1980; Favorite et al, 1977). Smelt migrate outward from inner Bristol Bay in a belt from the coast offshore to about 48 km until they reach the vicinity of Port Moller (Figures 81 and 82), after which they swing out to sea and eventually make their way through the Aleutian passes into the North Pacific. Under normal conditions, the greatest numbers of smelt within Bristol Bay are found northeast of Port Heiden from late May through late July (Straty and Jaenicke, 1980). Juveniles generally take six months or longer to reach the North Pacific, where they remain for one to four years (Table 13) before returning to Bristol Bay. On their outward migration along the coast of the Alaska Peninsula, most sockeye smelt remain in the upper meter or two of the water column where they feed on

zooplankton and smaller fishes. Preferred prey items seem to be euphausiids, copepods, cladocerans, and sandlance (Straty and Jaenicke, 1980) .

The migratory route of outgoing smelt is apparently determined by salinity gradient and water temperature (Straty and Jaenicke, 1980; Favorite et al, 1977), at least during the early stages. The smelt's activity level, and thus the speed of migration, appears to be directly related to water temperature (Straty and Jaenicke, 1980). Higher temperatures result in increased activity levels, more rapid migration, and faster growth. Increased growth rates are thought to be related both to elevated feeding activity resulting from higher temperatures and to earlier arrival into the zooplankton-rich waters offshore of the Alaska Peninsula (Straty and Jaenicke, 1980).

Adult sockeye salmon re-enter the Bering Sea from the North Pacific in early May, arriving in Bristol Bay starting about mid-June and peaking between 1 and 10 July. By late July to early August all adults have entered the river systems enroute to the nursery lakes (Straty and Jaenicke, 1980).

Though the inward migration of adult salmon occurs at the same time as the outmigration of juveniles, the migration routes of the two do not, in general, overlap. Adults usually stay well offshore until within the proximity of their home rivers (Figure 83), while juveniles remain close inshore until they reach the Port Moller vicinity. Though both are thought to be responding to environmental parameters such as salinity and temperature gradients, they apparently do so in slightly different ways. It is thought (Favorite et al, 1977) that juveniles remain close to shore on their outmigration principally in response to warmer water temperatures inshore, while adults may be directed primarily by salinity gradients and olfactory and physiochemical stimuli. Whatever the reasons for this separation of migration routes, it serves to reduce competition between the two age classes for food, and probably avoids consumption of the smelt by returning adults.

Unfortunately, data are inadequate to describe in any detail the migration routes or dates for salmon species other than sockeye in the Bristol Bay region. Salmon of one species or another, however, are known to be present in the area, either as juveniles or adults, from May through at least October (Figures 83-87) and probably constitute major food resources for several species of marine mammals and birds, including beluga whale, harbor seal, and probably Steller sea lion and northern fur seal.

From the limited data available, it appears that pink salmon smelt outmigrate later than sockeye, probably

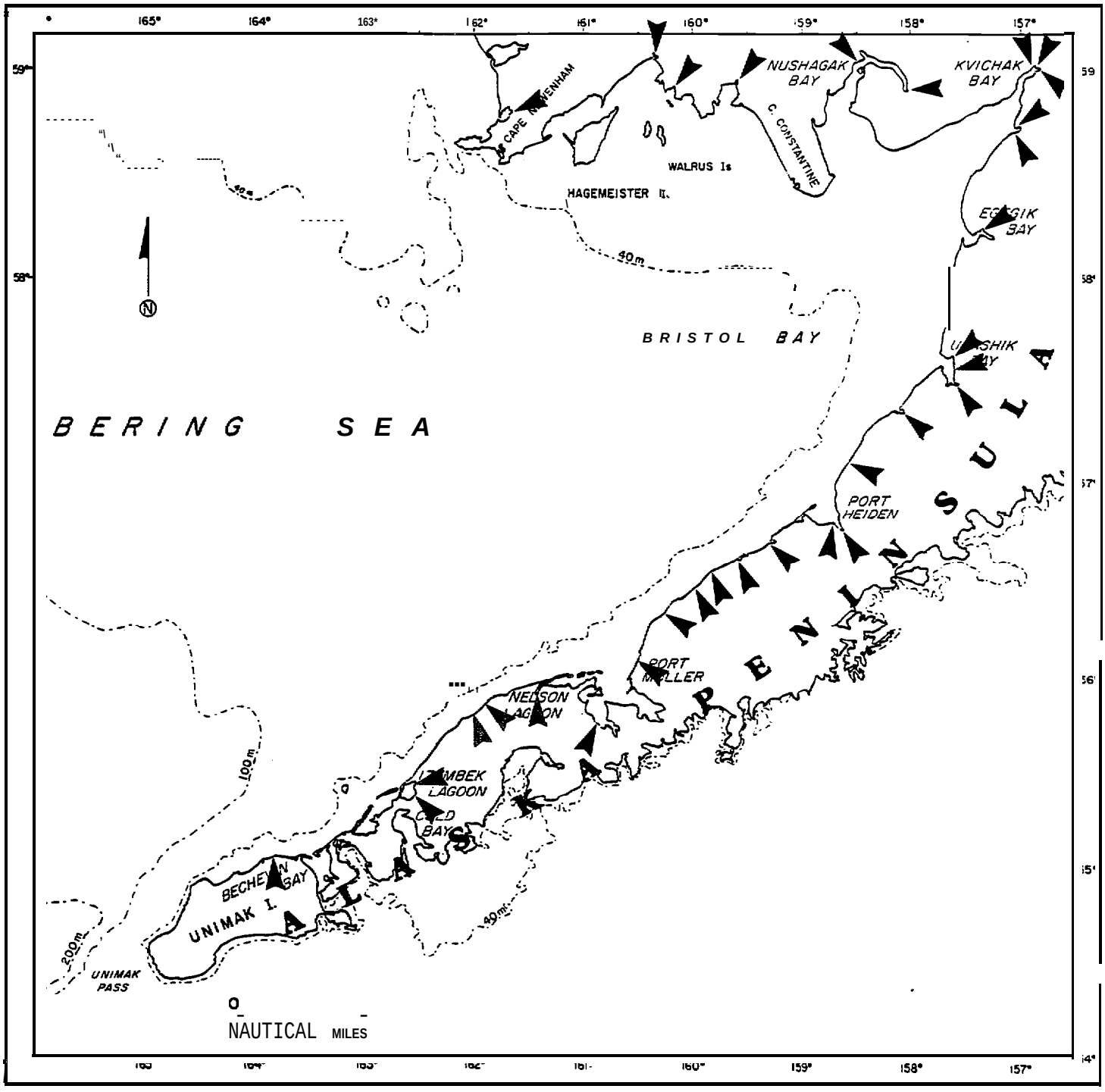


Figure 81. Locations of juvenile sockeye salmon entry into nearshore waters of the St. George Basin region (Stern et al, 1976).

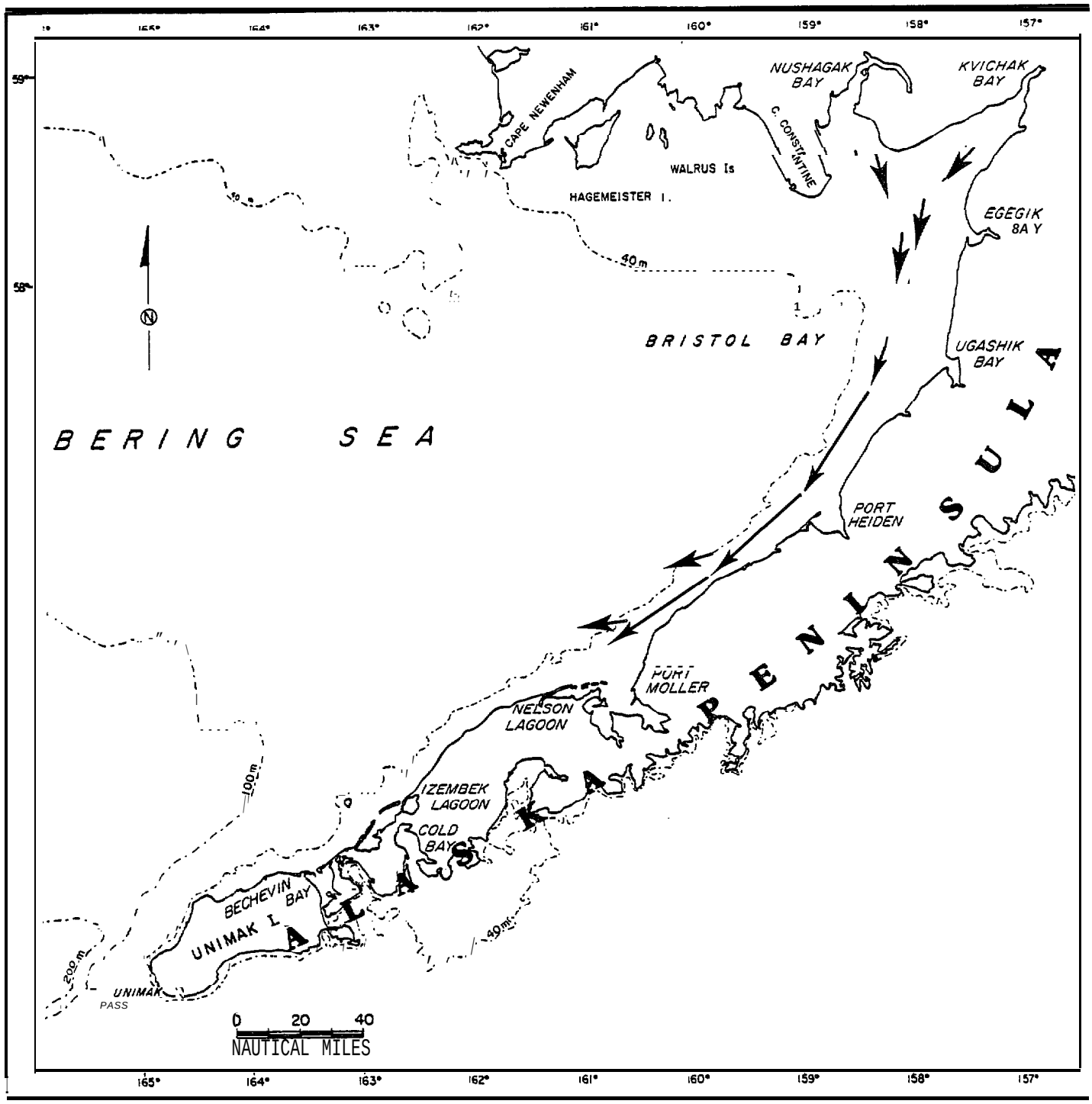


Figure 82. The migration route of juvenile salmon in coastal waters of the St. George Basin region as determined by experimental fishing (Stern et al, 1976).

Table 13. Summary of general l fe history features of salmonids i Alaska

es	Fresh-water habitat	Duration of time in freshwater as juvenile	Duration of time in marine habitat (years)	Year of life at spawning	Average weight (pounds	Average fecundity (eggs)
Pink	Short coastal str am	Less than one day	2	2	4.0	2,000
Chum	Shor coastal streams and major rivers	Less than one month	2-6	3-7	8.0	3.00
Sockeye	Short streams and lakes	2-36 months	1-4	3-8	6.	3.5
Coho	Short coastal streams, lakes and tributaries of major rivers	12-24 months	0-2	2-4	9.	3.5
Chinook	Major rivers	3-12 months	1-6	2-8	20.0	4.0
Sea-run cutthroat	Short coastal streams	12- 4 months	1-3	2-1	2.5	8
Steelhead	Short and long streams	months	-5	2-7	8.	8.
Pacific char	Shor streams	36-48 months	2-3	5-	2.	2.00

Sources: Sterns et al,(1976),p 3.

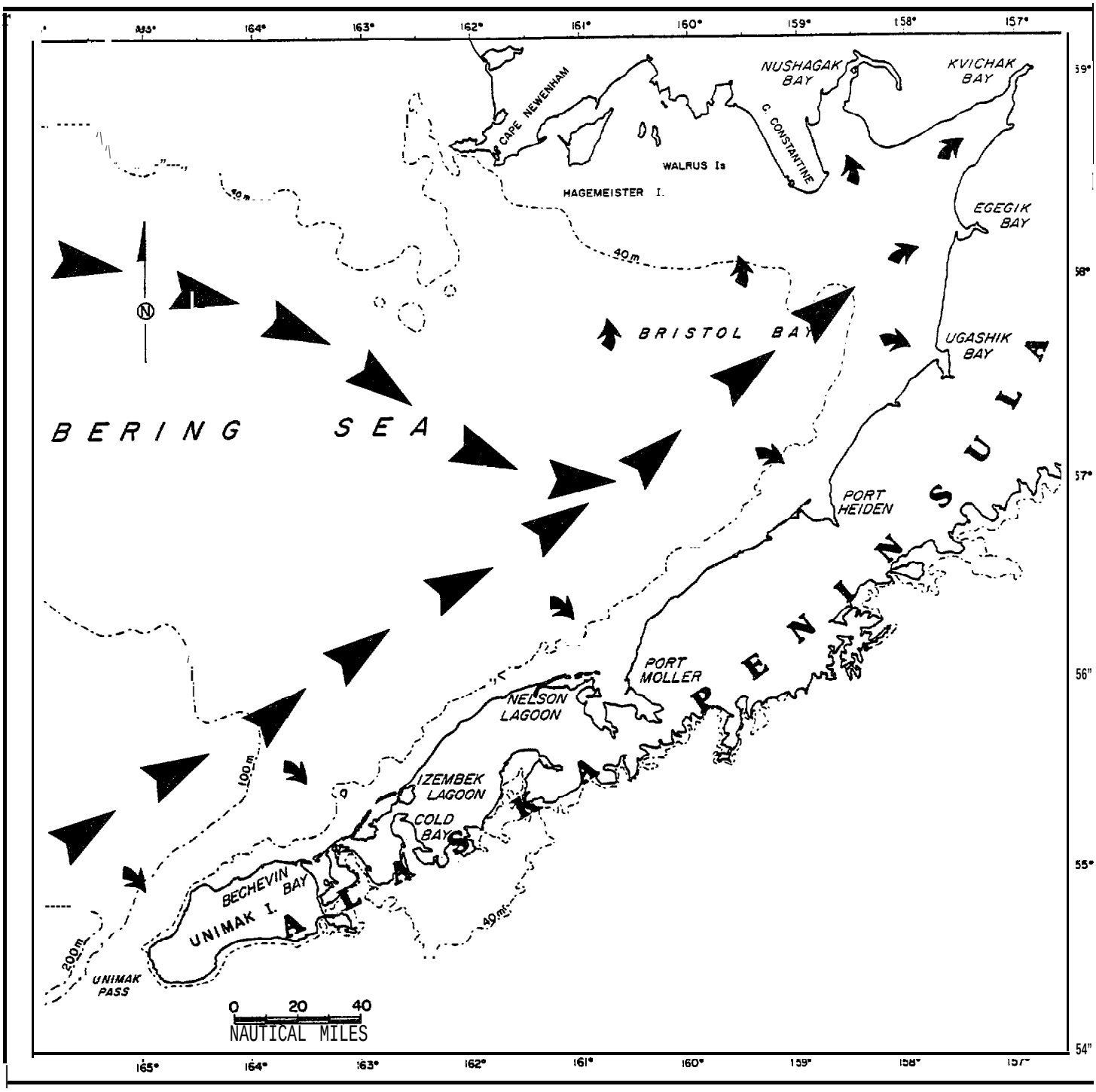


Figure 83. Migrat ion routes of sockeye salmon bound for spawning grounds in northern Alaska (Stern et al, 1976).

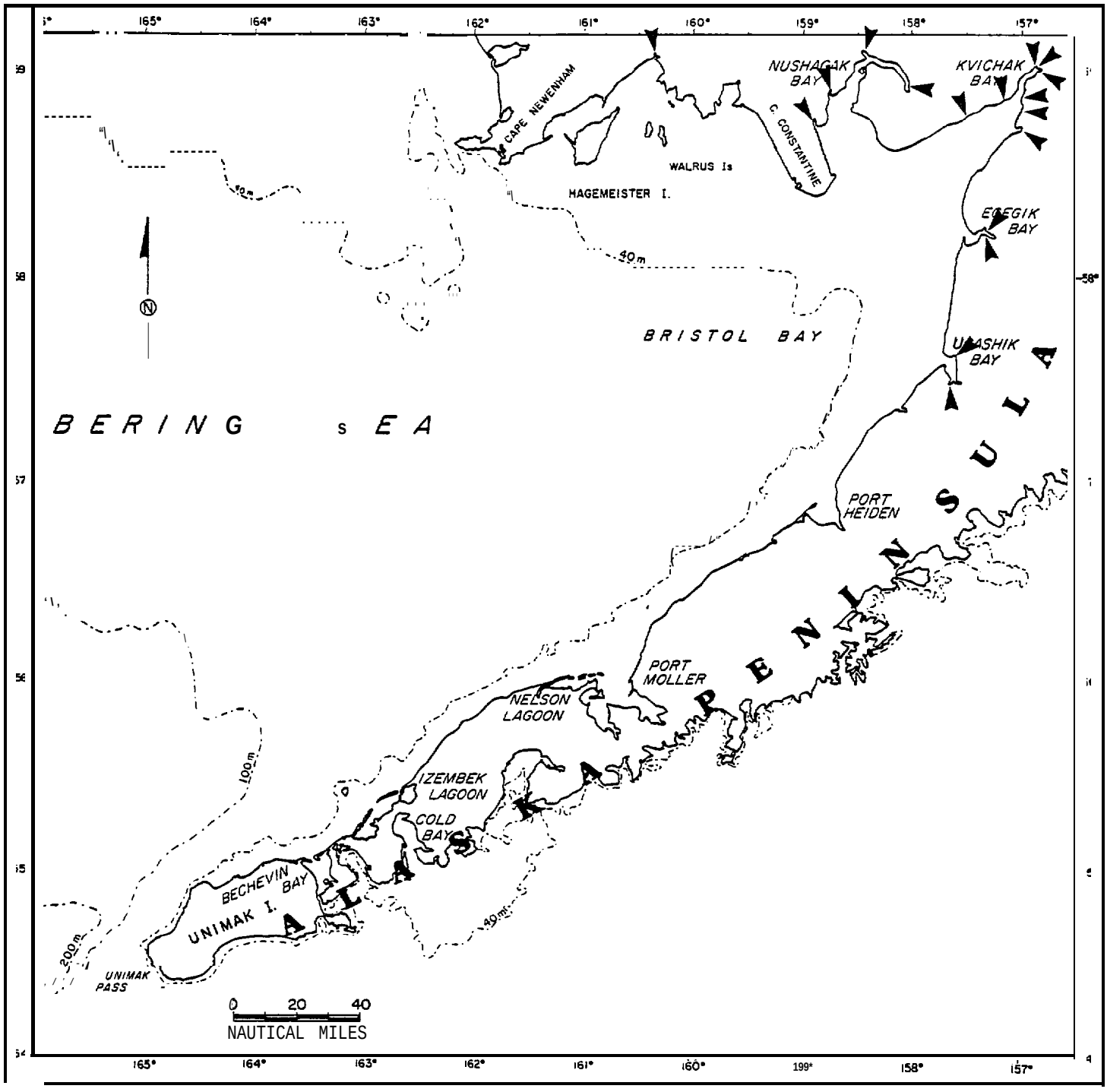


Figure 84. Locations of juvenile pink salmon entry into nearshore waters of the St. George Basin region (Stern et al, 1976).

Figure 85. Locations of juvenile coho salmon entry into nearshore waters of the St. George Basin region (Stern et al, 1976).

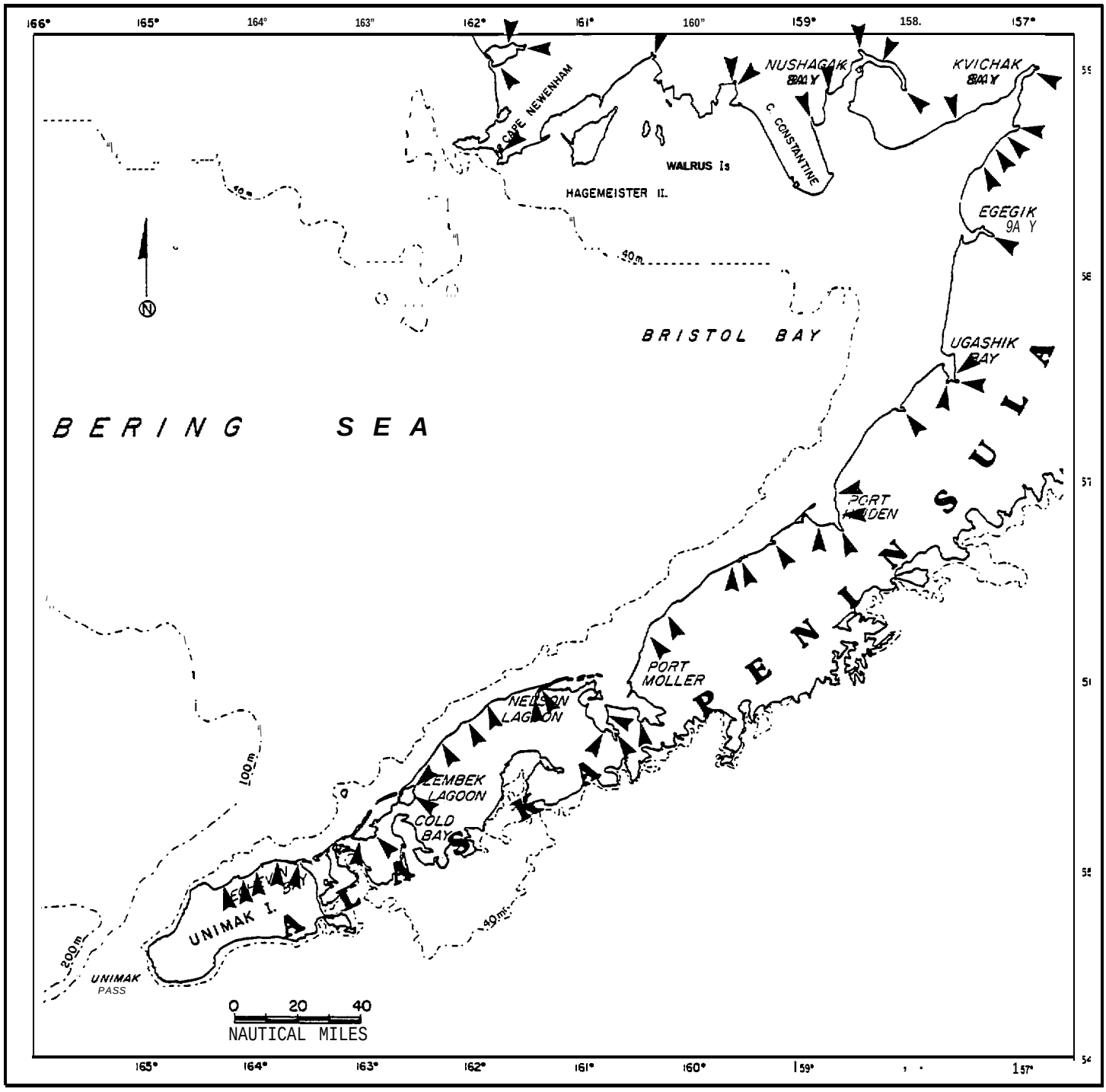


Figure 86. Locations of juvenile chum salmon entry into nearshore waters of the St. George Basin region (Stern et al, 1976).

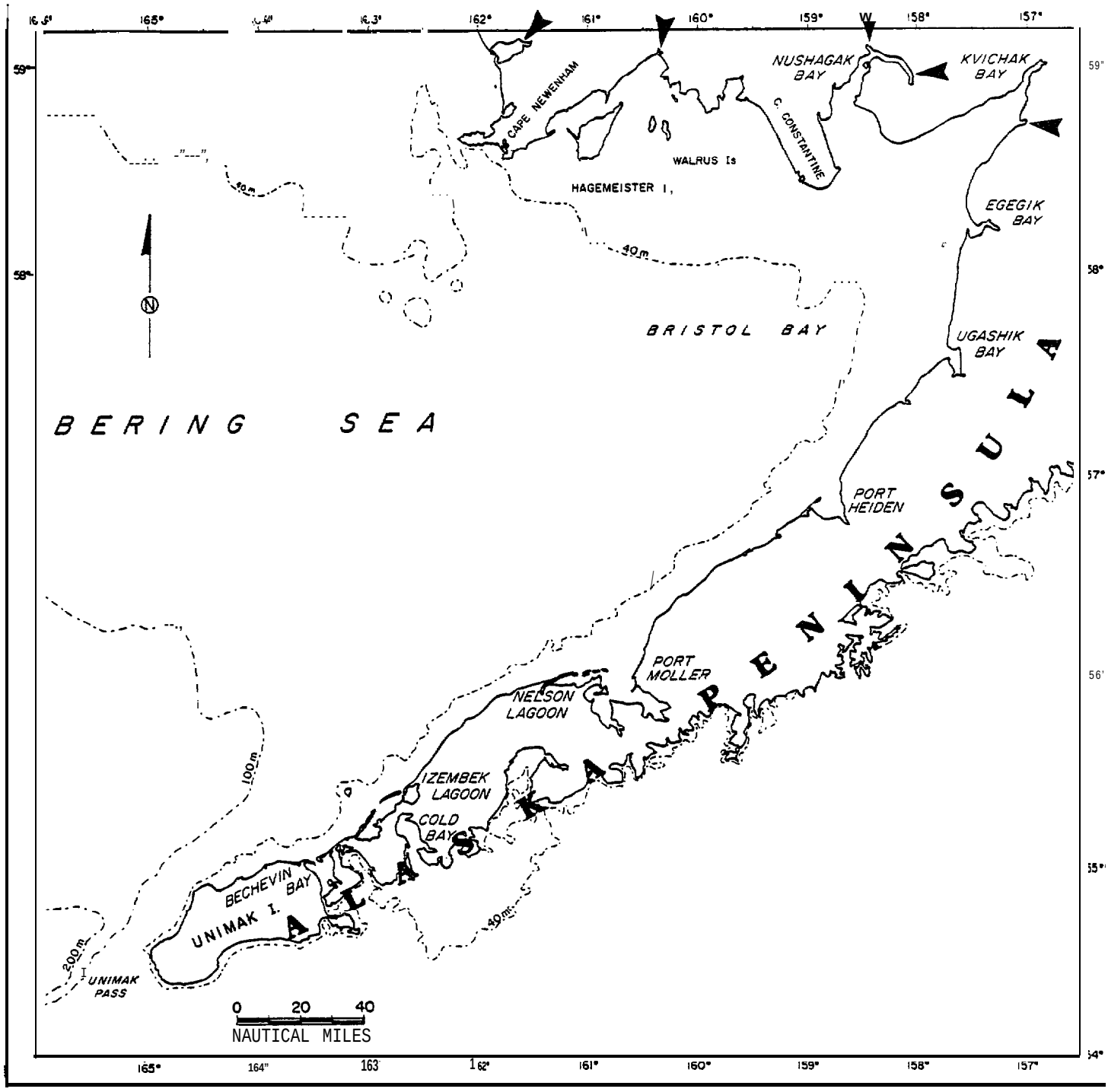


Figure 87. Locations of juvenile chinook salmon entry into nearshore waters of the St. George Basin region (Stern et al, 1976).

entering Bristol Bay waters from late June through mid-August (Thor stein son and Thorste inson, 1983). Chinook smelt, on the other hand, outmig rate earlier than sockeye, probably during May and early June. It also seems likely, from experimental fishing results (Thorsteinson and Thorsteinson, 1983), that chinook juveniles move offshore faster than other species and vacate the Bristol Bay-Aleutian Shelf area earlier.

Coho are probably the last species of salmon to outmigrate into Bristol Bay. Although they are recorded from the bay as early as mid-June, they do not become abundant in the nearshore waters until late June or early July and remain throughout August or even September (Thorsteinson and Thorsteinson, 1983).

In the case of returning adult salmon, chinook enter the Bristol Bay region earliest, followed by sockeye, summer chum, pink, fall chum, and finally coho. Adults seem to migrate in a belt extending 162 km offshore along the southeastern Bering Sea coast (Thorsteinson and Thorsteinson, 1983). Chinook begin entering the area in mid-to late May, with coho arriving last in mid-to late July.

Boreal Smelt

In addition to the various salmon species, large numbers of boreal (rainbow) smelt spawn in the rivers of inner Bristol Bay. Smelt seem to prefer rivers with large estuary systems, and probably do not venture far from these estuaries (Warner and Shafford, 1981). In the Port Heiden area they are considered to be the most common forage fish (smelt, herring, capelin, eulachon), and, though not fished commercially, are important for subsistence use by local residents (Barton et al, 1977).

Smelt normally spawn when two or three years old, and may spawn for several consecutive years. In most regions they overwinter upstream and spawn in tributaries soon after breakup, then migrate down to the estuaries to feed until autumn (Warner and Shafford, 1981). There are some indications, however, that in the Port Heiden area smelt remain year-round in the estuary, moving upstream to spawn during the day and back into the estuary at night (Barton et al, 1977).

Avifauna. The northern coast of the Alaska Peninsula and Bristol Bay region is recognized as an area of major or critical importance to numerous species of marine birds, waterfowl, and shorebirds. In the case of waterfowl and shorebirds, the region is used primarily for staging and foraging habitat during the spring and fall migrations to and from the nesting areas and, in some cases, as overwintering habitat. The most heavily used habitats for

waterfowl and shorebirds are the lagoons and estuaries along the north coast of the Alaska Peninsula, some of which are considered critical as staging, moulting, and foraging areas. Gill and Handel (1981), consider the northern coast of the Alaska Peninsula to be the most extensive and diverse expanse of intertidal shorebird habitat along the Pacific coast of the Americas.

The region also provides important nesting habitat and summer food resources for very large numbers of seabirds. The primary nesting habitats for seabirds occur in the Cape Newenham and Cape Peirce vicinity, Amak Island, the islands of northern Bristol Bay, and some of the lagoons and promontories of the Alaska Peninsula. Feeding seabirds (especially Shearwaters, kittiwakes, and murres) seem to rely heavily on the nearshore zone (less than 50 meters depth) of Bristol Bay and the Alaska Peninsula-northern Aleutian shelf, and on the oceanic front associated with the shelf break.

Seabirds

Seabirds rely very heavily on the Bristol Bay and Alaska Peninsula area both for feeding and nesting. During the summer, very dense populations of birds, particularly short-tailed shearwaters, common murres, and blacklegged kittiwakes, occupy the shelf and nearshore zone of Bristol Bay and the Alaska Peninsula (Figure 88). The highest concentrations of seabirds are found in Bristol Bay and along the Peninsula from June through October, with high concentrations remaining in the vicinity of Unimak Pass all year (Gould et al, 1982; Lensink and Bartonek, 1976). During summer, the most common birds in the area are short-tailed shearwaters, followed by common murres and black-legged kittiwakes. During fall and winter, common murres are numerically dominant. Northern fulmars and storm petrels are common in Unimak Pass and along the shelf break, but do not appear to frequent the nearshore shelf of Bristol Bay or the Peninsula in large numbers (Hunt et al, 1981c).

The total population of seabirds in the eastern Bering Sea is estimated at over 50 million birds (Hunt et al, 1981c). Estimates of species populations vary considerably. Hunt et al (1981c) estimate the shearwater population of the eastern Bering, during summer, to be at least 9 million birds, and feel that it may average as high as 20 million. Pelagic murre populations on the eastern Bering Shelf (common and thick-billed) are estimated at 5 million during summer and 2.5 million during fall by Hunt et al (1981c), while Sowls et al (1978) estimate a breeding population of 7.3 million. Conversely, Sowls et al (1978) estimate the breeding population of black-legged kittiwakes at 1.1 million, while Hunt et al (1981c) estimate a pelagic population (summer) of 2 to 3 million. Populations of tufted puffins in the eastern Bering Sea in summer are generally

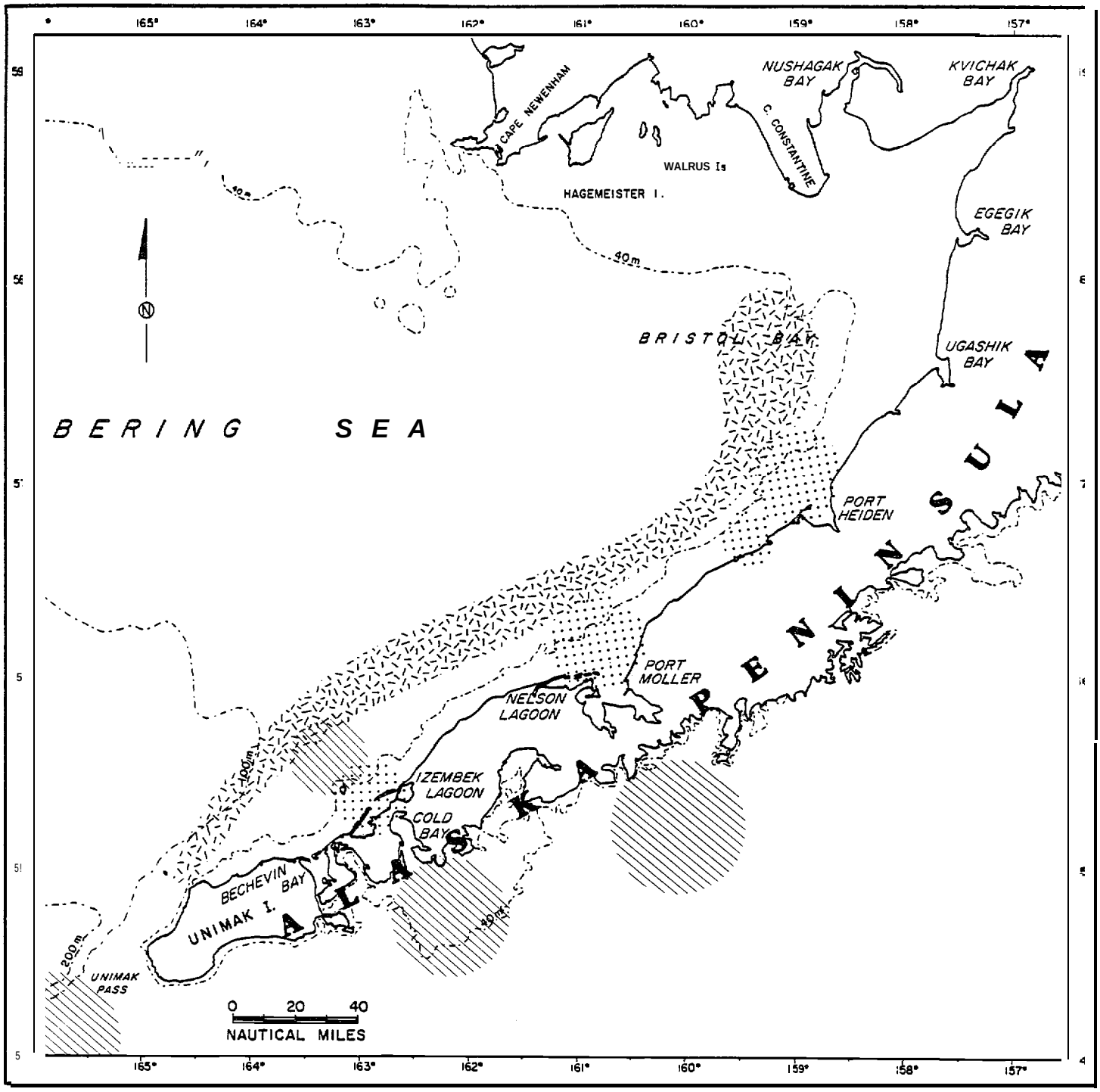


Figure 88. Generalized distribution and location of breeding areas for seabirds, shorebirds, and waterfowl of the North Aleutian Shelf (L.K. Thorsteinson ed, 1983 draft).

estimated to be about 1.5 to 1.7 million birds, horned puffins about 350,000 birds, and glaucous-winged gulls about 250,000 birds (Hunt et al, 1981c; Sowls et al, 1978).

Most breeding populations of seabirds in the Bristol Bay-Alaska Peninsula region are concentrated within large colonies in a few specific locations. This is particularly true of cliff-nesting species such as murres and kittiwakes, which are concentrated primarily on Cape Newenham, Cape Peirce, the islands of northern Bristol Bay, Amak Island, and a few minor locations on Unimak Island and along the Alaska Peninsula coast (Figure 89). It is estimated that at least one million common murres and between 300,000 and 500,000 black-legged kittiwakes, along with lesser numbers of at least eleven other species of seabirds, nest in this region (Sowls et al, 1978; Bartonek and Scaly, 1979). Trapp (1979) ranks the Cape Peirce colony as the eleventh most important seabird colony in the state, while the Walrus Island complex is ranked fifteenth and Amak Island sixteenth in importance. All in all, some 45 species of seabirds use the region for nesting, feeding, or migration (Hunt et al, 1981c).

Though dates are probably variable, most of the cliff-nesting species seem to lay from mid-May to early June, with the young fledging in late August or early September (Petersen and Sigman, 1977). Reproductive success seems strongly dependent on weather, particularly for surface-feeding species such as kittiwakes. Adverse weather during the spring and early summer not only results in destruction of the nests, eggs and young, but can curtail feeding activity to a serious degree (Hunt et al, 1981b; Threlfall et al, 1974).

In addition to cliff-nesting species, large nesting concentrations of glaucous-winged gulls occur in the Port Moller vicinity. Sowls et al (1978") estimate this nesting population at 13,000 to 14,000, one of the largest gull nesting colonies in the eastern Bering Sea.

Though the food preferences of seabirds vary somewhat from area to area, within each given area usually only a few species constitute the vast bulk of prey consumed. In general, fish (especially walleye pollock) form the mainstay of seabird diets (70% total) , followed by euphausiids, squid, amphipods, and other crustaceans. The total consumption by seabirds in the eastern Bering Sea is estimated to be between 550,000 and 1,200,000 metric tons per year, including about one-half as much walleye pollock as are landed each year (in the form of adults) by commercial fisheries (Hunt et al, 1981a). In general, shearwaters seem to prefer euphausiids, followed by amphipods, squid, and fish, while murres feed primarily on fish (especially pollock), supplemented by some euphausiids, amphipods, and squid. Blacklegged kittiwakes are seasonally variable in

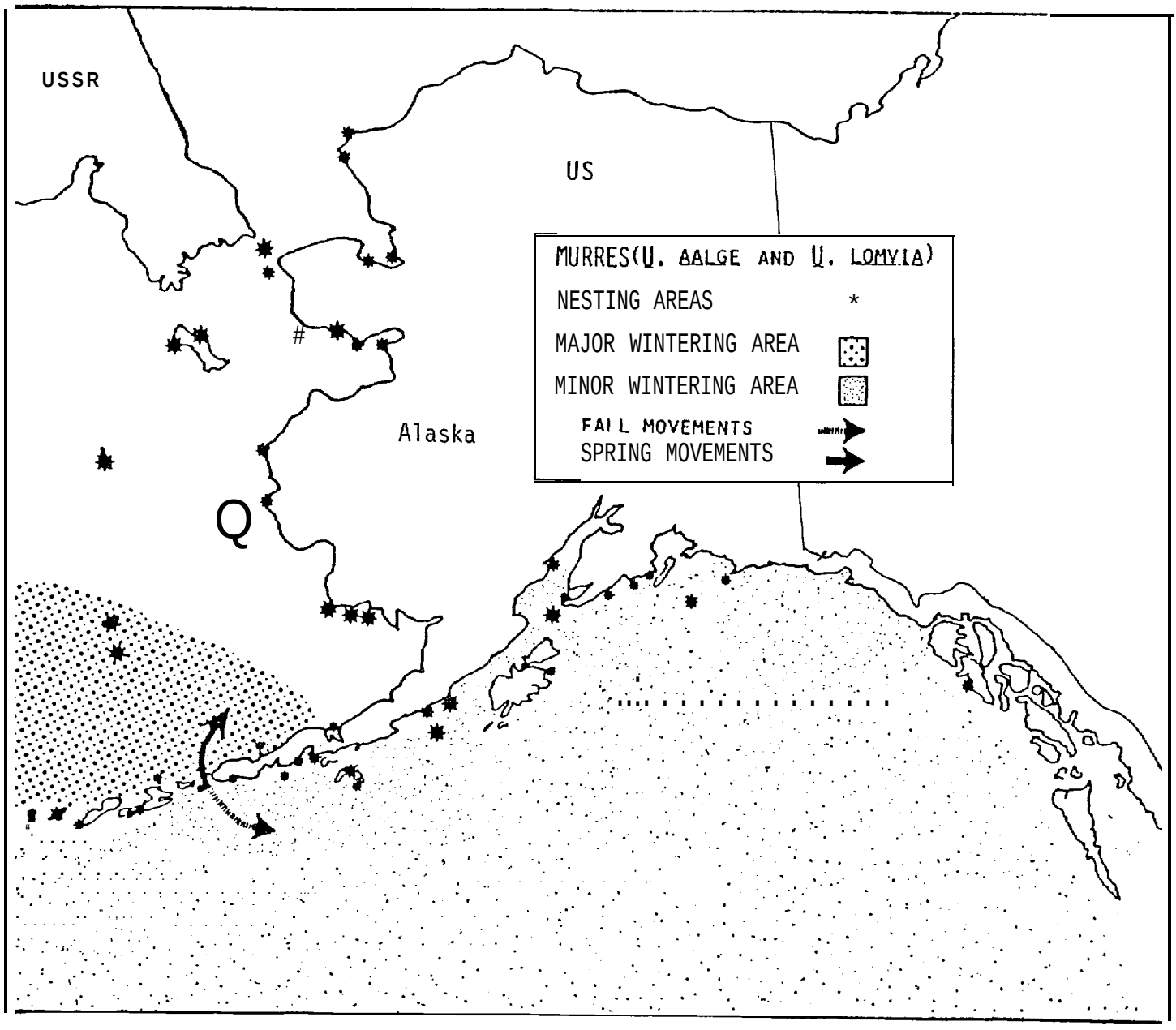


Figure 89. Breeding and winter distribution of murres in Alaska (Gill et al, 1979).

their food preferences, but eat primarily fish (especially pollock), along with some euphausiids and amphipods. Both murres and kittiwakes, and even more particularly arctic terns, are known to feed heavily on juvenile salmon in the region during certain times (Hunt et al, 1981a; Flock, 1932).

Populations of seabirds within this region, particularly cliff-nesting species, are probably limited either by habitat availability, by food resources, or by both (Hunt et al, 1981a). It seems that productivity levels and stability within colonies is dependent primarily on the availability, stability, and diversity of food resources. These factors are, in turn, dependent to a large deqree on weather and oceanic conditions. For instance, in April of 1970 a massive die-off of common murres was observed along the coast of the Alaska Peninsula and Unimak Island. First attributed to an unreported oil spill, the mass mortality was later assigned to starvation resulting from adverse weather conditions (Bailey and Davenport/ 1972). Surface feeders, such as kittiwakes, fulmars, and petrels, are probably more subject to feeding limitations caused by adverse weather and are thus more prone to reproductive failure than are subsurface feeders such as murres, auklets, puffins, and shearwaters.

In general, seabird distributions within the region are the result of complex interactions between biotic and abiotic factors, including extent and duration of ice cover, oceanographic frontal systems, regional weather. patterns, availability of nesting habitat, and food availability.

Shorebirds

The intertidal zone of the Alaska Peninsula and Bristol Bay is used to varying degrees by shorebirds as foraging habitat on the spring migration when en route to summer nesting grounds, as post-nesting feeding grounds, and as staging grounds during the fall migration. In most cases, however, use by shorebirds of this region is less intense in terms of both numbers and duration of occupancy during the spring migration than later in the season, after nesting is completed (Gill and Handel, 1981). Species most commonly encountered in this region during the spring migration are rock sandpipers, bar-tailed godwits, red knots, American golden plovers, and black-bellied plovers (Gill and Jorgensen, 1979; Gill and Handel, 1981; Gill et al, 1981; Figure 90). Upon completion of this brief spring migration period (mid-April to late May for most species), shorebirds generally move onto the inland breeding grounds and do not return to intertidal areas until after nesting is over.

The coastal fringe of the southeastern Bering Sea is an important nesting habitat for at least eight species of

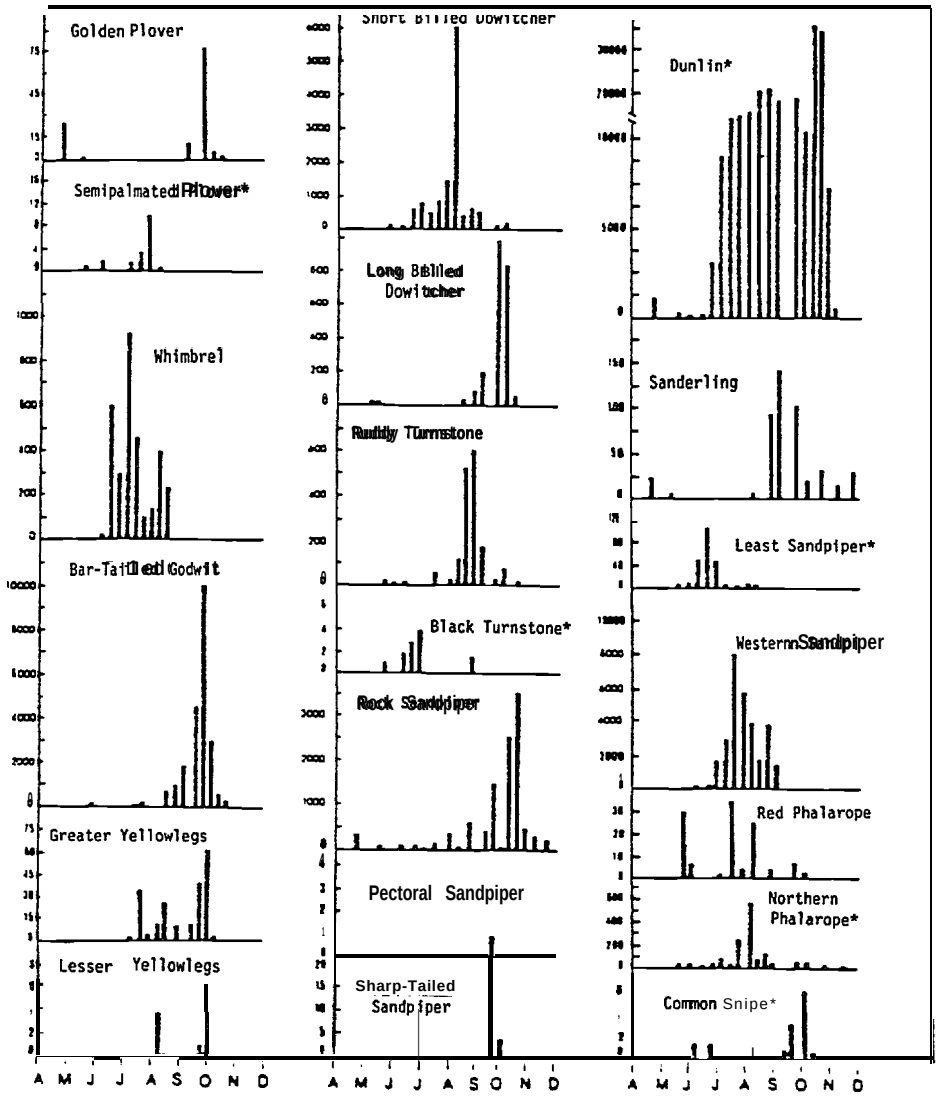


Figure 90. Comparative temporal abundance of 20 shorebird species at Nelson Lagoon, 22 April - 1 December 1976. Species histograms incorporate aerial as well as ground census data obtained prior to migratory buildups beginning in late June. Numbers prior to 1 July do not necessarily reflect overall shorebird use of the study area but do accurately reflect timing of migratory buildups. Species noted by an asterisk nested on the study area (Gill and Jorgensen, 1979).

shorebirds: semi-palmated plover, black turnstone, long and short-billed dowitcher, red and northern phalarope, semi-palmated sandpiper, and dunlin. The principal nesting grounds, in terms of numbers of birds, is the Yukon Delta, though some nesting occurs throughout the Bristol Bay and Alaska Peninsula region as well (Gill and Handel, 1981).

Upon completion of nesting, shorebirds generally move back into the intertidal foraging habitats. Again, the Yukon-Kuskokwim Delta is probably the most heavily occupied area, though the bays and estuaries of the Alaska Peninsula also support sizeable shorebird post-nesting populations (Gill and Handel, 1981). On the other hand, for reasons unknown, the extensive intertidal zones of northern Bristol Bay are used only slightly.

The post-breeding and fall migration occupancy by shorebirds of the intertidal zone of the region is much more intense and protracted than that occurring in the spring, often lasting from late June through September for many species. There is a major buildup of western sandpipers along the Alaska Peninsula coast in July and August, followed in September by an even larger buildup of dunlins. Some species, including dunlin, often remain in the area until mid-or even late October (Gill and Handel, 1981).

Some 30 species of shorebirds are known to occupy the area seasonally (Gill and Handel, 1981). Studies by Gill and Jorgensen (1979) indicate that about 326,000 shorebirds occupy the Nelson Lagoon area between July and December, of which roughly 80% (260,000) are dunlin. Other species of importance using this Nelson Lagoon area are western sandpiper (36,000), bar-tailed godwit (13,000), and short-billed dowitcher (8,600).

Other than Nelson Lagoon, the most important areas in the Bristol Bay-Alaska Peninsula region for shorebird habitat are Bechevin Bay, Izembek Lagoon, and Port Heiden. The Nelson Lagoon-Herendeen Bay-Port Moller complex is estimated to contain 44% (540 km^2) of the total estuarine habitat of the region (Gill and Jorgensen, 1979).

Unlike most marine birds, shorebirds generally do not follow along the coast and through Unimak Pass on their migrations to and from the region, but instead cross the Alaska Peninsula (Gill and Jorgensen, 1979).

Waterfowl

Some 33 species of waterfowl are known to frequent the Bristol Bay-Alaska Peninsula region. Seventeen of these are considered to be non-breeders in this area, another 16 are known or probable breeders (Gill et al, 1981). In general, however, most use of the region by waterfowl is for staging, moulting, and foraging during spring and fall migrations, and for wintering areas (King and Dau, 1981).

Principal habitats used for staging and foraging are, as with shorebirds, the lagoons and estuaries along the north side of the Alaska Peninsula. Waterfowl are most abundant in these lagoons and estuaries from August through October, during the fall migration.

An area of particular importance for this fall staging and migration is Izembek Lagoon, which seasonally supports the entire world's population of black brant (about 150-200,000), as well as large numbers of emperor geese, Steller's eiders, and Canada geese (U.S. Fish and Wildlife Service, 1980).

Most or all of the west-coast populations of several species, including black brant, emperor goose, red-throated loon, king and Steller's eiders, and cackling Canada goose migrate through the region during spring and fall (Petersen and Sigman, 1977; Petersen and Gill, 1982; Petersen, 1983; King and Dau, 1981), as well as large numbers of common eider, black scoter, common goldeneye, harlequin duck, greater scaup, green-winged teal, widgeon, oldsquaw, pintail, and red-breasted merganser (Petersen and Sigman, 1977).

The spring migration, of relatively short duration, normally occurs in April and May for most waterfowl species of the area. Peak concentrations of Steller's eider occur in April at Nelson Lagoon, Izembek Lagoon, and Bechevin Bay (Jones, 1965; Petersen, 1980). At Nelson Lagoon large numbers of king eider, common scoter, and oldsquaw are also present in April, as are black brant at Izembek and emperor geese at Izembek and Bechevin Bay (Jones, 1965; U.S. Fish and Wildlife Service, 1981; Gill et al, 1981). Somewhat further north, in the Cape Peirce area, spring migrations of black brant, emperor geese, and king and Steller's eider occur slightly later, in May and early June (Petersen and Sigman, 1977).

The fall migration, which is more protracted, lasts from August through October in most areas. At Izembek, black brant normally arrive sometime in September or early October, after molting, and remain in the area feeding on eelgrass until late October or early November (Jones, 1970; U*S. Fish and Wildlife Service, 1981). Some 10,000 brant normally overwinter at Izembek (U.S. Fish and Wildlife Service, 1982). At Nelson Lagoon, approximately 53,000 subadult Steller's eiders arrived in early August of 1977, with about the same number of adults arriving in late September (Petersen, 1980). In normal years, Steller's eiders molt in Nelson Lagoon and other lagoons and estuaries of the Alaska Peninsula, departing in October (Petersen, 1980; Jones, 1965), though Jones (1965) reports that in some years the birds do not arrive until after the molt, as late as November. Petersen (1980) reports that at Nelson Lagoon

almost all of the diet of Steller's eiders is made up of 0-1 year class mussels (Mytilus edulis) and amphipods (Anisogammarus pugettensis).

While most waterfowl depart the area in October or November, the open-water areas of Bristol Bay, the Alaska Peninsula coast, and Unimak Island are important wintering habitats for several species, including king and Steller's eider, scoters, scaup, and oldsquaw (Harrison; 1977; Lensink et al, 1976; F.H. Fay, personal communication) . In addition, the primary wintering grounds of the whistling swan in the lease area is on Unimak Island, particularly at Peterson Lagoon and Otter Point (U.S. Fish and Wildlife Service, 1981 and 1982).

In the case of both waterfowl and shorebirds it should be noted that, although virtually all of the lagoons and estuaries of the Alaska Peninsula support considerable numbers of birds during the spring and fall migrations and, in some cases, during the winter months, the habitats, food resources, and consequent avifaunal compositions are quite variable from one locale to another, making extrapolation of findings from area to area difficult to perform with any degree of confidence (Gill et al, 1978).

Marine Mammals. Though some 25 species of marine mammals are known to frequent the southeastern Bering Sea and Bristol Bay region upon occasion (Lowry et al, 1982), less than half this number can be considered major species in terms of abundance or trophic interaction within the nearshore zone. For these species, however, the Bristol Bay and northeastern Aleutian area constitutes important, if not critical, habitat in terms of food resources, hauling and breeding grounds, and migration routes. Species of particular importance or concern within the nearshore zone are harbor seal, Steller sea lion, Pacific walrus, sea otter, aray whale, and belukha whale. The following presentation is a synopsis of available information relating to population size and stability, seasonal and areal distribution, life history, and food preferences of these species. Ranges of marine mammal prey" items and residence times of marine mammals in Bristol Bay are summarized in Figures 91 and 92.

Harbor Seal (Phoca vitulina)

This is certainly the most abundant marine mammal within the nearshore zone of the region, with conservative population estimates of 28,000 to 30,000 animals based on aerial counts at major hauling grounds (Everitt and Krogman, 1979; Everitt and Braham, 1980). There is some feeling that this population may have been significantly underestimated using these methods, and that the actual population could be as high as 60,000 (F.H. Fay, personal communication). If

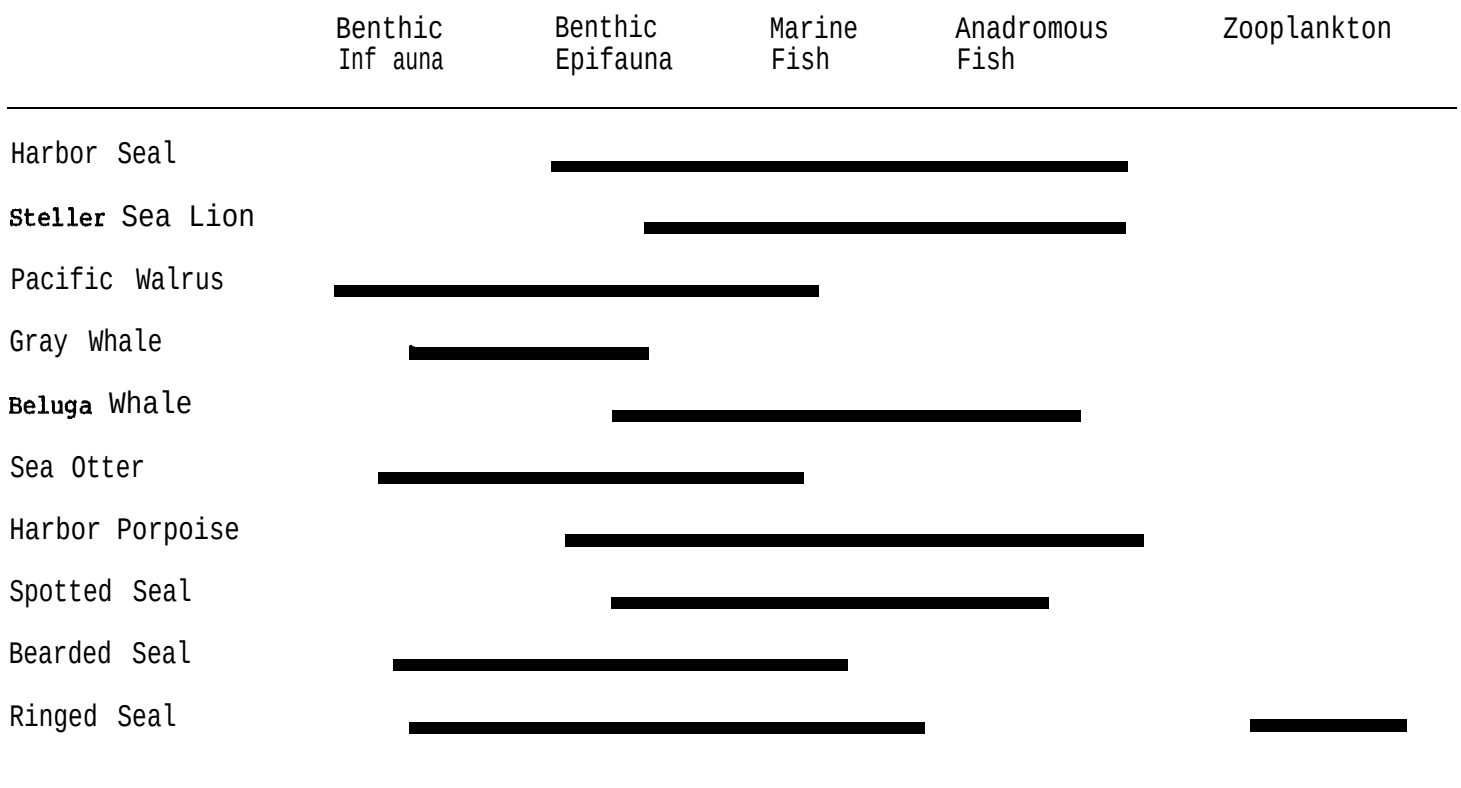


Figure 91 Ranges of prey items consumed by major marine mammal species of the Bristol Bay-northern Aleutian region.

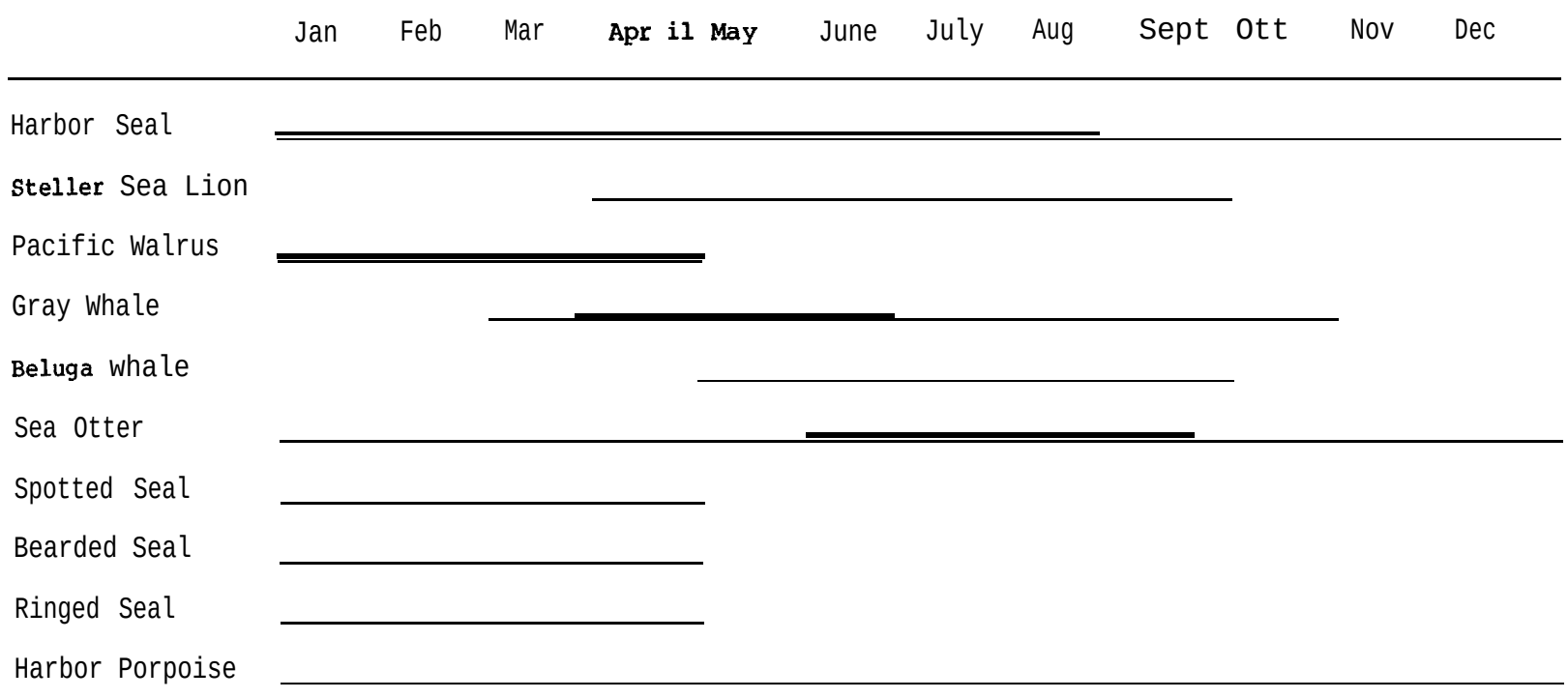


Figure 92 Residence times of major marine mammal species in the Bristol Bay - northern Aleutian area. Double horizontal lines indicate periods of peak populations in normal years.

Table 14. Concentration areas of harbor seals on the north side of the Alaska Peninsula, with highest total sighted at each location by Everitt and Braham (1980) from 1975-77.

Reference no.	Location name	Highest count
1	Egegik Bay	70
2	Ugashik Bay	438
3	Cinder River	4,503
4	North Point Heiden	48
5	Point Heiden	10,548
6	Seal Islands	1,137
7	Cape Seniavin	71
8	Port Moller	7,968
9	Cape Leiskof	199
10	Izembek Lagoon	2,034
11	Izanotski Islands	511
12	Amak Island	61

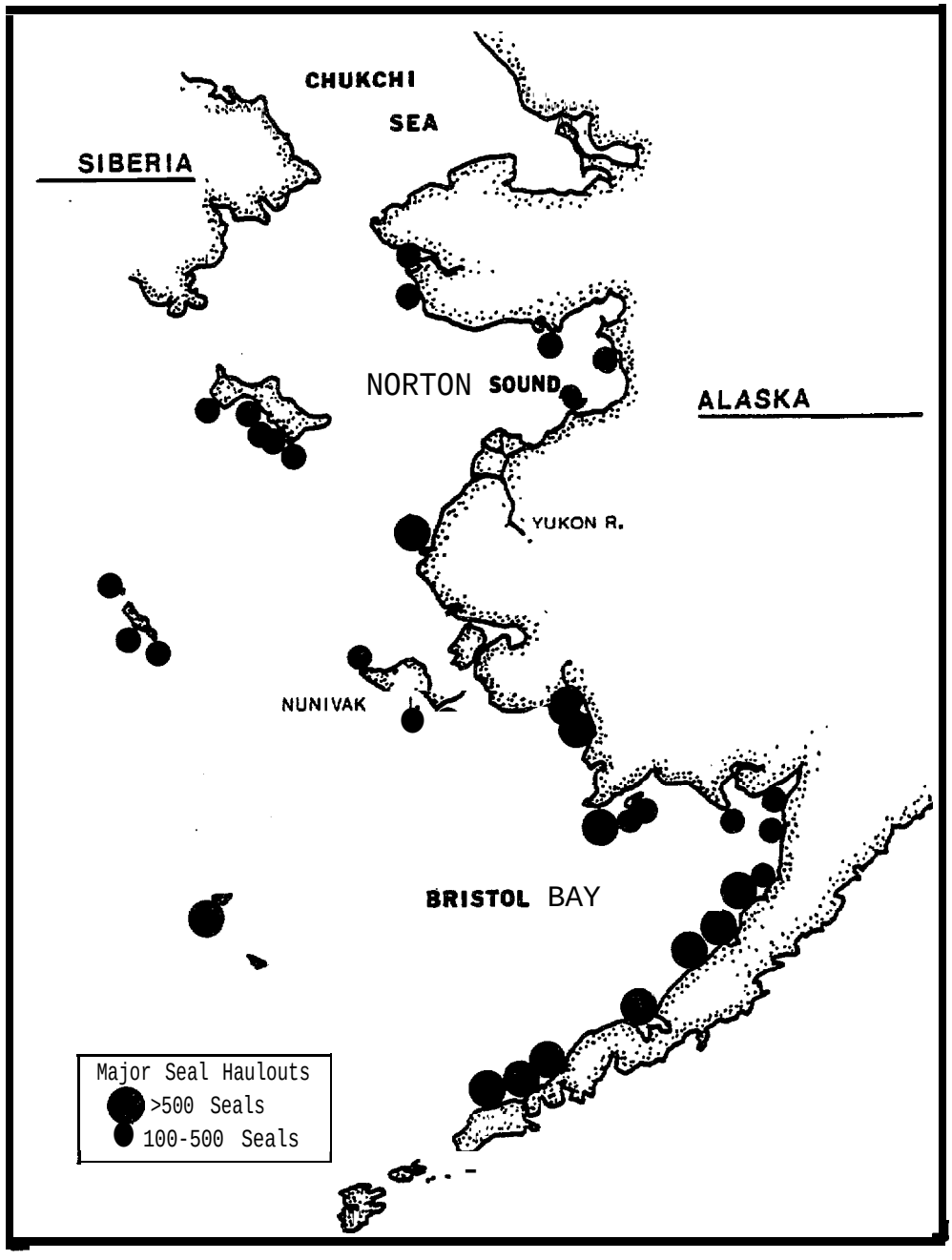


Figure 93. Map of the eastern Bering Sea showing major haulouts used by harbor and spotted seals. Large dots represent areas with maximum reported numbers of greater than 500 seals. Small dots represent haulouts of 100 - 500 seals (Frost et al, 1982).

the lower estimate of 28,000 to 30,000 is adhered to, then this Bristol Bay population of harbor seals constitutes roughly 15 percent of the total estimate for Alaskan waters (Everitt and Braham, 1980). Though little is known about the stability of this Bristol Bay population, there are some indications, again based on counts at the summer hauling grounds, that it may have declined somewhat in recent years (U.S. Fish and Wildlife Service, 1982).

Though harbor seals are ubiquitous throughout the region, approximately 80 percent of the animals counted during aerial surveys were observed at three hauling sites - Port Moller, Port Heiden, and Cinder River (Table 14). Other major hauling sites (Figure 93) along the north side of the Alaska Peninsula are Egegik Bay, Ugashik Bay, Seal Islands, Izembek Lagoon, and Bechevin Bay (Braham et al, 1977; Everitt and Braham, 1980). Though data for winter months are generally lacking, the assumption is that the population disperses somewhat with the onset of winter ice. Some of the animals may shift southward into the Aleutian Islands and even the North Pacific, while others appear to move into the fringe ice where they intermingle with seasonal (winter) populations of the closely related spotted seal (F.H. Fay, personal communication).

Harbor seals Pup on the beaches of Bristol Bay in June and July, and nurse for a period of from 3 to 6 weeks (Lowry et al, 1982). During this period the pups normally double in weight. As described by Johnson (1977), this is a somewhat critical period in that disturbance, particularly from low-flying aircraft, frequently results in separation of mothers and pups and starvation of the latter.

Harbor seals continue to grow rapidly after weaning, though at a reduced rate, until approximately ten years old. Average adult weights at this age are 85 kg for males and 76 kg for females, though body weights vary considerably between individuals and seasons, being generally highest in winter and lowest in summer during lactation and molting. Peak use of hauling areas occurs during pupping and molting in June and July, declining by September and October as seals spend increasing amounts of time feeding at sea.

Though the food of harbor seals is not well documented for the region in question, they are known to be opportunistic feeders on a wide variety of fishes, cephalopods, and crustaceans. Stomach contents of harbor seals collected along the north side of the Alaska Peninsula during October, 1981, indicated sandlance, sculpins, and smelt as major prey items of the 12 seals taken from the Cape Peirce-Port Heiden -Port Moller vicinities. Other items of significance were various flatfishes, pollock, Pacific cod, and greenling (Lowry et al, 1982). Based on dietary studies from adjacent areas, it is likely that they also take, during certain

times of year, herring, capelin, yellow fin sole, salmon, halibut, shrimp, Tanner crab, and king crab. The seasonal migration of herring into the Togiak spawning area may provide the most important source of nutrition to prelactating seals and, therefore, is very important to the well-being of the seal population (Bruce Mate, personal communication). The food intake of harbor seals ranges from 13 percent of total body weight daily during the first year to 3 percent per day at age nine (Ashwell-Erickson et al, 1978).

Steller (Northern) Sea Lion (*Eumetopias jubatus*)

Recent estimates (Braham et al, 1977, 1980; Braham and Rugh, 1978) place the sea lion population of the northeastern Aleutian-Bristol Bay region at between 15,000 and 25,000 animals. About 80 percent frequent rookeries in the Fox Islands, with most of the remainder at Amak Island (Figure 94). Minor, non-breeding rookeries have also been observed on Hagemeister Island, Crooked Island, Cape Newenham, the Twins, and other locations in northern Bristol Bay (U.S. Interagency Task Group, 1976).

It appears (Braham et al, 1980) that the sea lion population of the region may have declined by as much as 50 percent since the late 1950's and early 1960's, for reasons which are as yet undetermined. Possible explanations which have been offered are increased incidence of disease, particularly *Leptospira pomona*, commercial harvesting of pelts from 1970-1972, or decreased food resources and carrying capacity of the area due to commercial fisheries.

Females produce a single pup, born at coastal rookeries between May and early July. Most pups nurse for one year, though some continue to nurse until three years old. Though specific data are not available for this area, it is probable that low-flying aircraft or boat disturbance results in some pup mortality on the rookeries.

Little is known concerning seasonal movements and distributions of this population after they abandon the rookeries in the fall. It appears (Braham et al, 1977) that much of the population vacates the region during the winter months, possibly moving into the central Bering Sea along the edge of the ice front (Lowry et al, 1982).

Though data concerning feeding and food requirements of sea lions in the Bristol Bay region are sparse, studies from other areas indicate that they are broadly opportunistic feeders on many types of finfish, squid, and octopus. In recent years increasing numbers of animals have been observed at non-breeding rookeries in northern Bristol Bay, even though the overall population has apparently continued to decline (Lowry et al, 1982). Though reasons for this

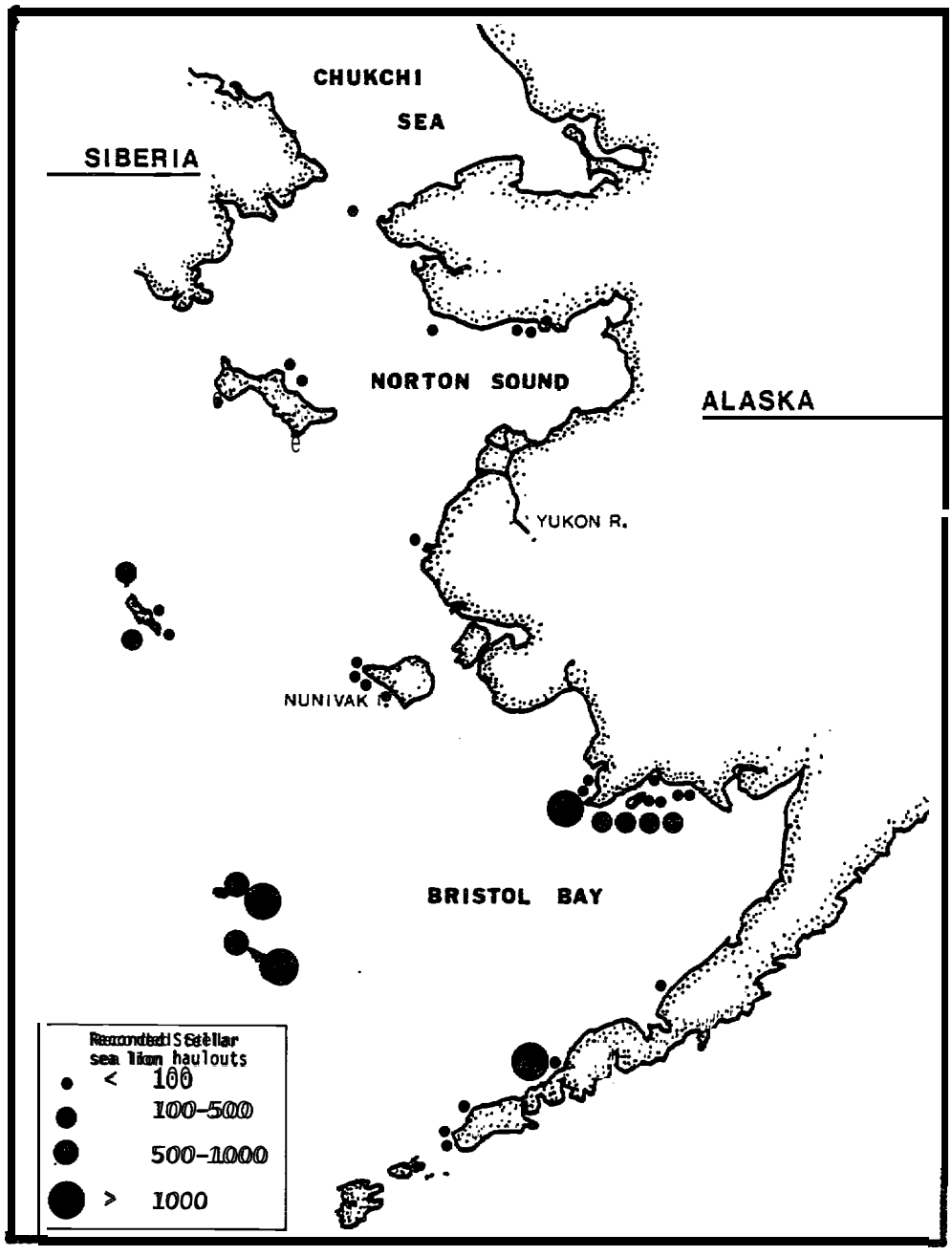


Figure 94. Map of the eastern Bering Sea showing locations where Stellar sea lion haulouts have been recorded (Frost et al, 1982).

trend are unclear, one possible explanation is that, because of reduced fish stocks in the southern areas, increasing numbers are attracted to the large spawning runs of capelin and herring in inner Bristol Bay.

Pacific Walrus (Odobenus rosmarus divergens)

The population of walrus in Bristol Bay, and the distribution of that population, varies seasonally and from year to year in response to winter ice conditions (Fay and Lowry, 1981; Burns et al, 1980). In winters of extensive sea ice, large numbers of animals utilize the area, with correspondingly fewer numbers during winters of light ice. On the average, this winter concentration in northern Bristol Bay constitutes about a quarter of the total Alaskan population, and forms a semi-discrete breeding population (Fay, 1982).

The migratory segment of the Bristol Bay walrus population (primarily cows and calves) moves into the area in late winter with the advance of the seasonal pack ice and remains until spring, when they follow the retreating ice northward. A resident population of between 12,000 and 20,000 animals, all males, normally remains through the summer months. Populations are usually highest from about February or March until the retreat of the pack ice in spring, and are less abundant and more widespread through the summer, fall, and early winter (Fay and Lowry, 1981).

The principal hauling ground for the summer population of males is Round Island, though they also haul on Walrus Island and, irregularly, on Amak Island, Cape Seniavin, Cape Constantine, and Cape Newenham (Figure 95). During the summer months, bulls normally spend one to six days ashore at a time on Round Island, separated by periods of two to eighteen days when they are at sea, presumably on feeding forays (Fay and Lowry, 1981).

The walrus population has increased rapidly during the last several decades, and has more than doubled since 1960. At present this population is estimated to be at least 250,000 animals, and is probably at or near maximum for the carrying capacity (food resources) of the environment. Recent studies (Fay et al, 1977; Fay and Stoker 1982 a and b) indicate that the population may be stressing its food resource, at least in the northern Bering Sea.

Females normally give birth to a single calf every other year. Calves are born from late April until early June on the pack ice during the northward migration. Weighing between 45 and 75 kg at birth, calves triple their weight in the first year, when they are solely dependent on nursing. Females reach their average maximum weight of 880 kg at 12 to 14 years of age, while males continue to grow

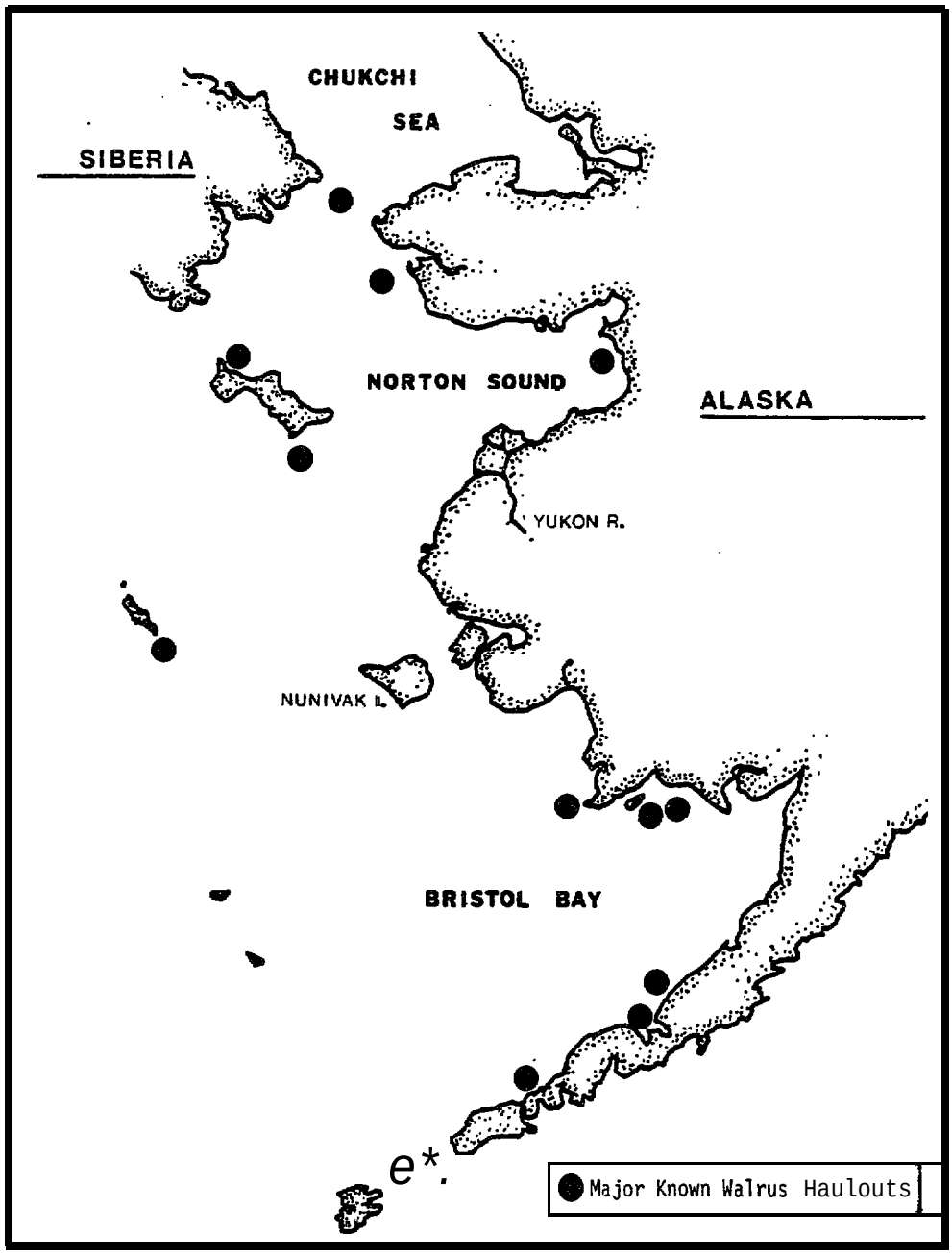


Figure 95. Map of the eastern Bering Sea showing major known haulouts of walruses (Frost et al, 1982).

until at least 16, when they attain an average maximum weight of 1,200 kg (Fay, 1982). In recent years there are indications that the birth rate has dropped somewhat (Fay and Stoker, 1982 a and b), and that the overall population is subject to some degree of physiological stress (reflected in decreased average blubber thickness), with an attendant increase in natural mortality (F. H. Fay, personal communication) .

Walrus feed primarily on benthic infaunal and epifaunal invertebrates, relying heavily on bivalve mollusks for the bulk of their diet (Fay et al, 1977; Fay and Stoker, 1982 a and b). During a recent study (Fay and Lowry, 1981), a total of 22 genera of benthic invertebrates were identified from stomach contents of walrus collected in the Bristol Bay area. More than 90 percent of the stomach content biomass, however, was comprised of five genera of bivalves (Serripes, Tellina, Spisula, Siliqua, Mya). The genera Tellina and Siliqua made up, jointly, 75 percent of the total content. Fay (1982) estimates that, for adult animals, the average daily net food consumption is about 6.2 percent of total body weight, or 16,300 kg per year for the average individual.

Sea Otter (Enhydra lutris)

Though population data on sea otters in the northeastern Aleutian-Bristol Bay area are somewhat sketchy, estimates range from 8,000 to 10,000 animals as of 1976 (Schneider, 1976) to 11,700 to 17,200 at present (Lowry et al, 1982). Apparently the range of the sea otter has expanded in this region over the same time period, indicating that the larger, more recent estimate may reflect a real population increase. The bulk of this population ranges between Cape Mordvinof (Unimak Island) to about Cape Leontvich, with lesser densities extending as far north as Port Heiden (Schneider and Fare, 1975). Results from recent aerial sea otter surveys conducted during 1982-83 in this region indicate that their abundances underwent significant seasonal and spatial changes (VTN Oregon, 1983e). Summer abundances were found to be over seven times greater than. were winter abundances. (Otters were also significantly more abundant in the Unimak and Izembek areas than in the Black Hills - Port Moller area)." During years of extensive sea ice this population shifts southward, and sometimes suffers significant mortality as the result of a rapid onset of winter ice.

Sea otters are voracious predators consuming between 20 and 25 percent of their body weight daily (Estes and Palmisano, 1974; Schneider, 1976). For juveniles, requirements are probably higher, ranging between 25 and 30 percent body weight per day. This equates, on the average, to between 3 and 5 kg per otter per day.

Though sea urchins seem to be preferred prey when available (Kenyon, 1969), otters will consume practically any available invertebrate species, including sea stars, and will prey upon slow-moving fish when the choicer invertebrate species are depleted (Lowry et al, 1982). In rocky intertidal and shallow subtidal areas, otter predation on invertebrate grazers results in significantly altered habitat characteristics and community structure, with greatly increased standing stocks of macrophytes (Estes and Palmisano, 1974). The small amount of data (9 scat samples taken from a single location over a two day period) available regarding sea otter feeding habits in the Bristol Bay Region indicates that yellowfin sole and rock sole may be important prey species (VTN Oregon, 1983d,e). These analyses also suggested reliance upon bivalve mollusks, gastropod mollusks, and various species of crabs.

In the Bristol Bay region, otters commonly occur in large pods, sometimes in excess of 1,000 animals per pod. They have been observed feeding in depths down to 60 meters and range as far as 30 miles offshore (Schneider, 1976), though such extremes are probably uncommon.

Though otters can and do breed and give birth at almost any season over most of their range (Kenyon, 1969), in the Aleutian and Bristol Bay area mating seems to normally occur in the fall (September-October), with birth of a single pup in the spring (Lowry et al, 1982). Pups are tended by their mothers for one year, with a pup born, on the average, every other year in the Aleutian area. Newborn pups weigh about 1.75 kg (average). Average adult weights are 28.3 kg for males and 21 .1 kg for females in the Amchitka vicinity (Kenyon, 1969).

From available information relating to habitat requirements and food resources, it seems probable that the otter population of the proximal Aleutian Island-Bristol Bay region is near maximal for the carrying capacity of the environment. During years of extensive sea ice, substantial sea otter mortality due to malnutrition has been documented for Bristol Bay (Schneider and Fare, 1975).

Gray Whale (Eschrichtius robustus)

The present population of gray whales is estimated to be at least 15,000 (Rugh and Braham, 1979; Lowry et al, 1982), almost all of which migrate seasonally into and from the Bering Sea via Unimak Pass,

The spring migration into the feeding grounds of the Bering and Chukchi Seas passes through Unimak from March until June, follows around Bristol Bay to the Nunivak Island vicinity (Figure 96) and from there across the northern Bering Sea past St. Lawrence Island and through the Bering Strait into the Chukchi Sea. Some animals make this entire journey, continuing to the northern limits of the Chukchi

Sea and even, rarely, venturing into the Beau fort Sea; others drop out along the way to spend the summer feeding on the benthos of the northern Bering and southern Chukchi Seas. Recent sightings indicate that this spring migration stays well inshore during its swing around Bristol Bay, and that some animals probably remain in Bristol Bay throughout the summer (Braham et al, 1977; Alaska Department of Fish and Game, unpublished observations). Gray whales have been reported in Nelson Lagoon from late April until late November (Gill and Hall, 1983), and are most numerous in August and September. As many as 8-10 whales have been observed at one time feeding in Nelson Lagoon, as evidenced by mud trails (R. Gill, personal communication).

The entire population migrates southward again in advance of the formation of seasonal sea ice, moves through Unimak Pass from late October until early January, and makes its way from there down the Pacific Coast to wintering grounds in Baja California.

Gray whales breed in the sheltered, shallow lagoons of Baja California from mid-November through early January, with a 13-month gestation period. Females give birth, on the average, every two years (Rice and Wolman, 1971). Calves average about 4.75 meters in length at birth, grow to seven to eight meters by weaning (August of the same year), and are a little over nine meters in length by the time of their first return migration from the Bering/Chukchi in early winter (Rice and Wolman, 1971). After this initially rapid growth, development slows as the average adult length of twelve meters is approached. Adult gray whales weigh as much as 34,000 kg (Lowry et al, 1982).

Gray whales are benthic feeders on epifauna and shallow infauna. The mainstay of their diet, in the northern Bering and southern Chukchi Seas at least, consists primarily of gammarid amphipods of the genera Ampelisca, Lembos, Anonyx, and Pontoporeia. Daily consumption, based on field observations, is estimated at 1,200 kg per animal per day (Lowry et al, 1982). Though grays do feed to some extent in their breeding and calving grounds in Baja California and along the Pacific coast and North Aleutian Shelf migration routes, the bulk of their energy requirements are apparently obtained and stored, as fat reserves, during their summer feeding migrations into the Bering and Chukchi Seas.

Though no firm estimates are available as to the number of gray whales which existed prior to commercial exploitation in the 19th century, the present population is probably approaching pre-exploitation levels, is increasing slowly, and may be near maximal for the carrying capacity of its food resource in the Bering and Chukchi Seas.

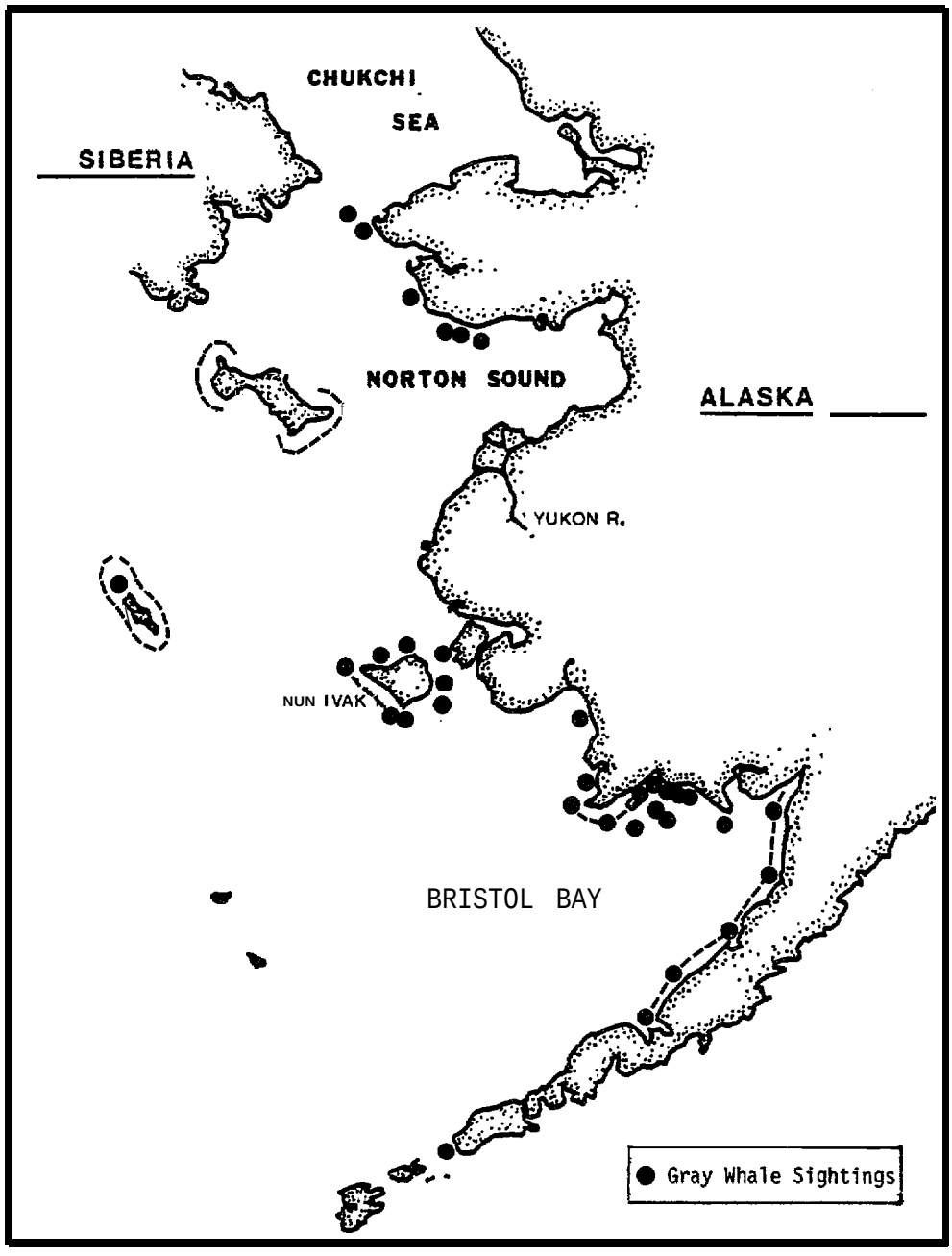


Figure 96. Map of the eastern Bering Sea showing locations where gray whales have been sighted (Frost et al, 1982).

Beluga Whale (Delphinapterus leucus)

Though the population of belugas in Bristol Bay is seasonally and, probably, annually variable, most authorities agree on average estimates of 1,000 to 1,500 animals (Brooks, 1955; Alaska Department of Fish and Game, unpublished data). Most of these are concentrated, during summer, in upper Bristol Bay near the Nushagak and Kvichak River mouths (Figure 97). This population represents almost ten percent of the total Bering/ Chukchi/Beaufort beluga population (estimated at 15,000 to 18,000), and may. or may not be a genetically discrete subpopulation (F.H. Fay, personal communication) . Both the general Bering/Chukchi/Beaufort and the Bristol Bay beluga populations appear to be stable at present.

Most beluga calves are born in July or early August, and nurse for a period of two years (Lowry et al, 1982). Females generally produce calves every third year. Newborn calves are about 150 cm in length and weigh about 80 kg. Like most marine mammals, they grow very rapidly at first, more than doubling their weight in the first year. By the age of ten they have normally attained physical maturity with an average length for males of 3.2-4.4 m (520-1,200 kg), 3.1-3.6 m (480-700 kg) for females.

Belugas are known to consume a wide variety of fish and invertebrates, though smelt and salmon seem to comprise a major part of their diet in the Bristol Bay region from May through August when they are present in large numbers in the vicinity of Kvichak and Nushagak Bays (Brooks, 1955). During May they apparently feed heavily on outmigrating smelt, shifting to sockeye salmon fingerlings in late May and June when smelt begin their seaward migration. About mid-June, belugas switch from outmigrating fingerling smelts to immigrating adult sockeye salmon enroute to the spawning grounds (Lowry et al, 1982).

During the winter months, the Bristol Bay population of belugas seems to disperse along the edge of the seasonal sea ice, where they probably depend heavily on pollock for their winter fare (Seaman et al, 1982).

Records from six captive belugas indicate a daily consumption rate of between four and seven percent of total body weight per day. If an average body weight of 700 kg is assumed, this equates to between 28 and 49 kg per day.

In addition to the species described above, numerous other marine mammals are seasonal or occasional visitors to the nearshore Bristol Bay and Aleutian region. Prominant among these are spotted seal, bearded seal, ringed seal, and harbor porpoise.

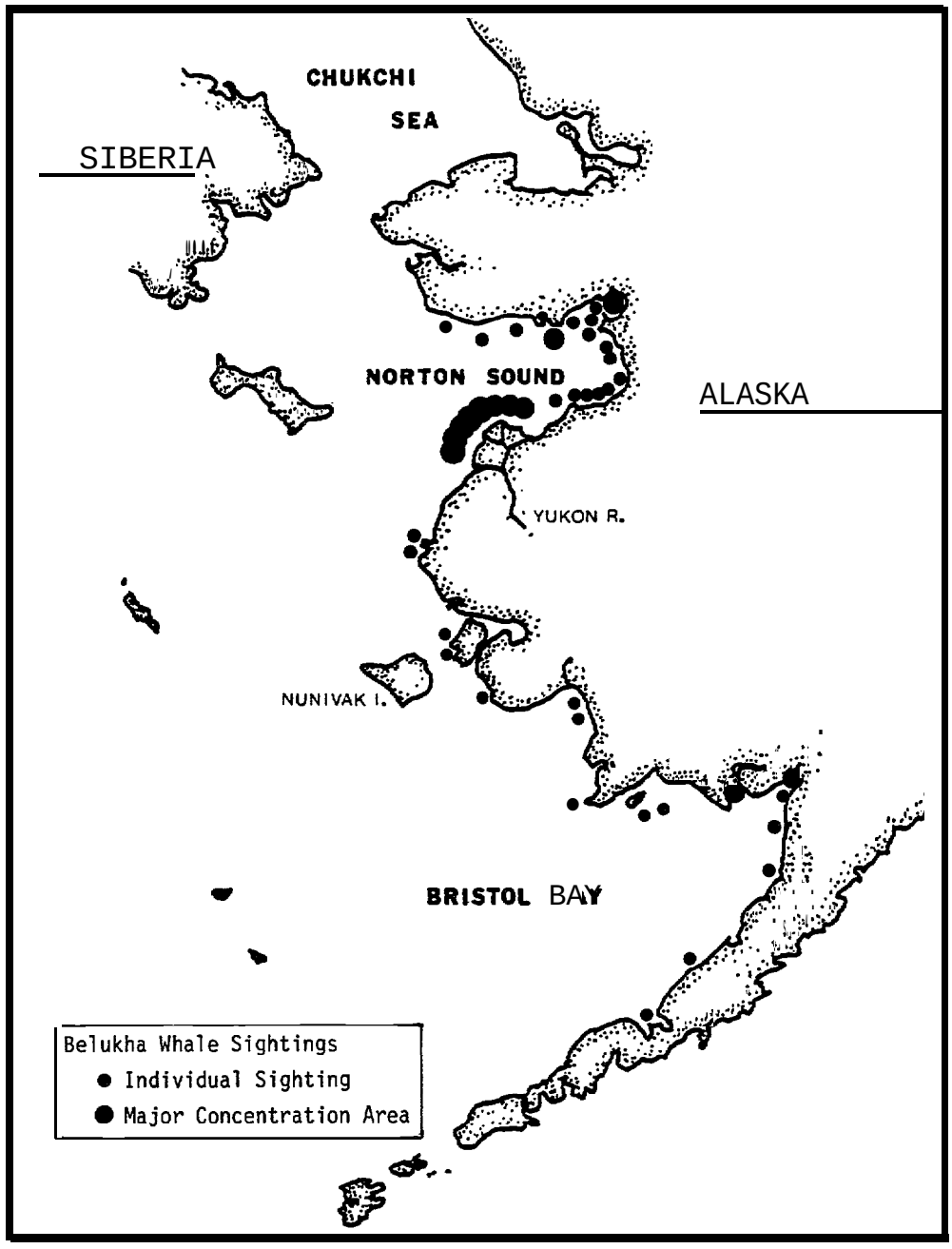


Figure 97. Map of the eastern Bering Sea showing sightings of beluga whales in the coastal zone. Small dots represent individual sightings. Large dots represent major concentration areas (Frost et al, 1982).

Spotted Seal (Phoca largha)

Spotted seals are primarily seasonal visitors to the Bristol Bay area, arriving with the onset of sea ice in late winter and, generally, departing with the retreat of the ice in spring (Burns et al, 1980; Braham et al, 1977). As the winter ice melts and retreats, however, some spotted seals remain. in northern Bristol Bay and assume an ice-free coastal existence for the summer months, mingling with the closely related harbor seals of the area (Lowry et al, 1982). Spotted seals are considered to be one of the most numerous species in the ice front of the Bristol Bay region during late winter and early spring, with populations varying according to ice conditions and extent (Burns et al, 1980; Braham et al, 1977). The total population of spotted seals in the Bering-Chukchi region is estimated at 280-330,000, and is probably stable (Lowry et al, 1982). In years of normal sea ice, spotted seals are pretty much confined to the ice front extending across northern Bristol Bay, and normally occur offshore of the five km nearshore zone (Figure 98).

Females usually give birth to a single pup each spring. Pups are born on the ice, normally in March or April, and nurse for a period of five to six weeks (Lowry et al, 1979). Spotted seal pups weigh 9.5 to 11.8 kg at birth, and by about four years of age have attained their maximum adult weight of 82 to 109 kg (Lowry et al, 1982).

During spring in the southeastern Bering Sea, spotted seals apparently feed heavily on capelin, though numerous other fish species (especially pollock and herring), octopuses, and shrimps are also eaten (Lowry et al, 1982). Ashwell-Erickson and Elsner (1981) estimate that the total spotted seal population of the Bering-Chukchi consumes about 216,700 metric tons of food per year, or about one metric ton per animal per year.

Bearded Seal (Erignathus barbatus)

Bearded seals, like spotted seals, walrus, gray whales, and ringed seals, are seasonal visitors to Bristol Bay, with numbers and distribution dependent on winter ice conditions. In years of extensive sea ice, bearded seals are common and widespread within the ice front of northern and central Bristol Bay; in years of light ice they are uncommon in the area (Burns et al, 1980; Braham et al, 1977; Lowry et al, 1982). When ice is present, bearded seals are more or less uniformly distributed throughout the ice front {Figure 98). The entire Bering-Chukchi population of bearded seals is estimated at about 300,000 (Lowry et al, 1982).

Females normally give birth to a single pup each spring. Pups are born on the ice from late March through

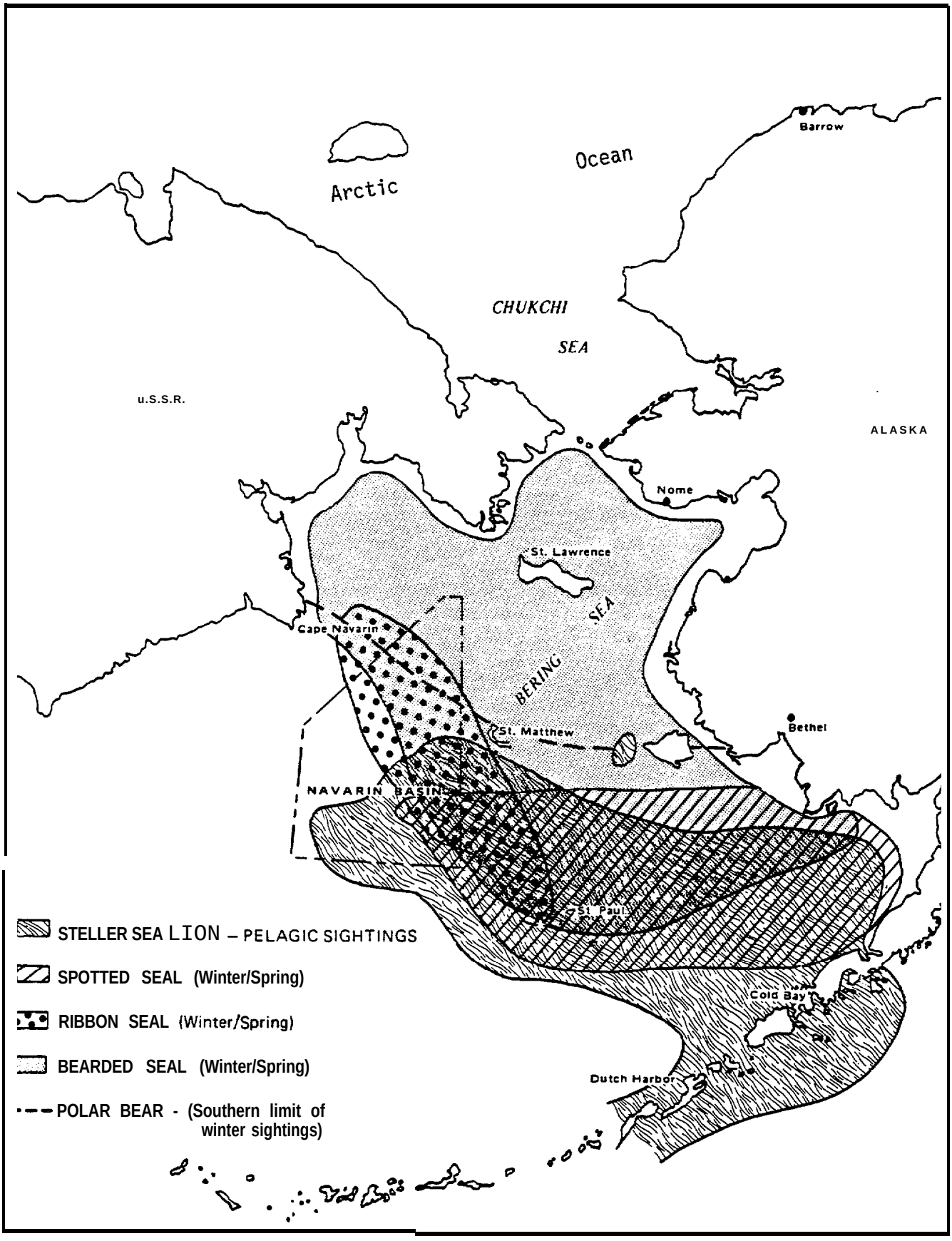


Figure 98. Distribution of breeding ice seals, sea lion pelagic sightings, and southern limit of polar bear sightings (Thorsteinson, 1983) .

early May, with mid-April as the peak period. Pups weigh about 34 kg at birth, and nurse for a period of only 12-18 days by which time their weight has increased to approximately 85 kg (Burns, 1967). By nine years of age they have attained their maximum adult weight of about 248 kg (Lowry et al, 1982).

Bearded seals feed on a wide range of invertebrates and fishes (Kosyqin, 1976; Lowry et al, 1982). Favored foods seem to be brachyuran crabs (Chionoecetes opilio and Hyas spp.), crangonid and pandalid shrimps, bivalve mollusks, octopuses, cod, pollock, sculpins, and various flatfishes. No data are available pertaining to normal energv requirements or intake rates.

Ringed Seal (Pusa hispida)

Like the other ice-inhabiting marine mammals of the Bering-Chukchi, the numbers and distribution of ringed seals in northern Bristol Bay varies from year to year depending on the extent of winter sea ice. In years of extensive sea ice, large numbers have been observed in northern Bristol Bay (F.H. Fay, personal communication), though densities are probably never as high as those encountered further north (Lowry et al, 1982; Burns et al, 1980). Ringed seals are the most numerous marine mammal found in Alaskan waters, with the total population estimated at about 1.5 million. Popov (1976) estimated that about 70-80,000 ringed seals inhabit the Berina Sea during winter.

Ringed seals are the smallest Alaskan phocid with adult weights, attained by about eight to ten years of age, of 48.1 kg for females and 51.6 kg for males. Pups weigh about 4.5 kg at birth and nurse for a period of five to seven weeks. A single pup is normally born to females every year. Females give birth in dens on the shorefast ice, usually in March or early April (Frost and Lowry, 1981).

The diet of adult seals is varied, including crangonid and pandalid shrimps, hyperid and gammarid amphiphods, mysids, euphausids, cod, sculpins, and sandlance. Daily food intake probably ranges from 2 to 9.5 percent of body weight, depending on the caloric value of the prey (Lowry et al, 1982).

As in the case of spotted seals and bearded seals, ringed seals are probably never numerous within the five km nearshore zone of Bristol Bay.

Harbor Porpoise (Phocoena phocoena)

No data are available regarding population densities of harbor porpoise in Bristol Bay. Though they are observed

there fairly commonly, populations are probably rather low (Lowry et al, 1982).

Though no information is available regardina feeding or food requirements of harbor porpoises in the Aleutian-Bristol Bay region, studies from other areas indicate that they feed on a wide range of finfish and invertebrates. Adults probably weigh 45 to 60 kg, and consume about ten percent of their body weight per day in food (Lowry et al, 1982). Little is known about the life history of this species, and it is unclear whether they calve every year or at longer intervals.

Other marine mammals known to occur at times in the northern Aleutian Island-Bristol Bay region are northern fur seal, ribbon seal, fin whale, minke whale, blue whale, sei whale, humpback whale, Pacific right whale, bowhead whale, sperm whale, Cuvier's beaked whale, Baird's beaked whale, Stejneger's beaked whale, killer whale, and Dan's porpoise. Most of these species are seasonal visitors, and none of them is ever numerous or common in the nearshore region (Fay, personal communication).

c. Feeding Relationships

Available data regarding the feeding relationships of dominant or otherwise important invertebrate, fish, mammal, and bird species were compiled in order to gain a better understanding of the functional operation of the food web in the nearshore area. Feeding relationships for each species are synthesized in the form of food web segments (Figures 99 through 117) which illustrate both primary predators and prey. Large gaps, however, exist in our qualitative as well as quantitative knowledge of the food webs of the nearshore zone.

Invertebrates. Included in this treatment will be red king crabs, the sea star, *Asterias amurensis*, and two bivalve mollusks, *Spisula polynyma* and *Tellina* lutes.

Red King Crab

A summary of the literature on red king crab food and feeding habits is reported in Feder and Jewett (1981), and partially presented here. A study by W. Pearson at Battelle, N.W. Laboratories is underway but results are unavailable at this time. Little is known about the food and feeding habits of red king crabs while they occupy the coastal waters of the southeastern Bering Sea; however, data from four studies are available for this species from deeper waters. In the summer and fall of 1975 and 1976 king crabs were examined from various depths. The dominant prey items, in decreasing percent frequency of occurrence? were a cockle (*Clinocardium ciliatum*), a snail (*Solariella* sp.), a clam (*Nuculana fossa*), brittle stars (Amphiuridae), a polychaete

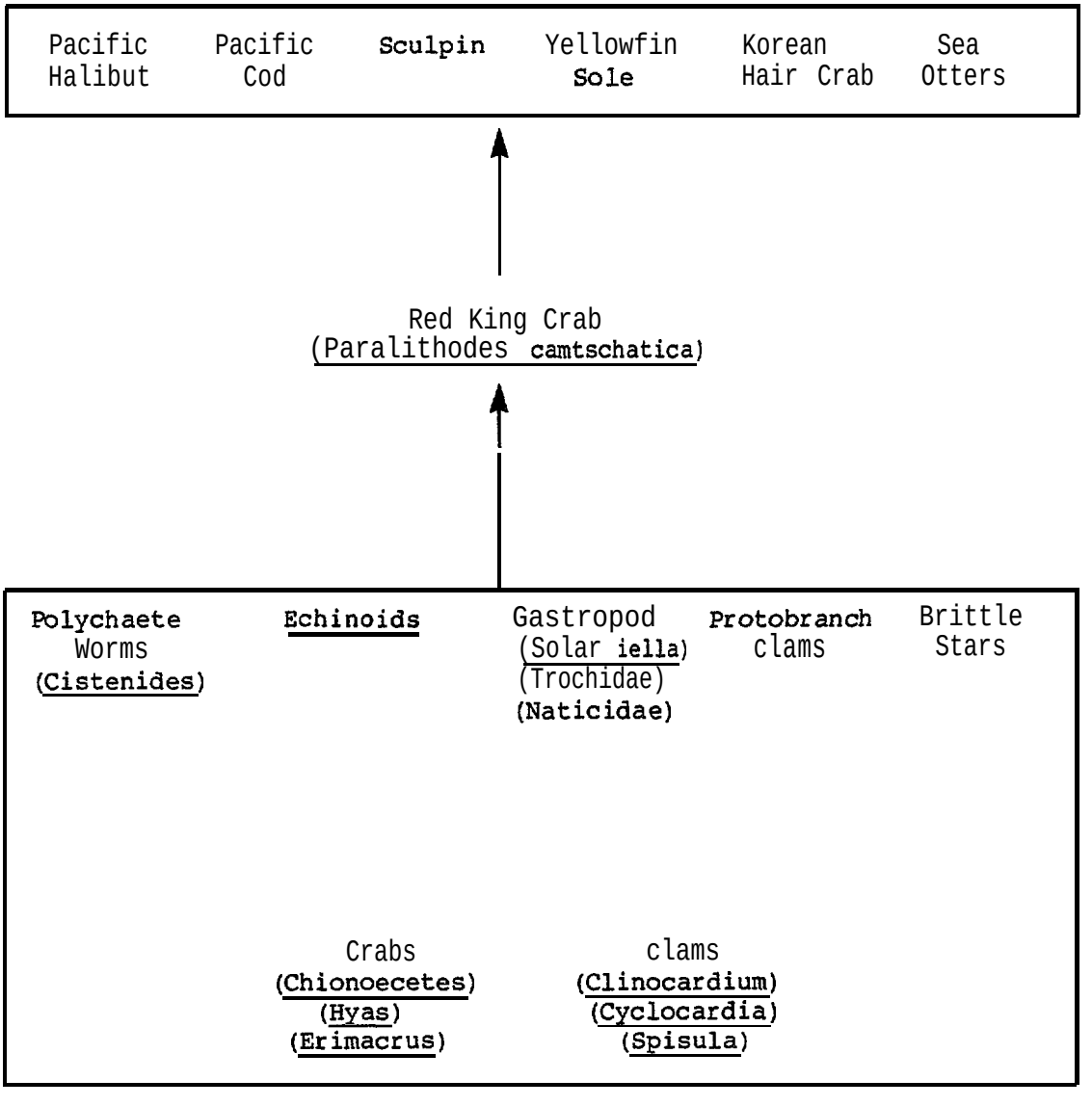


Figure 99. Basic trophic interactions of red king crab.

worm (Cistenides sp.), and Tanner crabs (Chionoecetes sp.) (Figure 99) (Feder and Jewett, 1980).

In a second study conducted in September and October 1972, food of red king crabs from 40-50 m depths of Bristol Bay were mainly polychaete worms, sand dollars (Echinarachnius parma), gastropod of the families Trochidae and Naticidae, and pelecypods (Yoldia, Nuculana, Nucula and Cyclocardia) (Tarverdieva, 1976).

In a third study where crabs were examined in July and August 1967 from depths of 78-90 m, echinoderms (a brittle star, Ophiura sarsi; a basket star, Gorgonocephalus sp.; a sea urchin, Strongylocentrotus sp; and a sand dollar, Echinarachnius parma) were the most important food, by percent of total food weight (49.1%) in the crab stomachs analyzed. Mollusks (bivalves-Nuculana radiata, Clinocardium californiense, Chlamys sp; snails-Solariella sp and Buccini-dae) and crustaceans (crabs-Hyas coarctatus alutaceus, Erimacrus isembeckii, and Pagurus sp) and sand fleas (Amphipoda) were next in importance by weight with 37.2 percent and 10.1 percent, respectively (Cunningham, 1969).

A fourth study examined crabs from various depths during June and July 1957. Primary foods were bivalve mollusks, echinoderms (asteroids, ophiuroids, and echinoids), and decapod crustaceans (shrimps) (McLaughlin and Hebard, 1961).

King crabs collected in shallow bays (5-10 ITI) of Kodiak Island mainly feed on clams (primarily Protothaca stamineas, Macoma spp.), cockles (Clinocardium spp.), and acorn barnacles (mainly Balanus crenatus). Analysis of king crab feeding data from the area of Kodiak and Afognak islands revealed significant differences in quantity of food consumed between sampling areas, periods, depths, and crab sizes and classes. Presumably these differences also exist among king crabs in the southeastern Bering Sea (Jewett and Feder, 1982).

The extensive Alaska surf clam (Spisula polynyma) resource along the North Aleutian Shelf is presumably prey for red king crab since this clam has been identified as an important prey species for king crab in Kachemak Bay (Cook Inlet), (Feder and Jewett, 1981).

Various predators of red king crabs have been identified, i.e., Korean hair crab, Pacific halibut, Pacific cod, sculpin, yellowfin sole, and sea otters (Figure 99). Korean hair crab have been observed preying on podding juvenile king crab in the nearshore waters of Kodiak Island (Powell and Nickerson, 1965). Pacific halibut are known to prey on king crab from waters deeper than 50 meters in the Gulf of Alaska (Gray, 1964). A study in 1980-81 from various depths

of the southeastern Bering Sea was the first to document consumption of red king crab by Pacific cod in the southeastern Bering Sea (Shimada and June, 1982). The proportion of king crab in the diet of Pacific cod was approximately eleven percent by weight and seven percent by frequency of occurrence. The sculpin, Hemilepidotus hemilepidotus is a known predator of small king crab. As many as five two-year old king crab (25 mm carapace length) have been found in the stomach of a single sculpin; stomachs of 56 sculpins from the nearshore waters off Kodiak Island contained 110 crab (Powell, 1974). In thousands of demersal fish stomachs examined from Gulf of Alaska and Bering Sea waters during the years 1975-80, king crab were rarely found (Feder and Jewett, 1981). Glaucothoe larvae of king crab have recently been found in the stomachs of yellowfin sole along the Alaska Peninsula in the southeastern Bering Sea (Haflinger and McRoy, 1983).

Sea otters have been observed to prey upon adult king crab from Prince William Sound waters (S. Jewett, personal observation); therefore, king crab are presumably taken by otters along the North Aleutian Shelf. Currently, an OCSEAP study is underway to examine the food of sea otters along the North Aleutian Shelf (VTN Oregon, 1983e). The distribution of sea otters and the distribution of the mating king crab is similar (Haynes, 1974; Armstrong et al, 1981; Schneider, 1981) . Recent expansion of a sea otter population in Prince William Sound, Alaska, into previously unoccupied habitat coincided with the demise of the Dungeness crab fishery through otter predation (Garshelis, 1983).

Asterias amurensis

The sea star Asterias amurensis feeds on a variety of organisms in the southeastern Bering Sea (Feder et al, 1978) . It has been estimated that food, primarily clams, consumed annually by A. amurensis in Japanese waters amounts to 8 x 10^3 mt, approximating the annual consumption of food (primarily clams) taken by bottom fishes (Hatanaka and Kosaka, 1958). The large standing stock of A. amurensis in the shallow waters of the southeastern Bering Sea prey intensively on the bivalve resources of the region (i.e., Tellina lutea, Cyclocardia spp., Macoma calcarea, and Spisula polynyma), and sand dollars (Echinarachnius parma) (Figure 100) . The food requirements for sea stars, crabs, and some species of bottom fishes in the coastal regions of the southeastern Bering Sea are similar, thus the size of seastar populations must have an important bearing on the production of commercially important crabs and fishes.

Sea stars are rarely preyed upon as adults (predator exceptions are king crabs and sea otters), and they are typically thought to be a "dead end" in the food web (Feder

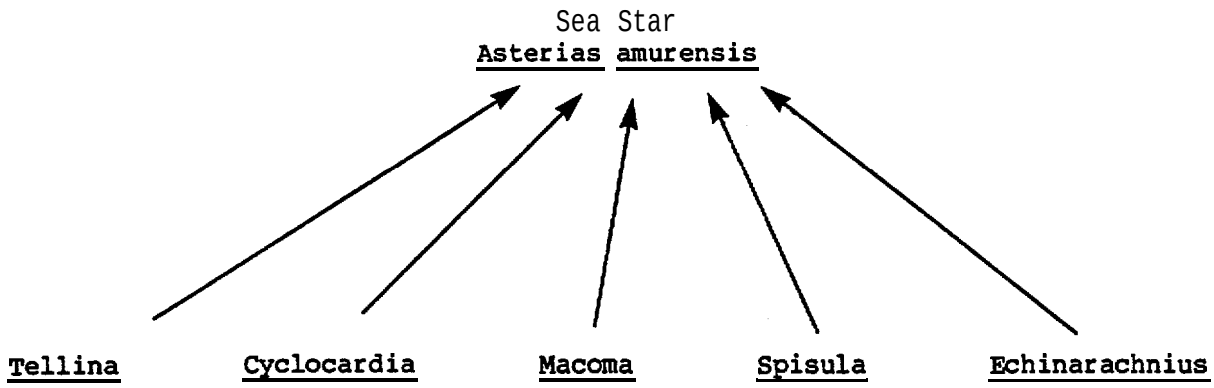


Figure 100. Basic trophic interactions of the sea star, Asterias amurensis.

and Jewett, 1981). However, a considerable portion of seastar carbon is, in fact, returned to the sea annually as gamete production. It has been calculated that 20-30 percent of the weight of adult Asterias is gonodal material which is extruded during spawning (Hatanaka and Kosaka, 1958). Such pulses of high-energy organic material released during spawning must represent important components of secondary production to the water column and the benthos (Feder and Jewett, 1981).

Spisula polynyma and Tellina lutea

The two bivalves, Alaska surf clam (Spisula polynyma) and great Alaska tellin clam (Tellina lutes), are both filter feeders, utilizing detritus and phytoplankton as carbon sources. They both are important prey items for red king crab, yellowfin sole, otters, and walrus (Figures 101 and 102).

Marine Fishes. Included in this section are Pacific herring, capelin, and yellowfin sole.

Pacific Herring

The following summary of Pacific herring food and feeding habits from throughout the Bering Sea is taken from Wespestad and Barton (1981). The first food of herring larvae is usually limited to small and relatively immobile plankton organisms. Microscopic eggs sometimes make up more than half of the earliest food; other items include diatoms and nauplii of small copepods. Herring do not have a strong preference for certain food species but feed on the comparatively large organisms that predominate in the plankton of a given area. Feeding generally occurs before spawning, and intensifies afterward. Feeding declines during winter, then ceases in late winter.

Stomachs in August were 84 percent filled with euphausiids, 8 percent with fish fry, 6 percent with calanoid copepods, and 2 percent with gammarid amphipods. Fish fry, in order of importance, were walleye pollock, smelt, capelin, and sandlance. In spring, food was mainly pelagic amphipods (Themisto), and chaetognaths (Sagitta). After spawning, the main diet was euphausiids, Calanus spp., and Sagitta spp. (Figure 103). Nearly 75 percent of herring stomachs examined in the spring from Bristol Bay to Norton Sound either were empty or contained only traces of food. Only 25 percent of the stomachs examined were at least 25 percent or more full, and only 3.4 percent were completely full. Major food items were cladocerans, flatworms, copepods, and cirripeds.

Herring are important prey for marine mammals (i.e., harbor seals, sea lions and beluga whales) and sea birds (i.e., black-legged kittiwakes and glaucous gulls). All of

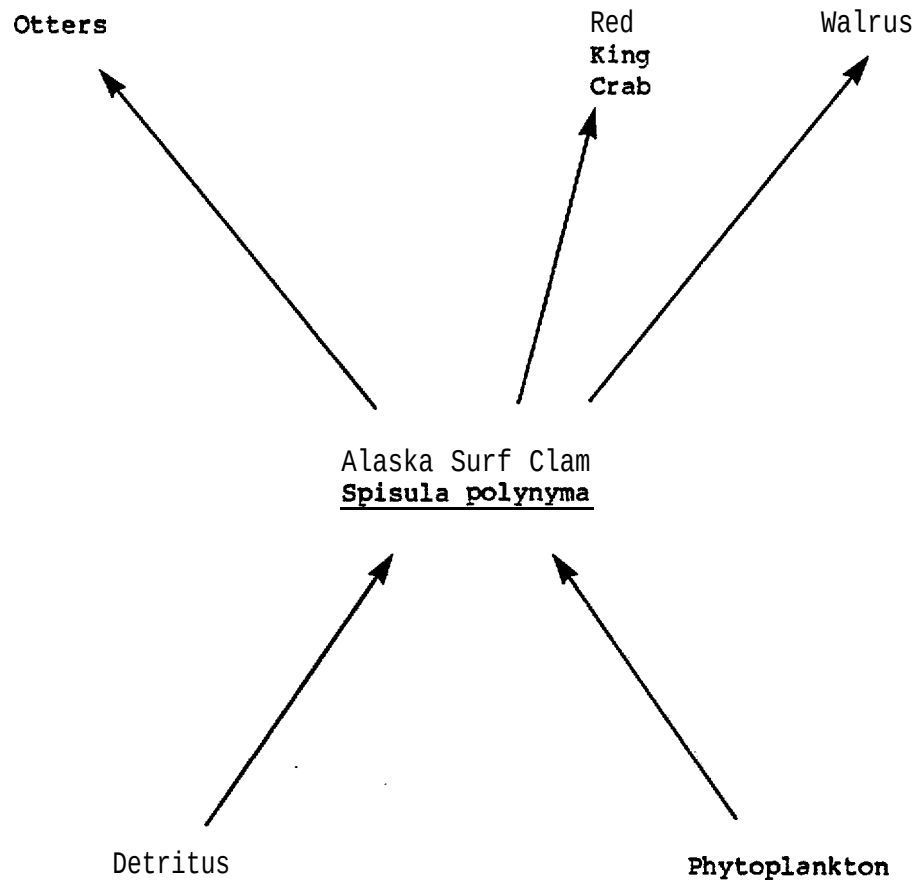


Figure 101. Basic trophic interactions of the Alaska surf clam.

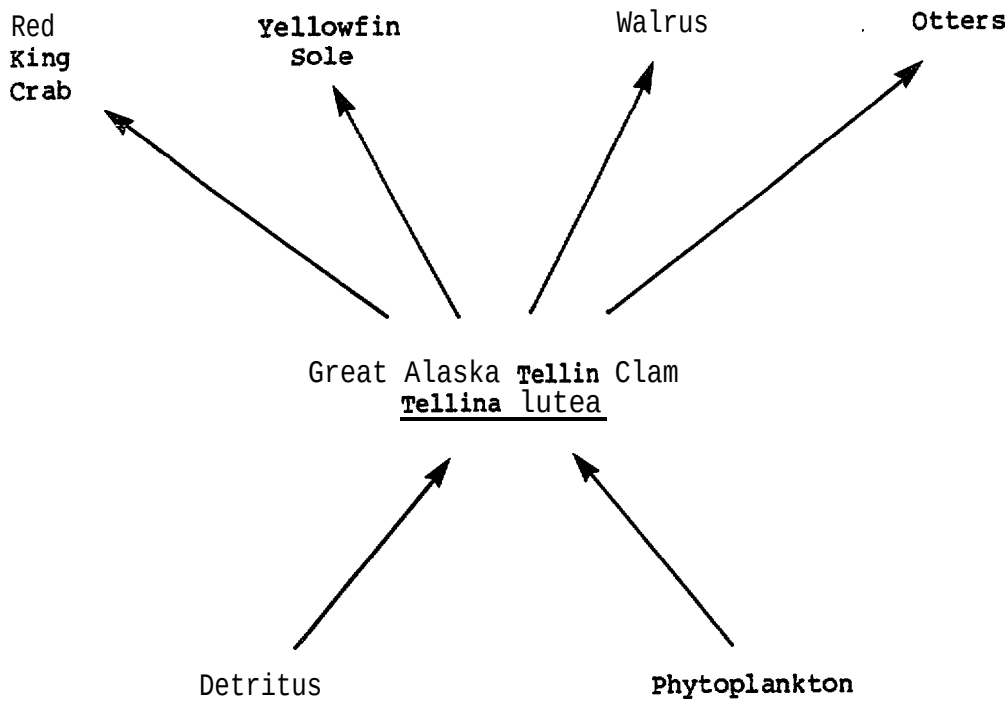


Figure 102. Basic trophic interactions of the great Alaska tellin clam.

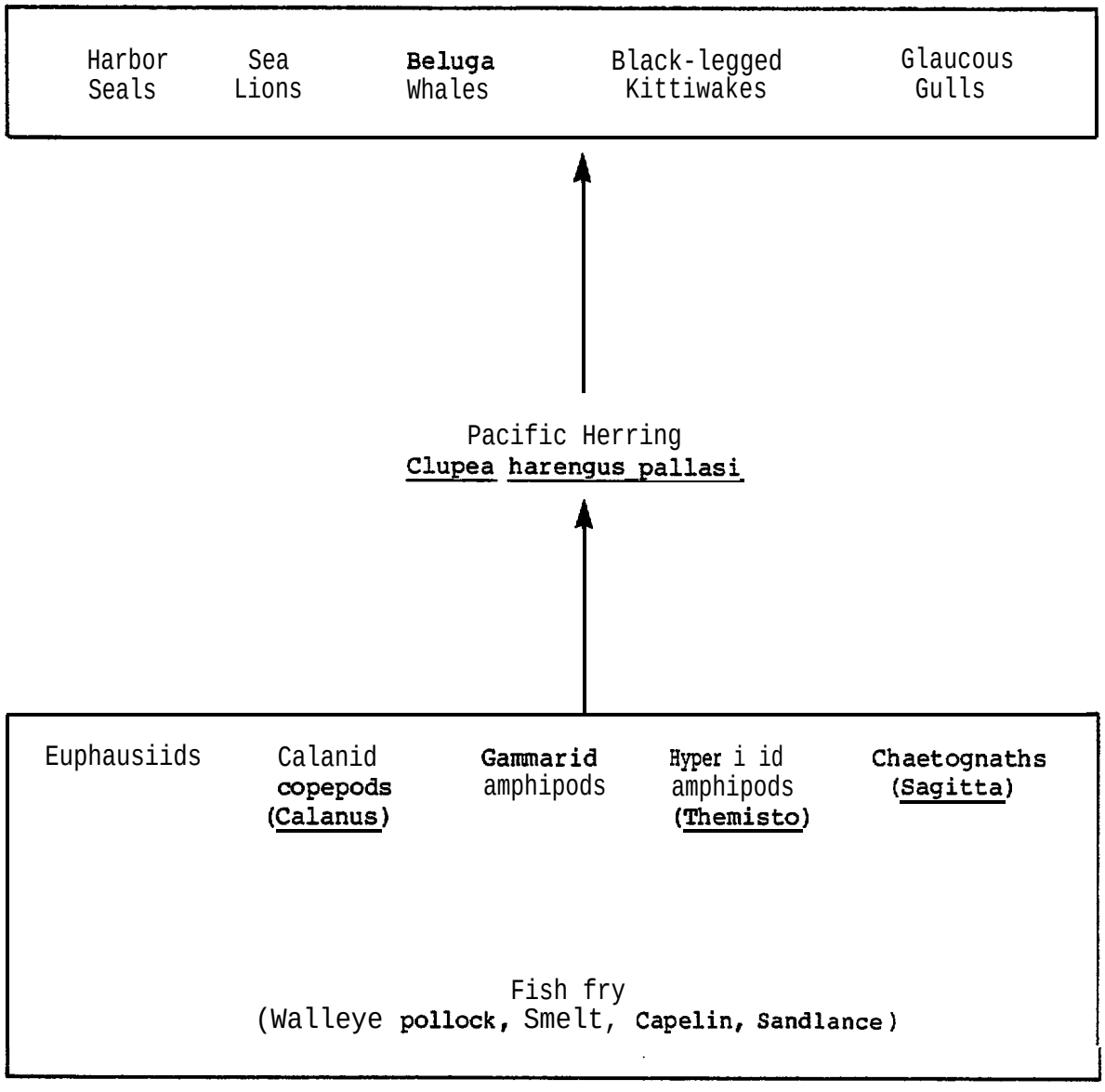


Figure 103. Basic trophic interactions of Pacific herring.

the commercial quantities and most of the subsistence quantities of herring come from the Togiak region of northern Bristol Bay (Barton et al, 1977).

Capelin

Little is known about the food and feeding habits of the capelin from the eastern Bering Sea. Smith et al (1978) examined the stomach contents of 135 feeding individuals "from the southeastern Bering Sea. All specimens were captured during the period from late spring to early fall. Therefore, no information is available on seasonality of feeding in the Bering Sea capelin. Only two phyla were represented among food organisms, the Arthropoda (all crustaceans) and the Chaetognatha. The most numerous prey organisms were calanoid copepods. The only identifiable genus was Calanus. Virtually all of the amphipods present were members of the pelagic Hyperiidae. Identifiable euphausiid specimens were all of the" genus Thysanoessa. The smallest food item, copepods, had its greatest volumetric and relative importance in the smallest fish. The same is true of the next smallest food items, the mysids (Figure 104).

Capelin are food for a variety of predators including seabirds of the family Alcidae, and fishes (e.g. , arrowtooth flounder, pollock, and Greenland halibut) (Smith et al, 1978).

Yellowfin Sole

Recent findings on the food of yellowfin sole in the southeastern Bering Sea along the Alaska Peninsula revealed that newly recruited surf clams Spisula polynyma (l-2 mm) were often encountered in the range of 100-500/stomach in the deeper waters (>30 m) off Port Moller, while various groups of polychaete worms, benthic amphipods, and the sand dollar Echinarachnius parma dominated the shallow water and Bristol Bay (Haflinger and McRoy, 1983). King crab glaucothöe larvae and Tanner crab (Chionoecetes bairdi) zoea were also taken as food; however, only two of 557 fish examined accounted for nearly all the crab consumption reported here. The overall incidence of king crab was 0.69/stomach. The overall incidence of Tanner crab was 0.27/stomach. Extrapolations from these rates to total numbers of crab consumed for one month in this area were 11.5 x 109 king crab and 4.5 x 109 Tanner crab.

A characterization of yellowfin sole food and feeding habits is presented in Bakkala (1981a) and summarized here. Yellowfin sole are capable of feeding on a variety of animals, from strictly benthic forms, such as clams and polychaete worms to zooplankton (mysids and euphausiids), to pelagic fishes (capelin and smelt).

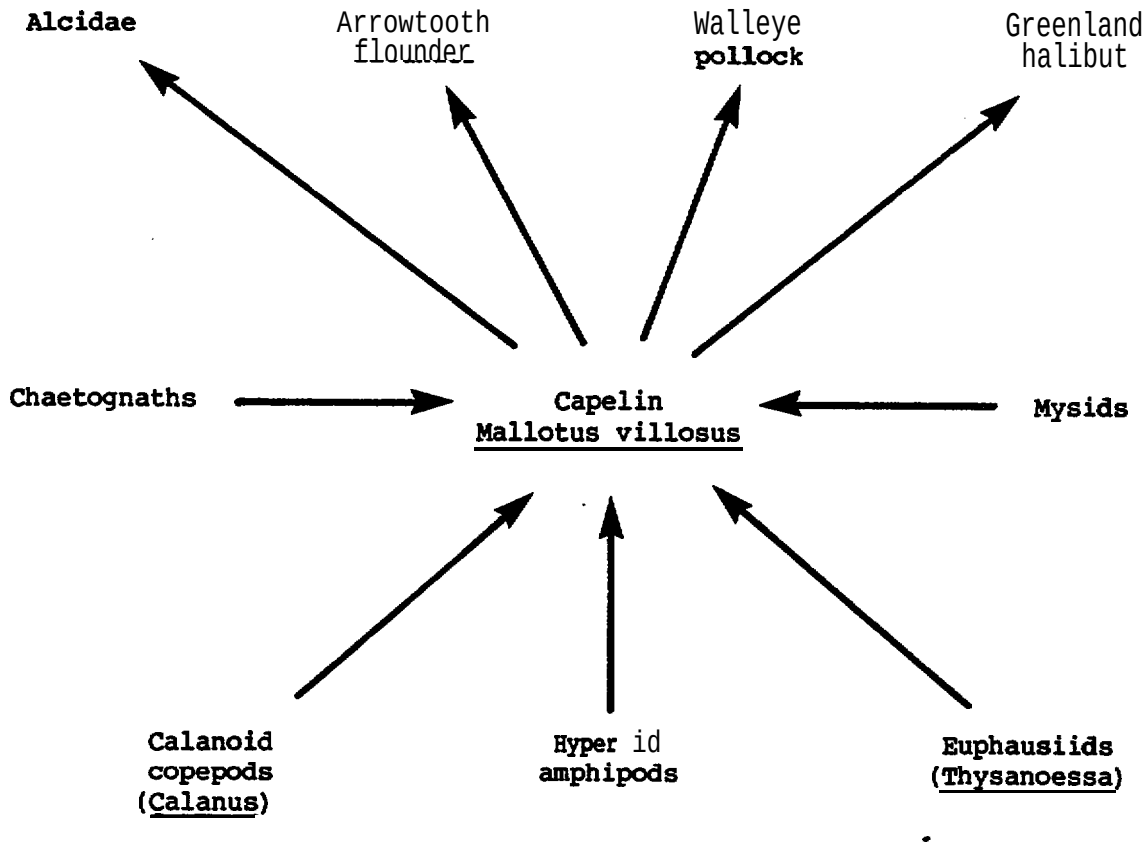


Figure 104. Basic trophic interactions of capelin.

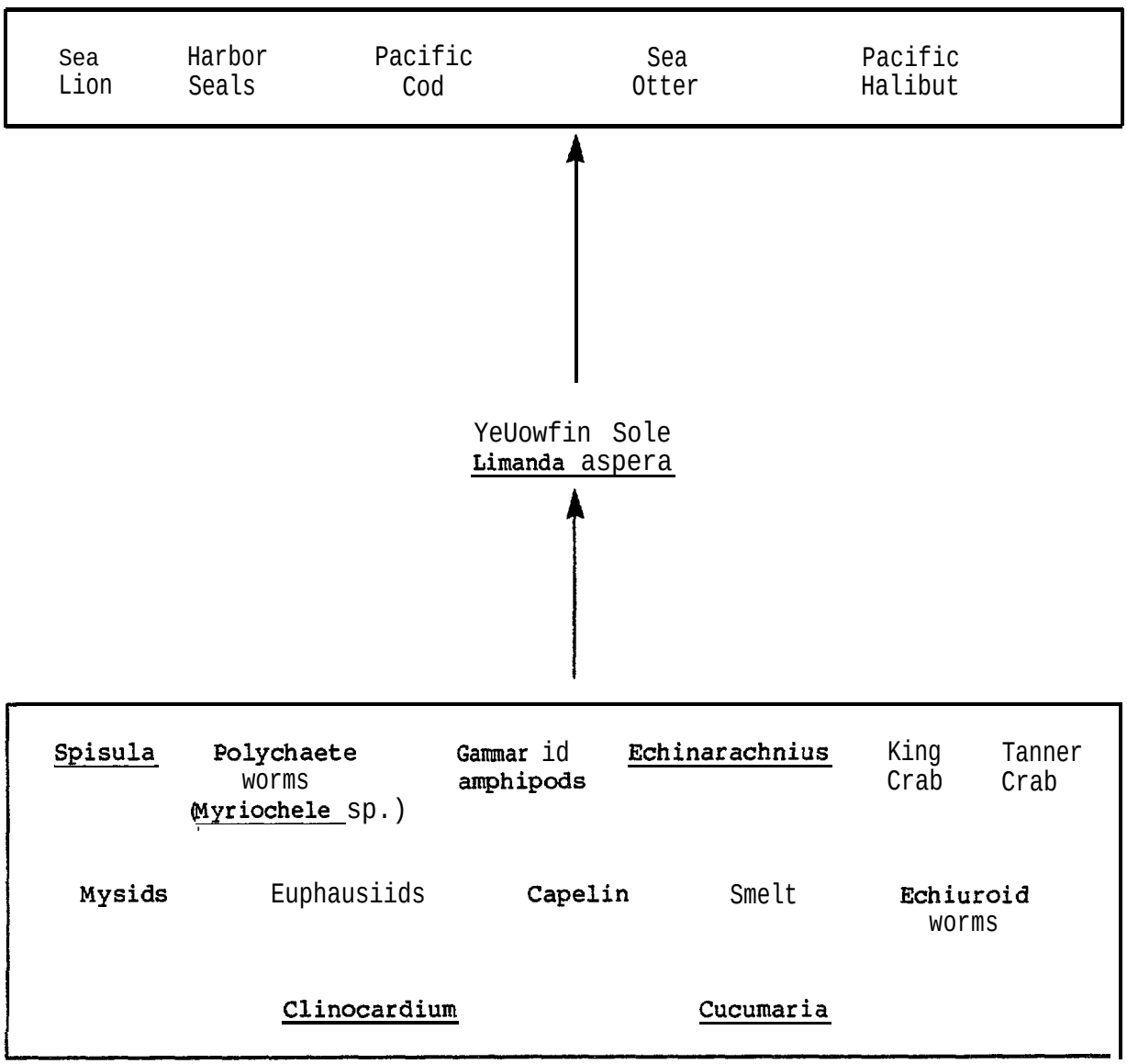


Figure 105. Basic trophic interactions of yellowfin sole.

About 50 different taxa have been found in stomachs of yellow fin sole in the eastern Bering Sea. The kinds of organisms consumed vary by season, area, and size of fish. Although feeding generally stops in winter, instances of fairly intense winter feeding have been recorded. During the onshore migrations in May and June 1971, 73 percent of the fish that had wintered near Unimak Island were feeding, but feeding intensity was low for fish that had wintered near St. George Island (0.05 percent) , St. Paul Island (19 percent), and in Bristol Bay (O percent). They fed more intensively as they moved onto the central shelf; diet varies by region, apparently depending on the' availability of food organisms.

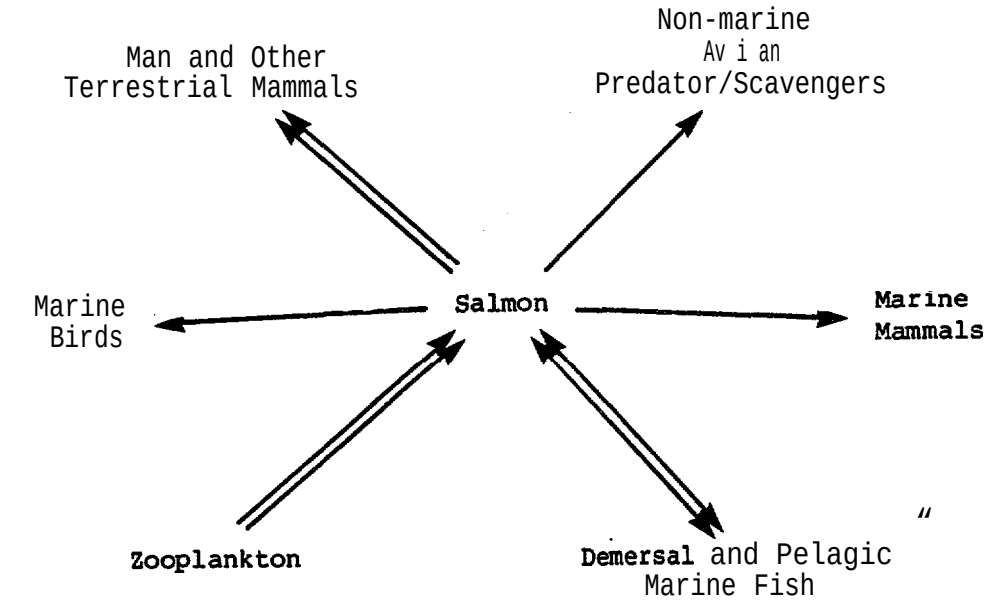
Contents of 2,357 stomachs taken over a broad area of the eastern Bering Sea show that the primary food items, representing 65 percent of stomach contents by weight, were bivalves, amphipods, polychaete worms, and echiuroid worms. Polychaetes and amphipods were the principal food items in smaller fish (10-20 cm) , polychaetes and bivalves; echiuroids and amphipods in larger fish (20-30 cm); and bivalves and echiuroids in fish longer than 30 cm (Figure 105).

A recent OCSEAP study conducted by VTN Oregon (1983e) examined the feeding habits of this species along the North Aleutian Shelf. Contents of 40 stomachs taken in two areas (off Port Moller and Bechevin Bay) and at 30 and 60 meters depth were summarized. The major taxa in their diets representing 51.2 percent of the total stomach volume were crustaceans (20.7 percent), bivalves (12.3 percent) echinoderms (9.5 percent), and polychaetes (8.7 percent). They found that prey items and age varied with transect and depth. Fish taken at 30 meters were found to be younger (three to four years) and ate fewer prey taxa (16 to 17) than fish taken at 60 meters (five to 10 years, 21 taxa) .

In recent years the Port Moller area has yielded approximately 35,000 mt of yellowfin sole to the commercial fishery (Bakkala, 1981a).

Pacific halibut are a dominant predator of yellowfin sole in the southeastern Bering Sea (Bakkala, 1981a; Pereyra et al, 1976). A close relationship between the distribution of halibut and yellowfin sole during the summer and fall suggests that the movements of halibut are governed to a large degree by the movements of its principal prey, yellowfin sole (Bakkala, 1981a). Yellowfin sole are also taken by Pacific cod (Shimada and June, 1982). A recent OCSEAP study has identified that sea otters also consume yellowfin sole along the North Aleutian Shelf (VTN Oregon, 1983d).

Anadromous Fish. Included in this category are salmon and boreal smelt.



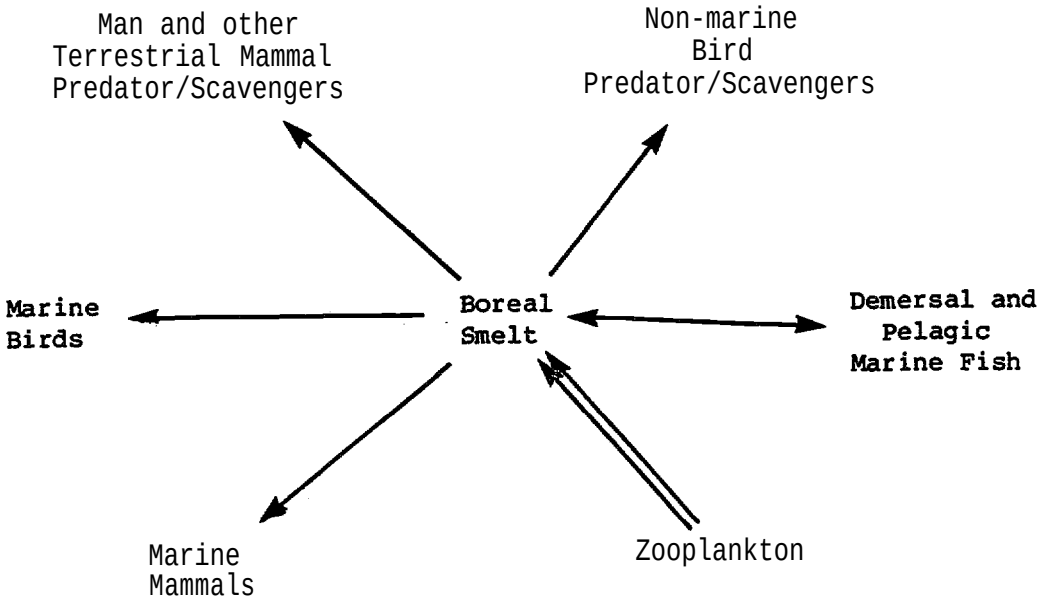


Figure 106. Basic trophic interactions of salmon and smelt. Double lines indicate primary reliance.

Salmon

Though all five species of Pacific salmon spawn in streams and lakes of the Bristol Bay-Alaska Peninsula region, sockeye salmon are the only species for which detailed information regarding life history and feeding habits within this area is available. Both adults and juveniles of sockeye feed on zooplankton (euphausiids, amphipods, copepods, cladocerans) and small fishes (particularly sandlance), though the species and age/ size composition of prey necessarily differs to some extent (Straty and Jaenicke, 1980). The prey of other salmon species is probably similar, though varying from species to species in proportions so that all salmon can be classified as third and fourth trophic level predators.

Salmon in turn provide an important food resource for numerous fish, invertebrates, marine and terrestrial mammals, marine bird species, and man (Figure 106). Though quantitative data from the Bristol Bay-Alaska Peninsula area are generally sparse or lacking, it can probably be assumed that both smelt and adults are fed upon by beluga whale, harbor seal, Steller sea lion, and perhaps to a minor extent by spotted seal. Marine birds, probably including shearwaters, kittiwakes, murres, and certainly glaucous-winged gulls and Arctic terns, also consume juvenile and adult salmon to varying degrees when they are available (Flock, 1932; Mossman, 1958). The impact of marine mammal and marine bird predation upon the population is unknown.

Boreal Smelt

Though boreal smelt are probably the numerically dominant forage fish within the Bristol Bay and Alaska Peninsula nearshore zone (Warner and Shafford, 1981), very little is known about their trophic status other than that the adults prey upon mysids, amphipods, other fish, and polychaete worms (Warner and Shafford, 1981). This probably places them in the third or fourth trophic level.

Essentially no information is available as to consumption of smelt by other predators, though it can probably be assumed with some degree of confidence that, since they are the most available forage fish in at least some locales, they are utilized to a considerable degree by coastal marine mammals (beluga whale and harbor seal) and coastal marine birds (arctic terns, glaucous gulls, probably murres, kittiwakes, puffins, cormorants, guillemots) when the ranges of these species and smelt overlap (Figure 106).

Marine Mammals. All of the marine mammals of the region are apex predators. Other than man and killer whales, virtually no natural enemies prey on them. Diet and

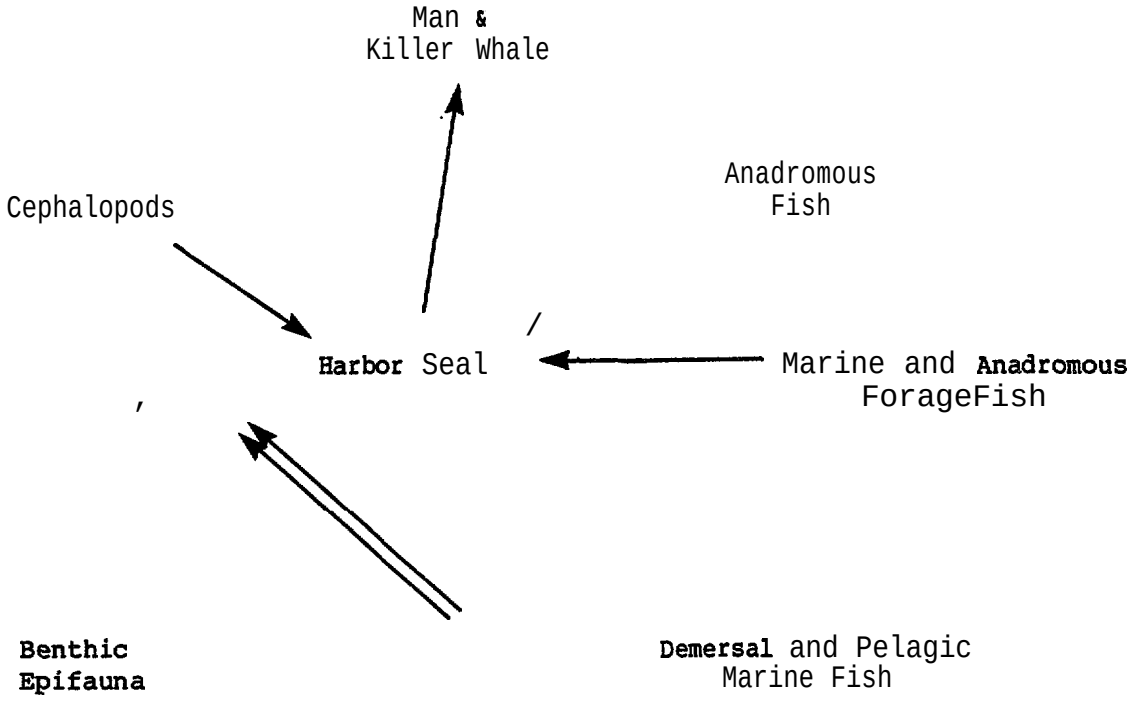


Figure 107. Basic trophic interactions of harbor seals. Double lines indicate primary reliance.

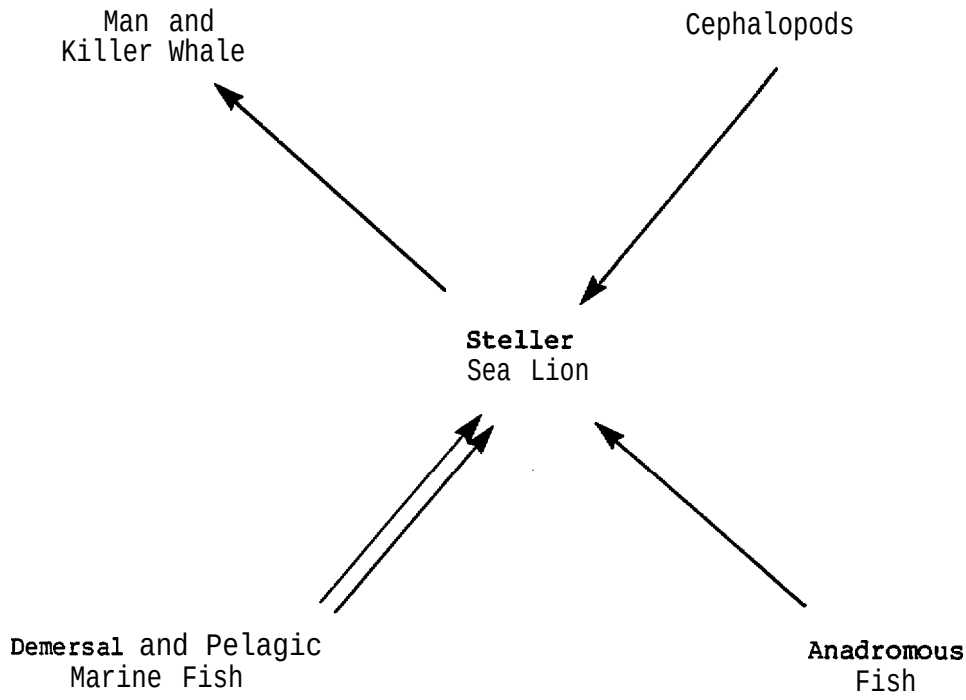


Figure 108. Basic trophic interactions of Steller sea lions. Double lines indicate primary reliance.

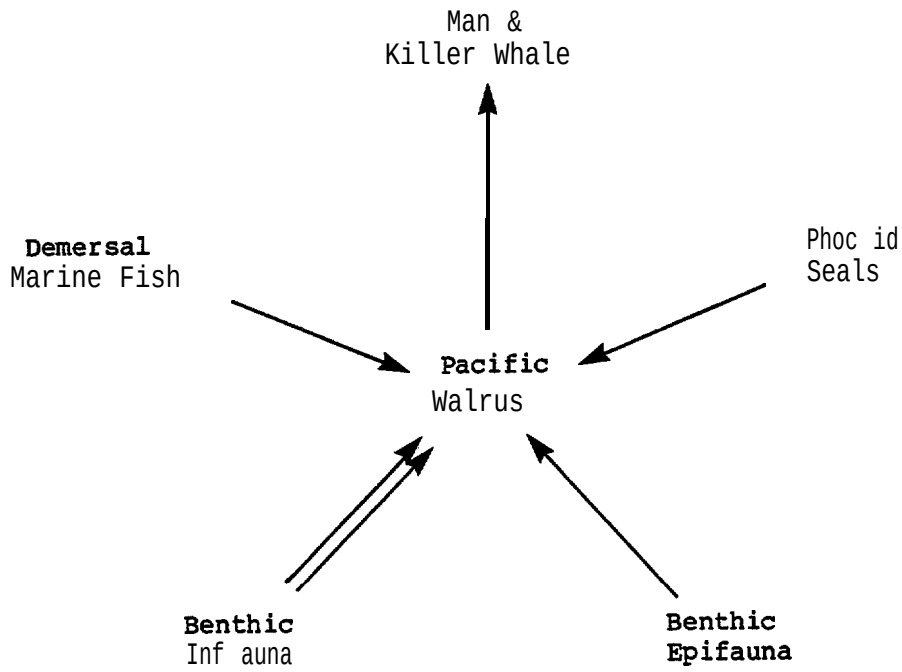


Figure 109. Basic trophic interactions of Pacific walruses. Double lines indicate primary reliance.

preferred prey species vary from species to species; in some cases seasonally ranging from marine and anadromous fish to benthic invertebrates. For major marine mammal species of the region, consumption rates and principal prey items are discussed briefly below.

Harbor Seal

Consumption by harbor seals ranges from 13% of total body weight daily during the first year, to three percent per day at age nine (Ashwell-Erickson et al, 1978). They are opportunistic feeders on a wide range of marine and anadromous fishes, shrimp, epibenthic crustaceans, and cephalopods (Figure 107). From limited numbers of stomach analyses in the Bristol Bay region (Lowry et al, 1982) it appears that, during fall at least, prey species include boreal (rainbow) smelt, sandlance, greenling, sculpins, pollock, various flatfishes, Pacific halibut, Pacific cod, and octopuses. It is also likely that they take, during certain times of the year, herring, capelin, yellowfin sole, salmon, shrimp, Tanner crab and king crab.

Stellar Sea Lion

Though data are sparse, it appears that Steller sea lions probably consume food weighing between six and ten percent of their body weight per day (Keyes, 1968). Sea lions are opportunistic feeders on a wide variety of finfish, squid, and octopuses (Figure 108). Available data indicate that preferred food items are (not necessarily in this order) capelin, sandlance, pollock, sculpins, flatfishes, cod, halibut, squid, octopus, and Atka mackerel (Lowry et al, 1982).

Pacific Walrus

Daily food consumption by adults is estimated (Fay, 1982) at 6.2 percent per day. Walrus are, primarily, feeders on benthic infauna and epifauna (Figure 109). In the Bristol Bay region, they have been found to take at least 22 genera of benthic invertebrates, including bivalve mollusks, 'gastropod mollusks, crabs (*Hyas* and *Chionoecetes* spp.), hermit crabs, crangonid shrimps, octopuses, tunicates, anemones, priapulids, echiuroids, and polychaete worms. More than 90 percent of their diet, however, seems to be composed of five genera of bivalve mollusks (*Serripes*, *Mya*, *Spisula*, *Tellina* and *Siliqua*), followed in importance by other bivalves (such as *Macoma*, *Astarte*, *Hiatella*), gastropod, and other minor taxa (Fay and Lowry, 1981). They are also known, on rare occasion, to prey on other seals (Fay et al, 1977), and to consume such diverse items as sandlance and jellyfish (Fay and Stoker, 1982a,b).

Sea Otter

Adult otters are known to consume between 20 and 25 percent of their body weight per day (Estes and Palmisano, 1974). They will prey on a wide range of benthic invertebrates and fish (Figure 110), though their favored food item seems to be sea urchins.

Information on the feeding habits of sea otters within the Bristol Bay region is limited to analyses of nine scat samples obtained over a two day period from Glazenap Island. This limited data indicated that crustaceans (crabs, shrimp, and amphipods), mollusks (clams and mussels), echinoderms (sand dollars) and chordates (fish) were the most frequently consumed prey. While crustaceans and mollusks were consumed more often, fish were suggested by this study to be the most important prey in terms of biomass.

Beluga (Belukha) Whale

Records of captive belugas indicate that they consume between four and seven percent of their body weight per day. Belugas are known to consume a wide variety of fish and invertebrates (Figure 111). Smelt and salmon seem to comprise a major part of their diet in the Bristol Bay area from May through August, when belugas are present in large numbers in the vicinity of Kvichak and Nushagak Bays (Brooks, 1955). During winter they apparently shift to the ice edge further offshore, where they probably rely heavily on pollock (Seaman et al, 1982). In other areas, they are also known to feed extensively on herring, saffron cod, and crangonid shrimps (Lowry et al, 1982).

Gray Whale

Gray whales probably consume food weighing between three and five percent of their body weight on the average, or about 1,200 kg, per day. They are known to feed extensively on gammarid amphipods of the genera Ampelisca, Lembos, Anonyx, and Pontoporeia in the shallow water summer feeding grounds of Norton Sound (Figure 112) (Lowry et al, 1982). 'During the spring migration through the North Aleutian Shelf area, however, gray whales feed on unknown quantities and species of invertebrates (Gill and Hall, 1983).

Birds. Birds being included in this section include seabirds, waterfowl, and shorebirds.

Seabirds

Though data are incomplete as to the nutritional requirements of seabirds, the total consumption by seabirds in the

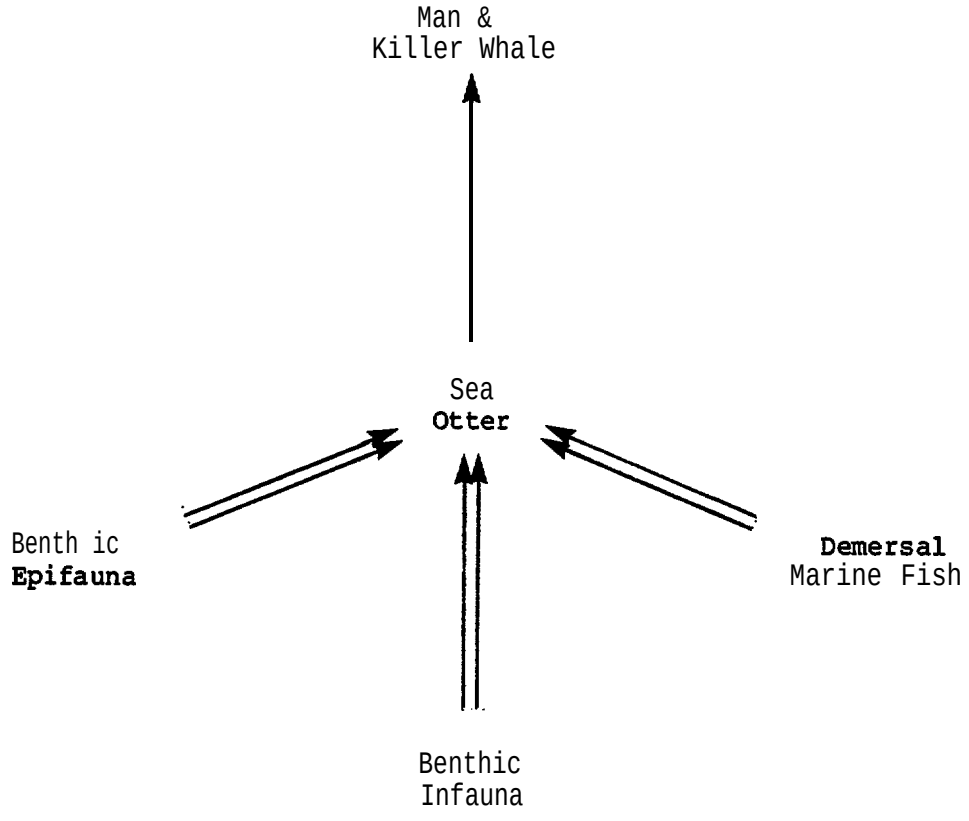


Figure 110. Basic trophic interactions of sea otters. Double lines indicate primary reliance.

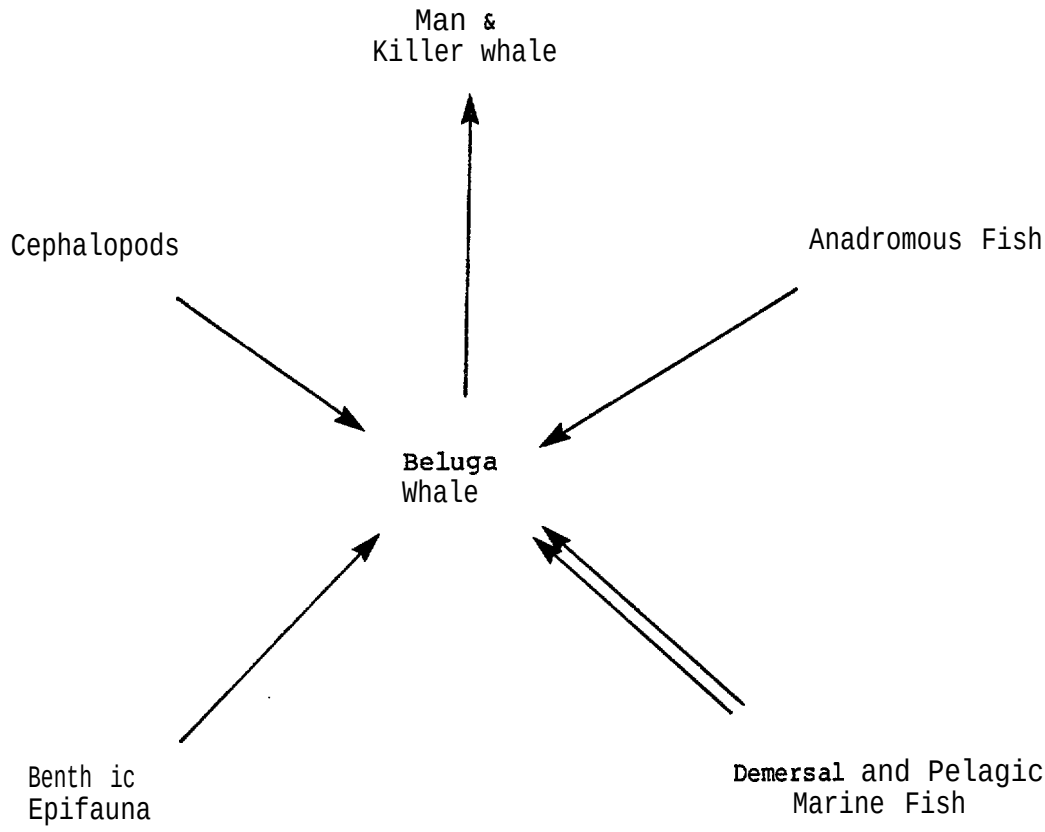


Figure 111. Basic trophic interactions of beluga whales. Double lines indicate primary reliance.

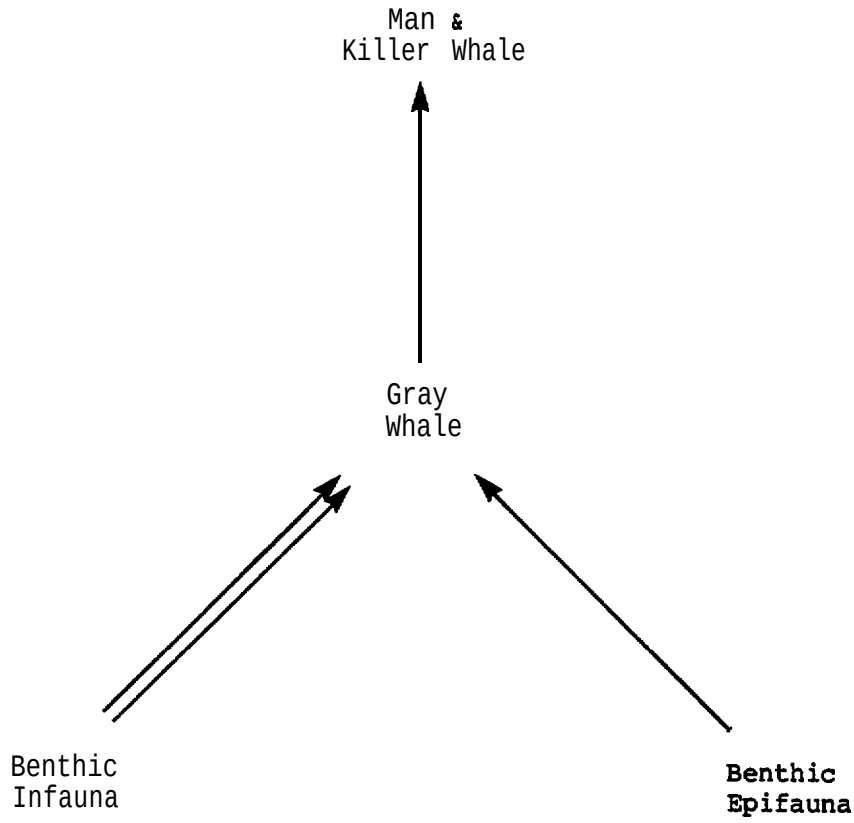


Figure 112. Basic trophic interactions of gray whales. Double lines indicate primary reliance.

eastern Bering Sea is estimated at between 550,000 and 1,000,000 metric tons per year (Hunt et al, 1981a). If a total population estimate of 53 million seabirds frequenting the eastern Bering Sea is applied to this figure (Hunt et al, 1981a), it appears that the annual consumption in this geographical region amounts to between 10 and 20 kg per bird. Such estimates are admittedly crude, and do not account for what are undoubtedly great differences in feeding rates from species to species depending on the caloric value of prey consumed. Hunt et al (1981a) assumes, for purposes of feeding calculations, that daily seabird consumption rates range between 10 and 20 percent of their body weight.

All seabirds of this region are predators, feeding on zooplankton, fish, and bivalves. In general, it is estimated that fish probably make up about 70 percent of the diet of seabirds of the area, followed in importance by zooplankton and squid (Hunt et al, 1981a). Pollock are probably the principal fish species consumed, with an estimated 150,000 metric tons eaten annually by seabirds on the eastern Bering Sea shelf (Hunt et al, 1981a). An additional 170,000 mt of other fish are eaten by seabirds annually over this shelf, as well as an estimated 80,000 mt of euphausiids, 80,000 mt of amphipods (primarily Parathemisto libellula), and 70,000 mt of squid [Figure 113 (Hunt et al, 1981a)]. In the nearshore zone, it is considered likely that seabirds also feed heavily, at least during certain times of year, on forage fish such as herring, capelin, and smelt, and on outmigrating juvenile salmon.

For the most part, seabirds seem quite prey-specific in their diets, with each species relying on a very few prey items (Hunt et al, 1981a; Ainley and Sanger, 1979). In summer, short-tailed shearwaters apparently feed very heavily on euphausiids in the Bering Sea (70% of their total diet), while amphipods, especially Parathemisto libellua, constitute 60% of the fall diet in the same area (Hunt et al, 1981a). In addition to these crustaceans, shearwaters are known to take squid, capelin, and probably other small fish (Ainley and Sanger, 1979). Shearwaters probably are restricted to feeding in the upper five meters of the water column (Hunt et al, 1981a).

Fish seem to constitute the mainstay of the diet of common murres over the eastern Bering Sea shelf (Figure 114), though cephalopods, crustaceans, and even polychaete worms are also eaten, with diets varying from location to location (Hunt et al, 1981a; Ainley and Sanger, 1979). Principal fish species consumed appear to be pollock, sandlance, capelin, and possibly juvenile salmon (Hunt et al, 1981a; Ainley and Sanger, 1979; Ogi and Tsujita, 1973). At times at least, and in certain areas, amphipods, euphausiids, cephalopods, and polychaetes are also known to

contribute significantly to the diet of common murres (Hunt et al, 1981a; Ogi and Tsujita, 1973).

The diet of black-legged kittiwakes seems to be somewhat variable, differing from season to season and probably from area to area (Hunt et al, 1981a). In the Pribilof Island region, kittiwakes rely primarily on amphipods (notably P. libellula) and euphausiids before nesting, shifting to fish (primarily pollock and myctophids) during incubation. Principal euphausiid species taken are Thysanoessa inermis, T. longipes, and T. raschii (Hunt et al, 1981a). In addition to pollock, kittiwakes are known to consume sandlance, cod and several other small fish species. Cephalopods are also taken to some extent (Figure 115).

Seabirds are essentially top predators, at the third or fourth trophic level, and are themselves rarely preyed upon by other marine species. A few are taken by falcons and hawks. Eggs and young are preyed upon by gulls; when accessible, by foxes and humans.

Waterfowl

Waterfowl represent a mixture of trophic levels and feeding types, from secondary consumers of eelgrass and other vegetation to predators, depending on species (Figure 116). While in general, geese and non-marine ducks, including black brant, emperor goose, pintail, teal, and widgeon, are herbivores, in the lease area, Macoma is the primary food item. Sea ducks such as eiders, scoters, oldsquaw and scaup are predators. The prey consumed by sea ducks varies from species to species and probably seasonally and from area to area, ranging from fish to zooplankton to benthic invertebrates. With the exception of oldsquaw, which takes a wide variety of food, most are probably rather prey-specific. Steller's eiders in the Nelson Lagoon area, for instance, feed almost exclusively on 0-1 year age class mussels (Mytilus edulis) and amphipods (Anisogammarus pugettensis) (Petersen, 1980).

Non-human predation on waterfowl is probably most intense during the nesting season. Eggs and young are eaten, when the opportunity arises by virtually all terrestrial mammal and avian predators. Adult birds are preyed upon by falcons, hawks, eagles, and by man.

Shorebirds

Shorebirds forage primarily in the intertidal zone on exposed beaches and mudflats of estuaries and lagoons along the Alaska Peninsula-Bristol Bay coast. Though detailed information is not currently available, it is presumed that principal prey items are infaunal and epifaunal crustaceans and polychaete worms (Figure 117).

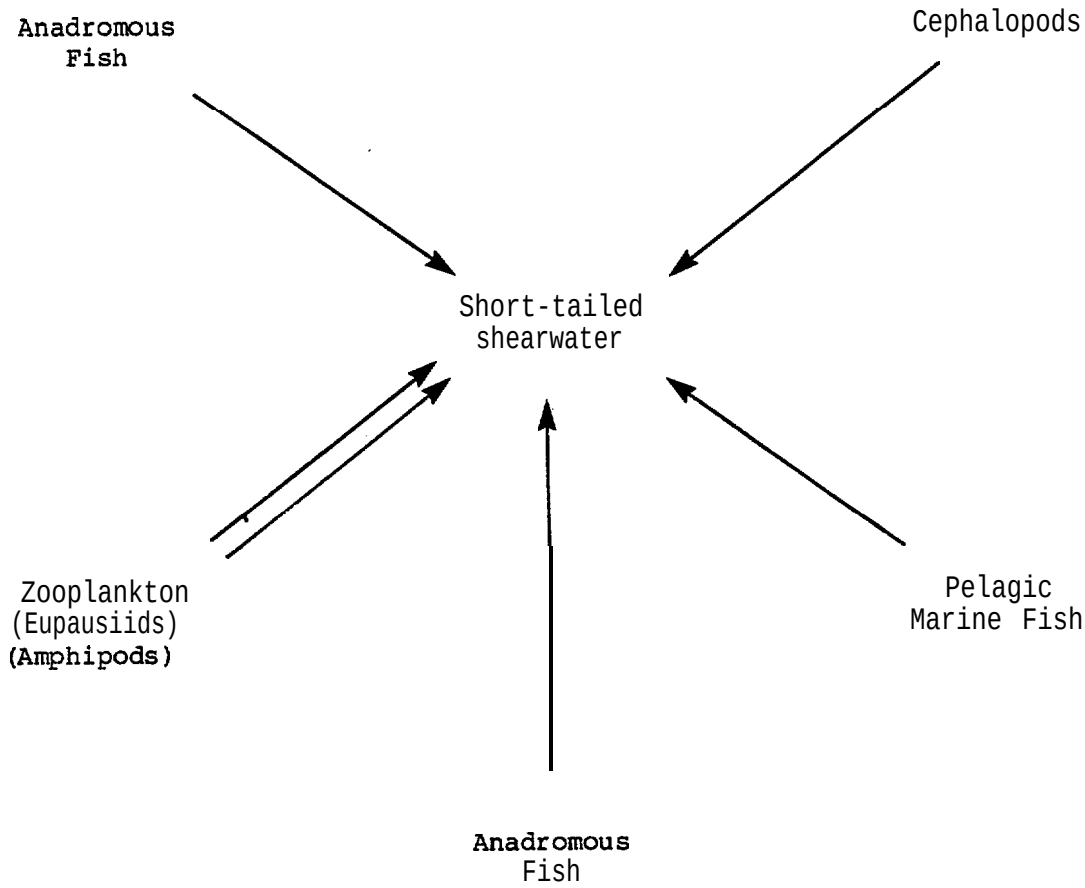


Figure 113. Basic trophic interactions of short-tailed shearwaters. Double lines indicate primary reliance.

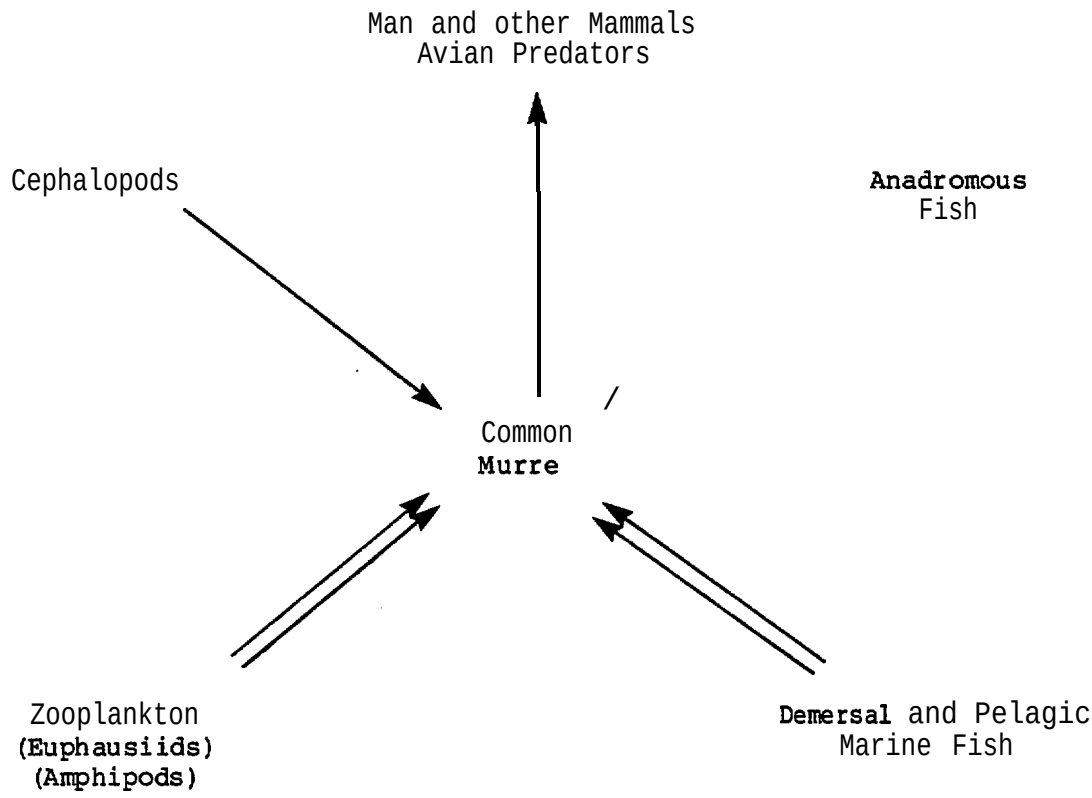


Figure 114. Basic trophic interactions of common murres. Double lines indicate primary reliance.

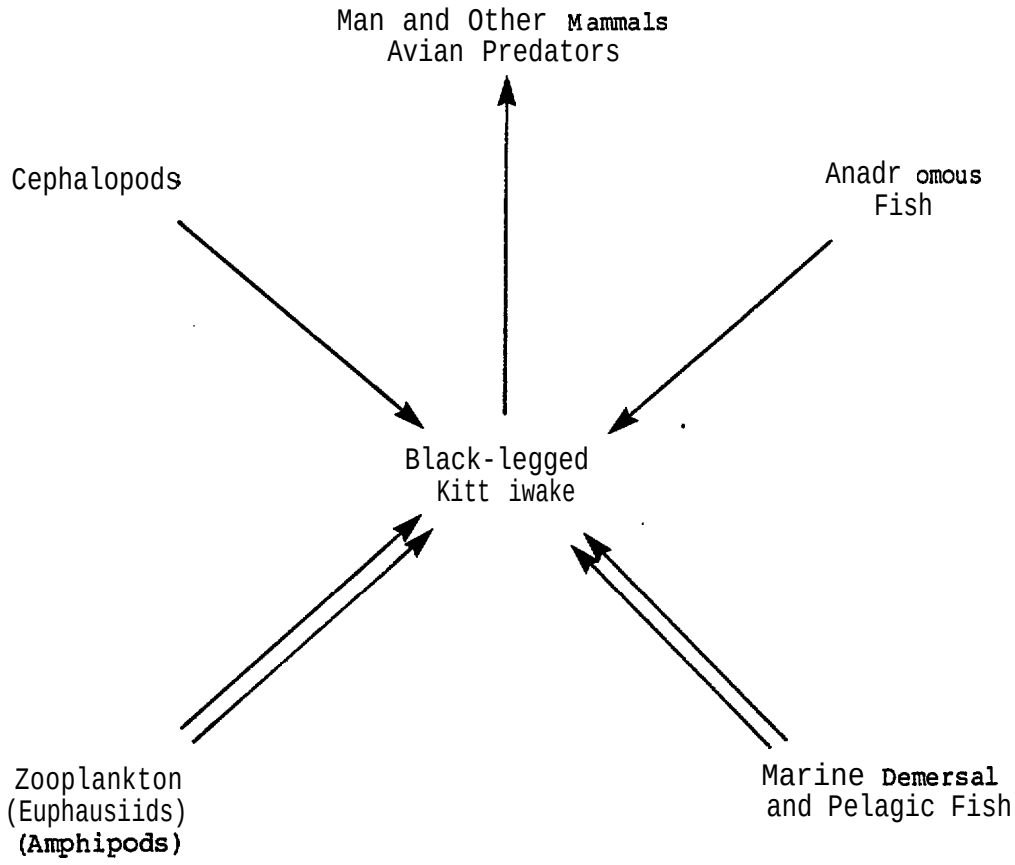


Figure 115. Basic trophic interactions of black-legged kittiwakes. Double lines indicate primary reliance.

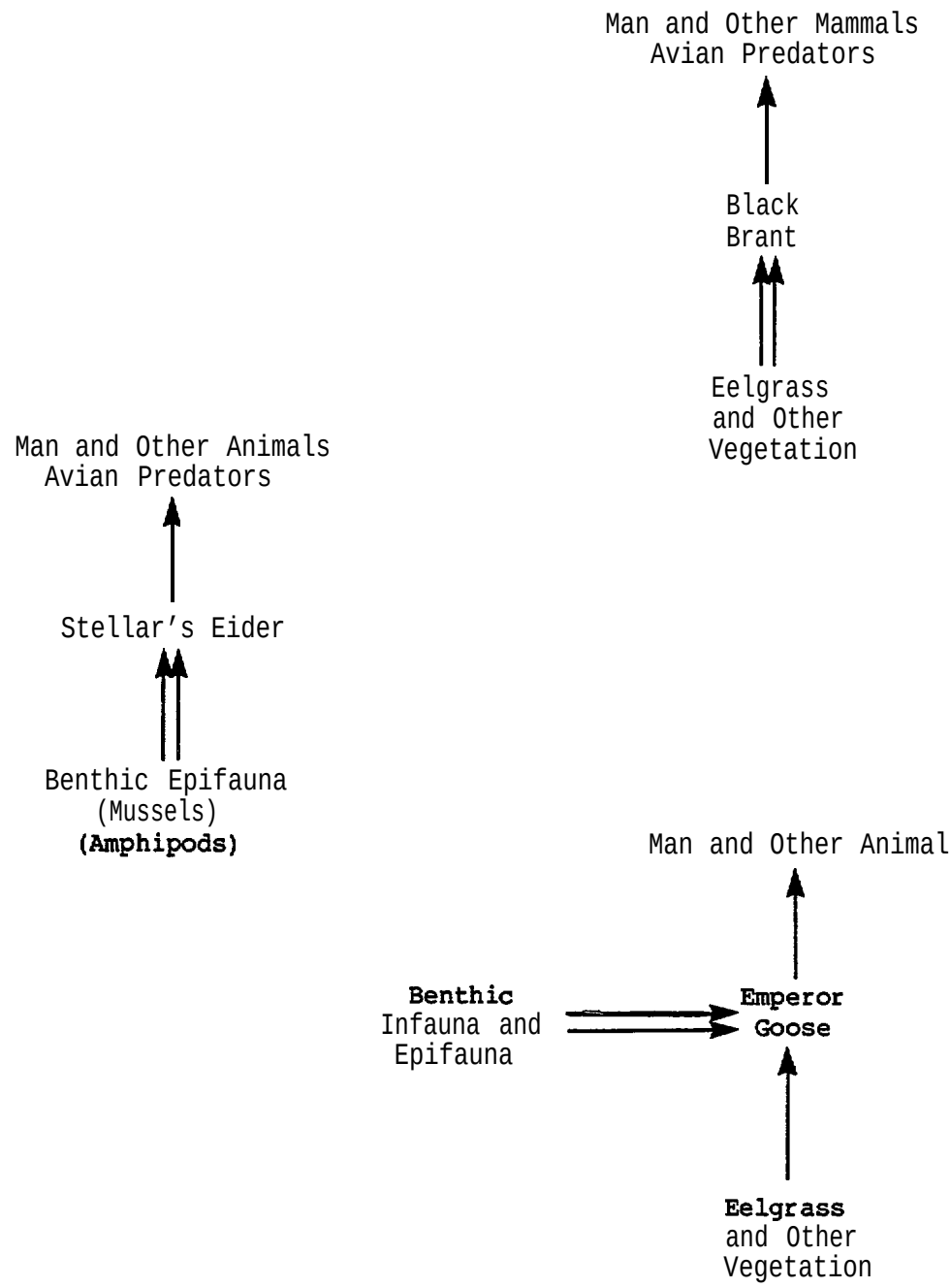


Figure 116. Basic trophic interactions of waterfowl. Double lines indicate primary reliance.

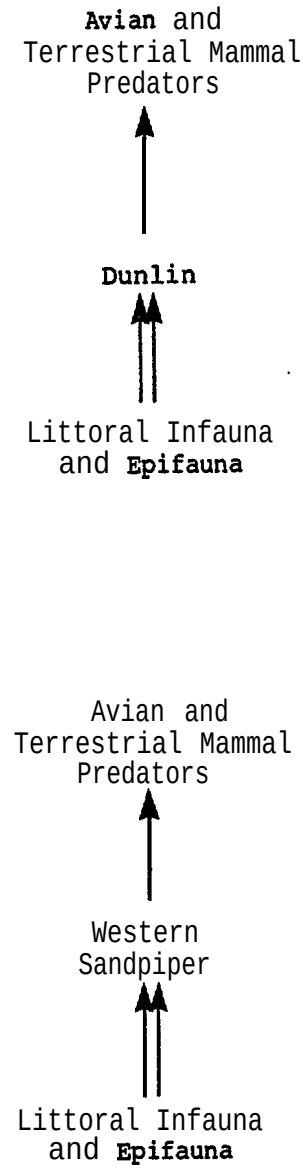


Figure 117. Basic trophic interactions of shorebirds. Double lines indicate primary reliance.

Shore birds are considered to be primarily third trophic level predators (Gill and Handel, 1981).

Like waterfowl, shorebirds are most vulnerable to predation during the nesting period, when young and eggs are consumed by most terrestrial mammal and avian predators of the region. At other times, they are taken to some extent by avian predators such as hawks and falcons.

d. Habitat Characterization

A classification of all shoreline types from Unimak Island to Cape Newenham is presented in Michel et al (1982), supported by earlier reconnaissance studies by Sears and Zimmerman (1979). A physical description of exposed coastal waters and protected nearshore waters from Unimak Island to Port Heiden is summarized in Armstrong et al (1982). The unprotected shoreline from Unimak Island to Port Heiden is comprised, for the most part, of large segments of coarse-grained sand beaches. This shoreline is also interspersed with small sections of mixed sand and gravel beaches. Coarse-grained beach vegetation is dominated by American dune grass (*Elymus* sp.), forming a dense carpet on the sand dunes backing beaches (Armstrong et al, 1982). The major embayments (i.e. , Izembek Lagoon, Port Moller, Nelson Lagoon and Port Heiden) mainly consist of sheltered tidal flats and marshes (Armstrong et al, 1982). Bristol Bay is made up of a variety of shoreline types; however, mixed sand-grain beaches and exposed tidal flats dominate (Michel et al, 1982).

The north coast of the Alaska Peninsula is generally characterized by long stretches of high-energy beaches interrupted by major estuaries and lagoons such as Bechevin Bay, Izembek Lagoon, Port Moller, Port Heiden, Ugashik Bay, and Egegik Bay. Inner Bristol Bay consists, on the eastern side, of low, broad tundra flats separated by large estuaries such as Kvichak Bay, Nushagak Bay, and Kulukak Bay. The coastal habitat of the western part of inner Bristol Bay consists primarily of steep, rocky headlands and nearshore islands dissected by estuaries and straits such as Togiak Bay and Hagemeister Strait.

The nearshore subtidal substrates throughout most of the North Aleutian Shelf and Bristol Bay region is mainly composed of medium-grained sand (0.25-0.5 mm). Portions of inner and northern Bristol Bay are composed of coarse (0.5-1.0 mm) and very coarse (1 .0-2.0 mm) sand. Grain size sorting in the surface sediment is described as "moderately poorly sorted" to "extremely poorly sorted" for most of the shelf; in Bristol Bay the sand is described as "moderately well sorted" to "well sorted" (McDonald et al, 1981). Existing data on distributions of the inshore sediments have

been presented as maps in the earlier section on Geological Setting.

For purposes of physical and biological description, the region may be divided into two major zones or areas: the coast north of the Alaskan Peninsula from Unimak Pass to about Ugashik Bay, and Inner Bristol Bay from about Ugashik Bay around to Cape Newenham. Shoreline habitats of this Bristol Bay area are summarized in Figures 118 through 122. Location of macrophyte habitats are given in Figure 123.

Alaska Peninsula Coast. The northern coast of the Alaska Peninsula can be further subdivided into a western zone, including Unimak Pass, Unimak Island and the tip of the peninsula, and the eastern peninsula from about Izembek Lagoon to Ugashik Bay. Coastal habitats of the western zone would include Unimak Pass and the rocky capes and headlands of Unimak and Amak Islands. The eastern zone is more properly characterized by high-energy sand and gravel beaches interrupted by major estuaries and lagoons and, infrequently, by headlands such as Cape Seniavin.

Within the western zone of this northern Peninsula coast, sensitive habitats are considered to be Unimak Pass, the capes and headlands of Unimak Island, and Amak Island.

Unimak Pass is of particular importance for several species of marine mammals, marine birds and anadromous fish, both as forage grounds and as a migration route. The entire gray whale population enters and exits the Bering Sea twice a year via Unimak Pass, as does most of the northern fur seal population, along with the central Bering Sea complement of sperm whales, and numerous other cetaceans and pinnipeds.

Unimak Pass is also the principal migration route for major marine bird and waterfowl populations, including shorttailed and sooty shearwaters, common and thick-billed murres, Leach's and fork-tailed storm petrels, fulmars, and various species of gulls, guillemots, puffins, auklets, eiders, scaups and scoters. In addition to its importance as a migratory route, Unimak Pass provides a year-round feeding habitat for large numbers of marine birds and sea ducks, and for marine mammals such as harbor seals and sea lions.

Severe ecological disruption of Unimak Pass habitats might be particularly disastrous during spring and fall when migrations of marine mammals and birds are at their peak. Catastrophic or chronic perturbations of Unimak Pass at any time of year would have negative impacts on at least several species of marine mammals and birds; particularly harbor seals, sea lions, sea otters, possibly gray whales and fur

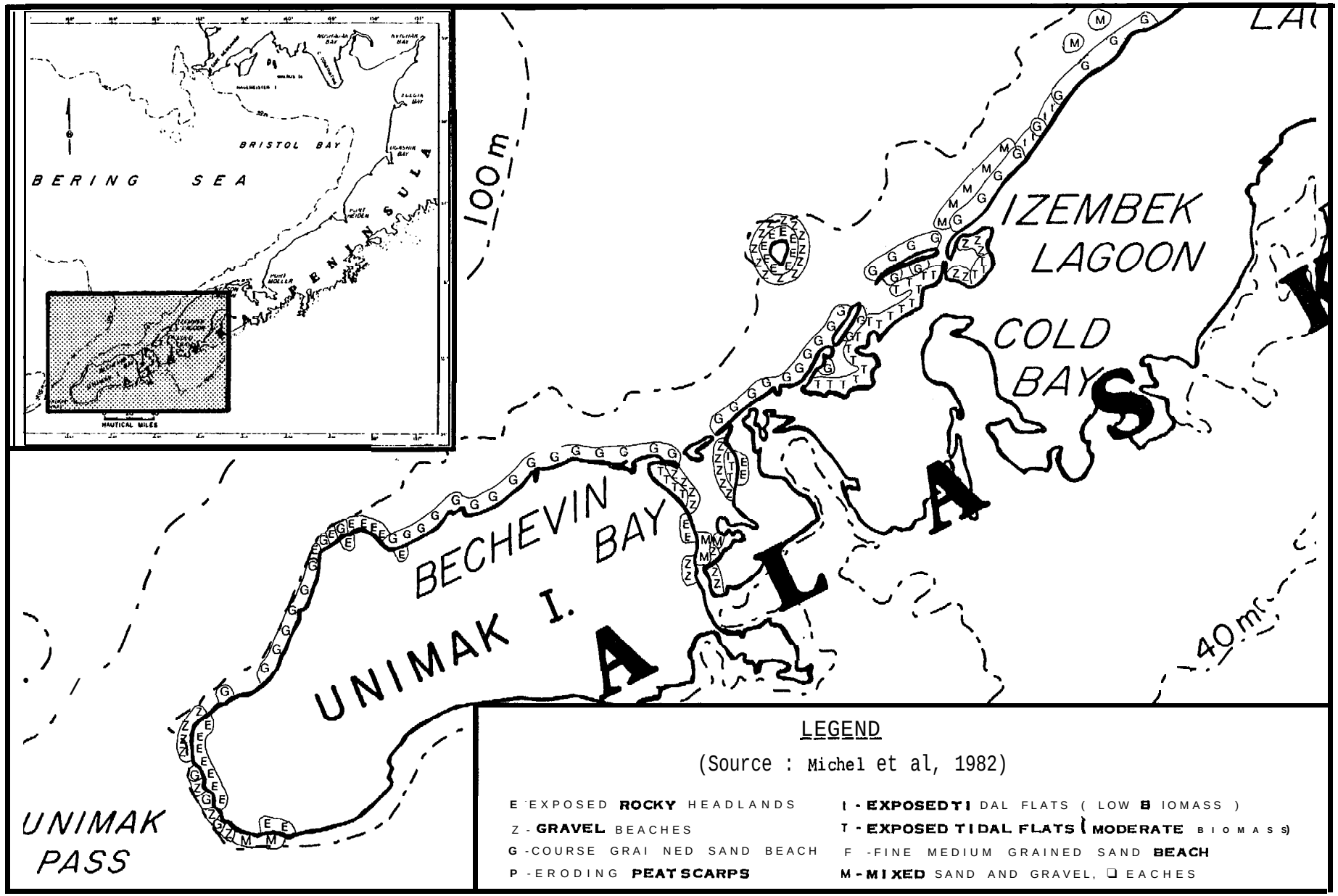


Figure 118. Bristol Bay coastal habitats, Unimak Island - Izembek Lagoon area.

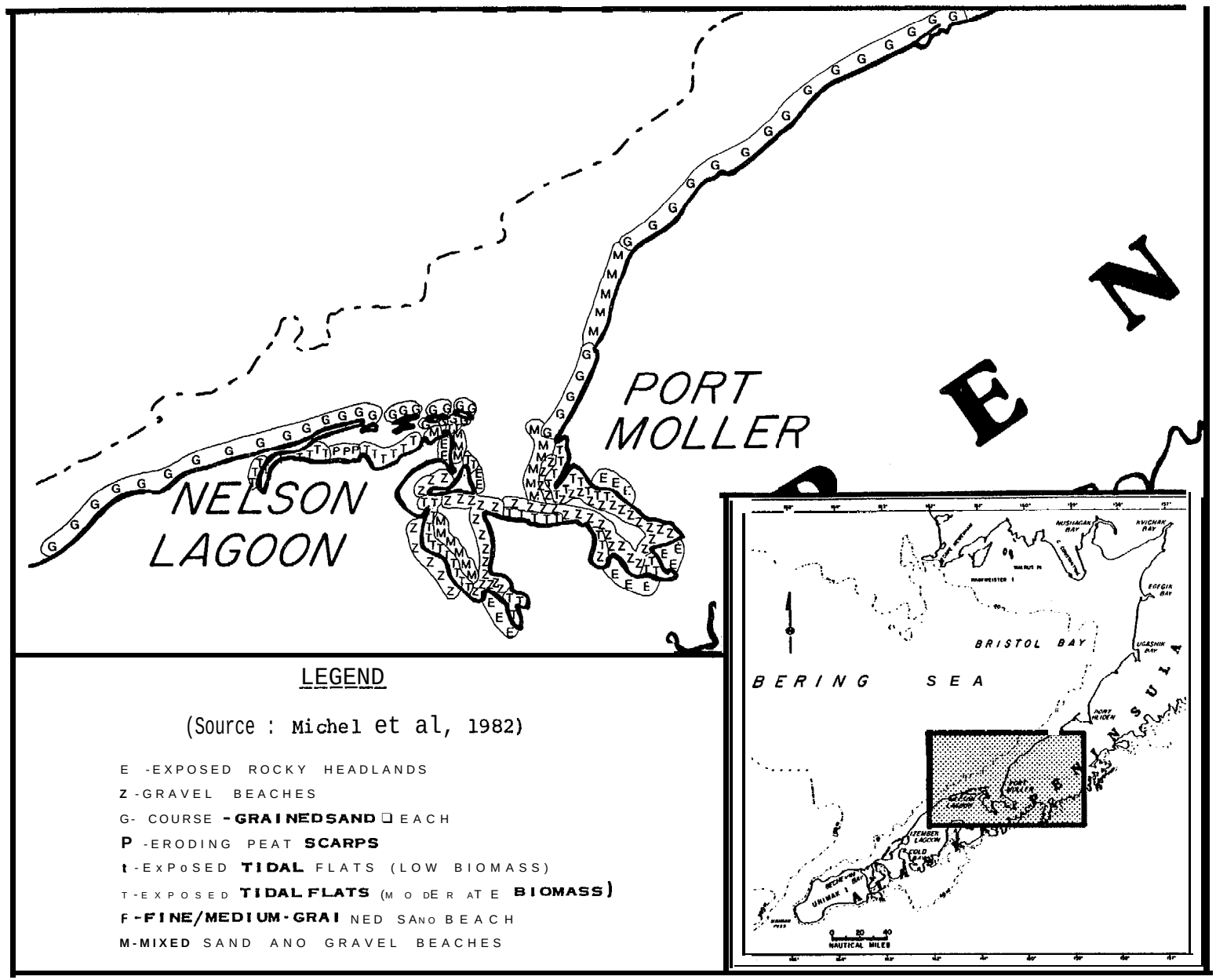


Figure 119. Bristol Bay coastal habitats, Port Moller area.

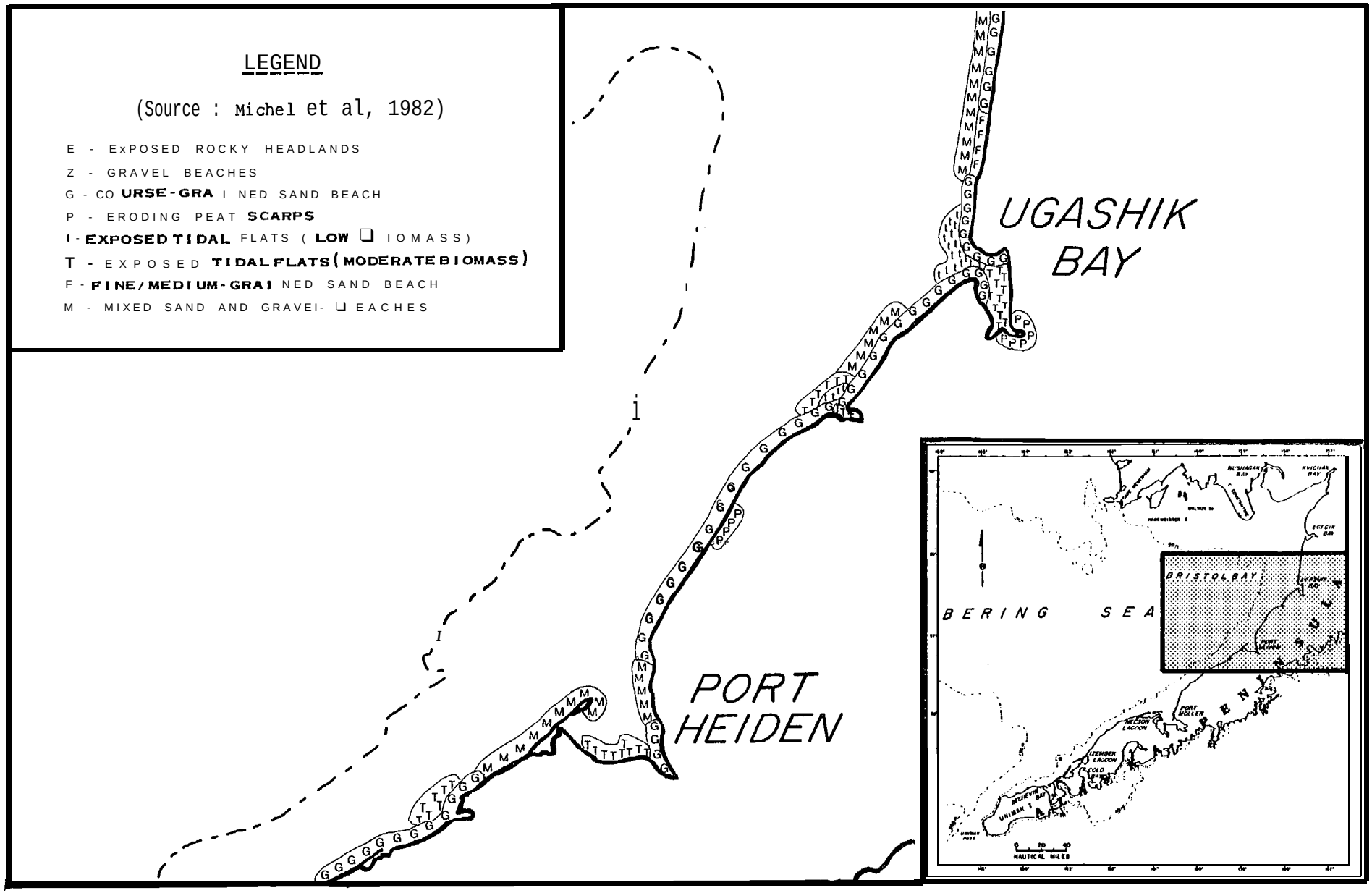


Figure 120. Bristol Bay coastal habitats, Port Heiden - Ugashik Bay area.

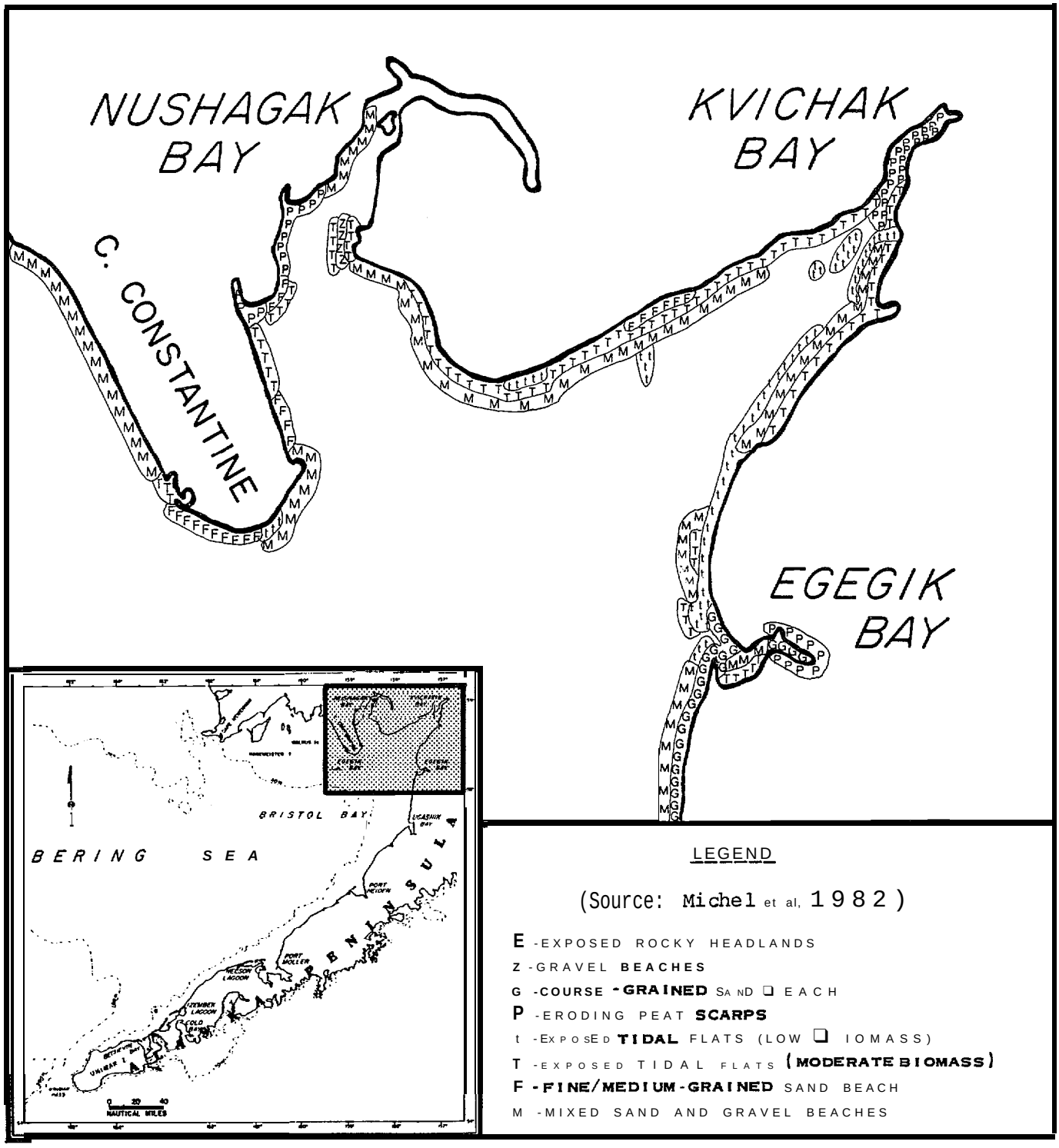


Figure 121. Bristol Bay coastal habitats, Kvichak Bay area.

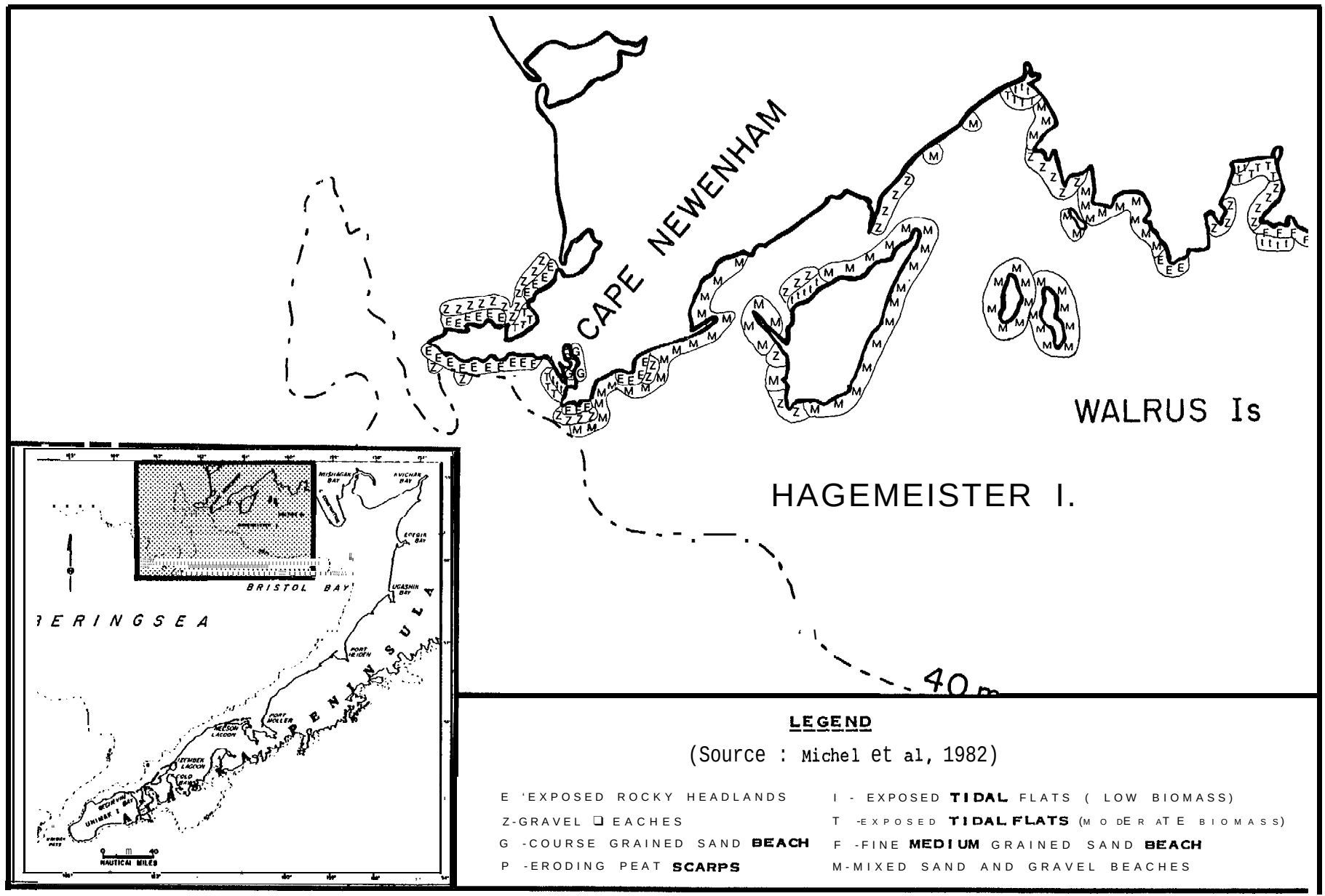
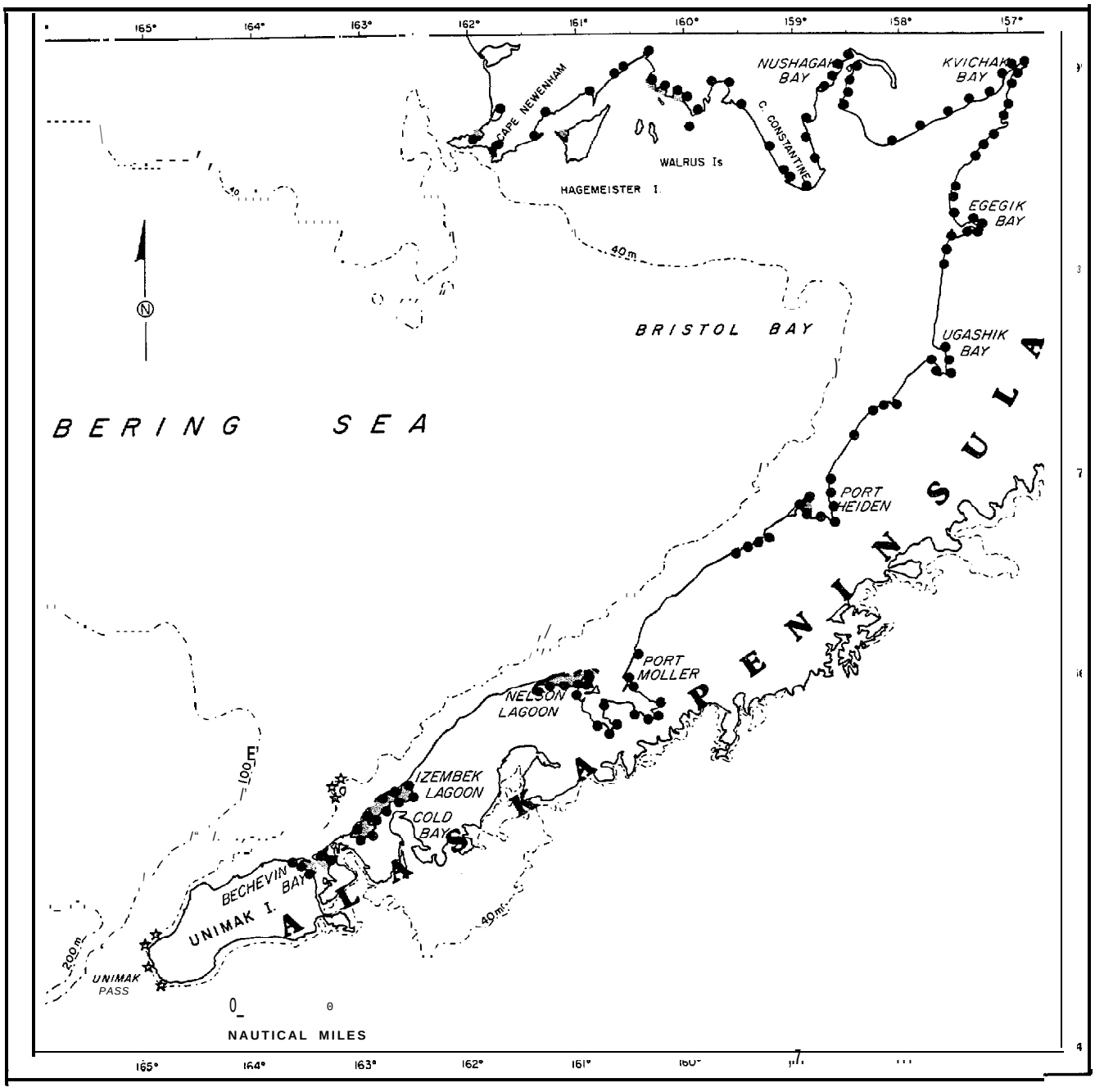


Figure 122. Bristol Bay coastal habitats, Togiak Bay - Cape Newenham area.



● - MARSHES (after Michel et al, 1982) - EELGRASS (McRoy , 1970)

* - KELP BEDS (Mc Roy - personal observation)

Figure 123. Locat ions of major macrophyte habitats.

seals, murres, shearwaters, petrels, puffins, fulmars, kittiwakes, terns, eiders, scoters, scaups, cormorants, guillemots, gulls, and auklets.

Also, Unimak Pass is the principal migration route for both juvenile salmon exiting the region and for adult salmon returning from the North Pacific (Straty and Jaenicke, 1980). Though disturbance effects, other than some knowledge concerning oil toxicity, are not well known for salmon, disruption of these migrations through Unimak and adjacent passes could have deleterious impacts on the largest salmon fishery in North America.

In addition to Unimak Pass itself, sensitive habitats within this western subzone include Cape Mordvinof, Cape Serichef, Otter Point, Urilia Bay and Cape Lapin on Unimak Island, Bechevin Bay on the Alaska Peninsula, and certainly Amak Island. All of these locales provide nesting habitats for marine birds, particularly cormorants and puffins on Unimak Island and for murres, kittiwakes and gulls on Amak Island (Sowls et al, 1978). These locales also are used intermittently as hauling sites, breeding rookeries, or forage zones for marine mammals such as harbor seals, Steller sea lions, and sea otters. Amak Island supports the only breeding rookery of Steller sea lions within the area (Braham et al, 1980).

Along the eastern region of the Alaska Peninsula coast, locales of critical or sensitive habitat include the lagoon estuary systems which seasonally support almost all of the region's population of harbor seals (Everitt and Braham, 1980). These areas are used also as molting, feeding, and staging areas for the world population of black brant, emperor goose, and Steller's eider. They are probably also critical for cackling Canada goose, dunlin, western sandpiper, and other species of shorebirds and waterfowl, and provide nursery grounds for anadromous and marine fish, including various salmon species, smelt, herring, capelin, and eulachon. The lagoons and estuaries are used extensively as forage, hauling, pupping, and molting habitat by harbor seals and as a forage and calving grounds by beluga whales (Straty and Jaenicke, 1980; Warner and Shaffold, 1981; Everitt and Braham, 1980; Brooks, 1955; Alaska Department of Fish and Game, unpublished data).

The critical or sensitive estuary and lagoon systems under consideration are Izembek Lagoon, the Port Moller complex including Nelson Lagoon, Port Heiden, Cinder River, and Ugashik Bay. It is known that shorebird and waterfowl abundances in the lagoons and bays steadily increase along the coast from Ugashik Bay to Izembek Lagoon (Gill et al, 1981). Sources of the birds' nutrition also increase along the coast in a southwesterly direction (Gill, personal communication). If this same trend also is true for other trophic levels and groups of consumers, then the major bay and lagoon habitats could be ranked in importance to the well-being of the communities they support.

Other sensitive habitats along the northern coast of the Alaska Peninsula include Cape Seniavin, Seal Island, and other islands, capes and headlands which are used, seasonally and/or intermittently, as nesting habitats for marine birds (particularly glaucous-winged gulls) and as hauling and/or pupping and moulting grounds for walrus, harbor seals, and sea lions.

Disturbance of these areas would have maximum impact during spring (April-May), summer (June-August) and early fall (September-October), when shorebirds and waterfowl are congregating in the estuaries and lagoons during the spring and fall migrations, during the post-breeding and molting period (Gill et al, 1981), and when marine mammals (beluga whale and harbor seal) are concentrated within and adjacent to lagoons and estuaries (Lowry et al, 1982).

Inner Bristol Bay. Like the Alaska Peninsula-Aleutian area, inner Bristol Bay can be viewed as essentially two habitat zones - eastern Bristol Bay and western Bristol Bay.

Eastern Bristol Bay includes the vast estuaries, intertidal flats, and low tundra coasts of Egegik Bay, Nushagak Bay and Kvichak Bay. These estuaries are known to support very large populations of forage fish (e.g. smelt, herring, capelin, and eulachon) and host the largest and most productive salmon fishery in North America (Stern et al, 1976). Probably because of this, they are also concentration areas for beluga whales, harbor seals, and harbor porpoises during the summer, and provide overwintering habitats for sea ducks (e.g. eiders, scoters, and scaups) (Gill et al, 1981). For reasons which probably relate more to migratory pathways than to forage potential, the extensive intertidal flats of eastern Bristol Bay are not used extensively by waterfowl and shorebirds as staging areas during spring and fall migrations (Gill et al, 1981).

Sensitive habitats within this eastern Bristol Bay area are Egegik Bay, Kvichak Bay, and Nushagak Bay. Perturbation effects might be particularly critical during the late spring and summer when the estuaries are most heavily used by forage fish, immigrating and outmigrating salmon, and marine mammals and birds. Chronic or periodic perturbations, however, could have long-term effects on any or all of these populations. The open-water zones of this region are also used as an overwintering habitat by large numbers of sea ducks (e.g. Steller's and king eiders, scoters, scaups, and oldsquaws), during which time they would be particularly susceptible to oil spills.

Sensitive and critical habitats of western Bristol Bay are primarily rocky headlands, capes and nearshore islands such as Round Island, Walrus Island, Cape Peirce, Cape

Newenham, Hagemeister Island, The Twins, High Island and Rocky Point. The rock cliffs of these locales provide nesting habitats (along with Amak Island and Capes Mordvinof and Seniavin) for almost all of the seabirds of the region including about one million common murres and several hundred thousand black-legged kittiwakes (Sowls et al, 1978). They also (primarily Round Island) are the focal point and principal hauling ground of the summer populations of walrus and Steller sea lions (Fay, 1982; Lowry et al, 1982). The vicinity of Cape Peirce is also used to a major extent by waterfowl (particularly black brant, emperor goose, and Steller's eider) during spring and fall migration to and from breeding grounds on the Yukon-Kuskokwim Delta and the Alaska-Siberia coast of the Bering and Chukchi Seas (Petersen and Sigman, 1977).

Effects of man-induced disturbance would be felt most during late spring and summer (May-August), when marine birds are nesting and when walrus and sea lions are concentrated on non-breeding hauling grounds.

Summary of Distribution of Key Biota. The biological utilizations of these nearshore habitats have been described earlier in the characterization of biological processes. Figures 125 through 130 summarize the resulting distributions of important or key species within these inshore habitats of Bristol Bay.

Conclusions . Critical or sensitive habitats within the region include Unimak Pass, Cape Mordvinof, Cape Sarichef, Cape Lapin, Otter Point, Bechevin Bay, Kudiakof Island, Izembek Lagoon, Amak Island, Cinder River, the Port Moller complex, Cape Seniavin, Seal Islands, Strogonof Point and the Port Heiden complex, Ugashik Bay, Egegik Bay, Kvichak Bay, Nushagak Bay, Kulukak Bay, Togiak Bay, Hagemeister Strait, Hagemeister Island, Cape Newenham, Cape Peirce, Round Island, Walrus Island, Crooked Island, The Twins and High Island.

Habitats or migratory routes used intensively within the regions of the Alaska Peninsula and inner Bristol Bay are important to several species of marine mammals, birds, and fish. Particularly critical areas include Unimak Pass, Izembek Lagoon, Amak Island, the Port Moller and Port Heiden complexes, Cinder River, Cape Seniavin, Ugashik, Egegik and Kvichak Bays, Nushagak Bay, Kulak Bay, Round Island, Cape Peirce and Cape Newenham.

Wider dispersed habitats, such as spawning and juvenile rearing areas for crab, sole, and forage fish are also of prime importance. Of similar importance are those areas utilized by sea otters, other marine mammals, migratory and feeding salmon, and for inshore bird feeding.

e. Key Species

Descriptions of key or indicator species at the upper trophic levels can be found in Appendix B. The format in which this material is presented is descriptive and includes distributions, commercial importance, population status, and life history and ecosystem relationships.

The species listed have been selected on the basis of 1) importance in food web relationships, 2) commercial value, 3) vulnerability to oil-spill effects, and 4) the amount of information available. Species selected are listed below.

Marine mammals

Harbor Seal
Steller Sea Lion
Pacific Walrus
Gray Whale
Beluga Whale
Sea Otter

Birds

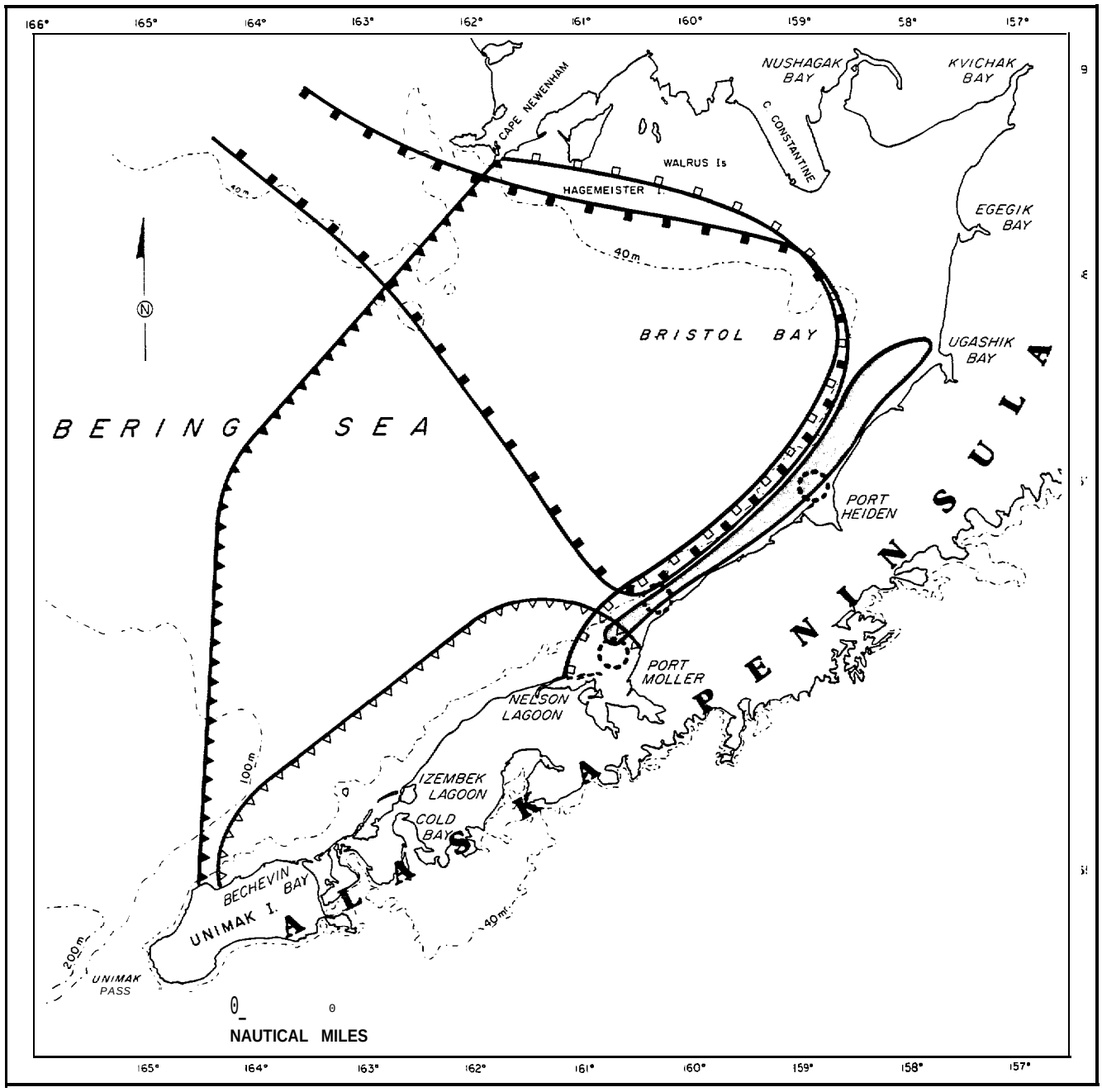
Common Murre
Short-Tailed Shearwater
Black-Legged Kittiwake
Black Brant
Emperor Goose
Steller's Eider
Dunlin
Western Sandpiper

Invertebrates

Red King Crab
Great Alaska Tellin
Asterias amurensis
Alaska Surf Clam

Fish

Sockeye (Red Salmon)
Boreal (Rainbow) Smelt
Yellowfin Sole
Pacific Herring
Capelin



RED KING CRAB
OVERALL DISTRIBUTION
(after Otto et al, 1981)

RED KING CRAB
AREA OF MAJOR LARVAE
HATCH ING, MATING & SPAWNING
(after Takeuchi, 1962; Haynes, 1974; ARMSTRONG et al, 1981; Otto et al, 1981; VTN Oregon, 1983 a, b, c)

RED KING CRAB
AREA OF MAJOR LARVAE
SETTLEMENT AND
JUVENILES (after Haynes, 1974; Armstrong et al, 1981; Otto et 01,1981 ;VTN Oregon, 1981 a,b)

GREAT ALASKAN TELL I N
(after McDonald et al, 1981)

ALASKAN SURF CLAM
(Pinkneck Clam)
(after Hughes & Bourne, 1981)

Fig. 124. Distribution of red king crab and clams in Bristol Bay.

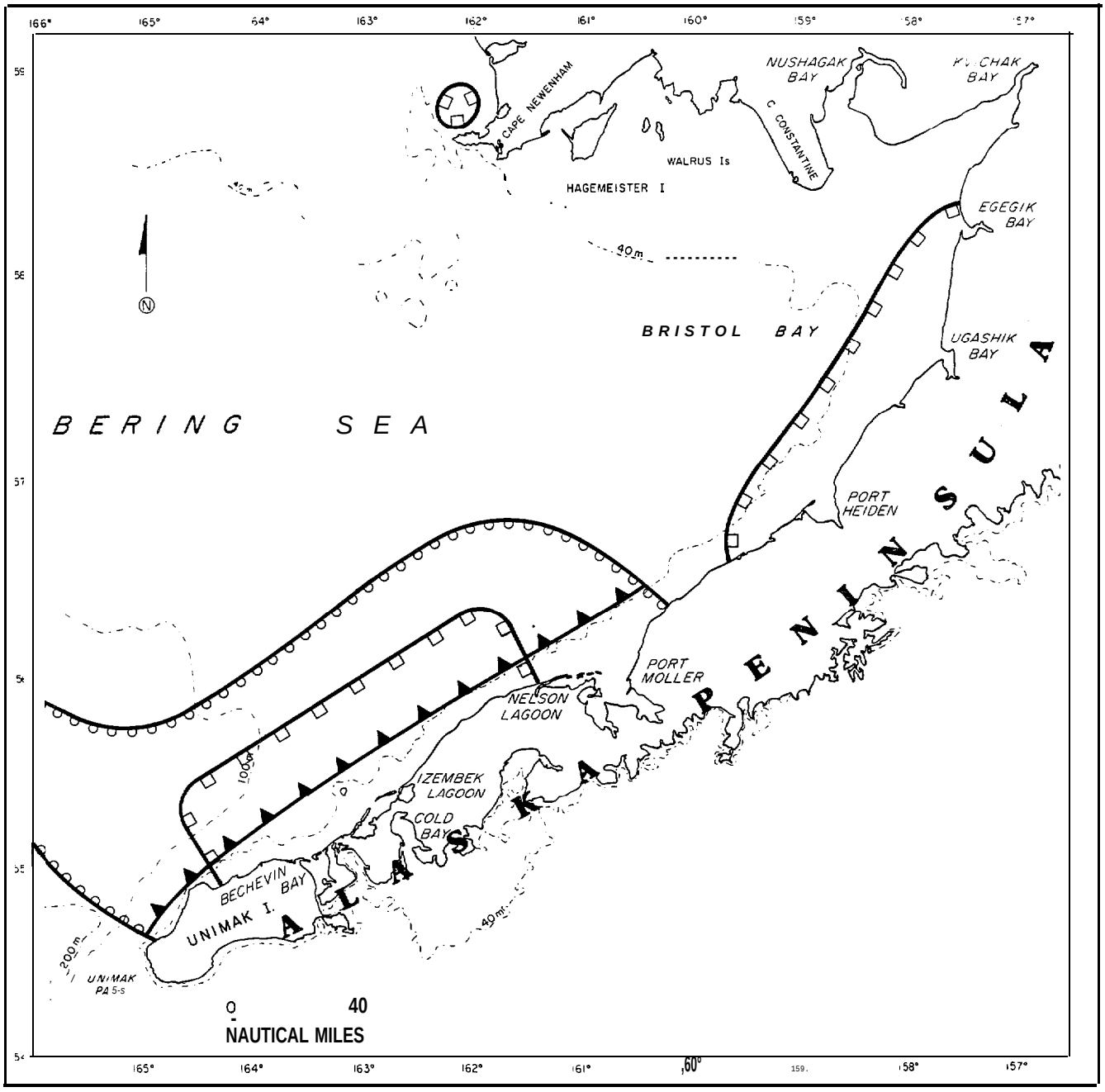
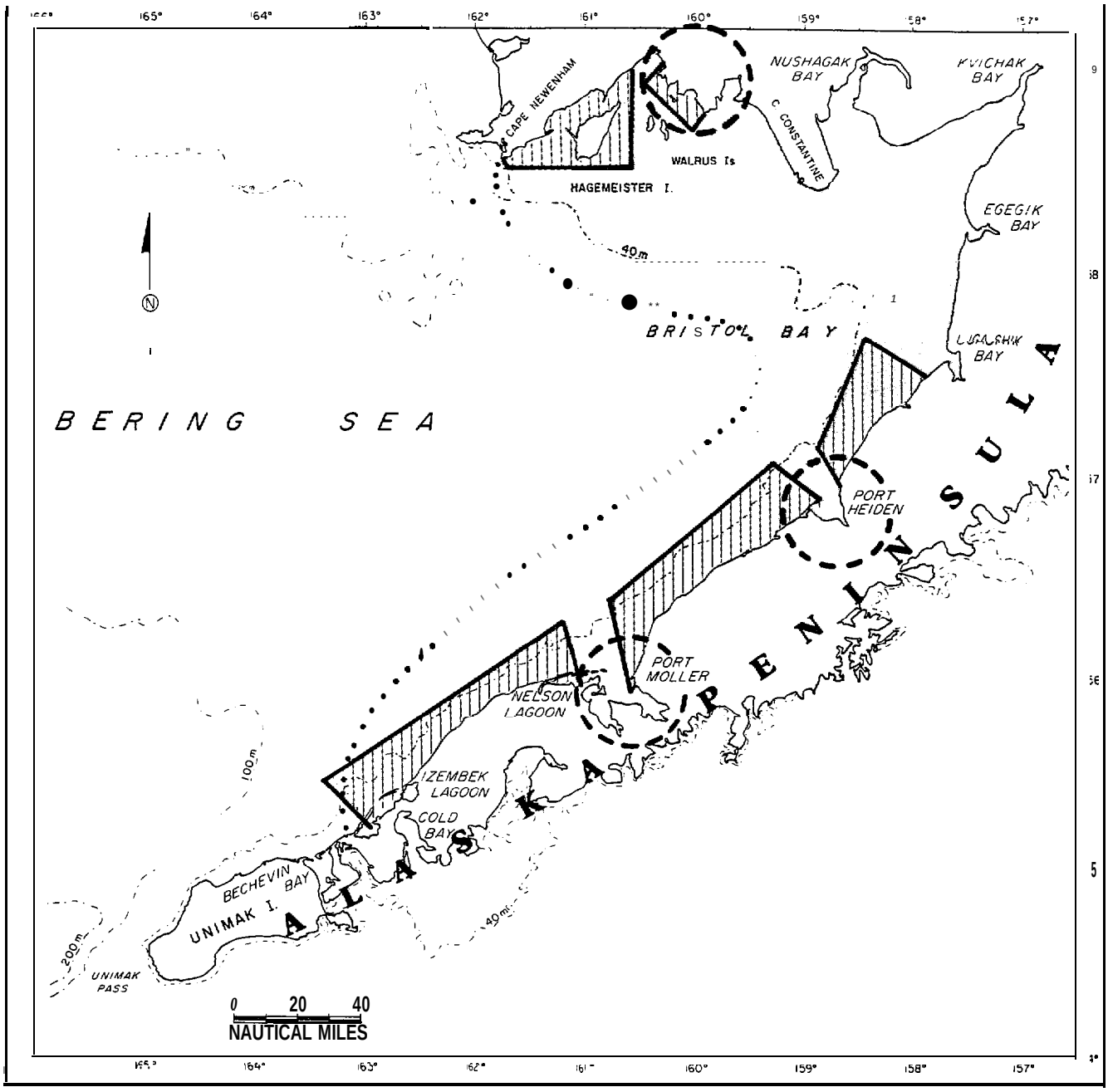


Fig. 125 . Distribution of Tanner crab and areas of high infaunal biomass in Bristol Bay.

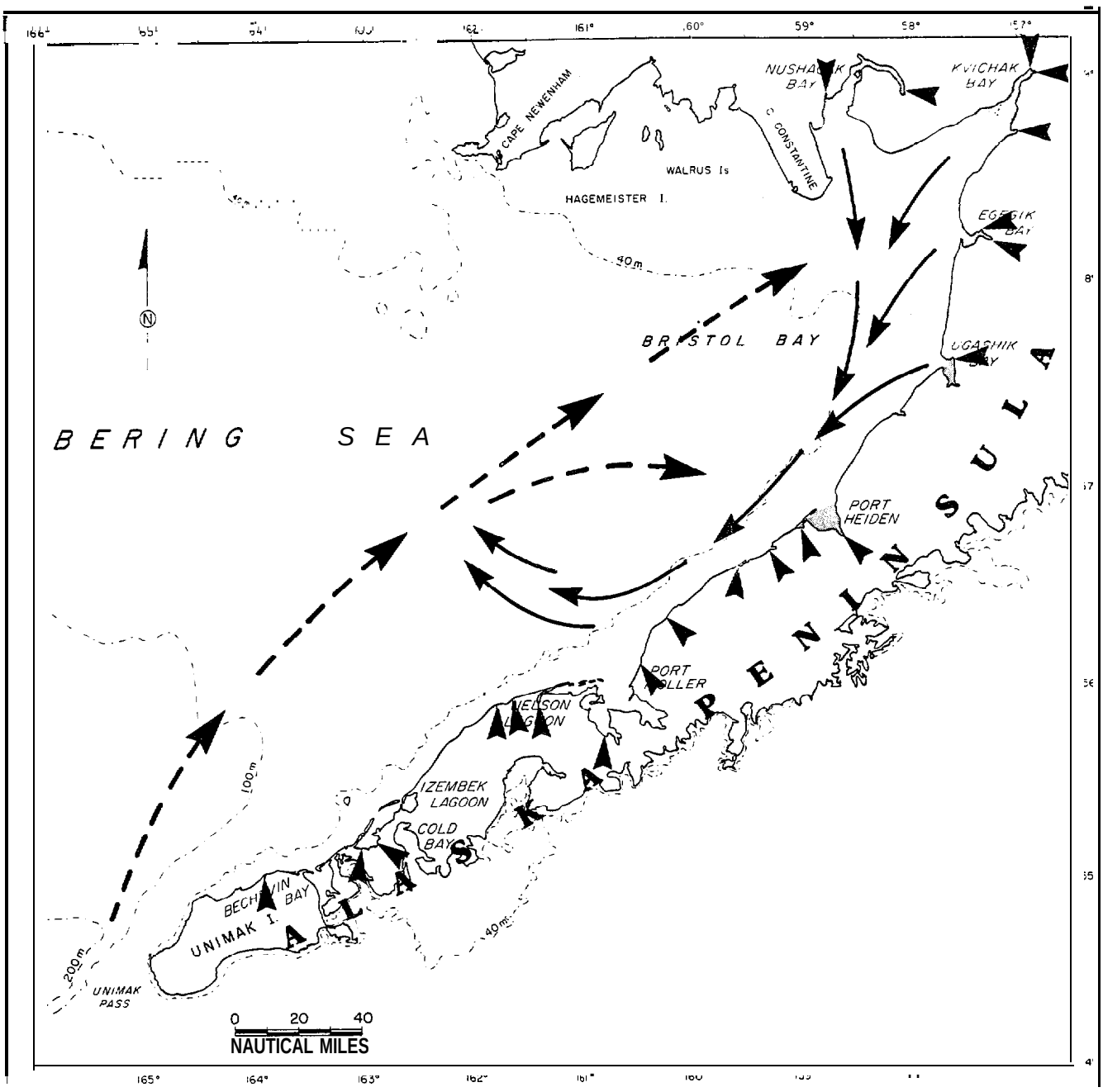


- PRIMARY HERRING SPAWNING (after Barton et al, 1977)

- YELLOWFIN SOLE DISTRIBUTION (after Bakkala, 1981a)

- PRIMARY CAPELIN SPAWNING (after Barton et al, 1977)

Fig. 126 . Distribution of important inshore fishes in Bristol Bay.



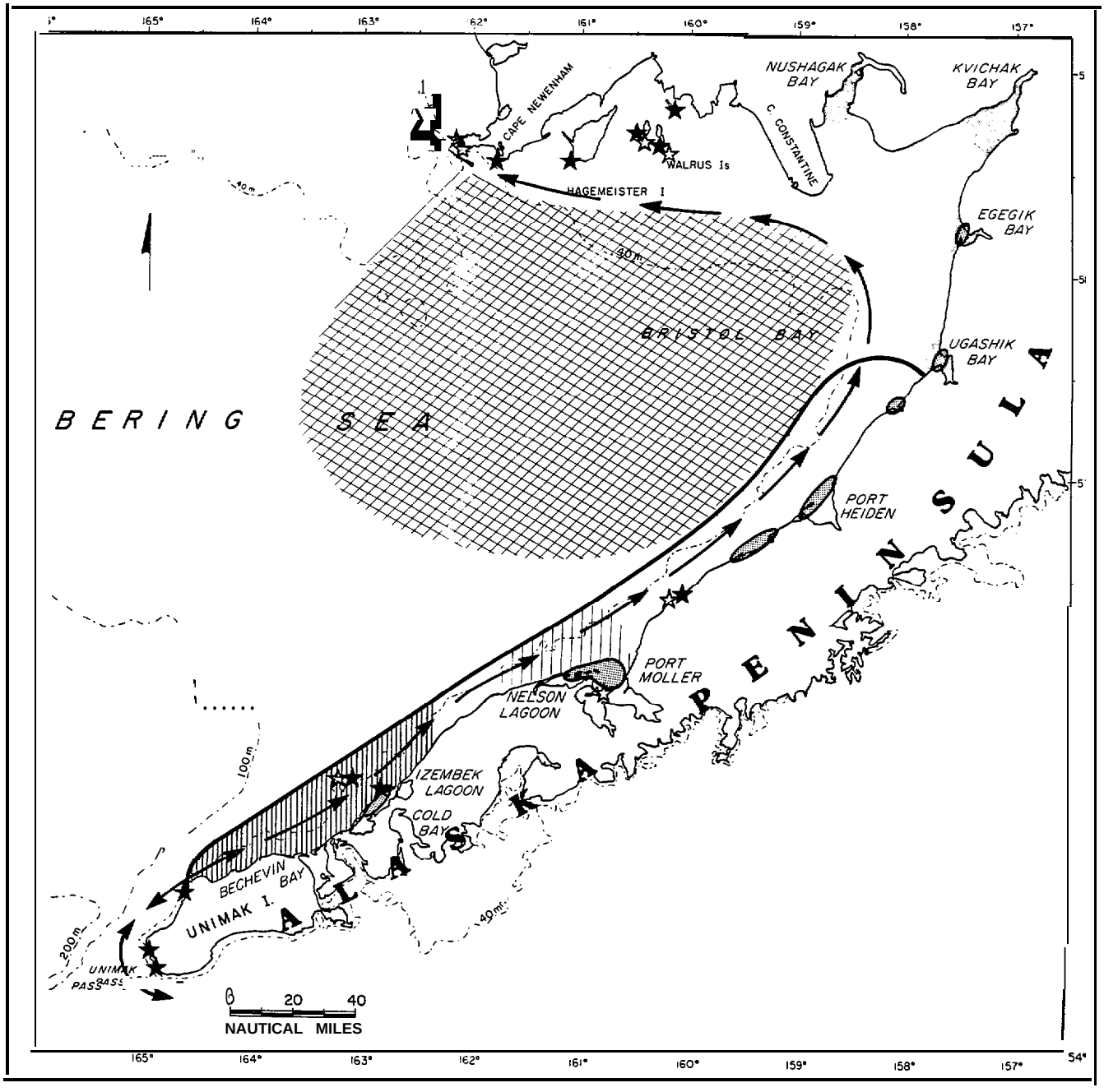
LOCATIONS OF JUVENILE SOCKEYE SALMON

PROBABLE CONCENTRATIONS OF BOREAL SMELT

JUVENILE SALMON MIGRATION ROUTE

ADULT SALMON MIGRATION ROUTE

Figure 127. Salmon migration paths in Bristol Bay.



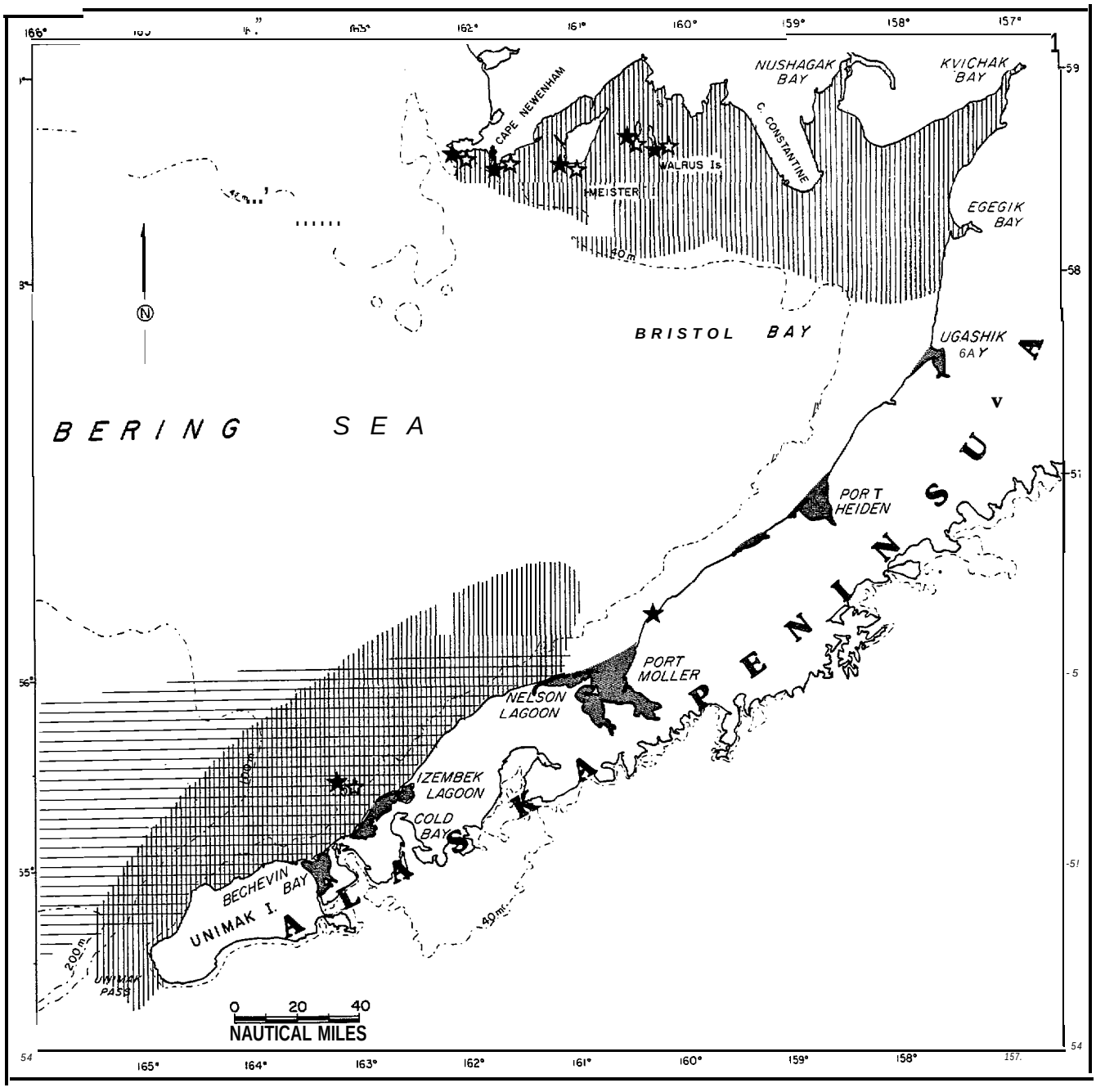
SEA OTTER RANGE
LOW DENSITY
MEDIUM DENSITY
HIGH DENSITY

★ KNOWN SEA LION ROOKERIES
☆ MAJOR KNOWN WALRUS HAULOUTS
CONCENTRATIONS OF HARBOR SEALS
MAJOR BELUGA CONCENTRATIONS

NORMAL WINTER DISTRIBUTION OF WALRUS, SPOTTED SEAL, BEARDED SEAL & RINGED SEAL.

GREY WHALE MIGRATION ROUTE

Figure 128. Distribution of important inshore marine mammals in Bristol Bay.



- SHOREBIRD & WATERFOWL SEASONAL CONCENTRATIONS

* - BLACK-LEGGED KITTIWAKE NESTING COLONIES

- AREAS OF SHEARWATER ABUNDANC

★ - MURRE NESTING COLONIES

- MURRE WINTER CONCENTRATIONS

Figure 129. Inshore distribution of key marine bird species in Bristol Bay.

HYPOTHESES OF ECOLOGICAL PROCESSES

The Bristol Bay area is exceptionally rich in wildlife and marine resources. The inshore regions of Bristol Bay have been shown in particular to be heavily utilized by ecologically important species and by those of major commercial importance. An understanding of these ecological processes which govern the inshore system is fundamental to the management of these resources. In particular, such an understanding is essential to assessing vulnerabilities and conflicts associated with oil and gas development.

The observed high utilization of these inshore areas is explained by two basic factors, that of food availability and that of suitable habitat. Sufficient food resources to support the high utilization must either be produced within the nearshore zone, or be transported into this zone by physical processes or by biological migratory processes.

In the case of Bristol Bay, the nearshore habitat is an interface between the rich marine resources of the southeastern Bering Sea and the rich resources of the river/lake and lagoon/estuary systems. Thus, in addition to feeding activity, much of the distribution of biota in this nearshore zone can be explained by the habitat requirements necessary to life cycle needs, such as spawning s-ubstrates, haulout sites, migratory corridors, and so on.

The first section of the hypotheses of controlling ecological processes explains the possible organic carbon budget used to examine the basic food relationships operative in the nearshore zones of Bristol Bay. The second section summarizes the habitat factors that contribute to the observed biotic distributions.

1. Carbon Budgets for the Coastal Domain

a. In-situ and Terrestrial Sources

Ecosystem dynamics in the coastal domain are determined in a basic way by the oceanography. To the extent that the physical oceanography of the region is understood, it is possible to construct a hypothesis explaining the functional controls of the food webs and how material and energy are transferred in the system. We have approached this problem by constructing carbon budgets for the region. We divided the inner shelf into two regions, the north Peninsula coast, and inner Bristol Bay (Figure 130). The justification for this division, although somewhat arbitrary, is based on the oceanography. The boundary approximately follows the position of the 31 ppt isohaline in summer (Ingraham, 1981).

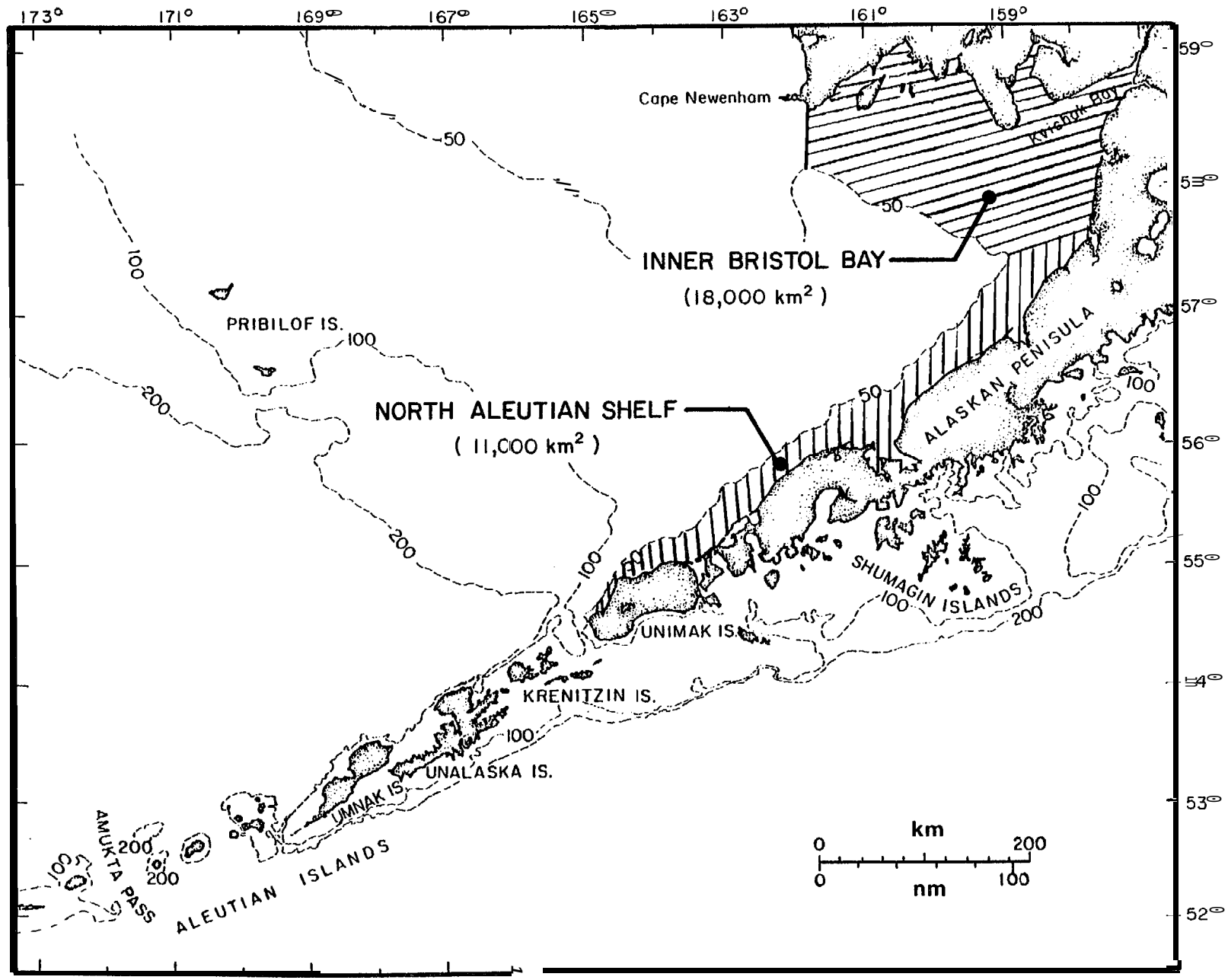


Figure 30. Subareas utilized for carbon budget calculations.

Inside this boundary the shelf is characterized by low salinity due to the several rivers emptying into Bristol Bay, to less concentrated sources of run-off along the Alaska Peninsula, and to inflow of low salinity water with the coastal current.

As reviewed earlier in the physical oceanography section, the shelf of the southeastern Bering Sea is characterized by three fronts that divide the shelf into three oceanographic domains (Coachman et al, 1980). The 0-5 km zone of the shelf is an indistinguishable part of the inner shelf or coastal domain. Consequently, we treat this as a single biological and oceanographic region bounded by the inner front, occurring over the 40-50 meter isobath, and the land boundary. This domain is normally characterized by an unlayered, well-mixed water column in which tidal mixing from the bottom overlaps with wind mixing from the surface. The mean flow acts as a conveyor belt, transporting water (2-5 cm/see) parallel to the coast along the Alaska Peninsula and into Bristol Bay (Kinder and Schumacher? 1981b), and then outward along the northern coast. This mean inshore flow may be more or less continuous with coastal flow southward along the south coast of the Peninsula and through Unimak Pass. However, cylonic storm events, on the frequency of approximately three to five events per month, undoubtedly dominate processes such as onshore/offshore transport and transport of nutrients from offshore into the coastal domain, including periods of longshore current reversals. Under these conditions, stratification can also develop within the coastal domain.

The inner Bristol Bay region receives more than twice the volume of freshwater from rivers as does the North Aleutian Shelf (50 vs 20 km^3/yr; U.S. Geological Survey, 1980). We calculate the area of the North Aleutian Shelf to be 11 x 10^9 m^2 and that of inner Bristol F3ay to be 18 x 10^9 m^2; the area of adjacent bays and lagoons is estimated to be 2 x 109 m^2.

The basis of any marine food web is the primary production of phytoplankton plus any organic detritus, added to the system by advection. In the coastal domain organic detritus can become quantitatively important and this is the major difference in similar budgets constructed for the outer and middle domains of the southeastern Berina Sea (Walsh and McRoy, 1983). In both the north Peninsula coast area and inner Bristol Bay we estimate the production by phytoplankton to be 90 g C/m^2 for the spring bloom and 25 gC/m^2 for the summer, resulting in a total annual production of 115 g C/m^2 (Figures 131 and 132). The contributions of dissolved and particulate carbon from rivers in these two areas are 12.4 g $C/m^2/yr$ for inner Bristol Bay and 10 a $C/m^2/yr$ for the north Peninsula coast area. These estimates were calculated from the carbon concentration and river flow data in each area. In the Peninsula

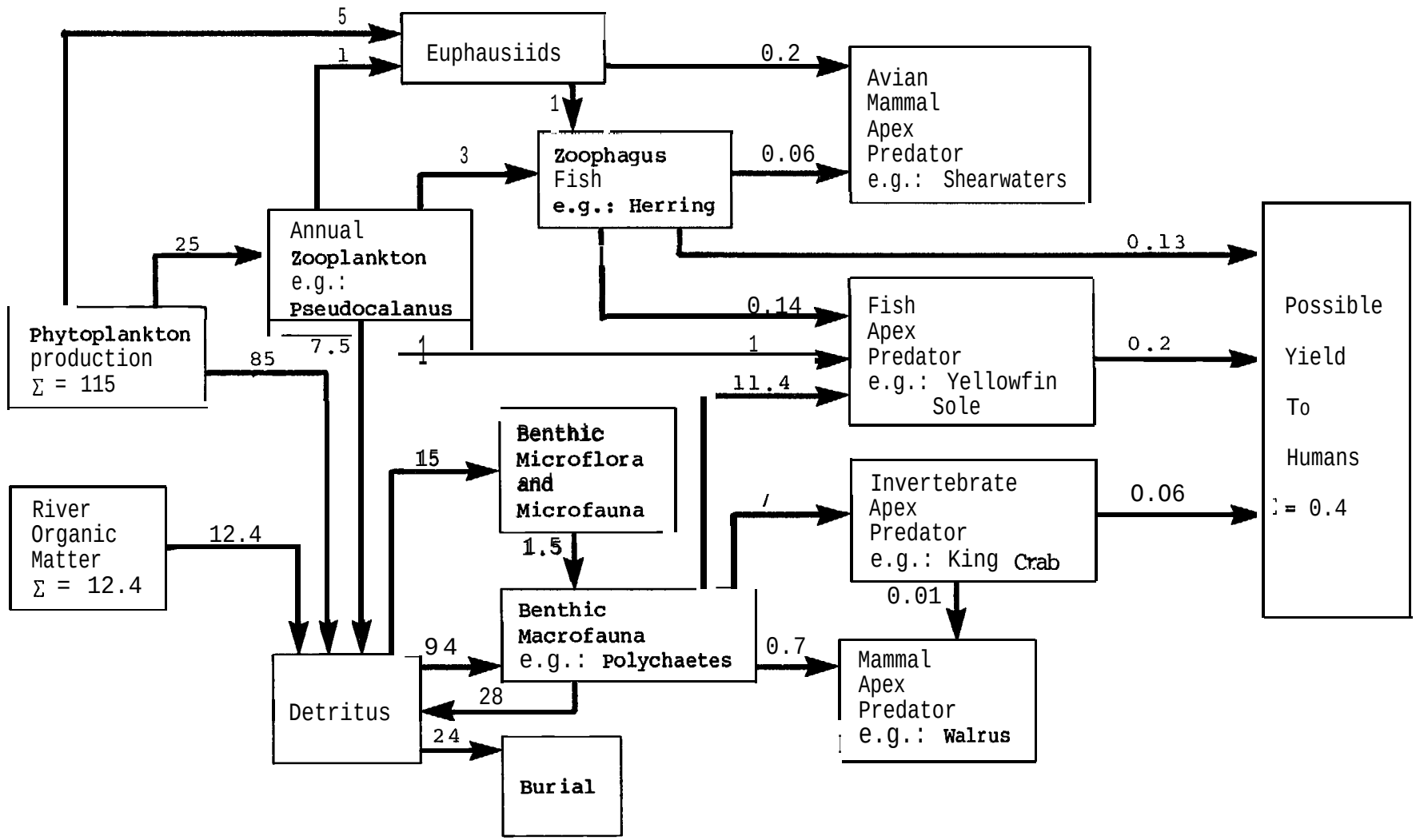


Figure 131. Hypothetical carbon budget (g m^{-2} yr^{-1}) for inner Bristol Bay (18 x 10^9 m^2).

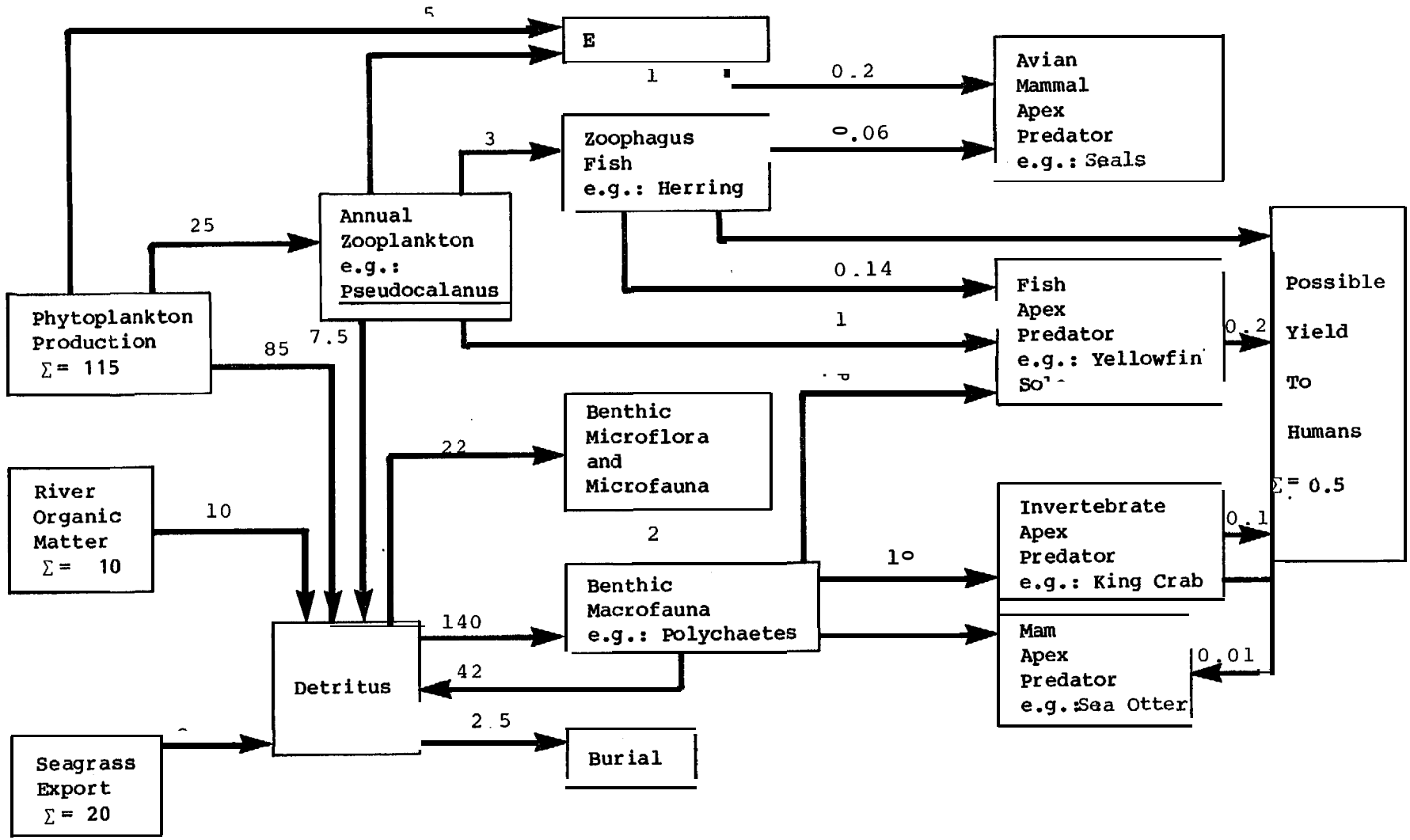


Figure 132. Hypothetical carbon budget (g m^{-2} yr^{-1}) for the North Aleutian Shelf (11 x 10^9 m^2).

area there is a third component in the budget, that of eelgrass detritus from the bays and lagoons. The major stand of eelgrass on this coast is in Izembek Lagoon and it is estimated that this single lagoon exports as much as 14 g $C/m^2/yr$ to the ocean. Further, we estimate t_hat other eelgrass areas may contribute as much as 6 g $C/m^2/yr$ for a total of 20 g $C/m^2/yr$. This budget assumes that the eelgrass is distributed evenly across the shelf, but this is probably not true. A given area, such as that just north of Izembek Lagoon, may receive a much higher amount.

Using the extensive work done in the southeastern Bering Se-a under PROBES and OCSEAP, we propose that the coastal domain supports primarily a benthic food web (Iverson et al, 1979). Consequently, due to the low abundance of zooplankton (Cooney and Coyle, 1982), most of the algal production and other detritus is probably ungrazed by pelagic herbivores and sinks to the bottom. In the coastal shelf as in the middle shelf, the" macrobenthos reaches its highest recorded abundance (Haflinger, 1981). The estimate for zooplankton consumption in the coastal shelf is the same as that calculated for the middle shelf by PROBES investigators (Walsh and McRoy, 1983). As in other studies, we use an assimilation efficiency of 70 percent, hence, 30 per cent of ingestion is returned as fecal matter. The same assumption was used for benthic macrofauna. Ecological transfer efficiencies of 20 per cent were assumed for zooplankton, euphausiids, and benthic macrofauna, while for other trophic components 10 per cent was used. In the absence of data, we assumed the euphausiid ingestion to be half that of the middle shelf since the water is shallower than their preferred depth range (S. Smith, personal communication).

The benthic food web is the major feature of the coastal shelf. Haflinger (1981) indicates that benthic biomass in the north Peninsula coastal area is approximately the same as that in the middle shelf; whereas that in inner Bristol Bay is only about two-thirds of the middle shelf. We have used these proportions in our calculations of benthic trophic dynamics. The carbon transfer to the. benthic microflora and microfauna in both the outer and middle shelf is estimated to be 22-29 g $C/m^2/yr$ (K. Haflinger and H. Feder, personal communication) and we used this value for the coastal area (applying the above proportions) . Again relying on the calculations of Feder and Haflinger, we used their estimate of 28 g $C/m^2/yr$ for middle shelf secondary production to get a consumption of 142 and 95.5 g $C/m^2/yr$ in the two areas (Figures 131 and 132).

The middle and coastal shelf of the Bering Sea is the habitat of numerous benthic predators. The region has large fisheries for yellowfin sole and king crab and contains large numbers of walruses, sea otters, and gray whales. The

amount of carbon consumed by these upper trophic levels in the coastal zone is largely guess work, and the same proportions were used here as those calculated for the middle shelf by Walsh and McRoy (1983). A further assumption was necessary to deal with animal populations in upper trophic levels in which the life of the animal can span several harvestable year classes. For estimating the yield to humans of fish and invertebrate predators, a Production/Biomass ratio of 0.1 was used. In contrast, for zoophagous fish such as herring and smelt, a P/B ratio of one was used.

As a check on the budget, we can calculate the carbon requirement of the 10,000 to 20,000 walrus that are resident in the area. Stoker (1981) calculates that a walrus can consume 16,300 kg wet wt/animal/yr which is five percent carbon. If the walrus only feed in the north Peninsula coastal area (probably not true) they would consume 1 .1 g $C/m^2/yr$. The carbon budget predicts 1.01 g $C/m^2/yr$ for this trophic level. This is a good agreement but suggests that the mammals, king crab and yellowfin sole may be competing for the benthos or we have overestimated the requirement of apex fish, birds, and invertebrate predators.

The carbon budget estimated for the north Peninsula coastal area, with only 1.5 percent of the carbon left for burial, is balanced but that for inner Bristol Bay has 18 percent of the carbon left for burial or export. Further, in both regions there is potentially a large yield of herring, smelt and similar fishes. Both budgets indicate the importance of detritus to the food webs of the coastal shelf. The potential yield of both regions is less than the 0.6-0.7 estimated for the middle and outer shelf.

b. Migratory Sources

The above carbon budget for the coastal domain is based upon in-situ productivity and carbon input from lagoons and rivers. Upon consideration of the information available, it seems likely that two, essentially independent, trophic systems are operational within the nearshore shelf zone of Bristol Bay, the Alaska Peninsula, and the proximal Aleutian Islands. One of these systems is probably more or less self-contained and endemic. The other is probably a seasonal "import-export" system. Of course, the two systems overlap to some degree.

The endemic (so to speak) system includes primary productivity, both marine and lagoonal/terrestrial, which is generated within the nearshore shelf zone, and which supports most, if not all, of the zooplankton, benthic epifaunal and infaunal, and marine fish productivity of the region. Most or all of the higher trophic level marine

mammal and bird species probably rely on this endemic system for nutritional maintenance to varying degrees.

There may also be a parallel "import/export" system, seasonal and pulsating in nature, comprised of the huge runs of anadromous fish which utilize the area, and their retinue of predators. The hypothesis in this regard is that these migratory populations of anadromous (and in some cases marine) fish such as salmon, smelt, herring, capelin, and eulachon satisfy most of their energy and growth requirements in other marine or, in the case of juvenile salmon, freshwater environments and "import" this biomass in seasonal pulses into the nearshore zone.

Supportive data are lacking but are needed. Some estimate of the relative importance of such an import system to the nearshore zone can be made, however, by considering just the out-migrating salmon smelt and the in-migrating adult salmon. Data given earlier in the characterization sections indicate that mean numbers of 500 million out-migrating smelt and 18 million in-migrating adult salmon pass through the inshore area each year. Converting this biomass to carbon on a year basis yields some 10^{10} gm C/yr, compared to some 10^{12} gm/yr contributed by primary productivity. Considering these migratory fish to be two to three trophic levels above primary productivity, and assuming a ten percent transfer efficiency, this amount of carbon is at least roughly equivalent to the amount at this trophic level expected to be derived from the in-situ primary productivity. Of course, much of this migratory carbon is not utilized in the inshore system, but is simply passed through.

It is conjectured, however, that these seasonal pulses of imported energy resources may be critical to the maintenance of the particularly high populations of some top predators, especially beluga whales and harbor seals; perhaps also to Steller sea lions and marine birds which frequent the area. It is perhaps of some significance in this regard that all of these predators either disperse or depart from the area in the fall, coinciding with the departure from the area of such migratory fish species.

2. Habitat Requirements

A consideration of key species serves to illustrate the high utilization of habitats in the coastal zone. In many cases, the distributions of these species in the nearshore zone are determined by specific habitat requirements. Table 15 summarizes the use of, and requirements for, various nearshore habitats for the selected key species. Many of the species that occupy the nearshore region of Bristol Bay and the Alaska Peninsula do so either on a seasonal basis or only during certain stages of their life cycle. It should

be emphasized that these species may be critically dependent on their habitats for reproduction or growth even though the time span they inhabit the neritic zone is limited.

One example of a required habitat is the macrophyte beds consisting of kelps, rockweeds and eelgrass along the shallow coastal waters of the eastern Bering Sea. These areas are utilized as a spawning substrate by the Pacific herring during the spring. Subsequent to spawning and summer feeding in the nearshore zone, herring migrate offshore to overwinter in colder, deeper waters.

Dunlin extensively utilize the littoral and supra-littoral areas of Bristol Bay and the Alaska Peninsula. They use these areas upwards of six months for nesting, breeding, foraging, and roosting prior to the fall migration. Also, approximately one-half of the world's population of black brant seasonally depends upon the habitat of Izembek Lagoon.

The sea otter population is concentrated in the nearshore zone (although they have been sited as far out as 30 miles) primarily due to feeding habitats. Sea otters mainly consume sessile invertebrates, and feed on these between the intertidal zone and depths of 40-60 meters. Apparently their distribution is further limited by prey availability coastal configuration, and the extent of winter sea ice.

Table 15. Inshore habitat usage by key species.

Key Species	Use of Habitat	Inshore Habitat Requirements
Marine Mammals		
Harbor Seal (**Phoca vitulina**)	Haul-out, Pupping, Molting, and Feeding	Sheltered rocks and beaches Inshore food resources: fish, , cephalopods, crustaceans.
Stellar Sea Lion (**Eumetopias jubatus**)	Haul-out Rookeries Feeding	Rocks and beaches throughout Bristol Bay Rookeries in the Fox Islands and on Amak Island. Opportunistic feeding: finfish, squid, octopus.
Pacific Walrus (**Odobenus rosmarus divergius**)	Haul-out Feeding	Rocky areas or beaches, especially northern islands in Bristol Bay. Benthic feeding: bivalve mollusks.
Gray Whale (**Eschrichtius robustus**)	Migratory Corridor Feeding	Migration in inshore zone, some summer use. Benthic feeding inshore: benthic infauna and epifauna, especially gammmarid amphipods.

Table 15. Inshore Habitat Usage by Key Species (continued).

Key Species	Use of Habitat	Inshore Habitat Requirements
Marine Mammals (cont.)		
Beluga Whale (Delphinapterus leucas)	Feeding	Inshore feeding, primarily in the upper part of Bristol Bay near Nushagak and Kvichak Rivers. Marine and anadromous fish, particularly salmon, smelt, and capelin.
Sea Otter (Enhydra lutris)	Haul-out	Rocks and beaches, primarily between Unimak Island and Cape Leontovich.
	Feeding	Inshore (to 50-60 meters depth); wide range of invertebrates and slow moving fish.

Table 15. Inshore Habitat Usage by Key Species (continued).

Key Species	Use of Habitat	Inshore Habitat Requirements
Birds		
Common Murre (*Uris aalge*)	Nesting/Breeding Over-wintering Feeding	Broad cliff ledges and flat rocky islands. Unknown - probably ice edge. Food source: fish, zooplankton, and squid.
Short-tailed Shearwater (*Puffinus tenuirostris*)	Migration Feeding	Summer utilization of eastern Bering Sea. Food source: euphausiids, fish, carrion.
Black-legged Kittiwake (*Rissa tridactyla*)	Nesting/Breeding Feeding	Vertical cliffs and rocky ledges on the Alaska Peninsula. Variable: small fish and crustaceans.
Black Brant (*Branta bernicla nigricans*)	Migratory staging Feeding	Protected lagoons, principally Izembek Lagoon. Shallow feeding on eelgrass.

Table 15. Inshore Habitat Usage by Key Species (continued).

Key Species	Use of Habitat	Inshore Habitat Requirements
Birds (cont.)		
Emperor Goose (*Philacte canagica*)	Migratory staging Feeding	Lagoons and estuaries, vegetated intertidal zone. Food source: bivalves, dune-associated vegetation, and eelgrass.
Steller's Eider (*Polysticta stelleri*)	Migratory staging and moulting Feeding	Protected lagoons of Bristol Bay and Alaska Peninsula during late summer. Intertidal and shallow feeding on bivalve mollusks and amphipods.
Dunlin (*Calidris alpina*)	Nesting/Breeding Moulting Roosting Feeding Migratory staging	Coastal fringe: Upper littoral areas of the Alaska Peninsula, primarily within estuaries and lagoons.
Western Sandpiper (*Calidris mauri*)	Feeding Roosting Migratory staging	Littoral and supra-littoral areas of lagoons on the Alaska. Peninsula.

Table 15. Inshore Habitat Usage by 'Key Species' (continued).

Key Species	Use of Habitat	Inshore Habitat Requirements
Fishes		
Sockeye (Red) Salmon (*Oncorhynchus nerka*)	Spawning	Stream-lake systems tributary to Bristol Bay and the Alaskan Peninsula; gravel beds.
	Seaward migration (juveniles)	General nearshore migration route along north side of the Alaska Peninsula (mid-May through Sept.) Upper water column during seaward migration.
	Feeding	Food source: zooplankton and small fish.
Boreal (Rainbow) Smelt (*Osmerus mordax*)	Spawning	Freshwater streams.
	Feeding	Inshore food resources: amphipods, polychaete worms, and small fish.
Yellowfin Sole (*Limanda aspera*)	Spawning, Nursery	Broad, nearshore area used for spawning.
Pacific Herring (*Clupea harengus pallasi*)	Spawning	Protected intertidal and shallow subtidal bays, inlets and channels for spawning on macrophytes: kelp, eelgrass, rockweeds, and other substrates.
	Migration	Summer route through nearshore Bristol Bay and Alaska Peninsula.
Capelin (*Mallotus villosus*)	Spawning	Beaches with fine gravel, also subtidal spawning to 60 meters.

Table 15. Inshore Habitat Usage by Key Species (continued).

Key Species	Use of Habitat	Inshore Habitat Requirements
Macroinvertebrates		
Red King Crab (*Paralithodes camtschatica*)	Mating/Spawning and Juvenile development	Broad, shallow area (<50m) along Alaskan Peninsula and northern and inner Bristol Bay.
Great Alaska Tellin (*Tellina* lutes)		Occurs on inner and middle shelf of Bristol Bay; primarily medium to fine sands.
Asterias *amurensis*		Common in shallow waters (<40m).
Alaska Surf Clam (*Spisula polynyma*)		Shallow depths between Port Moller and Ugashik Bay; medium sands to medium silt.

VULNERABILITY TO OIL AND GAS RELATED DEVELOPMENT

1. Identification of Development Activities

The boundaries of the proposed Lease Sale 92 encompass all of Bristol Bay (Figure 133) with probabilities of oil and gas occurrence rated high in much of this offshore area. Therefore, it is not known with surety which offshore locations will experience exploratory drilling and subsequent development. Thus the locations of activities likely to affect the nearshore areas are not known at this time. However, some reasonable estimates of these locations may be made from existing knowledge of the distribution of offshore source rocks and from the geographic locations of suitable onshore support sites.

The Bristol !3ay Tertiary Province (Marlow et al, 1980) is a northwest trending elongate sedimentary basin that parallels the long axis of the Alaska Peninsula and is located on the north side of the Peninsula. The basin extends northeast from the Black Hills for 595 km (370 miles) to about the west edge of Iliamna Lake. The areatest potential for hydrocarbons exists in the southwestern area, the Bristol Bay basin (Figure 133), between Port Moller and Amak Island where the thickest Cenozoic sediment (5000 ft) exists (Marlow et al, 1980). Similar thick potential source rocks exist in the Amak basin (Figure 134) just southwest of the Black Hills uplift. Conditional estimates (Marlow et al, 1980) for these areas of the North Aleutian Shelf for oil and gas resources are as follows:

	Probability		Statistical Mean
	95%	5%	
Oil (billions of barrels)	0.1	2.3	0.7
Gas (trillions of cubic feet)	0.1	5.8	1.5

Therefore, the nearshore areas along the Alaska Peninsula are likely to be affected by development from offshore drilling and production. Also, onshore facilities, particularly those associated with transportation of oil and gas products, are likely to be located along the Alaska Peninsula.

The likely technologies to be used to develop these petroleum resources have been reviewed by Dames and Moore (1980). For exploratory drilling, conditions prevailing in the area are within the present operational capabilities of semi-submersibles, drillships and jackup rigs (in the shallower portions).

The principal technical problem may occur if year-round capability is desired in areas where sea ice is a possibility between January and April. Following the lead of Dome Petroleum in the Canadian Beaufort Sea, where

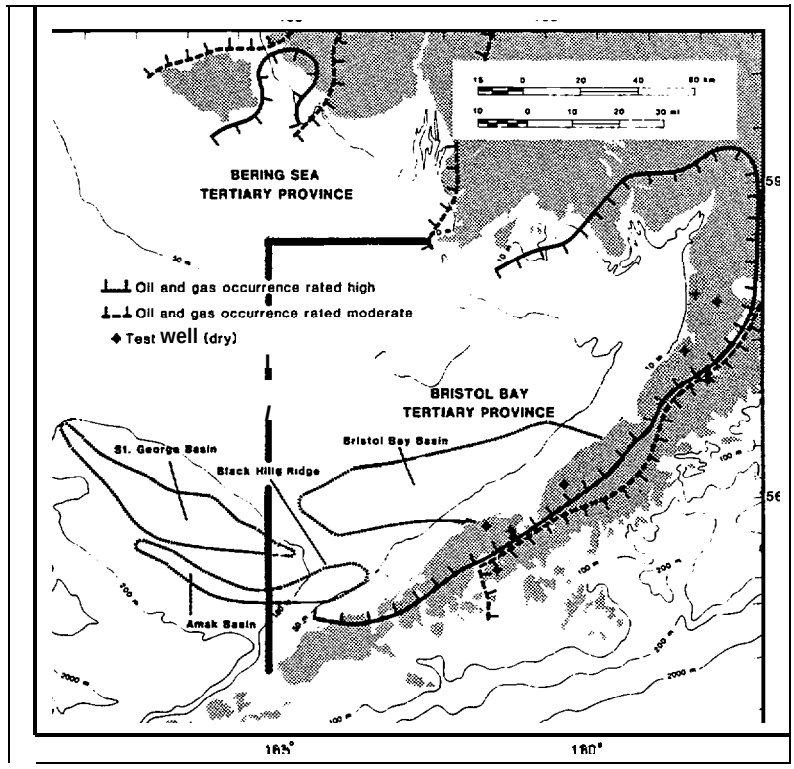


Figure 133. Offshore strata with high potential for petroleum, southeastern Bering Sea (SAI, 1981) .

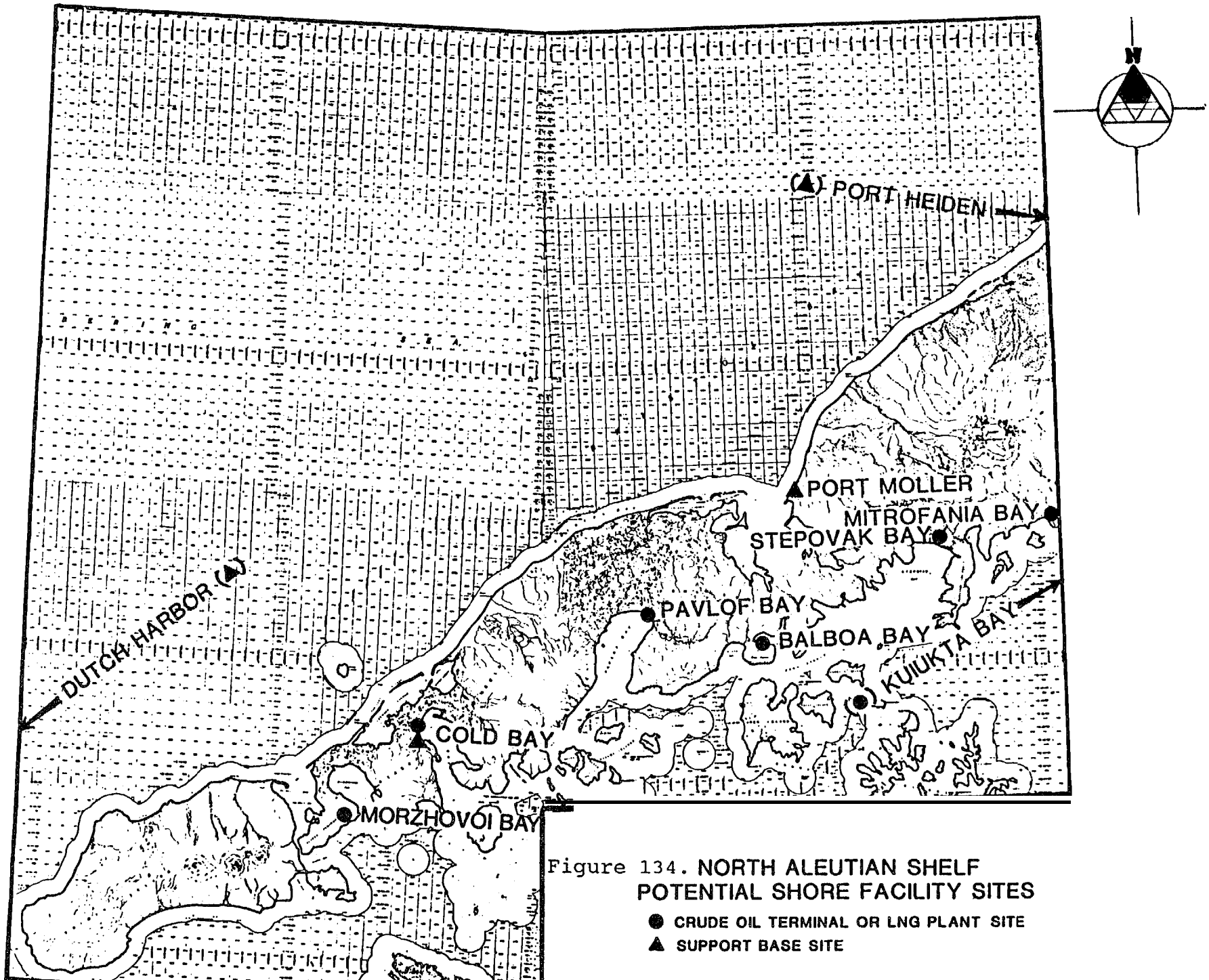


Figure 134. NORTH ALEUTIAN SHELF POTENTIAL SHORE FACILITY SITES

● CRUDE OIL TERMINAL OR LNG PLANT SITE

▲ SUPPORT BASE SITE

reinforced drillships supported by icebreakers drill well into the fall, similar equipment and techniques could make winter drilling feasible in this area of significantly less severe ice conditions. Dynamically positioned semi-submersibles or drillships, possibly supported by icebreakers, may also be an option for winter drilling. Other problems facing exploratory drilling in this area would include the high frequency of summer fogs and potentially severe structural icing in the winter that would pose hazards for both the rigs and their support vessels.

Conventional technology is likewise adequate for production platforms. Dames and Moore (1980) consider three representative water depths in the North Aleutian Shelf area: 15 meters (50 feet), 46 meters (150 feet), and 91 meters (300 feet). Conventional production platforms feasible for these representative water depths are presented below.

a. Steel Jacket

This could be a Cook Inlet structure, at least for the two shallower water depths (15 and 46 meters). The deep water structure (91 meters) probably would be one wherein the jacket would be supported by external skirt piles. A typical structure would have four legs. The platforms for the 15- and 46-meter sites would have internal piles; all would have conductors inside the legs. Until additional ice data are available, the necessary conservative approach requires that platforms must be designed for ice conditions, no matter how minimal the forces appear. External (or conventional) conductors would not be feasible. Steel jacket structures with well conductors protected from ice have successfully operated in Cook Inlet for over ten years.

b. Steel Gravity Structure

The North Aleutian Shelf is a high seismic risk area. Due to the possibility of seismic activity, conventional concrete gravity structures are not recommended. This is particularly true since problems have been encountered with them in the North Sea in the past. However, the steel gravity platform may be feasible, depending on bottom conditions. This platform probably would be a single leg or monopod structure with all conductors internal in the "neck". Although it may have more than one leg, all conductors would be internal. A steel gravity structure is now in operation in the North Sea (Maureen Platform) where wave conditions are significantly greater but where seismic conditions are much less.

The most likely method of transporting oil and gas will be by pipelines to shore terminals. Distances of offshore

pipelines will likely be less than 90-100 miles maximum, and must be buried in water depths of less than 200 feet (60 m). Another possible development which might be seen in the North Aleutian area is floating production systems. New technology would be required here because of the potential ice hazards. The technique utilizes a converted tanker or some other permanently moored floating system to produce oil and then transfer it to a transshipment tanker. The "incentive for using this method is the short time frame required to get the production stream going and the smaller capital investment required. This scenario could make relatively small reservoirs economic to produce. The hazards here would be the increased exposure to the Bristol Bay side of the Aleutian Chain due to transferring and transporting crude. However, offshore loading is a common practice in the North Sea, where more extreme sea conditions are encountered.

Dames and Moore (1980) also considered the onshore petroleum facilities that may be required for oil and gas development. These onshore petroleum facilities include temporary exploration support bases, construction support bases, permanent operation support bases, crude oil terminals, and an LNG plant. Possible support base sites are Cold Bay, Dutch Harbor, Port Moller and Port Heiden, which appear to be the only communities capable of acting as bases without major capital improvement.

The following sites were identified as potential locations for a crude oil terminal or LNG plant (from west to east on the Pacific Ocean coast of the Alaska Peninsula):

Morzhovoi Bay
Cold Bay
Pavlof Bay
Balboa Bay
Stepovak Bay
Mitrofania Bay
Kuiukta Bay

Each of these sites has environmental or geotechnical limitations. Except for Cold Bay and the northern portion of Pavlof Bay, all of these sites lie within the Alaska Peninsula National Wildlife Range. Depending upon discovery location and the pipeline landfall, the sites to the east of Pavlof Bay will require longer overland pipelines through more rugaed terrain than those from Pavlof Bay westward. For example, the minimum overland distance to Cold Bay from the Bristol Bay coast would be about 19 kilometers (12 miles), but through or near the environmentally sensitive Izembek Lagoon area. The overland distance to Mitrofania would be about 105 kilometers (65 miles).

The northwest coast of the Alaska Peninsula does not appear to offer any particularly attractive site for a shore terminal. While use of this shoreline for a terminal site would eliminate an overland pipeline that could be as much as 97 kilometers (60 miles) long, there are several negative aspects. These negative aspects include extreme distance to deep water, lack of natural shelter and increased potential for ice encounter.

These disadvantages could be overcome by using a combination of offshore loading, as at Drift River, with shelter provided by an offshore breakwater. It is possible that the additional costs of these facilities would be comparable to constructing 64-80 kilometers (40-50 miles) of pipeline across the Alaska Peninsula. Because of the similar nature of most of the coastal area on the Bristol Bay side of the Peninsula, individual sites have not been identified.

Because of the necessity of developing a port if a site on the north coast were selected, it is most likely that the selection would be on the south side of the Peninsula. Such a port on the southern side would avoid a longer tanker trip around the Peninsula through Unimak Pass as well as avoiding tanker operations in ice during the winter.

2. Spill and Discharge Scenarios

Oil spills occur during development, production and transportation of petroleum resources. They can occur from platforms (spills and blowouts), from pipelines, and from tankers. Lanfear and Amstutz (1983) have recently examined the occurrence rates of oil spills on the U.S. outer continental shelf from all sources. The USGS has also examined recent data involving blowout accidents (Fleury, 1983).

Oil spills of 1000 barrels or more from platforms on the U.S. continental shelf between 1964-1980 are summarized in Table 16 (Lanfear and Amstutz, 1983). Blowouts for the period 1979-1982 (Fleury, 1983), summarized in Tables 17 and 18, indicate that for frontier OCS areas, 91 wells were spudded without a blowout. This includes eleven wells off Alaska, 30 off the Atlantic coast, ten in the eastern Gulf of Mexico and 40 off southern California. In non-frontier areas, there were eight blowouts during exploratory drilling for the 1979-1982 period, none of which resulted in release of hydrocarbons. Tabulations of blowouts on the OCS (Table 17) and OCS drilling, production and spillage data during blowouts (Table 18) show a total of 64 barrels were spilled over the four year period due to blowouts during exploratory and production activities.

Table 16 from Lanfear and Amstutz (1983), summarizing data on spills from all sources for the 1964-1980 period,

Table 16. Oil spills of 1,000 barrels or more from platforms on the U.S. Outer Continental Shelf, 1964-1980.

DATE	MMS DATA-BASE ID NO.	LOCATION	SIZE (BBL)	CAUSE
8 Apr 64	200	Eugene Island 208	5,108	Collision
3 Ott 64	220-280	(7 Platforms)	17,500	Hurricane
19 Jul 65	360	Ship Shoal 29	1,688	Blowout
28 Jan 69	990	Santa Barbara	77,000[1]	Blowout
16 Mar 69	1,060	ship Shoal 72	2,500	Blowout, weather
17 Aug 69	1.,220	Main Pass 41	16,000	Tank spill, weather
10 Feb 70	1,430	Main Pass 41	30,500	Blowout
1 Dec 70	1,580	South Timbalier 26	53,000	Blowout
20 Jul 72	2,000	(Unspecified, Gulf of Mexico)	4,300	Unspecified
9 Jan 73	2,130	West Delta 79	9,935	Tank spill
23 Nov 79	4,230	Main Pass 151	1,500	Tank spill
17 NOV 80	4,590	Galveston	1,500	Tank spill

[1]Estimates vary

Lanfear and Amstutz (1983).

Table 17. Number of blowouts on the OCS, 1979 - 1982.

	DRILLING			NONDRILLING				
Year	Exploration	Development	TOTAL	Completion	Production	Workover	Total	TOTAL
1979	3	2	5	0	0	0	0	5
1980	3	1	4	1	1	2	4	8
1981	2	1	3	5	0	2	7	10
1982	0	4	4	1	0	3	4	8
	8	8	16	7	1	7	15	31

Fleury, (1983).

Table 18. OCS drilling, production and spillage data, 1979 - 1982.

	PRODUCTION			OIL SPILLAGE*DURING BLOWOUTS				
Year	New Wells Started	Oil and Gas Condensate (Million Barrels)	Gas (Billion MCF)	Exploration	Development	Completion	Production	Workover
1979	1,109	285.6	4.7	0	0	0	0	0
1980	1,079	277.4	4.6	0	0	0	1	0
1981	1,106	286.6	4.8	0	0	0	0	64
1982	1,155	321.1	4.7	0	0	0	0	0
	4,449	1,170.7	18.8	0	0	0	1	64

*Barrels of oil and oil condensate. Fleury, (1983).

shows that the last blowout which resulted in a spill during this period was in 1970 when 53,000 barrels were lost in the Gulf of Mexico. When data from Tables 16 and 17 are combined, it is obvious that the oil and gas industry has a better record during the more recent years.

Lanfear and Amstutz (1983) compute a spill rate from platforms of 1 .0 spill per billion barrels for spills of 1000 barrels or more.

It is expected that platforms would be located some 90-100 miles from land and the most likely mode of transporting oil to a shore facility would be via pipelines. Lanfear and Amstutz (1983) indicate that "using USGS accident data from 1964 through 1979 and basing exposure on U.S. OCS production (almost all U.S. OCS oil is transported by pipeline), a computed rate would indicate 1.82 spills per billion barrels for spills of 1.000 barrels or more." However, they further indicate that anchor dragging was the cause of 75 per cent of the larger pipeline spills. Since pipelines in water depths less than 200 feet must be buried, the exposure in the North Aleutian Shelf area will be limited to the deeper areas.

Depending on the shore crossing location, onshore pipelines will range between 15-100 miles and will probably transport oil to a terminal on the south side of the Aleutian Chain. Tankers will then take on the crude oil and transport it south. Lanfear and Amshutz (1983) show crude oil spills of 1,000 barrels or more resulting from spills in the open sea to be 0.9 spills per billion barrels transported. For spills in port, 0.4 spills per billion barrels is projected. Based on the most likely location of processing and shipment facilities, any spill that would occur from these sources would take place on the Pacific side of the Aleutian Chain.

In summary of past spill data and using a 0.7 billion barrels of oil projected as the mean reserves for the North Aleutian Shelf (Marlow et al, 1980), it would be expected that one spill greater than 1,000 barrels, but probably less than 10,000 barrels, would occur during the life of the field. However, there always exists a very small, but finite, possibility of a larger spill.

Other than oil, discharges of drilling fluids and cuttings from platforms will introduce contaminants into the marine waters. A well might typically produce 12,000-24,000 barrels of waste, consisting of about 2,500 barrels of cuttings, 7,000-17,000 barrels of drilling mud waste and some 3,500 barrels of washwater waste.

3. Spill Movements and Concentrations

The Bristol Bay area of Lease Sale 92 is a large area. The distance from Unimak Pass to Kvichak Bay is approximately 490 nmi and the distance across the mouth approximately 270 nmi, with a total area of over 3.6 x 104 nmi^2, or 1.2 X 105 km2. A likely oil spill will occupy only a fraction of this large area at any given time. Thus the persistence and movement of this spill over time will be very important as to the actual total damages that occur.

For example, the maximum slick size versus volume of oil spilled can be approximated by the results of Fay (1971) shown in Figure 135, based upon observations of real spills. Thus a spill of 1,000 to 10,000 barrels would cover an area of 10 to 100 km2 (10^{7-8} m2) or 0.01 to 0.1 percent of the total area, with a 100,000 barrel spill (Santa Barbara class) covering approximating 0.5 percent. For the case of the inshore area within the 50 mile depth contour, a major spill in this smaller area (1.1 x 104 km2) would cover several percent of this inshore zone.

A spill of a given size is not stationary, of course, but will move with the wind and currents. Thus a spill of a given area will affect a much larger area over its total lifetime. Oscillatory tidal currents in the inshore areas will streak oil out over six to twelve nautical miles during a tidal cycle. The mean currents within the coastal domain, 2 to 5 cm/see, are very slow and will usually have less effect on intermediate time movements of an oil slick than will the local winds. For example, a 5 cm/sec mean current (0.1 kt) would require about 40 days to transport oil 100 nautical miles. A 30 kt wind will move an oil slick (not the water column) at about 0.9 kt.

In this regard, the frequency of three to five storms per month is important. The cyclones that propagate through the area make this an event-dominated system. For the inshore area, strong onshore and longshore winds occur as the cyclone storm systems move through the area. Thus, oil slicks can be driven onshore or longshore by winds during storm events. Coastal currents, as reviewed earlier in the oceanography chapter, also respond as pulses of flow, reacting to local wind events. For example, longshore winds from the northeast will cause temporary reversals in the coastal flow along the Peninsula, and also cause offshore movement of surface waters and onshore movement of water at depth . Storms will also act to disperse an oil slick, dispersing oil down into the water column and into shallow sediments. Because of increased mixing from waves, the frequent storms in the North Aleutian Shelf region will probably shorten the lifetime of a spill to one to two weeks maximum.

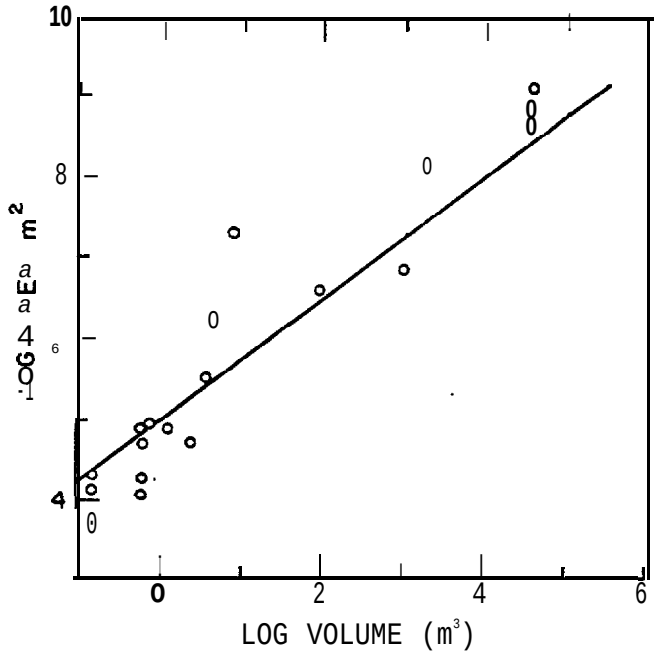


Figure 135. Maximum slick area as a function of volume (Fay, 1971).

A wind rose for the North Aleutian Shelf area indicates about an equal chance of wind from any direction? and is essentially an average of many cyclonic storm events. Because of low mean currents, movement of an oil slick will be greatly determined by this local wind. A reasonable likelihood therefore exists that oil released offshore can be brought ashore and into the lagoons and estuaries by storm associated wind events.

A number of large lagoons and embayments exist along the northern side of the Alaska Peninsula. Among them are Bechevin Bay, Izembek Lagoon, Herendeen Bay, Port Heiden, Ugashik Bay, and Egegik. The upper Bristol Bay and northern coast also have important estuaries which include Kvichak Bay, Nushagak Bay, Togiak Bay, and Kulukak Bay. Inshore movement of oil driven by wind could threaten such a bay or lagoon, if spill location and wind happened to act in concert. Information on exchange and residence times in these bays and lagoons is not presently available.

Manen and Pelto (1983) estimate from literature on field and laboratory experiments, as well as from a model, the concentrations of crude oil that might be expected in the water column and in the sediments under an oil spill on the North Aleutian Shelf. Their review of laboratory and field experimental data of oil concentrations in the water column show median values of from 300 to 1,000 ppb oil in the upper water column. From their model of two 10,000 barrel continuous oil spills in the North Aleutian Shelf area, they predict 650 ppb maximum concentrations in the water under the slick if the wind remains constant and there are no transverse currents.

Baker (1983) used literature data of laboratory loading of oil on sediment, along with his suspended sediment and sediment trap data from the North Aleutian Shelf. He estimated that sediment absorbed oil loadings might be 0.7 to 7 ppb in the inshore water column and 0.06 to 1 ppb in the offshore zone. Using sediment trap data and assuming particles caught in the trap were sedimenting to the bottom, he estimated that a flux of oil to the benthos could be 1-10 mg m^{-2} day^{-1} if the sediment were fully loaded with oil.

4. Toxicity Data

a. Petroleum Hydrocarbons

A thorough review of the petroleum hydrocarbon (PHC) toxicity literature (Appendix B) for eight taxonomic groupings of marine organisms was conducted to assist in assessing the vulnerability of these groups to potential oil spills. This review is synthesized in Tables 19 through 26.

Marine Macrophytes

Type of Test (acute/chronic/ field)	Test material (refined/ crude/WSF)	Life Stage	Number animal types tested	Number of chemicals tested	Range of Concentrations <100 hours	# of tests	>100 hours	# of tests	N/A
Acute	Refined	L J A							
	Crude	L J A							
	WSF	L J A							
Chronic	Refined	L J A	3	2			2,000 ppm	2	
	Crude	L J A	3	1			2,000 ppm	1	
	WSF	L J A							
Field	Refined	L J A	3	2				3	3
	Crude	J A							

Table 19. Synthesis of petroleum toxicity literature for marine macrophytes (WSF = water soluble fraction of crude oil, L = larva or egg, J = juvenile stage, and A = adult plus all unspecified life stages).

Annelids

Type of Test (acute/chronic/ field)	Test material (refined/ crude/WSF)	Life Stage	Number animal types tested	Number of chemicals tested	Range of Concentrations				
					<100 hours		>100 hours		N/A
						# of tests		# of tests	
Acute	Refined	L	3	1	0.5%	3			
		J	4	1	4.0-8.7 ppm	4			
		A	10	2	0.9-8.7 ppm	14	1.4-7.3 ppm	5	
	Crude	L							
		J	4	1	15.2-19.8 ppm	4			
		A	9	5	9.8->19.8 ppm	14	7.9-17.8 ppm	5	
	WSF	L							
		J							
		A	3		9.5-15.0 ppm	3	4-5 ppm	2	
Chronic									
							ppm		
	WS								
Field	Refined	L							
		J							
		A							
	Crude	J							
		A							

Table 20. Synthesis of petroleum toxicity literature for annelids (WSF = water soluble fraction of crude oil, L = larva or egg, J = juvenile stage, and A = adult plus all unspecified life stages).

Mollusks

Type of Test (acute/chronic/field)	Test material (refined/crude/WSF)	Life Stage	Number animal types tested	Number of chemicals tested	Range of Concentrations: <100 hours	# of tests	>100 hours	# of tests	N/A
Acute	Refined	L	8	4	194-3.8K ppm	19			
		J	1	1	0.006-0.54 ppm	1	10.6 ppm		
		A	15	5	0.006-15.6 ppm (1 @ 500 ppm)	14	0 [illegible] ppm	6	2
	Crude	L	3	2	500-1000 ppm	4			
		J	1	1	<1000 ppm	1			
		A	29	24	3.94-148 ppm (1 @ approx. 1,000 ppm)	56		7	33
	WSF	L	2	3	1 ppm	12			9
		J							
		A	3	4	4-168 ppm	5	4-14 ppm	2	
Chronic	Refined	L	1	LOW-MOD	1 ppm	3			
		J	2		15 ppm	1	10-100 ppm	1	
		A	7		1.7-59 ppm	5		5	
	Crude	L							
		J							
		A	6	4	4.3-24.9 ppm (one @ approx. 1,000)	3	3-[illegible] mg/l	5	3
	WSF	L							
		J							
		A	3	4	0.67-24.9 ppm	5	0.036-35 ppm	4	
Field	Refined	L							
		J							
		A	6	4		1	35-2,086 ppm	10	[illegible]
	Crude	L							
		A	5	5				6	5

Table 21. Synthesis of petroleum toxicity literature for mollusks (WSF = water soluble fraction of crude oil, L = larva or egg, J = juvenile stage, and A = adult plus all unspecified life stages).

Echinoderms

Type of Test (acute/chronic/ field)	Test material (refined/ crude/WSF)	Life Stage	Number animal types tested	Number of chemicals tested	Range of Concentrations <100 hours	# of tests	>100 hours	# of tests	N/A
Acute	Refined	L	4	3	0.5-12.5%	6	0.5%	1	
		J							
		A	2	1	>3.36->6.9 ppm	2			
	Crude	L	1	1	12.5%	1			
		J							
		A	5	2	>6.84->14.7 ppm	7			
	WSF	L	1	1	100%	1			
		J							
		A							
Chronic	Refined	L							
		J							
		A							
	Crude	L	1	4	up to 100%	4			
		J							
		A							
	WSF	L							
		J							
		A							
Field	Refined	L							
		J							
		A							
	Crude	J							
		A							

Table 22. Synthesis of petroleum toxicity literature for echinoderms (WSF = water soluble fraction of crude oil, L = larva or egg, J = juvenile stage, and A = adult plus all unspecified life stages).

Arthropods

Type Of TeSt (acute/chronic/ field)	Test material (refined/ crude/WSF)	Life Stage	Number animal types tested	Number of chemicals tested	Range of Concentrations <100 hours	# of tests	>100 hours	# of tests	N/A
Acute	Refined	L	7	6	0.17-100 ppm (1 @ 0.5%)	8			1
		J							
		A	42	10	10.006-350 ppm (2 @ >3K ppm)	72	1.95-5.24 ppm	3	11
	Crude	L	9	4	0.22-500 ppm (1 @ approx.1K)	16		1	
		J	3	2	1-560 ppm	2		1	
		A	27	9	0.87-1,000 ppm	46	1-1,000 ppm (one @ 10K)	6	1
	WSF	L	10	4	0.008->19.8 ppm	13			
		J							
		A	23	9	0.4-8.9 ppm	49	0.5-4.9 ppm	6	2
Chronic	Refined	L	3	3		1	0.008-0.22 ppm	3	1
		J	1	1			6 ppb	1	
		A	1	2	1.44 ppm	3	0.24 ppm	1	
	Crude	L	2	1	100-1,000 ppm	3			
		J							
		A	2	2	350 ppm	1			1
	WSF	L	3	2			0.008-1.87 ppm	3	1
		J							
		A	5	4	10,000 ppm	8	11 ppm	2	3
Field	Refined	L ,							
		J							
		A	1	1			>6,000 ppm	1	
	Crude	J							
		A	1	1			up to 500 ppm	1	

Table 23. Synthesis of petroleum toxicity literature for arthropods (WSF = water soluble fraction of crude oil, L = larva or egg, J = juvenile stage, and A = adult plus all unspecified life stages).

Fish

Type of Test (acute/chronic/field)	Test material (refined/crude/WSF)	Life stage	Number animal types tested	Number of chemicals tested	Range of Concentrations: <100 hours	# of tests	>100 hours	# of tests	N/A
Acute	Refined	L	9	7	<10-100 ppm (one @ 0.1%)	10	2-10 ppm (one @ 0.1%)	2	
		J	6	5	11-1,952 ppm	10	100-398 ppm	1	
		A	26	4	0.15-2,200 ppm (1 @ > 10K)	31	0.1-250 ppm	5	
	Crude	L	11	7	0.01-3 ppm (5K to 100K)	7	10-10,000 ppm	4	1
		J	3	3	42-840 ppm	6			
		A	17	4	2-80,000 ppm	25			
	WSF	L	6	6	3.0-10,000 ppm	4	10-10,000 ppm	7	1
		J	4	4	<1.0-10,000 ppm	11	2-3.4 ppm	2	
		A	10	4	1.3-19.8 ppm	15			
Chronic	Refined	L	2	3			0.01-10 ppm	3	
		J							
		A	8	8	~.2-10 ppm	~	0.4-5.6 ppm (one @ 3K)	3	2
	Crude	L	3	3	240 ppm	1	0.01-1 ppm	2	1
		J							
		A	6	4	0.2 ppm	2	520-700 ppm	8	7
	WSF	L	3	4	10,000 ppm	6	10,000 ppm	5	3
		J	1	1			0.4 ppm	1	
		A	4	2	0.35-2.22 ppm	3	0.8 ppm	2	
Field									

Table 24. Synthesis of petroleum toxicity literature for fish (WSF = water soluble fraction of crude oil, L = larva or egg, J = juvenile stage, and A = adult plus all unspecified life stages).

Birds

Type of Test (acute/chronic/field)	Test material (refined/crude/WSF)	Life Stage	Number animal types tested	Number of chemicals tested	Range of Concentrations: <100 hours	# of tests	>100 hours	# of tests	N/A
Acute	Refined	L	1	2			oil coverage	2	2
		J							
		A							
	WS								
Chronic	Refined	L	1	1			oil coverage		
		J							
		A	2	3			oral dose	3	3
	Crude	L							
		J	1	1			oral dose	1	1
		A	2	4			oral dose	4	4
	WSF	L							
		J							
		A							
Field	Refined	L							
		J							
		A							
	Crude	J							
		A							

Table 25. Synthesis of petroleum toxicity literature for birds (WSF = water soluble fraction of crude oil, L = larva or egg, J = juvenile stage, and A = adult plus all unspecified life stages).

Marine Mammals

Type of Test (acute/chronic/ field)	Test material (refined/ crude/WSF)	Life Stage	Number animal types tested	Number of chemicals tested	Range of Concentrations <100 hours	# of tests	>100 hours	# of tests	N/A
Acute	Refined	L J A							
	Crude	L J A	1	1	oil on water	1			1
	WSF	L J A							
Chronic	Refined	L J A							
	Crude	L J A	3	2			oil on coat	3	3
	WSF	L J A							
Field	Refined	L J A							
	Crude	J A							

Table 26. Synthesis of petroleum toxicity literature for marine mammals (WSF = water soluble fraction of crude oil, L = larva or egg, J = juvenile stage, and A = adult plus all unspecified life stages).

In general, the petroleum toxicity literature is characterized by a wide variation in reported test organism responses. This is due to a combination of three factors: 1) Experimental approaches, techniques, and test endpoints may vary radically, 2) organism sensitivities vary among species, life stages, and with specific testing conditions, and 3) toxicities of different test materials (sources of crudes, degrees of refinement, aging, and so on) vary markedly among reported experiments.

However, among the variability, a number of trends have become evident:

1. Acute lethal effects generally begin to appear in some testing situations in the 1-10 ppm range, usually within 48 hours.

2. Sub-lethal or chronic effects are occasionally evident in the sub-ppm range and often within one hour of exposure.

3. Most sub-lethal effects observed in the laboratory would probably be mortality in actual, long-term field situations.

Rice et al (1979) recently suggested a general pattern of sensitivity to oil for major phyletic groups of Alaskan species within different habitats (Table 27). Sensitivities to water soluble fractions of Cook Inlet crude oil tended to be greatest for pelagic fish and Crustacea. Benthic organisms tended to be less sensitive, and intertidal organisms were the least sensitive. While the general hydrocarbon toxicity data base indicates much higher variability than suggested by Rice et al, it does appear that adaptations of species to specific conditions within various habitats has served to influence general sensitivity to petroleum hydrocarbons.

Organism group	96-h LC50 in ppm HABITAT		
	Pelagic	Benthic	Intertidal
Fish	1-3	4->5	>12
Crab & Shrimp	1-5	3-5	8->10
Mollusk	--	4->8	8

From: Rice et al (1979).

Table 27. Ranges of sensitivities for different habitat groups exposed to Cook Inlet WSF.

Sensitivity of all species to petroleum hydrocarbons varies with life stage (Tables 19-26) . Larvae are consistently more sensitive than either juveniles or adults.

Moore and Dwyer (1974) indicate that larvae of marine organisms are typically 10-100 times more sensitive to the water soluble fractions of petroleum than adults. This general pattern of increasing sensitivity with younger life stages is altered slightly in the case of egg stages of most species. Egg stages are often not as sensitive to short term exposures due to slow transfer of hydrocarbons across the membranes. Under conditions allowing long-term exposure at low levels, eggs are often at least as sensitive as larvae.

b. Drilling Fluids

The discharge of muds utilized during the process of drilling provides another source of contaminants which could potentially impact species occupying nearshore habitats. Available literature on the sensitivities of marine organisms has recently been reviewed by a panel of experts assembled by the National Research Council (NAP, 1983). In addition, Rice et al (1983) have reviewed recent drilling fluid bioassays conducted at the Auke Bay Laboratory on larvae of Alaskan species of shrimp and crab.

NAP (1983) provided a synthesis of 400, 96-hour acute bioassays conducted with 62 different species utilizing 72 different drilling fluids (Table 28). Lower trophic levels (e.g. phytoplankton and copepods) were generally most sensitive to drilling fluids. One hundred percent of the thirteen tests performed with phytoplankton resulted in LC50 values of less than 10,000 ppm drilling fluids. Eighty percent of the tests performed using copepods as test organisms also resulted in LC50 values of less than 10,000. LC50's for all other species were predominantly between 10,000 and 100,000 ppm for 96-hour bioassays. As a whole, nearly 80 percent of the tests performed on all organisms, including many tests conducted with early life stages, resulted in LC50 values greater than" 10,000 ppm.

Recent unpublished tests conducted by Carls and Rice (Rice et al, 1983) indicate comparable sensitivities for larvae of Alaskan species of shrimp and crab (Table 29). LC50 values for 144 hour bioassays conducted on king crab and Dungeness crab ranged from 2,000 to 4,800 ppm for whole mud, and from 14,100 to 33,400 ppm for water-soluble fractions". Larvae of kelp Eualus suckleyi, and dock shrimp Pandalus danae, were found to be generally more sensitive.

Table 28. summary of results of acute lethal bioassays with drilling fluids and marine/estuarine organisms.[a] (NAP, 1983).

Organism	Number of Species Tested	Number of Fluids Tested[c]	Number of Bioassays
Phytoplankton	1	9	12
Invertebrates			
Crustaceans			
CopePods	2	17	39
Isopods	2	4	6
Amphipods	4	8	19
Mysids[b]	5	18	35
Shrimp[b]	10	40	76
Crabs[b]	6	18	35
Lobsters[b]	1	2	7
Mollusks			
Gastropod	5	5	10
Bivalves[b]	7	14	33
Echinoderms			
Sea Urchins[b]	1	2	4
Polychaetes	6	14	28
F inf ish[b]	12	32	90
TOTALS	62	72	400

[a]Most median lethal concentration (LC50) values are based on 96-hour bioassays and results are expressed as parts per million (mg/l or µ 1/1) mud added (Based on review of Petrazzuolo, 1981, with data from Carls and Rice, 1980; ERCO, Inc., 1980, Gilbert, 1981, Marine Bioassay Labs, 1982 and Conklin et al., in press, added) .

[b]Includes results for embryonic, larval and early life stages.

[c]In many cases, the same drilling fluid was used for bioassays with several species. In a few cases, more than one investigator evaluated the toxicity of a single drilling fluid.

Table 28. continued

Organism	Number of LC50 Values (ppm)					
	Not Determinable	100	100-999	1,000-9,999	10,000-99,999	100,000
Phytoplankton	5	6	0	7	0	0
Invertebrates						
Crustaceans						
Copepods	4	2	11	15	7	0
Isopods	0	0	0	0	1	5
Amphipods	0	0	0	0	5	14
Mysids[b]	1	0	1	0	21	18
Shrimp[b]	0	0	12	15	31	18
Crabs[b]	1	0	0	5	16	13
Lobsters[b]	0	0	0	1	3	3
Mollusks						
Gastropod	0	0	0	0	2	8
Bivalves[b]	0	0	0	1	15	17
Echinoderms						
Sea Urchins[b]	0	0	0	0	1	3
Polychaetes	0	0	0	0	9	19
Finfish[b]	0	0	0	3	52	35
TOTALS	11	2	24	47	163	153
Percentage, as a fraction of the total number of drilling fluid bioassays.	2.8	0.50	6.0	11.75	40.75	38.25

[a]Most median lethal concentration (LC50) values are based on 96-hour bioassays and results are expressed as parts per million (mg/l or µl/l) mud added (Based on review of Petrazzuolo, 1981, with data from Cares and Rice, 1980; ERCO, Inc., 1980, Gilbert, 1981, Marine Bioassay Labs, 1982 and Conklin et al., in press, added).

[b]Includes results for embryonic, larval and early life stages.

[c]In many cases, the same drilling fluid was used for bioassays with several species. In a few cases, more than one investigator evaluated the toxicity of a single drilling fluid.

Table 29. Tolerance of shrimp and crab larvae to suspensions and water-soluble fractions (WSF) of Cook Inlet mud.

Species	144-h LC50 in %(vol/vol) Complete mud	Mud WSF
King crab	0.48	3*34
Dungeness crab	0.20	1.41
Kelp shrimp	0.44	0.47
Dock shrimp	0.05	0.3

From: Rice et al (1983)

Sublethal and chronic effects of drilling fluids to marine organisms (Table 30) varies substantially between species tested and endpoint responses (NAP, 1983). In the case of mollusks, inhibition of initial shell formation has been identified at concentrations as low as 100 ppm for 96-hour exposures. Minimum concentrations at which responses have been identified for Crustacea are similar to those observed for Mollusca. However, larvae of king and tanner crabs exposed to used euochrome lignosulphate fluids indicated a relatively low sensitivity to lower concentrations. In the case of king crab larvae, responses (indicated by cessation of swimming by 50 percent of the larvae) were elicited for whole mud at a concentration of 2,800 ppm over a 144 hour exposure period, and for water soluble fractions at 12,900 ppm. Tanner crab larvae tested in a similar manner responded to slightly lower concentrations of water soluble mud fractions.

Since acute toxicity tests are seldom carried out on fish, information on the sublethal and chronic effects of drilling fluids on fish (Alaskan species particularly) is almost nonexistent. A single test conducted by Houghton et al (1980), however, indicated that a relatively high concentration of drilling fluids (30,000 ppm) affect gill tissues of pink salmon.

Based upon review of drilling fluid toxicity data and both theoretical calculations and empirical observations of dispersion rates in the water column, it has been estimated that toxic responses of pelagic organisms would need to occur within an hour at concentrations lower than 100 ppm (NAP, 1983). Since the zone around a discharge where concentrations exist at levels greater than 100 ppm would typically be on the order of tens of meters, it is expected that drilling fluids would have little impact on pelagic species.

Studies conducted to date indicate the benthos is the principal habitat where the effects of drilling fluids

Table 30. Summary of investigations of sublethal and chronic effects of drilling fluids on Marine animals (the lowest concentration of drilling fluid eliciting a particular response) (NAP, 1983).

Species	Drilling Fluid Type	Exposure Concentration and Duration	Responses	References
(%elente.eaten (corals) Montastrea cavernosa Montastrea annularis Diploria str igosa	Used FeCr-lignosulfonate	25 ml., 1:1 seawater: fluid	Unable to clear horizontal surfaces	Thompson and Bright, 1977
Montastrea annularis	Freshly prepared FeCr-lignosulfonate	2-4 mm layer applied 4 times at 2.5 h intervals	Decreased growth rate at 6 months	Hudson and Robbin, 1980
Montastrea annular is Porites asteroides	Used Cr-lignosulfonate, offshore Louisiana	Burial under 10-12 cm for 8 h	All colonies dead after 10 days	Thompson, 1980
Montastrea annular is	Used Cc-1 ignosulfonate, offshore Louisiana	Thin cover ing	Partial clearing in 26 h, some dead POlyps, extruded zooxanthel lae	Thompson, 1980
Madracis decactis	Used Mobil Bay Cr-lignosulfonate with added Cr-lignosulfonate	100 ppm	Depressed respiration and NH_3 excretion rate	Krone and Bigg S, 1980
Porites furcata, P. astroides, Montastrea annularis, Acropora cervicornis, Agaricia agaricites	Used Cr-lignosulfonate, offshore Louisiana	100 ppm, 96 h	Partial polyp detraction, excess mucus product ion	Thompson, 1980; Thompson and Bright, 19801 Thompson et al. , 1980
Porites divar icata	Used Cr-lignosulfonate, offshore Louisiana	316 ppm, 96 h	Partial polyp retraction, excess mucus production	Thompson, 1960; Thompson and Bright, 1980; Thompson et a 1., 1980
Dichocoenia stokesii	Used Cr-lignosulfonate, offshore Louisiana	1,000 ppm, 96 h	Partial polyp retraction	Thompson, 1980; Their.pmm and Bright, 19801 Thompson et a i. , 1980
Montastrea annularis	Uaad Cr-lignosul fonate with diesel, Jay Field, Fla.	100 ppm, 6 weeks, flowthrough	84% reduction in calcification rate, 40% reduction in respiration rate, 26% reduct ion In photosynthesis, 499 reduction in NO_3 and NH_3 uptake, inhibition of feeding	Szmant-Froel ich et al. , 1982
Montastrea annularis	Used Cr-lignosulfonate with diesel, Jay Field, Fla.	100 ppm, 6 weeks, flowthrough	Reduction in skeletal growth rate	Dodge, 1982
Montastrea annularis	Used Cr-lignosulfonate with diesel, Jay Field, Fla.	1-100 ppm, 6 weeks, low through	Growth inhibition, alteration of biochemical pathways and composition, bacterial infection	Whit; et al., 1982

Table 30. continued

Species	Drilling Fluid Type	Exposure Concentration and Duration	Responses	References
Mollusks				
Pacific oyster *Crassostrea gigas*	Used medium- and high-weight Cr-lignosulfonate, Gulf of Mexico	5,000 ppm, 6 weeks, static	Decreased shell growth, decreased condition index	Neff, 1980
Atlantic oyster *Crassostrea virginica*	Used Cr-lignosulfonate, Mobile Bay, Ala.	100 ppm, 100 days, flowthrough	Reduced rate of shell regeneration	Rubenstein et al., 1980
C. virginica	Unidentified Cr-lignosulfonate	4,000 ppm	Altered tissue-free amino acid concentrations and ratios	Powell et al., 1982
Mussel *Modiolus modiolus*	Used high-weight Cr-lignosulfonate, Cook Inlet, Alaska	30,000 ppm	Reduced rate of byssus thread formation	Houghton et al., 1980
Mussel *Mytilus edulis*	Used medium- and high-weight Cc-1 lignosulfonate, Gulf of Mexico	33,000 ppm	Decreased filtration rate, increased rate of respiration and NH_3 excretion	Gerber et al., 1980
M. edulis	Used medium- and high-weight Cr-lignosulfonate, Gulf of Mexico	250 ppm[a]	Decreased rate of shell growth	Gerber et al., 1980, 1981
Ocean scallop *Placopecten magellanicus* (juveniles	Used medium- and high-weight Cr-lignosulfonate, Gulf of Mexico	49.4 ppm[a]	Decreased rate of shell growth	Gerber et al., 1981
P. magellanicus (2-day larvae)	Filtered suspension (liquid phase) of used Cc-1 lignosulfonate, Mobile Bay, Ala., May 15 fluid	1,000 ppm, 96 h	Significant inhibition of shell formation	Gilbert, 1981
	May 29 fluid	100 ppm, 96 h	Significant inhibition of shell formation	Gilbert, 1981
P. magellanicus (2-day larvae)	Liquid phase of used Cr-lignosulfonate fluid, Mobile Bay, Ala., September 4 fluid	< 100 ppm, 96 h	Significant inhibition of shell formation	Gilbert, 1981
P. magellanicus 12-day larvae)	Liquid phase of used "Gilsonite" fluid	3,000 ppm, 96 h	Significant inhibition of shell formation	Gilbert, 1981
P. magellanicus (2-day larvae)	Liquid phase of used low-density lignosulfonate	10,000 ppm, 96 h	Significant inhibition of shell formation	Gilbert, 1981

Table 30. continued

Crustaceans				
Opossum shr Imp Mysidopsis bahia	Used Cr-lignosulfonate Mobile Bay, Ala.	50 ppm, 42 days, flowthrough	50% survival from postlarva to adult	Conklin et al. , 1980
M. almyra	Liquid phase of used Cr-lignosulfonate, Gulf of Mexico	10,000 ppm, 7 days	Decreased food assimilat ion and growth ef f iciency, reduced growth rate	Carr et al. , 1980
Coonstripe shrimp Pandalus hypsinotus (adults)	Used high-weight Cr-lignosulfonate, Cook Inlet, Alaska	100,000-ppm suspens ion	Gill histopathology	Houghton et al. , 1900
P. hypsinotus (Stage I larvae)	Used FeCr-lignosulfonate Conk Inlet, Alaska	2, 000-ppm suspen-sion, 144 h, 3, 250-ppm liquid phase, 144 h	Cessation of swimming by 50% of larvae	Carls and Rice, 1980
Dock shr imp Pandalus danae (Stage I larvae)	Used FeCr-lignosulfonate Cook Inlet, Alaska	500-ppm suspen-sion, 144 h, 1, 050-ppm 1 iqu id phase, 144 h	Cessation of swimming by 508 of larvae	Carls and Rice, 1980
Kelp shrimp Eualus suckleyi (Stage I larvae)	Used FeCr-lignosulfonate Cook Inlet, Alaska	5, 000-ppm suspen-sion, 144 h	Cessation of swimming by 50% of larvae	Carls and Rice, 1980
Grass shr imp Palaemonetes pugio larvae	Used medium- and high-we ight Cr-lignosulfonate, Gulf of Mexico	10,000-15,000 ppm liquid phase for duration of larval development	No effect on duration of any intermolt periods or on dur-ation of larval development, significantly increased mortality at molting	Neff, 1980
Sand shrimpCrangon septemspinosa	Used low-weight Cr-l ignosulf onate, mid-Atlantic OCS	33,000-ppm liquid phase, 96 h	Decrease in activity of the enzyme glucose-b-phosphate dehydrogenase in muscle tissue	Gerber et al., 1980
Atlantic Cancer crab Cancer irroratus	Liquid phase of used Cr-lignosulfonate, Mobile Bay, Ala., September 4, 1979	100 ppm, 20 days, f lowthrough	No effect on survival or molting rate	Gilbert, 19S1
C. irroratus (Stage III larvae)	Liquid phase of used Cr-lignosulfonate, Mobile Bay, Ala. , September 4, 1979	100 ppm, 4 days	Temporary inhibition of feeding	Gilbert, 1981
Cancer crab _ boreal is	Used med ium-weight Cr-lignosulfonate, Gulf of Mexico	160,000-ppm suspen-sion, 96 h 33,000-ppm liquid phase, 96 h	increase in activity of enzymes aspartate aminotransferase and glucose-6-phosphate dehydrogenase in heart tissue	Gerber et al., 1981

Table 30. continued

Species	Drilling Fluid Type	Exposure Concentration and Duration	Responses	References
Crustaceans (continued)				
Green crab *Carcinus maenus*	Used low-weight Cr-lignosulfonate, mid-Atlantic OCS	33,000-ppm liquid phase, 96 h	Increase in activity of enzymes aspartate aminotransferase and glucose-t-phosphate dehydrogenase in muscle	Gerber et al., 1980
King crab *Paralithoides camschatica* (Stage I larvae)	used FeCr-lignosulfonate, Cook Inlet, Alaska	2,800-ppm suspension, 144 h 12,900-ppm liquid phase, 144 h	Cessation of swimming by 509 of larvae	Carls and Rice, 1980
Tanner crab *Chionoecetes bairdi* (Stage I larvae)	Used FeCr-lignosulfonate, Cook Inlet, Alaska	2,800-ppm liquid phase, 144 h	Cessation of swimming by 50a of larvae	Carls and Rice, 1980
Mud crab *Rhithropanopeus harrisii* larvae	Used low-weight Cr-lignosulfonate, Jay Field, Fla.	100,000-ppm fluid aqueous fraction and suspended particulate phase, complete larval development	No effect on survival or development rate to first crab stage	Bookhout et al., 1982
Blue crab *Callinectes sapidus* larvae	Used low-weight Cr-lignosulfonate, Jay Field, Fla.	50,000-ppm fluid aqueous fraction and suspended particulate phase, complete larval development	Significant decrease in survival of megalops, altered larval behavior	Bookhout et al., 1982
American lobster *Homarus americanus* (adults)	Used low-weight Cr-lignosulfonate, mid-Atlantic GCS	10,000-ppm liquid phase, 96 h	Increase in activity of the enzyme aspartate aminotransferase and decrease in activity of enzyme glucose-6-phosphate dehydrogenase in heart tissue	Gerber et al., 1980
H. americanus (larvae)	Used medium-weight Cr-lignosulfonate, Gulf of Mexico	2,000-ppm liquid phase	Increase in duration of larval development by 3 days	Gerber et al., 19S1
H. americanus (adults)	Used medium- and high-weight Cr-lignosulfonate, Mobile Bay, Ala.	10-ppm suspension, 3-5 min	Decreased chemosensory response of walking leg chemosensors to food cues	Derby and Atema, 1981
H. americanus (adults)	Unknown	1-2 mm layer, 4 days	Inhibition of feeding behavior	Atema et al., 1982

Table 30. continued

Crustaceans (continued)				
H. americanus (adults]	Used Cr-lignosulfonate, Mobile, Ala., June 26, 1979	?-mm layer, 4 days	No effect on feeding behavior	Atema et al., 1982
H. americanus (Stage IV larvae)	Used Cr-lignosulfonate, Jay Field, Fla., July 29, 1980	7. 7-ppm suspension, 36 days	Partial inhibition of molting, delayed detection of food cues	Atema et al., 1902
H. americanus (Stage IV and V larvae)	Used CC-1 lignosulfonate fluids, Jay Field, Fla., and Mobile Bay, Ala.	1-4 mm layer	Delays in burrow construction, altered burrowing behavior	Atema et al., 1982
Polychaete Worms				
Lugworm *Arenicola cristata*	Used Cr-lignosulfonate fluids, Mobile Bay, Ala.	10-ppm suspension flowthrough with an accumulation of 4.5 mm at 100 days	339 mortality	Rubinstein et al., 1980
Echinoderms				
Sand dollar *Echinarachnius parma* (embryos)	Used Cr-lignosulfonate, MobileBay, Ala., June 26, 1979	3,816-ppm[a] suspension, duration of development	Depressed fertilization, delayed development, developmental anomalies	Crawford and Gates, 1981
Bat starfish *Patiria miniata* (embryos)	13 used Cr-lignosulfonate fluids, Santa Barbara Channel, Cal if.	500-100,000 ppm fluid. aqueous fraction, 48 h	Significant decrease in growth rate, increased incidence of deve lopmental abnormalities	Chaffee and Spies, 1982
Teleost Fish				
Killifish *Fundulus heteroclitus* (embryos)	Used Cr-lignosulfonate, MobileBay, Ala., June 26, 1979	3,816-ppm[a] suspension, duration of development	Retarded embryonic development, depressed embryonic heart beat rate	Crawford and Gates, 1981
F. heteroclitus [embryos)	Used freshwater Cr-1 ignosul f onate Gulf of Mexico	10,000-ppm l iquid phase, duration of development	Depressed hatching success, depressed embryonic heart beat rate, developmental anomal ies	Sharp et al., 1982
Pink salmon *Oncorhynchus gorbuscha*	Used high-weight Cr-l ignosul f onate Cook Inlet, Alaska	30,000-ppm suspension	Gill histopathology	Houghton et al., 1980

[a]Concentrations original ly reported as ppm suspended solids, conver ted here to estimated ppm total flu id added.

would be evident. Under high energy regimes characteristic of much of the nearshore areas of the North Aleutian Shelf, a conservative estimate of the largest distance of impact to the benthos from a point source would probably be less than 1,000 meters. In field studies conducted around drilling fluid discharges in low to moderate energy regimes, the furthest point of detectable influence on the benthic community has been 1,000 meters (NAP, 1983). The primary concern of most researchers in this field is for discharges in the vicinity of hard substrates where habitat is limited and communities longer-lived.

5. Vulnerability Analysis

The vulnerability of a given species to potential disturbances resulting from oil and gas development is extremely difficult to determine with a high degree of certainty. Vulnerability is a complex function of numerous factors. Among the more important factors influencing vulnerability are the sensitivities of each organism to various types of disturbances (e.g. oil spills, drilling fluid discharges, increased air and marine traffic), temporal and life cycle differences in geographical ranges, population size and productivity, feeding habits, and general behavioral characteristics.

While many of the various disturbances associated with development of oil and gas reserves may be of major importance to one or several taxonomic groups, a potential catastrophic oil spill in the coastal zone is of paramount concern. In assessing the vulnerability of the flora and fauna of species utilizing coastal areas of the North Aleutian Shelf, it is important to consider the differences in vulnerability of the principal habitats to an oil spill.

The location of an oil spill in the coastal zone is a major factor controlling its ultimate influence on the wildlife resources. The physical characteristics of different coastal environments largely control the behavior and persistence of the oil. A spill occurring in a high energy, rocky intertidal area would be expected to coat the rocks with a tough, tarry "skin" resulting in direct mortality of plants and animals due to smothering. With the constant exposure to wave action, sunlight, and air, this tarry layer of oil would gradually be altered and eroded from the surfaces of the rocks. Erosion rates would decrease with increased weathering of the oil. Up to 50 percent of the oil may be removed within 1.5 to 2 years but the remainder could persist for many more years. Oil stranded in pools in the upper intertidal may remain for many years virtually unaltered beneath a weathered film. Spills occurring on cobble and coarse sand beaches can penetrate well into the interstices of the substratum.where the oil may be retained in relatively unaltered form, slowly leaching back into the

overlying water. In finer substrates, oil penetration would be expected to be minimal. Areas with fine sediments, however, are typically low energy environments where dilution and dissipation of oil might be extremely slow, allowing the oil to persist in a concentrated form for long periods of time. Oil entering embayments along the Alaska Peninsula such as Izembek Lagoon could be retained for many years.

Thorsteinson (1983) provides a thorough review of the vulnerability of most key species present in the study area. The following discussion is a brief synthesis of the key points addressed in Thorsteinson's review, along with information specifically relevant to the vulnerability of key species in other areas of Bristol Bay. The reader should refer to this review for further insight into the vulnerability of species common to the entire Bristol Bay region.

a. Marine Mammals

Fur-bearing mammals are likely to be the most vulnerable of the marine mammals that utilize the nearshore habitat of the North Aleutian Shelf and Inner Bristol Bay. These species rely in varying degrees on both their specialized pelts and layers of blubber to assist in thermoregulation. Oil deposited directly on the fur can severely reduce the ability of the animal to thermoregulate and may result in direct mortality. This group of species would be particularly vulnerable to an oil spill due to their direct dependence upon the air/sea interface and haulout areas.

Sea otters are clearly the most vulnerable of the furbearing mammals to a potential oil spill. Both the young and adult sea otters rely upon their pelts for thermoregulation. In other species present in the region, only young pups that had not yet developed adequate layers of blubber for insulation would be extremely sensitive to oiling (Brahm et al, 1982).

Distributional limitations of sea otters, both longshore and offshore, during the spring and summer months tend to concentrate a large proportion of the population into a relatively small area. With the bulk of the estimated population of 11,000 to 17,000 animals distributed in the coastal region between Cape Mordvinof and Cape Leontvich and occurrence of occasional pods in excess of 1 ,000, the population could suffer extremely high mortality due to the direct effects of even a small spill.

Indirect impacts on the sea otter population might also result through decreased abundance of prey or ingestion of prey contaminated by petroleum hydrocarbons. Data are presently inadequate regarding both the feeding habits of

sea otters and sublethal or chronic effects of exposure to hydrocarbons through foodweb relationships. However, based upon present information that suggests that the sea otters are near the present carrying capacity of the environment, any reduction in food resources associated with a catastrophic oil spill could reduce the present population abundances (Schneider and Faro, 1975; Lowry, 1922; Kenyon, 1969).

The harbor seal and Steller sea lion populations are considered far less vulnerable to oil pollution due to their primary reliance on protective layers of blubber rather than fur to reduce heat loss associated with oiling as well as to their much broader distribution. For both harbor seals and sea lions, oiling is primarily a problem with young pups that have not yet developed adequate layers of blubber (Braham et al, 1982) . Vulnerability of harbor seals to a spill would therefore be highest in the vicinity of Port Moller, Port Heiden and the Cinder River areas during pupping in the months of June and July. Similarly, the sea lion population would be most susceptible to an oil spill occurring between May and July in the vicinity of either Fox Islands or Amak Island. The rookeries of the Fox Islands, which are frequented by approximately 80 percent of the population, would be the most critical habitat.

There is little evidence that non-forbearing mammals would be directly affected by short-term exposure to water accommodated petroleum hydrocarbons or to surface oil. Gray whales which utilize the nearshore region as a migratory pathway, principally between April and July, could potentially encounter a spill but can likely avoid it without problems. Other whales, such as Belugas, would also be expected to be capable of avoiding an oil spill or minimizing contact with the surface slick. While it is suspected that an oil spill would have little impact on these mammals, current data are far from sufficient to determine their vulnerability.

Many of the marine mammals found in this region may also be sensitive to increased air and marine traffic associated with oil and gas development. This is of particular concern in the vicinity of rookeries. These types of disturbances could result in increased pup mortalities (Johnson, 1977).

b. Birds

Oil spills in regions of high densities of birds can result in significant mortalities due to direct physical effects of contact with the oil. Upon contact with surface oil, a bird's feathers rapidly become matted, losing both their waterproofing and insulating qualities. The loss of

waterproofing results in absorption of water into the feathers and consequently requires substantially more energy to fly, swim, or dive for food. The loss of thermal insulation also results in a significant expenditure of energy due to the increased metabolic rates necessary to maintain body heat. Ultimately, a heavily oiled bird will succumb to exhaustion, unable to obtain even maintenance rations.

A lightly oiled bird may be capable of preening the oil from its feathers; however, temperature plays an important role in the ability of an oiled bird to survive. Birds tend to be more sensitive to oiling in colder climates where loss of body heat can rapidly deplete energy reserves.

One of the most devastating and longlasting effects that an oil spill could have on bird populations would be a decrease in reproductive success. Transport of oil back to nests containing incubating eggs can result either in direct mortality or reduced hatching success. In laboratory tests, coverage of only 5 percent of the total surface area of mallard eggs has resulted in substantially lower hatching success (Albers, 1977). Ingestion of "lubricating oil under laboratory conditions has been demonstrated to temporarily inhibit egg formation and laying (Gray et al, 1977).

The ecological impact of reduced reproductive success is directly related to the reproductive strategies of each particular species. Populations of short-lived species with high fertility rates would be least vulnerable to impacts of an oil spill. Longer lived species with lower turnover rates (one to two eggs/yr/pair, e.g. alcids) could be extremely vulnerable to an oil spill.

The major factors influencing the vulnerability of various bird species to an oil spill include the amount of time they spend on the water, how strongly they tend to aggregate, the proportion of their life spent in the study area, whether or not they breed in the region, and their population turnover rate. The indirect influence of an oil spill on food resources of limited distribution may also contribute to the vulnerability of several species. Birds most vulnerable to an oil spill include seabirds that breed in the Bristol Bay region, such as the alcids (primarily the common murre), the black-legged kittiwake, and the waterfowl that heavily utilize the coastal lagoons.

Many of the species that utilize the lagoons and marshes are particularly vulnerable to oil spills. Increased retention times would increase the possibility of direct contact with the oil as well as exacerbating the situation by prolonging exposure to food resources. A major spill in Izembek Lagoon, for instance, could drastically reduce the population of black brandt, eiders, and Emperor geese.

c. Fish

The sensitivity of fish to oil pollution varies both with life stage and habitat type. As a general rule, early life stages are more sensitive than adults and pelagic species tend to be more sensitive than either demersal or benthic species. Also, many larvae concentrate near the surface where potential damage from oil is highest.

In the nearshore zone of the Bristol Bay region, species most vulnerable to an oil spill would be littoral spawners such as capelin and Pacific herring. Other species, such as the osmerids (eulachon and boreal smelt), which enter the rivers to spawn but utilize the nearshore zone as a nursery ground and adult habitat would also be considered vulnerable. Yellowfin sole larvae may also be abundant and potentially vulnerable in the region. Older life stages susceptible to oil pollution would include primarily pelagic species. Since older juveniles and adults are more mobile and less sensitive to water soluble Petroleum hydrocarbons, they are generally considered to be far less vulnerable. Outmigrating salmon may be an exception since they are initially limited to surface waters of the inshore region.

Capelin are extremely vulnerable to an oil spill during much of their life history. Oil spills encountering the fine gravel beaches utilized as spawning habitat by capelin may penetrate well into the substratum where it would slowly leach back into the water column, subjecting deposited eggs to continuous low level concentrations of petroleum hydrocarbons. Upon hatching, capelin larvae, like most osmerids, are found in larger abundance in the surface waters. Neuston nets have been found to be more effective than standard bongo nets at collecting osmerid larvae in the Bering Sea region (Waldron, 1981). Under a spill situation, their location in the water column would thus expose them to high concentration of petroleum. It is postulated that larvae of other smelts (mostly boreal smelt and eulachon) that spawn in rivers would drift out into littoral nursery areas where they would be subject to similar exposure to petroleum hydrocarbons.

Pacific herring populations could also be heavily impacted by oil releases. As adults, herring remain offshore but yearly enter the nearshore zone for spawning, when hydrocarbons in the environment may be accumulated in the eggs. Once the eggs are spawned and become water hardened, uptake of lower molecular weight hydrocarbons would be minimal. upon hatching, larvae are likely to be highly concentrated due to the relatively restricted spawning habitat. During this time period the population could suffer substantial losses from a major spill event. As the larvae disperse and further develop into juveniles it is unlikely that a spill could impact the population.

The migratory patterns of salmon (primarily sockeye), through the Bristol Bay region are such that only juvenile salmon would be potentially subject to impacts of a spill. Adults are typically well dispersed offshore as they return to their spawning rivers. Outmigrating juveniles, however, are relatively restricted in their distribution. Juvenile salmon leaving the spawning rivers remain in a relatively narrow band along the Alaska Peninsula until reaching the region of Port Moller where they veer out to sea. During their outward migration juvenile salmon remain in the upper one to two meters where they would most likely encounter high levels of petroleum hydrocarbons from a major spill. Laboratory bioassays suggest that losses could occur at hydrocarbon concentrations of greater than 1 ppm for a period of 3-5 days. However, it is not known how they may immediately respond to a spill under field conditions nor what sublethal effects may eventually affect their survival.

d. Invertebrates

The red king crab is considered to be the most vulnerable invertebrate species and certainly one of the most sensitive of all fauna in the Bristol Bay region to oil and gas development. Release of larvae and mating occur in the inshore areas of Bristol Bay which also have the greatest potential petroleum reserves. Larvae released between April and June remain in the nearshore zone, drifting further into Bristol Bay before settling out to take up a benthic existence. King crabs may remain in the coastal regime for 4 to 5 years prior to initiation of adult migratory behavior (Powell and Nickerson, 1965).

Crustacean larvae are among the most sensitive to petroleum hydrocarbons. Bioassays conducted with red king crab larvae have resulted in 96 hour LC50's as low as .1.3 ppm. This suggests that a large-scale spill occurring along the coast between Cape Mordvinof and Port Moller between April and May could have a significant effect on the larval crab population. Thorsteinson (1983) estimated a potential loss of 3-5% of the population from a 10,000 barrel spill.

Due to the current scarcity of data regarding the distribution and habitat requirements of juvenile king crab it is difficult to assess their vulnerability to oil development. The difficulties in locating habitats utilized by these juvenile crabs may suggest that either suitable habitats are extremely limited or that sampling methods have been inadequate. If juveniles are found to be densely aggregated into limited areas, they would be extremely vulnerable to a variety of different types of disturbances.

RESEARCH NEEDS AND DATA GAPS

Bristol Bay is a region of unmatched commercial importance. The bay is also of major ecological importance to numerous species of birds, fishes, and mammals. Nevertheless, large data gaps exist which hamper management decisions regarding these resources, particularly when oil and gas developments are added to the present problems.

As a framework for consideration of these data needs the conceptual model developed in the earlier hypotheses section is utilized. The conceptual ecological model developed in this earlier section is first summarized. Then testable hypotheses are formulated regarding the important processes involved and data gaps are identified which are associated with each hypothesis. The conceptual model thus serves as a guide to the interpretation and synthesis of the future data for the North Aleutian Shelf.

1. Conceptual Model Summary

The conceptual ecological model formulated in the earlier hypotheses section is summarized in Figures 136, 137, and 138. This conceptual model is based upon the premise that the observed richness of biological resources in the nearshore area can be explained by two factors, 1) food availability and 2) suitable habitat.

The first factor, that of high biological productivity within the nearshore shelf zone of Bristol Bay, is hypothesized to be based upon two somewhat independent trophic systems. One of these systems is more or less self-contained and endemic. The other system is a seasonal "import-export" system. Of course, the two systems overlap to some degree.

a. Endemic Trophic System

A conceptual model of the endemic trophic system is given in Figure 136 for the north Alaska Peninsula coast, and in Figure 137 for the inner Bristol Bay region. This endemic trophic system is heavily dependent on marine productivity. However, seagrass imported from the lagoons may contribute about 14% of the available organic carbon, if averaged over the north Peninsula nearshore coast, and perhaps more locally. Detrital material from rivers also adds approximately 7 and 10% respectively to the north Peninsula and inner Bristol Bay nearshore zones. This input from rivers and lagoons is as detrital organic matter, not as soluble nutrients. From the conceptual model and using available data, it appears that this endemic trophic system is a benthic-rich system in that much of the detrital carbon and in-situ phytoplankton production reach the benthos,

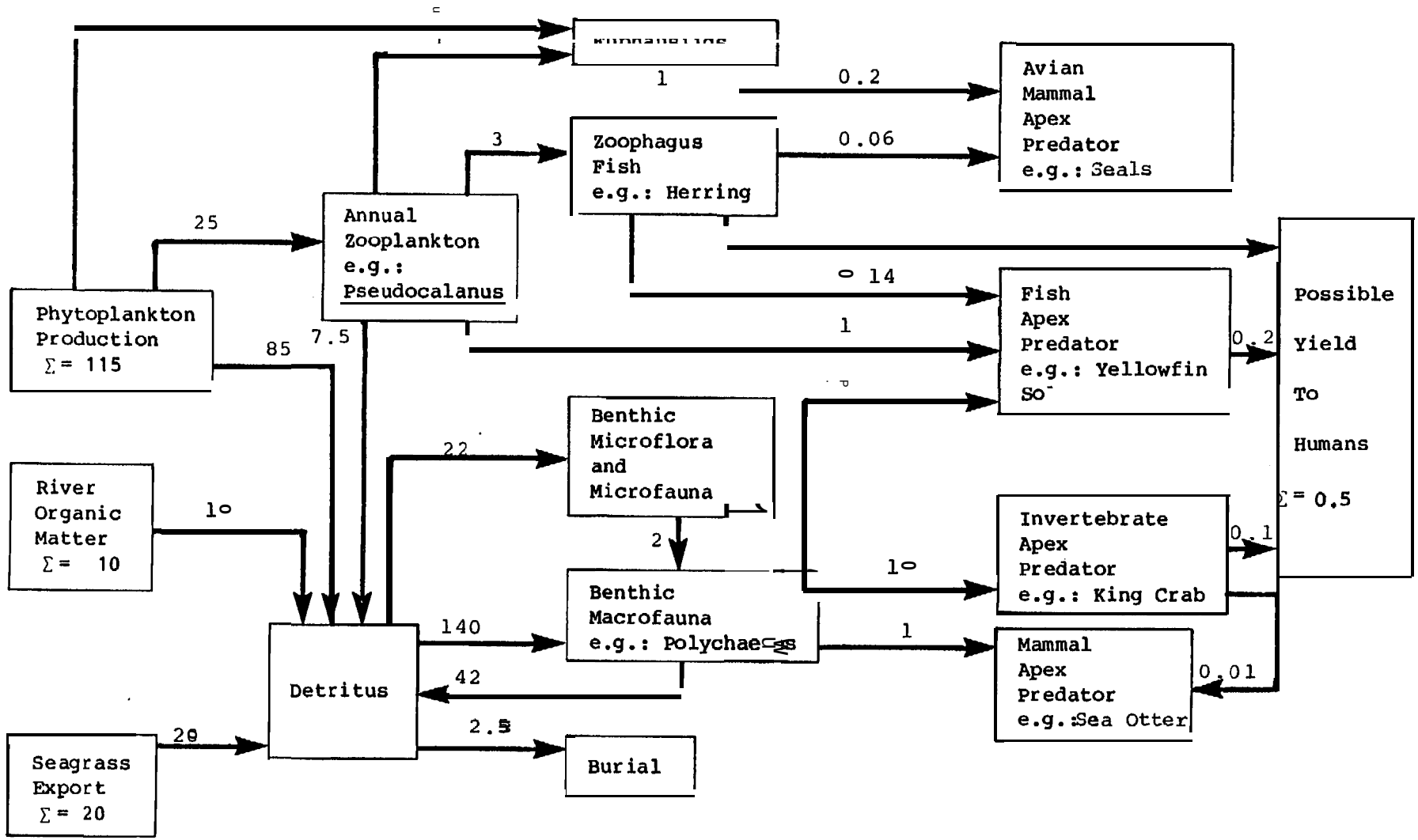


Figure 136. Conceptual endemic system model for the North Aleutian Peninsula nearshore zone. Hypothetical carbon budget in g m^{-2} yr^{-1}.

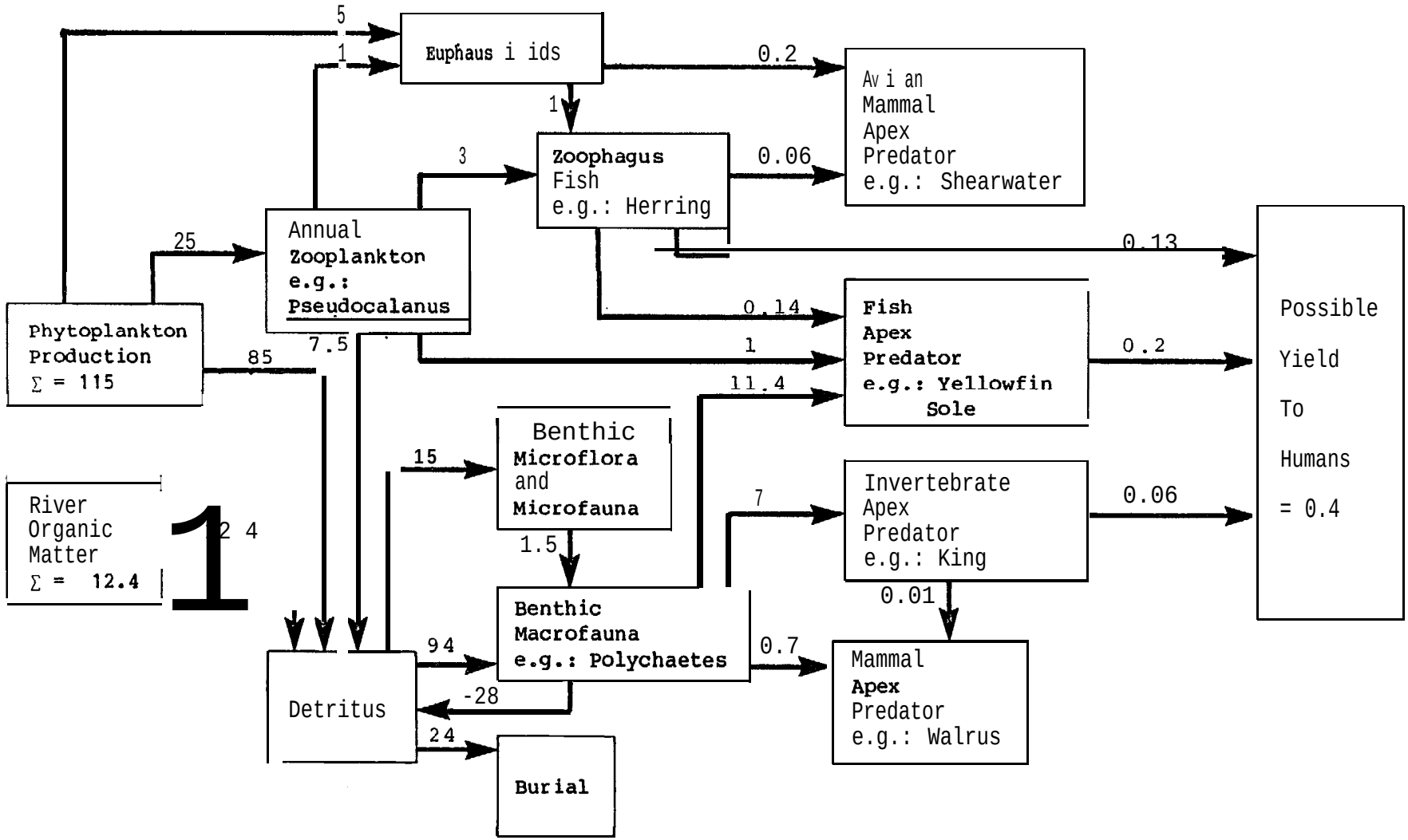


Figure 137. Conceptual endemic system model for Inner Bristol Bay. Hypothetical carbon budget in g m^{-2} yr^{-1}.

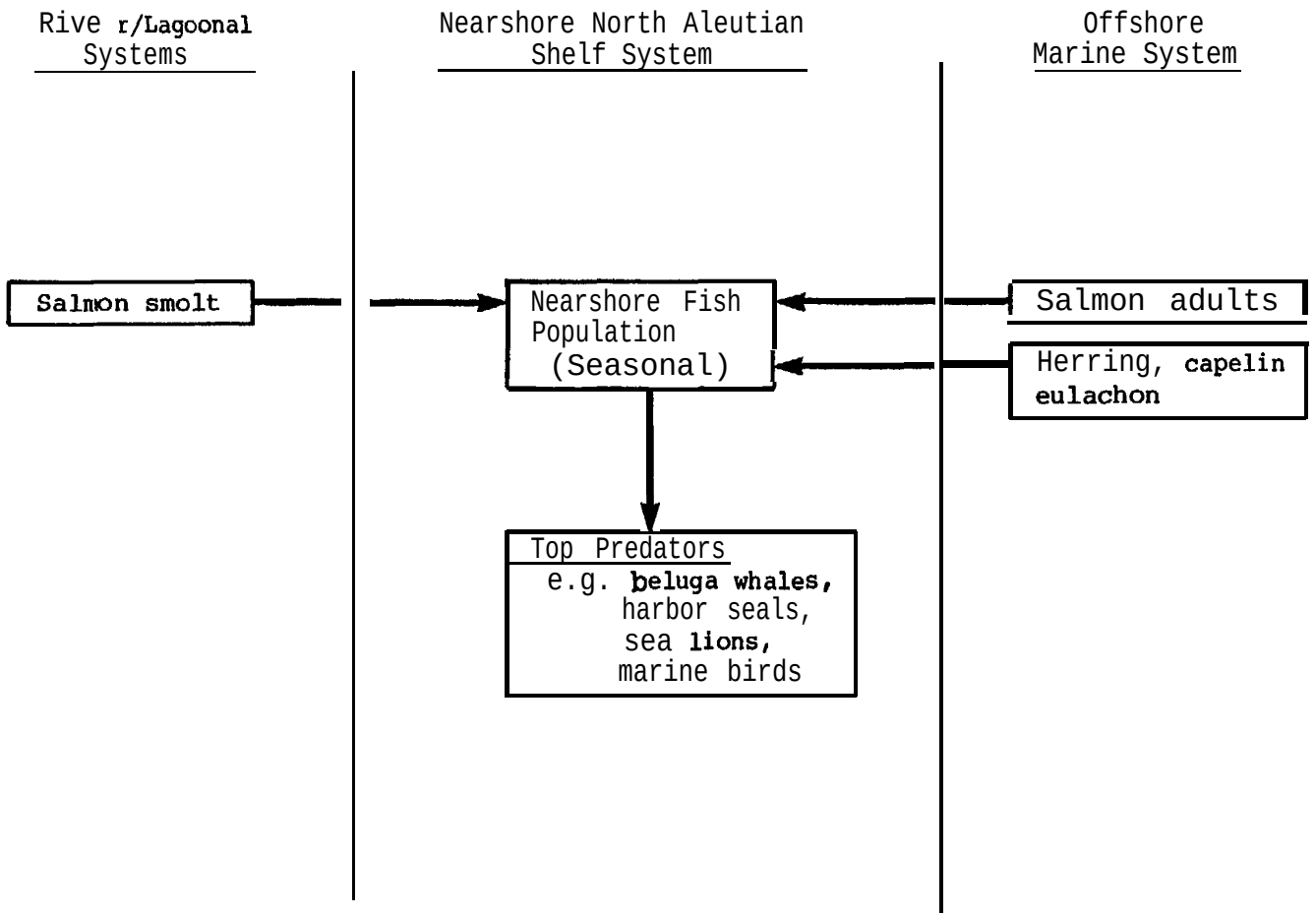


Figure 138. Conceptual "Import-Expor t" trophic system model for North Aleutian Shelf.

rather than being consumed in the water column. This endemic system supports most, if not all, of the zooplankton, benthic infaunal, and fish productivity of the nearshore region. Most of all of the higher trophic level marine mammal and bird species probably rely on this endemic system for nutritional maintenance to varying degrees.

b. Import-Export Trophic System

The second trophic system (Figure 138), a parallel but interacting import-export system, is seasonal and pulsating in nature, and is comprised of the huge runs of anadromous fish which utilize the area, along with their retinue of predators. The hypothesis in this regard is that these migratory populations of anadromous (and in some cases marine) fish such as salmon, smelt, herring, capelin, and eulachon statisfy most of their energy and growth requirements in other marine or freshwater environments and import this biomass in seasonal pulses into the nearshore zone.

Supportive data are lacking but are needed for this second system. Some estimate of the relative importance of such an import system to the nearshore zone can be made, however, by considering just the outmigrating salmon smelt and the immigrating adult salmon. Data given earlier in the characterization sections indicate that mean numbers of 500 million outmigrating smelt and 18 million inmigrating adult salmon pass through the inshore area each year. Converting this biomass to carbon on a year basis yields some 10^{10} gm C/yr, compared to some 10^{12} gm/yr contributed by primary productivity. Considering these migratory fish to be two to three trophic levels above primary productivity, and assuming a ten percent transfer efficiency, this amount of carbon is at least roughly equivalent to the amount at the trophic level expected to be derived from the in-situ primary productivity. Of course, much of this migratory carbon is not utilized in the inshore system, but is simply passed through.

It is conjectured, however, that these seasonal pulses of imported energy resources may be critical to the maintenance of the particularly high populations of some top predators, especially beluga whales and harbor seals; and perhaps also to Steller sea lions and marine birds which frequent the area. It is perhaps of some significance in this regard that all of these predators either disperse or depart from the area in the fall, coinciding with the departure from the area of such migratory fish species.

c. Habitat Factors

Along with food requirements, suitable habitat is an important parameter explaining the nearshore distribution of many species. As an interracial zone between rich terrestrial and marine systems, the nearshore waters, shallow

benthic areas, and shoreline features are highly utilized, especially by species who have particular needs for these specialized habitats. Often these habitats are used only during critical stages of life cyles or maybe on a seasonal basis.

Examples of such nearshore habitat usage by key species were summarized earlier in Table 15. Usage for haul-out, pupping or rookeries, feeding, or as migratory corridors apply to such key mammal species as harbor seals, Steller sea lions, Pacific walruses, grey whales, beluga whales, and sea otters. For birds, usage of the bay/lagoon systems, shoreline features, and nearshore marine areas is heavy. Usage consists of migratory staging, as a migratory corridor, nesting and breeding, and feeding for such key bird species as common murres, short-tailed shearwaters, black-legged kittiwakes, black brant, emperor geese, Steller's eider, dunlin, and western sandpiper.

The inshore zone also is heavily utilized by fishes and macroinvertebrates. Examples of such use by key species include the migration of salmon and salmon smelt between the inshore freshwater systems and the ocean, including maintenance feeding enroute. Smelt also spawn in freshwater streams and heavily utilize the inshore area feeding on amphipods, polychaete worms, small fish, and like food resources. Marine fishes such as yellowfin sole, Pacific herring, and capelin utilize the nearshore zone for spawning, nursery grounds, and feeding. Red king crab use the broad, shallow area (<50 m) along the Alaska Peninsula and northern and inner Bristol Bay for mating/spawning and juvenile development. The shallow benthic habitats, enriched by the carbon flux from marine productivity and riverine/lagoonal organic detritus, support large populations of bivalves such as the Alaska surf clam and the great Alaskan tellin.

2. Hypotheses for Testing and Approach

a. Introduction

The most obvious data gaps are those concerning a) fundamental food web relationships and b) utilization and importance of nearshore habitats.

We have hypothesized that the high biological productivity in the nearshore area is based upon two somewhat independent systems. One system, heavily dependent upon marine productivity, but with important lagoonal/river contributions, is an endemic, benthic-rich system. The second, an import/export system based primarily on migratory anadromous fishes, is probably of equal importance to higher predators. The data to verify and quantify these hypothetical food webs, and to identify critical linkages potentially vulnerable to oil impacts, are very fragmented.

For example, the inshore marine primary productivity and that contributed by lagoonal/riverine systems has been estimated from very sparse data. The critical roles of lower level consumers, and even of their locations, are not documented. Zooplankton grazing rates, potentially important roles for mysids and euphausiids, the importance of detrital material in the nearshore area, and infaunal standing stock and production estimates are all topics for which directed research is needed so that importance and potential vulnerability of food web links maybe understood. Similar conditions exist with regard to good data on higher trophic level consumers, starting with almost nothing on major forage fishes (such as smelts) and proceeding with large data gaps on feeding of key marine mammal and bird species (such as otters, sea lions, harbor seals, and seabirds).

A similar situation exists with regard to utilization of nearshore habitats. It would be. expected that the large lagoonal areas would be extensively utilized as nursery grounds for marine species. Yet, sampling designed to look at such broad utilization (covering only three to four weeks) has been carried out in only one lagoon (Izembek). An assessment of importance cannot be made from such limited data. The extensive shallow estuarine bays surrounding Bristol Bay have also not been studied as to their real importance as nursery or feeding grounds, though some work has been started on the open Peninsula coast regarding inshore utilization and feeding by crabs and otters. Major effort should be placed upon studies of these lagoons and embayments in order to document their suspected multifaceted importance to Bristol Bay food webs, in addition to their obvious bird habitat importance.

b. Summary of Data Gaps

A summary of identified research needs and of data gaps pertaining to "the North Aleutian Shelf, nearshore zone is given in Table 31. This summary identifies hypotheses for testing and associated experimental approaches.

c. Discussion of Data Gaps

Biological Processes. Carbon budgets for the North Aleutian Shelf and Inner Bristol Bay regions were developed based upon the best available data regarding primary production (both phytoplankton and seagrasses), faunal abundances, and trophic relationships. It was often necessary to extrapolate utilizing data from deeper water areas of the shelf or from other inshore areas. The general model suggests that the coastal zone supports primarily a benthic food web. Grazing of detrital material and phytoplankton by zooplankton is considered to be low. Expected low abundances of euphausiids in nearshore waters is estimated to

Table 31. Summary of research needs and data gaps

Ecosystem Component	Hypothesis for Testing	Approach
1. Primary producers/ carbon sources		
a. Marine phytoplankton	1. In-situ phytoplankton production contributes approximately 80-90% of the organic carbon available to the endemic inshore food web.	1. Determine phytoplankton standing crops, distributions, productivity, and nutrient regimes in the near-shore areas of Bristol Bay.
b. Lagoonal seagrass export	1. Eelgrass exported from lagoons contributes approximately 14% of the organic carbon available to the endemic food web in the north Peninsula inshore zone.	1. Determine standing stock and productivity of vegetation within the lagoons and bays along the Alaska Peninsula on which sufficient data do not now exist.
c. River organic matter	1. Riverborne detrital organic material contributes approximately 7 to 10% of the organic carbon available to the endemic inshore food web.	1. Measure detrital organic carbon in north Peninsula and inner Bristol Bay rivers. Estimate' flows from gauging data, or from rainfall drainage area relationships.
d. Migratory fishes	1. Migratory fishes effectively import carbon equivalent to that of the 2nd or 3rd trohpic level of the endemic system and this carbon is important to seasonally high populations of top predators.	1. Determine distribution, abundance, and usage of the inshore areas, including bays and lagoons of a) migratory fishes (anadromous and marine) and b) of top predators (fish, mammals, birds). 2. Conduct food habit studies on top predators feeding in the inshore zones, including stomach analyses where appropriate.

Table 31. (Continued)

Ecosystem Component	Hypothesis for Testing	Approach
	2. A large flux of detrital material (80-90% marine origin; 10-20% river/lagoon origin) is cycled through the benthic food web, with an unknown portion being passed up to higher predators.	1. Use carbon and nitrogen isotope techniques to elucidate food web relationships and document pathways of detrital carbon from lagoonal and terrestrial origins, with emphasis on both areas of possible sources (e.g. , Izembek Lagoon) and an area where phytoplankton sources would dominate.
3. Higher Level Consumers		
a. Fish	1. Forage fish are a very important link in the inshore food web and quantitatively very significant in transferring organic productivity to apex predators.	1. Conduct basic biological research on major forage fish species (osmerid smelts and herring) that utilize the nearshore areas, including life-history parameters. Determine seasonal distribution and spawning habitats, fecundity and recruitment, growth rates, age-specific mortality rates, and age-specific feeding habits (e.g. stomach analyses). DO herring spawning surveys to supplement existing data or other efforts.
	2. Yellowfin sole are benthic predators, important in transferring benthic productivity to apex predators. They also prey on and compete with other benthic predators such as crab.	1. Obtain additional data on the feeding habits of yellowfin sole in the inshore areas to supplement data existing for one subarea, include seasonal variations and size-specific data.
b. Crabs	1. The North Aleutian Shelf nearshore zone is important to the red king crab population of the southeastern Bering Sea.	1. Obtain additional information on the inshore distribution and abundance of larval and juvenile crabs, the location and function of podding activities in later stage juveniles, and on feeding relationships within the nearshore zone.

Table 31. (Continued)

Ecosystem Component	Hypothesis for Testing	Approach
2. Lower level consumers		
a. Zooplankton	1. Zooplankton grazing within the nearshore zone consumes only about 26% of the in-situ phytoplankton carbon; the remainder enters the benthic food web.	1. Obtain basic distribution and abundance data for zooplankton in nearshore areas and lagoons (Izembek, Port Heiden, Port Moller) by field surveys. 2. Determine grazing rates for zooplankton in the nearshore zone by shipboard grazing experiments using natural populations.
	2. Euphausiids and mysids may furnish important links from phyto- and zooplankton to higher predators such as marine birds and forage fish.	1. Sample nearshore area with techniques appropriate to capture euphausiids and also mysids, and determine abundance and distributions. 2. Do stomach analyses of forage fish and appropriate marine birds.
	3. Epibenthic crustaceans (e.g., amphipods) may provide an important link from detrital carbon to higher predators through forage fish.	1. Sample nearshore areas with techniques appropriate to sample epifauna. 2. Do stomach analyses of forage fish.
b. Benthic	1. A rich benthic community is quantitatively a major element in the nearshore ecosystem, involving perhaps 75% of the organic carbon of the endemic trophic system.	1. Supplement presently inadequate data in the inshore areas on standing stocks and distributions of benthic organisms. Include suitable sampling (e.g., hydraulic dredge) for deeper living bivalve" mollusks believed to be quantitatively very important. 2. Estimate benthic production by sequential field sampling and measurement of life history parameters (size, sex, fecundity) of the biomass-dominant species.

Table 31. (Continued)

Ecosystem Component	Hypothesis for Testing	Approach
c. Mammals	1. The distribution of harbor seals, the most numerous marine mammal species in the nearshore area, is related to habitat and food availability; their vulnerability to development is greatest through their supporting food chain; and they compete with commercial fisheries. Similar hypotheses apply to sea lions.	1. Determine the general feeding habits (including seasonality in prey selection) and seasonal shifts in population distribution for both harbor seals and sea lions. 2. Obtain data on the population biology of Steller sea lions to document or help explain the apparent population decline, include work on breeding success and productivity, incidence and causes of natural mortality, and general condition of the population.
	2. Sea otters are an important controlling element in the structure of the inshore benthic ecosystem.	1. Obtain additional information on the feeding habits of the sea otter and distributional characteristics relative to their food resources.
	3. Sea otters utilize False Pass to migrate to the southern side of the Alaska Peninsula in the winker.	1. Determine if False Pass is a major migratory pathway.
d. Birds	1. Seabirds (including shearwaters, murres, and kittiwakes) depend upon both the endemic food web and the migratory resources in the inshore areas for their sustenance.	1. Obtain regional information in the nearshore zone on the feeding ecology of seabirds, emphasizing shearwaters, murres, and kittiwakes.
	2. Fall and winter are times of most vulnerability for overwintering species.	1. Determine fall and winter distributions and feeding habits of overwintering species such as common murres, Steller's and king eiders, oldsquaws, and black scoters.

Table 31. (Continued)

Ecosystem Component	Hypothesis for Testing	Approach
4. Circulation and transport affecting other ecosystem components	1. The NAS is on a meteorological knife-edge with large interannual variability in storm tracks, north of or along the Aleutian Chain/Alaska Peninsula (Overland and Pease, 1982) associated with large scale meteorological patterns. Nearshore flow is event dominated, with periods of wind-driven counter-flow close to shore, probably statistically very significant but variable, and important to larval distribution of inshore spawning species upwelling and inshore density structure, inshore/offshore mixing of detrital organic material, and the movements of food organisms and predators.	1. Determine the currents in the nearshore region of Bristol Bay with special emphasis on synoptic regional coverage and on/offshore variability. Utilize moorings located in eastern Unimak Pass, along the nearshore zone of the Alaska Peninsula, in the inner Bristol Bay, and along the northern bay shore, including inshore and offshore moorings. Correlate data with regional meteorological data. 2. Determine the influence of nearshore currents and density structure on dispersion and transport of carbon and nutrients; also determine the relationship between meteorological events and material fluxes across the inner front boundary of the coastal domain. Utilize hydrographic and chemical sections, including detrital organic matter, determined seasonally.
	2. Exchange between the waters of bays and lagoons with the nearshore marine waters is important to nutrient (organic matter) export, to lagoonal ecology, and to potential pollutant contamination.	1. Determine water exchange between lagoons/inner bays and the nearshore zone as well as residence times in these embayments.
	3. The addition of organic material and nutrients to the nearshore zone, along with their subsequent transport, affects the distribution of biota which depend upon the benthic rich endemic system.	1. Determine lagoonal/riverine export of organic matter and nutrients as a function of season, along with their subsequent spatial distribution. Correlate with benthic population and, distributional data.

further reduce grazing pressures relative to the Middle Shelf Domain. Estimation of consumption of zooplankton by small forage fish (herring and osmerid smelts) may be inaccurate due to the very limited data regarding their distribution and abundances in this area. Further inaccuracies in the carbon budgets may result from estimates of carbon flux to the numerous benthic predators which occupy the nearshore region during all or portions of their life history.

It is evident that substantial data gaps still exist in our understanding of the biological processes occurring in the nearshore areas of the North Aleutian Shelf and Inner Bristol Bay regions. A number of questions still need resolving before the proposed carbon budget can be confirmed or refined. Further refinement of the carbon budget will greatly enhance its utility in identifying critical energy pathways through the system.

The following topics have been identified within each of the major trophic levels as components of the system which require further research to refine the proposed carbon budgets. A few of these areas have been addressed in studies conducted in 1982 for which final reports have not yet been submitted. A few may still require further research if an adequate data base was not established.

Primary Producers/Carbon Sources

1. Determine the standing stock and productivity of vegetation within the lagoons and bays along the Alaska Peninsula.

Standing stocks of the dominant vegetation in Izembek Lagoon have been estimated at about 430 g C/m^2 or about 56,000 metric tons of carbon. Similar estimates have not been established for other bays and lagoons.

Productivity data have been obtained only from Izembeck Lagoon where carbon production in the eelgrass meadows was estimated to range from 3.3 to 8.0 g $C/m^2/day$ or 177,000 metric tons per year. Again, estimates are unavailable for other lagoons and bays.

Carbon inputs from lagoons and marshes to the entire North Aleutian Shelf were estimated in this report to be 20 g $C/m^2/year$ with Izembeck Lagoon contributing as much as 14 g $C/m^2/year$ and all others contributing a total of 6 g $C/m^2/$ year. This carbon contribution to the coastal domain is estimated to be 14 percent of the total carbon input including total organic matter from rivers and phytoplankton production. While this input comprises a significant amount of the total carbon when assumed to be

distributed evenly across the entire coastal domain of the North Aleutian Shelf, it is more likely that regions in the immediate vicinity of these lagoons and marshes receive a much greater percentage of their carbon from these sources.

2. Additional data regarding phytoplankton standing crops and productivity in the nearshore zone are required.

Inshore standing crops have been estimated to range from 1x105 to 109 cells per/m^3 with an annual production of 115 to 120 g C/m^2/year. These estimates, however, are based upon few collections from the offshore oriented PROBES studies. Spatial and temporal patterns have not been well established in this zone, particularly in reference to possible nutrient point sources.

Lower Level Consumers

1. Obtain basic distribution and abundance data for zooplankton in nearshore areas and lagoons, (Izembek, Port Heiden, and Port Moller).

While community structure and production of zooplankton assemblages in many areas of the Bering Sea have been well studied, little information is available from the nearshore region of the North Aleutian Shelf. Data on nearshore assemblages is primarily from, the northern side of outer Bristol Bay off Cape Newenham. This region differs in both hydrography and general bathymetry from the nearshore zone of the North Aleutian Shelf. These assemblages may be similar to those of the nearshore area of inner Bristol Bay but it is unlikely that they resemble the assemblages present along the Alaska Peninsula.

The roles of both euphausiids and mysids in these region should be examined. We have estimated that euphausiids are present at standing stocks of half the level found over the mid-shelf area strictly on the basis of 'depth preferences. Less is known about the role of mysids in this area. Mysids are extremely important in many similar areas. Sampling methods appropriate to sampling mysids have apparently not been applied in either the lagoons or nearshore areas.

2. Establish zooplankton grazing rates in the nearshore zone.

Zooplankton grazing within the nearshore zone has been estimated to be relatively low. Approximately 22 percent of the carbon produced by phytoplankton is estimated to be consumed by annual zooplankton species. Another four

percent of this carbon is estimated to be consumed by euphausiids. The remainder of the phytoplankton production is believed to enter the benthic food web as detritus. More accurate estimates of grazing rates would greatly enhance the proposed carbon budget.

3. Both standing stock and production estimates are needed for infaunal assemblages (production to biomass ratios).

Infaunal data in the nearshore zone are usually sketchy and generally based upon small sample sizes. Less than twelve stations were within the nearshore area in Haflinger's (1981) survey" of benthic infaunal communities of the southeastern Bering Sea shelf. A more recent study which has not yet been submitted in final form has significantly increased the data base on the species composition of infaunal assemblages from Cape Sarichef to Cape Seniavin but did not provide production or biomass estimates.

Bivalve mollusks believed to be important in this region are undoubtedly underestimated. Sampling with a hydraulic dredge is recommended in order to effectively sample these deeper living species which may play an important role in the nearshore foodweb.

4. Benthic food web relationships within the nearshore zone need further work to evaluate the role of detrital material (both from seagrasses and phytoplankton).

It appears that detrital material originating from the coastal lagoons and from unconsumed phytoplankton provide an important carbon source for the benthos. Present data are not adequate to determine or document the pathways through which this energy source is channeled.

Carbon and nitrogen isotope work would be useful in establishing the pathways through which these different types of detrital material are made available to higher trophic levels. Work should be conducted both near major point sources of seagrass detritus (Izembek Lagoon) and in areas distant from these point sources where phytoplankton detritus would be expected to be the predominant carbon source.

Higher Level Consumers

1. Basic biological research is needed for all major forage species of fish (osmerid smelts and herring) that utilize the nearshore areas.

Osmerid smelts, including capelin and boreal smelt, have been identified as dominant forage species in this region yet information on their life histories within the study area is nearly nonexistent. Slightly more is known of the life history of herring within the nearshore areas due to their commercial importance.

Data regarding general population parameters (for example: age-specific mortality rates, growth rates, and recruitment rates), seasonal distribution, and spawning habitats are needed. Spawning surveys should be conducted for herring in order to obtain accurate estimates of the adult population which utilize the area as spawning habitat.

Osmerid smelts and herring are believed to be of major importance to birds, mammals and other fish. These trophic interactions need further study to clearly establish the role of forage fish in the carbon budget. Age specific feeding habits of forage fish should also be examined, particularly in light of the relatively low standing stocks of zooplankton which are expected in this area.

2. Information on the age/size specific feeding habits of yellowfin sole should be obtained.

The feeding habits of yellowfin sole have recently been studied in a portion of the study area. These data have been grouped to characterize the feeding habits of the species as a whole. Size-specific feeding habit data may be available from this data base. If this is true, then data may only be necessary for the inner Bristol Bay regions not included in this study.

3. Data regarding the general feeding habits (including seasonality in prey selection) and seasonal shifts in population distribution are needed for both harbor seals and sea lions.

Information on the feeding habits of harbor seals, which are the most numerous marine mammal species found in the area, is extremely scanty. A total of only 20 harbor seals has been analyzed from the region for stomach contents, 19 of which were collected between 4 and 12 October 1981 (Lowry et al, 1982). This sample size is certainly too small to provide a comprehensive view of feeding habits and prey selection of harbor seals in this area, and tells us nothing about seasonal changes in prey selection. Such dietary information is essential for assessing perturbation impacts upon this population and for assessing the predation impact of the species upon commercial fisheries of the region.

Also, data concerning seasonal shifts in harbor seal distribution within the region are almost nonexistent. All

population surveys have in the past been conducted during the summer when seals were hauled on the beaches during pupping and molting. Other than surmise and anecdotal information, there is virtually nothing known about population distributions once seals leave the beaches. Again, such information is crucial to forming any assessment of perturbation impacts upon that population.

Essentially the same situation exists regarding data needs for sea lions. Though the diets of Steller sea lions have been studied extensively in other areas, only twelve have been analyzed from the Bering Sea and. most of these were taken in the Pribilof vicinity (Lowry et al, 1982). Clearly, much more complete information regarding sea lion feeding behavior in this region is needed, both in order to assess perturbation impacts upon the population and to evaluate sea lion-commercial fisheries competition and interaction. This information is particularly needed in the case of sea lions in light of recent population declines, perhaps the result of depleted stocks of commercial fish species (Braham et al, 1980).

4. The population biology of Steller sea lions in the nearshore region needs further study.

In view of the recent decline in the sea lion population, it would be helpful to have information regarding breeding success and productivity of the population, incidence and causes of natural mortality, and general condition of the population.

5. Further research is needed regarding sea otter feeding habits and distributional characteristics relative to their food resources.

Present data on the feeding habits of sea otters in the nearshore zone are limited to analysis of nine scat samples collected in two days from a single location.

6. The proposed hypothesis that sea otters utilize False Pass to migrate to the southern side of the Alaska Peninsula in the winter needs to be tested.

Use of False Pass as a migratory route to the south would make this region extremely important to sea otters. An oil spill in this region during migratory periods could severely impact the population. This hypothesis should therefore be tested to determine whether this region is a major migratory pathway and, if so, to determine the timing of migrations through the area.

7. Further information is needed on the feeding ecology of seabirds (including shearwaters, murres, and kittiwakes) in the nearshore zone.

Information regarding marine bird feeding ecology, though fairly well known for adjacent areas such as the Pribilofs, is sketchy for the Bristol Bay-Alaska Peninsula coastal region. Additional information is necessary in order to assess probable impacts on seabirds resulting from environmental disturbance and in order to assess the impact of seabird populations on commercial fish stocks such as salmon, herring, and pollock. Studies are needed for major species such as common murres, short-tailed shearwaters, and black-legged kittiwakes. It is particularly important to determine the role of forage fish such as herring and osmerid smelts as well as seasonal aggregations of outmigrating juvenile salmon in the diets of these species.

8. Winter and fall distributions of seabirds and waterfowl species known to overwinter in the area need to be established. Species warranting investigation in this regard include common murres, Steller's and king eiders, oldsquaws, and black scoter.

This information is crucial in assessing the vulnerability of these species to the potential environmental disruption associated with development of the hydrocarbon resources in this area.

9. The ecological relationships between red king crab and the nearshore habitats need to be clearly established.

It is well-known that the shallow water areas are important to the red king crab population of the southeastern Bering Sea. The functional relationships of the nearshore zone to the success of this important species, however, are poorly understood. Information is needed on factors controlling the distribution and abundance of larval and juvenile crabs, the location and function of podding activities in later stage juveniles, and feeding relationships within the nearshore zone.

Physical, Chemical, and Geological Processes. The integration of physical and meteorological oceanographic efforts with ecological studies was an unique and successful feature of previous PROBES and OCSEAP studies in the southeastern Bering Sea. This close cooperation should be continued for the needed studies in the nearshore zone and in the lagoons and inner bays.

Physical, meteorological, geological, and chemical studies need to be done for two general purposes. One purpose is to confirm the movement of oil or other pollutants in the inshore zone or into lagoons and bays. The major purpose, however, is to understand those transport processes that control the distribution of biota and general ecology of the nearshore zone.

The following are topics which require additional research in order to address the questions of nutrient and carbon transport in the nearshore zone throughout Bristol Bay.

1. Determine the currents in the nearshore region of Bristol Bay, with special emphasis on synoptic regional coverage and on offshore variability.

It has been demonstrated that a slow mean counterclockwise flow exists in Bristol Bay. Flow through Unimak Pass and up along the Alaska Peninsula has also been demonstrated, indicating that the coastal jet flow of the Gulf of Alaska and Kenai Current may furnish more or less continous source waters to the Bristol Bay inshore flow. From stations north of the Peninsula, it has been shown that inshore flow characteristics are dominated by frequent storm events. Under such conditions, counterflow systems are possible with northeast flow seaward of a narrow, wind-driven southwest coastal jet (see Figures 27 and 29 in Schumacher and Moen, 1983). Little work has been done in the inner bay or along its northern edge, nor have simultaneous measurements been taken around the bay to see how the bay responds to storm events. Simultaneous moorings are needed in eastern Unimak Pass, along the nearshore zone of the Alaska Peninsula, in inner Bristol Bay, and along the northern bay shore in order to learn how bay waters respond to storm events.

2. Determine the influence of nearshore currents and density structure on dispersion and transport of carbon and nutrients; also determine the relationship between meteorological events and material fluxes across the inner front boundary of the coastal domain.

Hydrographic and chemical sections are needed seasonally in the inshore region of the bay in order to quantify carbon and nutrient transport assumptions of the endemic food web hypothesis. Potential sources of nutrients from the Unimak Pass and region, to the west, and flux (event dominated?) through the coastal domain boundaries need to be measured. Each seasonal effort needs to bracket some storm events, since processes on these time-scales may well be most important to transport.

3. Determine water exchange between lagoons/inner bays and the nearshore zone as well as residence times in these important embayments.

The nearshore flow regimes near the mouths of important embayments, and the exchange between inshore waters and the embayments need to be studied such that transport of pollutants into and particulate organic matter and nutrients out of these embayments can be quantified. Since meteorological events may be important to these transport processes, time-series measurements are needed.

4. Determine the spatial distribution of nutrients with export contributions from lagoons and rivers as a function of season.

In support of primary productivity measurements described earlier and augmenting the data taken for nutrient transport purposes, spatial and seasonal data sufficient to identify sources are needed. The lagoonal and riverine export of carbon is undoubtedly highly seasonal and may be more important locally than over the entire inshore region. Any sources from the west in the region of Unimak Pass also would need to be mapped.

1. Text References

Ainley, D. G. and G. A. Sanger. 1979. Trophic relations of seabirds in the northeaste.rn Pacific Ocean and Bering Sea. USFWS Wildlife Res. Rep. 11:95-112.

Alvarez-Borrego, S., L. I. Gordon, L. B. Jones, P. K. Park, and R. M. Pytkowitz. 1972. Oxygen-carbon dioxide-nutrients relationships in the southeastern region of the Bering Sea. J. Oceanogr. Sot. Japan 28:71-93.

Armstrong, D. A., L. S. Incze, J. L. Armstrong, D. L. Wencker, and B. R. Dumbauld. 1981. Distribution and abundance of decapod crustacean larvae in the S.E. Bering Sea with emphasis on commercial species. Environmental Assessment Alaksa Continental Shelf. Ann. Rep. of PI, March 1981, Vol. II:365-596. OCSEAP, NOAA.

Armstrong, D., G. Oliver, and C. Manen. 1982. Coastal species and habitats. In: Draft North Aleutian Shelf synthesis report, chapter 3. OCSEAP, NOAA. Juneau, Alaska.

Armstrong, D., L. Thorsteinson, and C. Manen. 1983. Coastal habitats and species. In: L.K. Thorsteinson cd., 1983 draft.

Arsen'ev, V. S. 1967. Currents and water mases of the Bering Sea. Izd. Nauka, Moscow (transl., 1968, NMFS, Northwest Fish. Center, Seattle, WA). 135 pp.

Ashwell-Erickson, S. and R. Elsner. 1981. The energy cost of free existence for Bering Sea harbor and spotted seals. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea shelf: oceanography and resources, Vol. II, pp. 869-901. Univ. of Washington Press, Seattle.

Ashwell-Erickson, S., R. Elsner, and D. Wartzok. 1978. Metabolism and nutrition of Bering Sea harbor and spotted seals. Inst. of Mar. Sci. Contr. No. 30. Univ. of Alaska, Fairbanks. 22p.

Bailey, E. P. and G. H. Davenport. 1972. Die-off of common murres on the Alaska Peninsula and Unimak Island. Condor 74:215-219.

Baker, E. T. 1981. North Aleutian Shelf transport experiment. Research Unit #594 NOAA/OCSEAP. Pacific Marine Environmental Laboratory, Seattle, WA. 10 pp. + figures.

Baker, E. T. 1983. Suspended particulate matter distribution, transport, and physical characteristics in the North Aleutian Shelf and St. George Basin lease areas. Final Report-Research Unit #594. Office of Mar. Pollution Assess. OCSEAP, Pacific Mar. Env. Lab., Seattle, WA. 134 pp.

Bakkala, R. G. 1981a. Population characteristics and ecology of yellowfin sole. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Vol. I, pp.553-574. NOAA, Univ. of Washington Press, Seattle, WA.

Bakkala, R. 1981b. Pacific cod of the eastern Bering Sea. Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Vancouver, Canada, Oct. 1981. Northwest and Alaksa Fisheries Center, NMFS, NOAA, Seattle, WA. 49 pp.

Barber, N. F. and M. J. Tucker. 1962. Wind waves. In: Hill, M. N., ed. The sea, Vol. I, pp. 664-669. Interscience Pub., New York.

Barsdate, R. J., M. Nebert, and C. P. McRoy. 1974. Lagoon contributions to sediments and water of the Bering Sea. In: Hood, D. W. and E. J. Kelley, eds. Oceanography of the Bering Sea, pp. 553-576. Inst.. of Mar. Sci., Univ. of Alaska, Fairbanks.

Barton, L. H., I. M. Warner, and P. Shafford. 1977. Herring spawning surveys-southeastern Bering Sea. Environmental assessment of the Alaska Continental Shelf. Final rep. of PI, Vol. VII:1-112. OCSEAP, NOAA.

Bartonek, J. C. and S. G. Scaly. 1979. Distribution and status of marine birds breeding along the coasts of the Chukchi and Bering Seas. In: Bartonek, J. C. and D. N Nettleship, eds. Conservation of marine birds of northern North America, pp. 21-31. USFWS

Baxter, R. 1976. Inshore Marine Resources, Bristol Bay, Alaska. Unpublished report. Alaska Department of Fish and Game, Box 96, Bethel, Ak. 99559.

Beardsley, G. F., Jr., H. Pak, and K. Carder. 1970. Light scattering and suspended particles in eastern equatorial Pacific Ocean. J. Geophys. Res. 75:2837-2845.

Bowden, K. F. 1962. Turbulence. In: Hill, M. N., ed. The sea, Vol. I, Section 6, pp.802-825. Interscience Pub., New York.

Braham, H. W., R. D. Everitt, B. D. Krogman, D. J. Rugh, and D. E. Withrow. 1977a. Marine mammals of the Bering Sea: a preliminary report on distribution and abundance, 1975-76. NMFS, NOAA, Northwest and Alaska Fish. Center, Marine Mammal Div., Seattle, WA. Processed Rep. 90 pp.

Braham, H. W. , R. D. Everitt, and D. J. Rugh. 1980. Northern sea lion population decline in the eastern Aleutian Islands. J. Wildlife Management, 44:25-33.

Braham, H. W., C. Fiscus, and D. Rugh. 1977* Marine mammals of the Bering and southern Chukchi Seas. Environmental assessment of the Alaskan Continental Shelf, Ann. Rep. of PI for year ending March, 1977, vol. 1, pp. 1-99.

Braham, H., G. Oliver, C. Fowler, K. Frost, F. Fay, c. Cowles, D. Costa, K. Schneider, and D. Calkins. 1982. Marine mammals. Pp. 55-81. In. J. Hameedi cd., The St. George Basin Environment and Possible Consequences of Planned Offshore Oil and Gas Development. Proc. Synthesis Meeting, Juneau, Alaska, 1981. NOAA/OCSEAP, Juneau.

Braham, H. W. and D. Rugh. 1978. Baseline characterization of marine mammals in the Bering Sea: distribution and abundance. Environmental Assessment of the Alaska Continental Shelf Ann. Rep. for 1978, Vol. 1, p. 1-14. 1-14.

Broeker, W.S. and T.H. Peng. 1982. Tracers in the sea. Lamont-Doherty Geological Observatory, Palisades, N.Y. 690 pp.

Brooks, J. W. 1955. Beluga investigations. Alaska Dept. Fish and Game Annual Rep. for 1955,- pp. 98-106. Alaska Dept. Fish and Game, Juneau.

Brewer, W. A., Jr., H. W. Searby, H. F. Diaz, and J. L. Wise. 1977. Climatic atlas of the Outer Continental shelf waters and coastal regions of Alaska. Vol. II, Bering Sea. U.S. Dept. of Interior, Bureau of Land Management. NOAA/OCSEAP. 43 pp. AEIDC Pub. B-770.

Brower, W.A., Jr., H.W. Searby, and J.L. Wise. 1977. Climatic atlas of the outer continental shelf waters and coastal regions of Alaska. 2. Bering Sea. NOAA/OCSEAP, AEIDC Pub. B-770.

Burns, J. J. 1967. The Pacific bearded seal. Alaska Dept. Fish and Game, Juneau. 66 pp.

Burns, J. J., L. H. Shapiro, and F. H. Fay. 1980. Relationship of marine mammal distributions, densities, and activities to sea ice conditions. In: Environmental Assessment of the Alaska Continental Shelf Final Reports of PI, NOAA/OCSEAP, Boulder, Colo. Vol. II pp. 489-670.

Burrell, D. C., K. Tommos, A. S. Naidu, and C. M. Hoskin. 1981. Some geochemical characteristics of Bering Sea sediments. In: Hood , D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, pp. 305-319. Us. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle, WA.

Businger, J.A. and S. P.S. Arya. 1974. Height of mixed layer in the stably stratified planetary boundary layer. In: Advances in Geophysics. New York. Academic Press. Pp. 73-92.

Cacchione, D. A. and D. B. Drake. 1982. Measurement of storm generated bottom stresses on the continental shelf. J. Geophys. Res. 87:1952-1961.

Carls, M.G., and S.D. Rice. 1980. Toxicity of oil well drilling fluids to Alaskan larval shrimp and crabs. Research unit 72. Final report. Project No. R7120822. Outer Continental Shelf Energy Assessment Program. Bureau of Land Management, U.S. Department of the Interior. 29 pp.

Clark, R. C. and D. W. Brown. 1977. Petroleum: properties and analysis in biotic and abiotic systems. In: Effects of petroleum on arctic and subarctic—marine environments and organisms, p. 1-90. Academic Press, New York.

Cline, J. D. 1981. Distribution of dissolved LMW hydrocarbons in Bristol Bay, Alaksa. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Chapter 27, pp. 425-444. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Cline, J., C. Katz, H. Curl, Jr. 1981. Circulation processes in Bristol Bay, Alaska using dissolved methane as a tracer. Annual Report. Office of Marine Pollution Assessment? OCSEAP, Pacific Marine Lab. Seattle, WA. 56 pp.

Cline, J. D., K. Kelley-Hansen, and C. N. Katz. 1982. The production and dispersion of dissolved methane in southeastern Bering Sea. Final Report, Office of Marine Pollution Assessment, OCSEAP. Contribution No. 548, Paricif Env. Lab., Seattle, WA. 99 pp.

Coachman, L. K., and L. Charnell. 1979. On lateral water mass interaction--a case study, Bristol Bay, Alaska. J. Phys. Ocenogr. 9:278-97.

Coachman, L,K. and R.L. Charnell. 1977. Finestructure in outer Bristol Bay, Alaska. Deep-Sea Research. vol. 24:869-889.

Coachman, L. K., T. H. Kinder, J. D. Schumacher, and R. B. Tripp. 1980. Frontal systems of the southeastern Bering Sea shelf. In: Carstens, T. and T. McClimans, eds. Stratified flows, pp. 917-933. Second IAHR Symposium, Trondheim, June 1980. Tapir, Trondheim, Norway.

Coachman, L. K. and J. J. Walsh. 1981. A diffusion model of cross-shelf exchange of nutrients in the southeastern Bering Sea. Deep-Sea Research. Vol 28A(8): 819-846.

Codispoti, L. A., G. E. Friederich, R. L. Iverson, and D. W. Hood. 1982. Temporal changes in the inorganic carbon system of the southeastern Bering Sea during spring 1980. Nature 296(5854):242-245.

Conklin, P. J., D. Drysdale, D. G. Doughtie, K. R. Rae, J. P. Kakareka, T. R. Gilbert, and R. F. Shokes. 1983. Comparative toxicity of drilling mods: role of chromium and petroleum hydrocarbons. Mar. Environ. Res. 10:105-125.

Cooney, R. T. 1981. Bering Sea zooplankton and micronekton communities with emphasis on annual production. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 947-975. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Cooney, R. T. and K. O. Coyle. 1982. Trophic implications of cross-shelf copepod distribution in the southeastern Bering Sea. Mar. Biol. 70:187-196.

Coulter, H. W. et al. 1965. Map showing extent of glaciation in Alaksa. U.S. Geol. Survey. Misc. Geologic Investigations Map 1-415.

Cranwell, P. A. 1976. Decomposition of aquatic biota and sediment formation. Freshwater Biol. 6:41-48.

Cunningham, D. 1969. A study of the food and feeding relationships of the Alaskan king crab, Paralithodes camtschatica, Master's Thesis. San Diego State College. 78pp.

Dames and Moore. 1980. North Aleutian Shelf Petroleum Technology Assessment. Technical Report No. 63. Alaska OCS Socioeconomic Studies Program. Bureau of Land Management, Alaska Outer Continental Shelf Office.

Dames and Moore. 1983. Data summary, 1983 pilot test fishing program. Bristol Bay underdeveloped commercial fisheries potential study. For State of Alaska, Department of Community and Regional Affairs, Municipal and Regional Assistance Division.

Dennison, W. 1979. Light adaptations of plants: a model based on the seagrass Zostera marina L. M.S. Thesis, University of Alaska, Fairbanks. 70 pp.

Didyk, B. M., B. R. T. Simoneit, S. C. Brossell, and G. Eglinton. 1978. Geochemical indicators of paleoenvironmental conditions of sedimentation. Nature 272:216-222.

Deitz, R. S., A. J. Carsola, E. C. Buffington, and C. J. Shipek. 1964. Sediments and topography of the Alaska shelves. In: Miller, R. L., ed. Papers in marine geology, pp. 241-256. MacMillan, New York.

Dodimead, A. J., F. Favorite, and T. Hirano. 1963. Review of oceanography of the subarctic Pacific region. International North Pacific Fisheries Commission. Vancouver, Canada. Bulletin Number 13:195 pp.

ERCO. 1980. Results of joint bioassay monitoring program. Final report to the Offshore Operators Committee under direction of Exxon Production Research Co., Houston Tex. ERCO, In"c., Cambridge Mass.

Estes, J. A. and J. F. Palmisano. 1974. Sea otters: their role in structuring nearshore communities. Science 185:1058-1060.

Everitt, R. D. and H. W. Braham. 1980. Aerial survey of Pacific harbor seals in the southeastern Bering Sea. Northwest Science 54(4):281-288.

Everitt, R. D. and B. D. Krogman. 1979. Harbor seal distribution and abundance in the Bering Sea: Alaska Peninsula and Fox Islands. Science in Alaska, Proc. 29th Alaska Sci. Conf., Fairbanks, Aug. 15-17, 1978. 21 pp.

Barrington, J. W., N. M. Frew, P. M. Girchwend, and B. W. Tripp. 1977. Hydrocarbons in cores of northwestern Atlantic coastal and continental margin sediments. Est. Coastal Mar. Science 5:793-808.

Favorite, F., A. J. Dodimead, and K. Nasu. 1976. Oceanography of the subarctic Pacific region. International North Pacific Fisheries Commission. Vancouver, Canada. Bulletin Number 33.

Favorite, F., T. Laevastu, and R. R. Straty. 1977. Oceanography of the northeastern Pacific Ocean and eastern Bering Sea, and relations to various living marine resources. U.S. Dept. Comm., NOAA, NMFS, Northwest and Alaska Fish. Cent. Processed Rep. 280 pp.

Favorite, F. and G. Pedersen. 1959. Bristol Bay oceanography, August-September 1938. USFWS Special Sci. Rep. Fisheries, Number 311. 31 pp.

Favorite, F., J. W. Schantz, and C. R. Hebard. 1961. Oceanographic observations in Bristol Bay and the Bering Sea, 1939-41 (USCGT Redwing). USFWS Spec. Sci. Rep. Fisheries, No. 381. 323 pp.

Fay, F. H. 1982. Ecology and biology of the Pacific walrus, Odobenus rosmarus divergens (Illiger). USFWS, N. Amer. Fauna No. 74, 279 pp.

Pay, J.A. 1971. Physical processes in the spread of oil on a water surface. In: Proceedings of Joint Conference on Prevention and—Control of Oil Spills. American Petroleum Institute, Washington D.C. pp. 463-467.

Fay, F. H., H. M. Feder, and S. W. Stoker. 1977. An estimation of the impact of the Pacific walrus population on its food resources in the Bering Sea. Final Rep. MMC, Contracts MM4AC-006 and MM5AC-024, U.S Marine Mammal Comm., Washington, D.C. NTIS Publ. PB-273 505. 38 pp.

Fay, F. H. and L. F. Lowry. 1981. Seasonal use and feeding habits of walruses in the proposed Bristol Bay clam fishery area. Final Rep., N. Pacific Fish. Manag. Council Contract No. 80-3.

Fay, F. H. and S. W. Stoker. 1982a. Analysis of reproductive organs and stomach contents from walruses taken in the Alaskan native harvest, spring 1980. USFWS Final Rep. 14-16-0007-81-5216. Amended, 86 pp.

Fay, F. H and S. W. Stoker. 1982b. Reproductive success and feeding habits of walruses taken in the 1982 spring harvest, with comparisons from previous years. contract rep. to Eskimo Walrus Comm., Kawerak, Inc., Nome, AK. 91 pp.

Feder, H. M., J. Hilsinger, M. Hoberg, S. C. Jewett, and J. Rose, 1978. Survey of the epifaunal invertebrates of the southeastern Bering Sea. In: Environmental assessment of the Alaskan Continental Shelf. Annual rep. of PI for year ending March 1978, Vol. IV:1-126. OCSEAP, NOAA.

Feder, H. M. and S. C. Jewett. 1980. Survey of the epifaunal invertebrates of the southeastern Bering Sea with notes on the feeding biology of selected species. Rep. Inst. Mar. Sci. Univ. Alaska. R78-5, 105 pp.

Feder, H. M. and S. C. Jewett. 1981. Feeding interactions in the eastern Bering Sea with emphasis on the benthos. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Chapter 27, pp. 1129-1263. U.S. Dept. of commerce, NOAA. Univ. of Washington Press, Seattle.

Feely, R. A. 1975. Major element composition of the particulate matter in the near-bottom nepheloid layer of the Gulf of Mexico. Mar. Chem. 3, 121-126.

Feely, R. A., E. T. Baker, J. D. Schumacher, G. J. Massoth, and W. D. Landing. 1979. Processes affecting the distribution and transport of suspended matter in the northeast Gulf of Alaska. Deep-Sea Research. 26(4A): 445-464.

Feely, R. A., G. J. Massoth, A. J. Paulson, M. F. Lamb and E. A. Martin. 1981. Distribution and elemental composition of suspended matter in Alaskan coastal waters. NOAA Tech. Memorandum ERL PMEL-27. NOAA Pacific Marine Env. Lab. Contrib. No. 494. 129 pp.

Fisher, R. B. 1980. The joint venture for yellowfin sole, Bering Sea, summer 1980: a case study in fishery

Fleury, M.G.R. 1983. Outer Continental Shelf oil and gas blowouts 1979 - 1982. U.S. Geological Survey, Open File Report 83 - 562.

Flock, C. 1932. Notes on the arctic tern in Bristol Bay region, Alaska. Murrelet 13:26.

Fried, S. and J. Skrade. 1982. Bering herring: it's more than just bail. Alaska Fish Tails and Game Trails, summer 1982, 10-11 & 16 pp.

Frost, K. J. and L. F. Lowry. 1981. Foods and trophic relationships of cetaceans in the Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume II, pp. 825-837. . U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Frost, K. J., L. F. Lowry, and J. J. Burns. 1982. Distribution of marine mammals in the coastal zone of the Bering Sea during summer and autumn. In: Environmental Assessment of the Alaska Continental Shelf. Final Reports of Principal Investigators. 20:365-561.

Garshelis, D. L. 1983. Ecology of sea otters in Prince William Sound. Ph.D. dissertation, University of Minnesota, Minneapolis. 321 pp.

Gearing, P., J. N. Gearing, T. F. Lytle, and L. S. Lytle. 1976. Hydrocarbons in 60 northeast Gulf of Mexico shelf sediments. Geochim. Cosmochem. Acts 40:1005-1017.

Gilbert, T. R. 1981. A study of the impact of discharged drilling fluids on the Georges Bank environment. New England Aquarium. H. E. Edgerton Research Laboratory. Progress Rept. No. 2 to U. S. EPA, Gulf Breeze, Fla. 98 pp.

Gill, R. E., Jr. and J. D. Hall. 1983. Use of nearshore and estuarine areas of the southeastern Bering Sea by gray whales (Eschrichtius robustus). Arctic Vol. 36(3):275-281.

Gill, R. E., Jr. and C. M. Handel. 1981. Shorebirds of the eastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The Eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 719-738. U.S. Dept. of Commerce, NOAA . Univ. of Washington Press, Seattle.

Gill, R. E., Jr., C. Handel, and M. Petersen. 1979. Migration of birds in Alaska marine habitats. In: Environment Assessment of the Alaskan Continental Shelf. Final Report. Vol. 5:245-288.

Gill, R. and P. Jorgensen. 1979. A preliminary assessment of timing and migration of shorebirds along the north central Alaska Peninusla. Studies in Avian Bio. 2:113-123.

Gill, R., M. Petersen, C. Handel, J. Nelson, A. DeGange, A. Fukuyama, and G. Sanger. 19.78. Avifaunal assessment of Nelson Lagoon, Port Moller, and Herendeen Bay, Alaska 1977. U. S. Fish and Wildlife Service. Office of Biological Services, Coastal Ecosystems? Anchorage? AK., 131 pp.

Gill, R. E., Jr., M. R. Petersen, and P. L. D. Jorgensen. 1981. Birds of the northcentral Alaska Peninsula, 1976-1980. Arctic 34:286-306.

Gill, R. E. Jr., and G. A. Sanger. 1979. Tufted Puffins nesting in estuarine habitat. Auk 96:792-794.

Gordon, D. C. 1970. Some studies of the distribution and composition of particulate organic carbon in the North Atlantic Ocean. Deep-Sea Res. 17:233-234.

Gould, P. J., D. J. ForSell, and C. J. Lensink. 1982. Pelagic distribution and abundance of seabirds in the Gulf of Alaska and eastern Bering Sea. USFWS, Biological Serv. Pro., Anchorage. FWS/OBS-82/48 . 294 pp.

Grant, W. D. and G. M. Glenn. In Press. Continental shelf bottom boundary layer model: theoretical model. Vol I. Woods Hole Oceanographic Institution Technical Memorandum. 160 pp.

Grant, W. D. and O. S. Madsen. 1979. Bottom friction under waves in the presence of a weak current. NOAA TM ERL/Mesa-29. 150 pp.

Grant, W. D. and O. S. Madsen. 1976. Combined wave and current interaction with a rough bottom. J. Geophys. Res. 84:1797-1808.

Gray, G. W., Jr., 1964. Halibut preying on large Crustacea. Copeia 1964:590.

Griffiths, R. P., B. A. Caldwell, J. D. Cline, W. A. Broich, and R. Y. Morita. 1982. Field observations of methane concentrations and oxidation rates in the southeast Bering Sea. Applied and Env. Microbiology 44:435-446.

Grim, M. S. and D. A. McManus. 1970. A shallow-water seismic profiling survey of the northern Bering Sea. Mar. Geol. 8:293-320.

Haflinger, K. 1978. A numerical analysis of the distribution of the benthic infauna of the southeastern Bering Sea shelf. MasterJs Thesis, Univ. of Alaska, Fairbanks. 139 pp.

Haflinger, K. 1981. A survey of benthic infaunal communities of the southeastern Bering Sea shelf. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume II, pp. 1091-1103. Us. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Haflinger, D. E. and C. P. McRoy. 1983. Yellowfin sole (Limanda aspera) predation on three commercial crab species (Chionoecetes opilio, C. bairdi, and Paralithodes camtschatica) in the southeast Bering Sea. Final report to NMFS. 28 pp.

Hameedi, M. J., ed. 1982. Proceedings of a synthesis meeting: the St. George Basin environment and possible consequences of planned offshore oil and gas development, Anchorage, Alaska, April 28-30, 1981. U.S. Dept. of Commerce, OCSEAP, NOAA, Juneau. 162 pp.

Han, J. and M. Calvin. 1969. Hydrocarbon distribution of algae and bacteria, and microbiological activity in sediments. Proc. Nat. Acad. Sci. U.S.A. 64:436-443.

Handa, N. 1969. Carbohydrate metabolism in the marine diatom Skelelonema costatum. Mar. Biol. 4:208-214.

Handa, N. and E. Tanoue. 1981. Organic matter in the Bering Sea and adjacent areas. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Chapter 23, pp. 359-381. U.S. Dept. of Commerce, NOAA. Univ.. of Washington Press, Seattle.

Hang, A. and S. Myklestad. 1976. Poly-saccharides of marine diatoms with special reference to Chaetoceros species. Mar. Biol. 34:217-222.

Harrison, C. S. 1977. Aerial surveys of marine birds. Environmental assessment of the Alaska Continental Shelf. Ann. Rep. of PIs. Vol. 3, pp. 285-593.

Hatanaka, M. and M. Kosaka. 1958. Biological studies on the population of the starfish, Asterias amurensis, in Sendai Bay. Tohoku J. Agric. Res. 9:159-178.

Hatcher, P. G., B. R. Simoneit, and S. M. Gerchakov. 1977. The organic geochemistry of a recent sapropelic environment: Mangrove Lake, Bermuda. In: Campos, R. and J. Goni, eds. Advances in organic geochemistry, 1975, pp. 469-484.

Haynes, E. B. 1974. Distribution and relative abundance of larvae of king crab, Paralithodes camtschatica, in the southeastern Bering Sea, 1969-70. Fishery Bulletin 72:804-812.

Hood, D. W. 1981. Preliminary observations of the carbon budget of the eastern Bering Sea shelf In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Chapter 22, pp. 347-358. Us. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Hood, D. W. and J. A. Calder, eds. 1981. The eastern Bering Sea shelf: oceanography and resources. U.S. Dept. of Commerce, NOAA, Univ. of Washington Press, Seattle.

Hood, D. W. 1970. Proc. symp. organic matter in natural waters. Occa. Pub. No. 1. Inst. Mar. Science, Univ. of Alaska. 625 p.

Hood, D. W. 1966. Occurrence and concentration of organic matter in sea water. U. S. Navy Journal of Underwater Acoustics. 16:577-589.

Hood, D. W. 1963. Chemical oceanography. In: H. Barnes, ed., Oceanogr. Mar. Biol. Ann. Review. 1:129-155.

Hood, D. W. and L. A. Codispoti. In press. The effect of primary production on the carbon dioxide components of the Bering Sea. shelf. In: McBeath, J. H., ed. The potential effects of carbon dioxide induced climatic change in Alaska. School of Agriculture and Land Resources Management, Univ. of Alaska, Fairbanks.

Hood, D. W. and T. C. Loder. 1973. Microbial conversions of dissolved organic carbon compounds in seawater. In: Guarraia, J. and R. K. Ballantine, eds. The aquatic environment. EPA, Supt. of Documents #5501-00615. 244 pp.

Hood, D. W. and W. S. Reeburgh. 1974. Chemistry of the Bering Sea: an overview. In: Hood, D. W. and E. J. Kelley, eds. Oceanography of the Bering Sea. Inst. of Mar. Sci., Univ. of Alaska, Fairbanks Occ. Pub. #2. 623 pp.

Hopkins, D. M., ed. 1967. The Bering land bridge. Stanford University, Stanford, CA. 494 pp.

Hopkins, D. M. 1972. The paleogeo and climatic history of Beringia during Late Cenozoic time. Internord 12:121-150.

Hopkins, D. M. 1978. Benthos-sedimentary substrate interactions. Research Unit #290. NOAA, OCSEAP, Inst. of Mar. SCi., Univ. of Alaska, Fairbanks Occ. pub, #2. 623 pp.

Houghton, J. P., D. L. Beyer, and E. D. Thielk. 1980. Effects of oil well drilling fluids on several important Alaskan marine organisms. In: Proceedings of a Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Washington, D. C.: Courtesy Associates. Pp. 1017-1043.

Hughes, S. E. and N. Bourne. 1981. Stock assessment and life history of a newly discovered Alaska surf clam (Spisula polynyma) resource in the southeastern Bering Sea. Can. Jour. of Fish. and Aquatic Sci. 38:1173-1181.

Hughes, S. E., R. W. Nelson, and R. Nelson. 1977. Initial assessments of the distribution, abundance, and quality of subtidal clams in the S.E. Bering Sea. U.S. Dept. Comm., NOAA, NMFS, Northwest and Alaska Fish. Center, Seattle, WA. 43 pp. + appendix.

Hunt, G. L., Jr., B. Bergeson, and G. A. Sanger. 1981a. Feeding ecology of se-abird-s of the eastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 629-647. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Hunt, G. L., Jr., Z. Eppley, and W. H. Drury. 1981b. Breeding distribution and reproductive biology of marine birds on the eastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 649-687. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Hunt, G. L., Jr., P. J. Gould, K. J. Forsell, and H. Peterson, Jr. 1981c. Pelagic distribution of marine birds in the eastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 689-718. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Ingraham, W. J., Jr. 1981. Shelf environment. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume I, pp. 455-469. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Institute of Marine Science. 1971. Bristol Bay and southeastern Bering Sea: descriptive physical and chemical oceanographic data report. Data Report R71-10 to the National Science Foundation Grant No. GB-8274. Unpub. manuscript. Univ. of Alaska, Fairbanks.

Iverson, R. L., L. K. Coachman, R. T. Cooney, T. S. English, J. J. Goering, G. L. Hunt, Jr., M. C. Macauley, C. P. McRoy, W. S. Reeburgh, and T. E. Whitledge. 1979. Ecological significance of fronts in the southeastern Bering Sea. In: Livingston, R. J., ed. Ecological processes in coastal and marine systems, pp. 437-466. Plenum Publ. Co., New York.

Jewett, S. C. and H. M. Feder. 1981. Epifaunal invertebrates of the continental shelf of the eastern Bering and Chukchi Seas. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 1131-1155. U.S. Dept. Of Commerce, NOAA. Univ. of Washington Press, Seattle.

Jewett, S. C. and H. M. Feder. 1982. Food and feeding habits of the king crab Paralithodes camtschatica near Kodiak Island, Alaska. Mar. Biol. 66:243-250.

Johnson, B. W. 1977. The effect of human disturbance on a population of harbor seals. Environmental assessment of the Alaska Continental Shelf. Ann. Rep. of PI for year ending March, 1977, Vol. I:422-432.

Johnson, R. W. and J. A. Calder. 1973. Early diagenesis of fatty acids and hydrocarbons in a salt marsh environment. Geochem. Cosmochim. Acts 37:1943-1955.

Jones, R. D., Jr. 1965. Refuge narrative report: Aleutian Islands National Wildife Refuge and Izembek National Wildlife Range. Unpub. Rep., USFWS, Bur. Sport Fish., Cold Bay, AK. 44 pp

Jones, R. D., Jr. 1970. Reproductive success and age distribution of black brandt. J. Wildlife Management 34(2):328-333.

Keeling, C. D. 4968. Carbon dioxide in surface ocean waters, 4, global distribution. J. Geophys. Res. 73(14):4543-4553.

Kelley, J. J. and D. W. Hood. 1971. Carbon dioxide in the Pacific Ocean and Bering Sea: upwelling and mixing. J. Geophys. Res. 76(3):745-752.

Kelley, J. J., L. L. Longerich, and D. W. Hood. 1971. Effect of upwelling, mixing, and high primary productivity on C02 concentrations in surface waters of the Bering Sea. J. Geophys. Res. 76(36):8687-8693.

Kennett, J. P. 1982. Marine geology. Prentice-Hall. Englewood Cliffs, New Jersey. 813 pp.

Kenyon, K. W. 1969. The sea otter in the eastern Pacific Ocean. USFWS . N. Amer. Fauna No. 68. 352 pp.

Keyes, M. C. 1968. The nutrition of pinnipeds. In: Behavior and physiology of pinnipeds, R. J. Harrison, R. C. Hubbard, R. S. Peterson, C. E. Rice, and R. J. Schusterman, eds. Appleton-Century-Crofts, New York.

Kinder, T. H. 1981. A perspective of physical oceanography in the Bering Sea, 1979. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, pp. 5-13. U.S. Dept. of Commerce, NOAA . Univ. of Washington Press, Seattle.

Kinder, T. H. and J. D. Schumacher. 1981a. Hydrographic structure over the continental shelf of the southeastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, pp. 31-52. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Kinder, T. H. and J. D. Schumacher. 1981b. Circulation over the continental shelf of the southeastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Chapter 27, pp. 53-75. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

King, J. G. and C. P. Dau. 1981. Waterfowl and their habits in the eastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 739-753. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Kischner, C. E. and C. A. Lyon. 1973. Stratigraphic and tectonic development of Cook Inlet petroleum province. In: Petcher, M. G., ed. Proceedings of second international symposium on arctic geology. Amer. Assoc. Petrol. Geol. Mere. 19:396-407.

Kosygin, G. M. 1976. Feeding of the bearded seal Erignathus barbatus nauticus (Pall as) in the Bering Sea during the spring-summer period. Fisheries and Marine Science Translation No. 3747. 14 pp. Dept. of the Environment, Fish. and Mar. Serv. Arctic Biol. Station. Ste. Anne de Bellevue, P. Q., Canada.

Kummer, J. T. and J. S. Creager. 1971. Marine geology and Cenozoic history of Gulf of Anadyr. Mar. Geol. 10:257-280.

Lanfear, K.J. and D.E. Amstutz. 1983. A reexamination of occurrence rates for accidental oil spills on the U.S. Outer Continental Shelf. 1983 Oil Spill Conference. Minerals Management Service, U.S. Dept. of the Interior, Washington, D.C.

Lensink, C. J. and J. C. Bartonek. 1976a. Seasonal distribution and abundance of marine birds: Part 1, shipboard surveys. Environmental assessment of the Alaska Continental Shelf. Ann. Rep of PI, Vol. 3:197-644. OCSEAP, NOAA.

Lensink, C. J., and J. C. Bartonek. 1976b. Population dynamics of marine birds. Environmental Assessment of the Alaskan Continental Shelf. Ann. Rep. of PI, Vol. 4:345-361. OCSEAP, NOAA.

Lensink, C. J., J. C. Bartonek, and G. A. Sanger. 1976. Feeding ecology and trophic relationships of Alaskan marine birds. Environmental assessment of the Alaskan Continental Shelf Ann. Rep. of the PI, Vol. 4:321-344. OCSEAP, NOAA.

Lisitsyn, A. P. 1966. Recent sedimentation. In: The Bering Sea (in Russian), Inst. Okeanol. Akad. Naub USSR. Transl. by Israel Program for Sci. Translations. Available from U.S. Dept. Commerce, Clearinghouse for Fed. Sci. and Tech. Info. 1969, 614 pp.

Loder, T. C., III. 1971. Distribution of dissolved and particulate organic carbon in Alaskan polar, sub-polar, and estuarine waters. Ph.D. Dissertation. Inst. of Mar. Sci, Univ. of Alaska, Fairbanks. 236 pp.

Loder, T. C., III and D.W. Hood. 1972. Distribution of organic carbon in a glacial estuary in Alaska. Limnol. Oceanogr. 17:349-355.

Long, C. E. 1981. A simple model for time-dependent stably stratified turbulent boundary layers. Special report No. 95. Dept. of Oceanography, Univ. of Washington, Seattle. 17opp.

Lowry, L. F. and K. J. Front. 1981. Feeding and trophic relationships of phocid seals and walruses in the eastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 813-825. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Lowry, L. F., K. J. Frost, and J. J. Burns. 1979. Trophic relationships among ice-inhabiting phocid seals. Environmental assessment of the Alaska Continental Shelf. Ann. Rep. of PI for year ending March, 1977, vol. I:303-390.

Lowry, L. F., K. J. Frost, D. G. Calkins, G. L. Swartzman, and S. Hills. 1982. Feeding habits, food requirements, and status of Bering Sea marine mammals. N. Pacific Fish. Manag. Council Dec. No. 19, 291 pp. plus annotated biblio.

MacIntosh, R. A. and D. A. Somerton. 1981. Large marine gastropod of the eastern Bering Sea. In: Hood, D. w. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 1215-1228. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Manen, C. A. and M. J. Pelto. 1983. Transport and fate of spilled oil. In: L. K. Thorsteinson cd., 1983 Draft.

Marine Bioassay Laboratory. 1982. Drilling fluids bioassays. Texaco Habitat Platform Well A-1 Pitas Point Lease Sale Unit: Acanthomysis sculpts and Macoma nasuta. Report submitted to Texaco, Inc., Los Angeles, CA., and IMCO Services, Houston, Tex. , by Marine Bioassay Labs., Watsonville, CA.

Marlow, M. S., H. McLean, A. K. Cooper, T. L. Vallier, D. w. Scholl, J. V. Gardner, R. McMullin, and M. B. Lynch. 1980. A preliminary summary of regional geology, petroleum potential, environmental geology, and technology for exploration and development for proposed OCS lease sale #75, Northern Aleutian Shelf, Bering Sea, Alaska. U.S. Geological Survey Open-File Report 80-653. January 1980.

Martin, S. and J. Bauer. 1981. Bering Sea ice-edge phenomena. In: D. Hood and J. A. Calder, The Eastern Bering Sea Shelf: Oceanography and Resources. Vol. I. U. S. Dept. of Commerce.

McCarty, P. L. 1964. The methane fermentation. In: Heukelekian, H. and N. C. Dondero, eds. Principles and applications in aquatic microbiology, pp. 314-343. John Wiley, New York.

McConnaughey, T. and C. P. McRoy. 1979. 13_c label identified eelgrass (Zostera marina) in an Alaskan estuarine food-web. Mar. Biol. 53:263-269.

McDonald, J., H. M. Feder, and M. Hoberg. 1981. Bivalve mollusks of the southeastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 1155-1204. Us. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

McLaughlin, P. A. and J. F. Hebard. 1961. Stomach contents of the Bering Sea king crab. Bull. Int. N. Pacific Fish. Comm. 5:5-8.

McNult, S. L. 1981. Remote sensing analysis of ice growth and distribution in the eastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, pp. 141-165. . U.S. Dept. of Commerce, NOAA. Univ. of--Washington Press, Seattle.

McRoy, C. P. 1970. Standing stocks and other features of eelgrass (Zostera marina) populations on the coast of Alaska. J. Fish. Res. Bd. Canada 27:1811-1821.

McRoy, C. P., R. J. Barsdate, and M. Nebert. 1972. Phosphorus cycling in an eelgrass (Zostera marina L.) ecosystem. Limnol. Oceanogr. 17:58-67.

McRoy, C. P., J. J. Goering, and W. E. Shiels. 1972. Studies of primary production in the eastern Bering Sea. In: Takenouti, A. Y., ed. Biological oceanography of the northern north Pacific Ocean, pp. 199-216. Idemitsu Shoten, Tokyo, Japan.

McRoy, C. P. and C. McMillan. 1977. Production ecology and physiology of seagrasses. In: McRoy, C. P. and Helfferich, C., eds. Seagrass ecosystems, pp. 53-87. Marcel Dekker, Inc., New York.

Menzel, D. W. 1967. Particulate organic carbon in the deep sea. Deep-Sea Res. 14:229-238.

Michel, J., D. D. Domeracki, L. C. Thebeau, C. D. Getter, and M. O. Hayes. 1982. Sensitivity of coastal environments and wildlife to spilled oil of the Bristol Bay area of the Bering Sea, Alaska. In: Environmental assessment of the Alaskan continental shelf. Research Planning Inst., Inc. RPI/R/82/1/15-1, 117 pp. + 106 maps. Prep. for NOAA, OCSEAP, Juneau, AK.

Moore, S. F. and F. L. Dwyer. 1974. Effects of oil on marine organisms: A critical assessment of published data. Water Res. 8:819-827.

Mossman, A. S. 1958. Selective predation of glaucous-winged gulls upon adult red salmon. Ecology 39:482-486.

Muench, R. D. and K. Ahlnäs. 1976. Ice movement and distribution in the Bering Sea from March to July, 1974. J. Geophys. Res. 81(24):4467-4476.

Naidu, A. S. and T. C. Mowatt. 1977. Composition, source, and dispersal pattern of clay minerals in southeast Bering Sea, Alaska. Geol. Sot. Amer. meeting, Alaska.

Nelson, C. H., D. M. Hopkins, and D. W. Scholl. 1974. Cenozoic sedimentary and tectonic history of the Bering Sea. In: Hood, D. W. and E. J. Kelley, eds. Oceanography of the Bering Sea, Chapter 26, pp. 485-516. Inst. of Mar. Sci. , Univ. of Alaska, Fairbanks Occ. Pub. No. 2.

Niebauer, H. J. 1981. Recent fluctuations in sea ice distribution in the eastern Bering Sea. In: Hood , D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, pp. 143-140. U.S. Dept. of Commerce, NOAA . Univ. of Washington Press, Seattle.

Northwest and Alaska Fisheries Center. 1979-1982. Trawl survey data printouts from the southeastern Bering

OCSEAP Final Reports. 1983. Environmental assessment of the Alaskan continental shelf, final reports of principal investigators. vol. 20.

OCSEAP . 1977. Climate atlas of the outer continental shelf waters and coastal regions of Alaska, 2, Bering Sea. Arctic Environmental Information and Data Center, Anchorage, Alaska.

Ogi, H. 1973. Ecological studies on juvenile sockeye salmon, Oncorhynchus nerka (Walbaum) in Bristol Bay with special reference to its distribution and population. Hokkaido Univ. Bull. Fat. Fish. 24:14-41.

Ogi, H., and T. Tsujita. 1973. Preliminary examination of stomach contents of murres (Uris spp.) from the eastern Bering Sea and Bristol Bay, June-August, 1970 and 1971. Jap. J. Ecol. 23:201-209.

Otto, R. S., R. A. Macintosh, T. M. Armetta, W. S. Meyers, and K. L. Stahl. 1981. United States crab research in the eastern Bering Sea during 1981. (Document submitted to the annual meeting of the International North Pacific Fish. Comm., Vancouver, British Columbia, October 1981).

Overland, J. E. 1981. Marine climatology of the Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, pp. 15-22. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Overland, J. E. and C. H. Pease. 1982. Cyclone climatology of the Bering Sea and its relation to sea ice extent. In: Monthly Weather Review 110:5-13.

Palacas, J. G., P. M. Gerrild, A. H. Love, and A. A. Roberts. 1976. Baseline concentrations of hydrocarbons in barrier island quartz sand northeastern Gulf of Mexico. Geology 4:81-84.

pearson, C. A. , E. Baker, and J. D. Schumacher. 1980. Hydrographic, suspended particulate matter, wind and current observation during reestablishment of a structural front: Bristol Bay, Alaska. Unpub. manuscript. Pacific Mar. Environ. Lab., Seattle, WA.

Pearson, C. A., H. O. Mofjeld, and R. B. Tripp. 1981. Tides of the eastern Bering Sea shelf. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, pp. 111-130. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Pereyra, W. T., J. E. Reeves, R. G. Bakkala. 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Northwest Fisheries Center Processed Report. NMFS, NOAA, 619 pp.

Petersen, M. R. 1980. Observations of wing-feathered molt and summer feeding ecology of Steller's eiders at Nelson Lagoon, Alaska. Wildfowl 31:99-106.

Petersen, M. R. 1983. Observations" of emperor geese feeding at Nelson Lagoon, Alaska. Coudor 85:367-368.

Petersen, M. R. and R. E. Gill, Jr. 1982. Population and station of emperor geese along the north side of the Alaska Peninsula. Wildfowl 33:31-38.

Petersen, M. R. and M. J. Sigman. 1977. Field studies at Cape Peirce, Alaska-1976. Environmental assessment of the Alaska Continental Shelf. Ann. Rep. of PI, Vol. 4:633-693.

Petrazzuolo, G. 1981. Preliminary report. An environmental assessment of drilling fluids and cuttings released onto the outer continental shelf. vol. 1: Technical assessment. vol. 2: Tables, figures and Appendix A. Draft report prepared for Industrial Permits Branch, Office of Water Endorsement and Ocean Programs Branch, Office of Water and Waste Management, u. s. Environmental Protection Agency, Washington, D.C.

Powell, G. and G. McCrary. 1982. Is the gold rush over? Alaska Fish Tales and Game Trails, summer 1982:17-19.

Powell, G. C. and R. B. Nickerson. 1965. Aggregations among juvenile king crabs (Paralithodes comtschatica, Tilesius) Kodiak, Alaska. Animal Behavior 13:374-380.

PROBES, 1978, 1979, 1980, 1981, 1982. Progress reports to National Science Foundation. Goering, J. J., PI, Inst. Mar. Sci., Univ. of Alaska, Fairbanks, AK.

Reeburgh, W. S. and D. T. Heggie. 1977. Microbial methane consumption reactions and their effect on methane distributions in freshwater and marine environments. Limnol. Oceanogr. 22:1-9.

Reed, R. K. 1978. The heat budget of a region in the eastern Bering Sea, summer 1976. J. Geophys. Res. 83:3636-3645.

Rice, S. D., D. A. Moles, J. F. Karinen, S. Kern, M. G. Carls, C. C. Brodersen, J. A. Gharrett, M. M. Babcock. 1983. A comprehensive review of all oil effects research on Alaskan fish and invertebrates conducted by the Auke Bay Laboratory, 1970-1981. In: Environmental Assessment of the Alaskan Continental—Shelf. 145 pp.

Rice, S. D., D. A. Moles, T. L. Taylor and J. F. Karinen. . 1979. Sensitivity of 39 Alaskan marine species to Cook Inlet crude oil and No. 2 fuel oil. In: API, EPA, and USCG, 1979 Oil spill conference (prevention, behavior, control, cleanup), Proceedings, pp. 549-5S4. American Petroleum Institute, Washington, D.C.

Rice, D. W. and A. A. Wolman. 1971. The life history and ecology of the gray whale (Eschrichtius robustus). Am. Sot. Mammal. Spec. Publ. No. 3. 142 pp.

Riley, G. A. 1970. Particulate organic matter in seawater. Adv. Mar. Biol. 8:1-118.

Rogers, D. E. 1977. Determination and description of knowledge of the distribution, abundance, and timing of salmonids in the Gulf of Alaska and Bering Sea: covering salmonids in Bristol Bay (St. George Basin Region). Univ. Washington Fish. Res. Inst. FRI-UW-7736, Suppl. to Final Rep.

Royer, T. C. 1981a. Baroclinc transport in the Gulf of Alaska. Part I: seasonal variations of the Alaska Current. Jour. of Mar. Res. 39(2):239-249.

Royer, T. C. 1979. On the effect of precipitation and runoff on coastal circulation in the Gulf of Alaska. J. of Phys. Oceanog. 9:555-563.

Royer, T. C. 1981b. Baroclinic transport in the Gulf of Alaska. Part II: a freshwater driven coastal current. J. of Mar. Res. 39(2):251-266.

Rugh, D. J. and H. W. Braham. 1979. California gray whale (Eschrichtius robustus) fall migration through Unimak Pass, Alaska. 1977. Rep. Int. Whaling Comm. 29, 20 pp.

Sambrotto, R. N. 1983. Nitrogen utilization during spring phytoplankton bloom development in the southeast Bering Sea. Ph.D. dissertation. Univ. of Alaska, Fairbanks, AK. 225 pp.

Sanger, G. A. and P. A. Baird. 1977. Aspects of the feeding ecology of Bering Sea avifauna.Environmental Assessment of the Alaska Continental Shelf. Ann. Rep. of PI, Vol. 12: 372-417.

Schneider, D. 1982. Fronts and seabird aggregations in the southeastern Bering Sea. Mar. Eco. Prog. Ser. 10: 101-103.

Schneider, K. 1976. Distribution and abundance of sea otters in southwestern Bristol Bay. Environmental Assessment of the Alaska Continental Shelf. Quarterly Rep. Dec., 1976:469-526.

Schneider, K. B. 1981. Distribution and abundances of sea otters in the eastern Bering Sea. In: Hood, D. w. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 837-869. Us. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Schneider, K. and J. B. Fare. 1975. Effects of sea ice on sea otters (Enhydra lutris). J. Mammal. 56(1):91-101.

Scholl, D. W. and E. C. Buffington. 1970. Structural evolution of Bering continental margin: Cretaceus to Eocene. Amer. Assoc. Petrol. Geol. Bull. 54:2503.

Scholl, D. W., E. C. Buffington, and M. S. Marlow. 1974. Plate tectonics and the structural evolution of the Aleutian-Bering Sea region. In: Forbes, R. B., ed. The geophysics and geology fo—the Bering Sea region. Geol. Sot. Amer. Mere. 151.

Scholl, D. W. and J. S. Creager. 1971. Deep sea drilling project, Leg 19. Geotimes 16:12-15.

Scholl, D. W"., H. G. Greene, and M. S. Marlow. 1970. The Eocene age of the Adak "Paleozoic?" locality, Aleutian Islands, Alaska. Geol. Sot. Amer. Bull. 81:3583-3592.

Schumacher, J. D. and T. H. Kinder. 1983. Low-frequency current regimes over the Bering Sea shelf. J. of Phys. Oceanog. 13:607-623.

Schumacher, J. D., T. H. Kinder, D. J. Pashinski, and R. L. Charnell. 1979. A structural front over the continental shelf of the eastern Bering Sea. J. of Phys. Oceanog. 83:79-87.

Schumacher, J. D. and P. D. Moen. 1983. Circulation and hydrography of Unimak Pass and the shelf waters north of the Alaska Peninsula. NOAA Tech. Mere. ERL PMEL-47. 75 pp.

Schumacher, J. D., C. A. Pearson, and J. E. Overland. 1982. On exchange of water between the Gulf of Alaska and the Bering Sea through Unimak Pass. J. of Geophys. Res. 87(C8) :5785-5795.-

Schumacher, J. D., and R. K. Reed. 1980. Coastal flow in the northwest Gulf of Alaska: The Kenai Current. J. of Geophys. Res. 85(C11):6680-6688.

Science Application, Inc. 1981. Resource assessments, North Aleutian Lease Area, 21 plates. Prepared for u. s. Dept. of Commerce, National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment.

Scranton, M. I. and P. G. Brewer. 1977. Occurrence of methane in the near surface waters of the western subtropical North Atlantic. Deep-Sea Res. 24:127-138.

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

Sears, H. S. and S. T. Zimmerman. 1979. Alaska Intertidal survey atlas. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest and Alaska Fisheries Center Auke Bay Laboratory, Auke Bay, AK.

Sharma, G. D. 1974. Contemporary depositional environment of the eastern Bering Sea. In: Hood, D. W. and E. J. Kelley, eds. Oceanography of the Bering Sea, pp. 517-552. Inst. of Mar. Sci., Univ. of Alaska, Fair- banks Occ. Pub. #2.

Sharma, G. D. 1979. The Alaskan shelf: hydrographic, sedimentary, and geochemical environment. Springer Verlag, New York.

Sharma, G. D. 1971. Bristol Bay: a model contemporary graded shelf. In: Hood, D. W., ed. Oceanography of Bering Sea. Phase I. Inst. of Mar. Sci, Univ. of Alaska, Fairbanks, Report No. R-71-9, 212 pp..

Sharma, G. D., A. S. Naidu, and D. W. Hood. 1972. Bristol Bay: model contemporary graded shelf. Petroleum Geologists Bull. 56:2000-2012.

Shaw, D. G. and E. R. Smith. 1981. Hydrocarbons of animals of the Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Chapter 24, pp. 383-388. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Shimada, A. and J. June. 1982. Eastern Bering Sea Pacific cod food habits. Personal memorandum to staff of the Northwest and Alaska Fisheries Center, Resource Assessment and Conservation Engineering Division. 35 pp.

Smith, A. M. and R. J. Cook. 1974. Implications of ethylene production by bacteria for biological balance of soil. Nature 252:702-705.

Smith, R. L., A. C. Paulson, and J. R. Rose. 1978. Food and feeding relationships in the benthic and demersal fishes of the Gulf of Alaska and Bering Sea. Environmental assessment of the Alaska Continental Shelf. Final Rep. of PI, Vol. 1:33-107.

Sowls, A. L., S. A. Hatch, and C. J. Lensink. 1978. Catalog of Alaskan seabird colonies. USFWS Biol. Serv. Prog, Anchorage, AK. 32 pp.

Stern, L. J., D. E. Rogers, and A. C. Hartt. 1976. Determination and description of knowledge of the distribution, abundance, and timing of salmonids in the Gulf of Alaska and Bering Sea. Environmental Assessment of the Alaska Continental Shelf. Final Rep. of PI for 1976, Vol. 2:586-748.

Stoker, S. 1981. Benthic invertebrate macrofauna of the eastern Bering/Chukchi continental shelf. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 2, pp. 1069-1090. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Straty, R. R. 1977. Current patterns and distribution of river waters in inner Bristol Bay, Alaska. NOAA Tech. Rep. NMFS, SSRF, 713. Pp. 1-13.

Straty, R. R. and H. W. Jaenicke. 1980. Estuarine influence of salinity, temperature, and food on the behavior, growth, and dynamics of Bristol Bay sockeye salmon. In: McNeil, W. J. and D. C. Himsworth, eds. Salmonid ecosystems of the north Pacific. Oregon State Univ. Press, Corvallis, OR. 331 pp.

Stringer, W. J. 1981. Nearshore ice characteristics in the eastern Bering Sea. In: D. W. Hood and J. A. Calder, eds., Bering Sea Shelf: Oceanography and Resources. U. S. Dept. of Commerce. vol. 1:167-187.

Stuermer, D. H., K. E. Peters, and I. R. Kaplan. 1978. Source indicators of humic substances and proto-kerogen. Geochem. Cosmochim. Acts 42:989-997.

Swimmerton, J. W. and R. A. Lamontague. 1974. Oceanic distribution of low-molecular-weight hydrocarbons. Envir. Sci. and Technol. 8:657-663.

Takenouti, Y. and K. Ohtani. 1974. Currents and water masses in the Bering Sea: a review of Japanese work. In: Hood, D. W. and E. J. Kelley, Oceanography of the Bering Sea, pp. 39-57. Inst. of Mar. Sci., Univ. of Alaska, Fairbanks Occ. Pub. No. 2.

Takeuchi, I. 1962. On the distribution of zoae larvae of king crab, Paralithodes camtschatica, in the southeastern Bering Sea in 1960. Bull. of the Hokkaido Reg. Fish. Res. Lab. 24:163-170. Fish." Res. Board of Canada Trans. Ser. No. 1191, 1968.

Tarverdieva, M. I. 1976. Feeding of the Komehatka king crab, Paralithodes camtschatica and tanner crabs, Chionoecetes bairdi and Chionoecetes opilio in the southeastern part of the Bering Sea. Soviet J. Mar. Biol. 2:34-39.

Thorsteinson, L. K. ed. 1983. Draft. Proceedings of a synthesis meeting: the North Aleutian Shelf and possible conse quences of oil and gas development. Anchorage, Alaska, 9-11 March 1982. U.S. Dept. of Interior, Minerals Manag. Serv., OCSEAP, Juneau, AK.

Thorsteinson F. V. and L. K. Thorsteinson. 1983. Fish resources. In: L. K. Thorsteinson, ed., 1983 draft. Pp. 1-87.

Thorsteinson, F. V. and L. K. Thorsteinson eds. 1982. Finfish resources, Pp. 111-139.

Trapp, J. L. 1979. Concept plan for the preservation of migratory bird habitat, Part 2: seabirds. Unpubl. manuscript on file at USFWS, Anchorage, AK. 59 pp.

Threlfall, W., E. Eveleigh, and J. E. Maunder. 1974. Seabird mortality in a strom. Auk 91:846-849.

Us. Department of Commerce. 1981a. Tide tables. West Coast of North and South America. National Ocean Survey.

U*S. Department of 'Commerce. 1981b. Tide tables. West Coast of North and South America. National Ocean Survey.

Us. Fish and Wildlife Service. 1980, 1981, 1982. National Wildlife Refuge System. U. S. Dept. of the Interior, Annual Narrative Reports, Izembek National Wildlife Range. Cold Bay, AK.

Us. Geological Survey. 1980. Water resources data for Alaska water year 1980. U.S. Geological Survey water-data report AK-80-1. Prepared in cooperation with the State of Alaska and other agencies.

Us. Interagency Task Group. 1976. Draft environmental impact statement in consideration of a waiver of the moratorium and return of management of certain marine mammals to the state of Alaska. U.S. Dept of Commerce NOAA, NMFS, Washington, D.C.

Venkatesan, M. I., S. Brenner, E. Ruth, J. Bonilla, and I. R. Kaplan. 1980. Hydrocarbons in age-dated sediment cores from two basins in the Southern California Bight. Geochem. Cosmochim. Acts 44:789-802.

Venkatesan, M. I., M. Sandstrom, S. Brenner, E. Ruth, J. Bonilla, I. r. Kaplan, and W. E. Reed. 1981. Organic geochemistry of surficial sediments from the eastern Bering Sea. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea shelf: oceanogrpahy and resources , Chapter 25, pp. 389-409. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

VTN Oregon. 1983a. Cruise report: Cruise MF 83-1 (RP-MF-83A, Leg 1), 18 April - 7 May 1983, OCSEAP red king crab distribution. VTN Oregon, Inc. Wilsonville, OR. 5 pp.

VTN Oregon. 1983b. Cruise report: Cruise MF 83-3 (RP-MF-83A, Leg III), 2-17 June 1983, OCSEAP red king crab distribution. VTN Oregon, Inc. Wilsonville, OR. 5 pp.

VTN Oregon. 1983c. Cruise report: Cruise MF 83-2 (RP-MF-83a, Leg II), 9-23 September 1983, OCSEAP red king crab distribution. VTN Oregon, Inc. Wilsonville, OR. 5 pp.

VTN Oregon. 1983d. Ecological characterization of shallow subtidal habitats in the northern Aleutian Shelf. Pers. comm. with Dr. Robert Cimberg of VTN Oregon to Stephen Pace of Kinnetic Laboratories, Inc., September 1983. Re: Food of sea otters.

VTN Oregon. 1983e. Ecological characterization of shallow subtidal habitats in the north Aleutian shelf. Draft final report for NOAA, OCSEAP, Juneau, AK. 93 pp. + appendices.

Wagner, F. S., Jr. 1969. Composition of the dissolved organic compounds in seawater: a review. Contrib. Mar. Sci. 115-153.

Wahrhaftig, C. J., J. A. Wolfe, E. B. Leopold, and M. A. Lamphere. 1969. The coal-bearing group in the Nenana coal Field, Alaska. U.S. Geol. Survey Bull. 1274-D. 30 pp.

Waldron, K. D. 1981. Ichthyoplankton. In: D. W. Hood and J. A. Calder, eds., The Eastern Bering Sea Shelf: Oceanography and Resources. vol. 1:471-493, NOAA, Distributed by University of Washington Press, Seattle, WA.

Walsh, J. J. and C. P. McRoy. 1983. Component 5: ecosystem analysis and synthesis in the southeast Bering Sea. PROBES final progress report (1976-1983). Unpub. Univ. of Alaska, Fairbanks. 58 pp.

Warner, I. M. and P. Shafford. 1981. Forage fish spawning surveys-southern Bering Sea. Environmental assessment of the Alaskan continental shelf. Final rep. of PI for year ending 1980, Vol. 10, pp. 1-64.

Wespestad, V. G. and L.. H. Barton. 1981. Distribution, migration, and status of Pacific herring. In: Hood, D. W. and J. A. Calder, eds. The eastern Bering Sea Shelf: oceanography and resources, Volume 1, pp. 509-525. U.S. Dept. of Commerce, NOAA. Univ. of Washington Press, Seattle.

Williams, P. B. 1969. The distribution and cycling of organic matter in the ocean. Rudolfs Conference, Rutgers Univ. 1969.

Wilson, D. F., J. W. Swimmerton, and R. A. Lamontague. 1970. Production of carbon monoxide and gaseous hydrocarbons in seawater: relation to dissolved organic carbon. Science 168:1577-1579.

Yamamoto, S. J., B. Alcauskas, and T. E. Grozier. 1976. Volubility of methane in distilled water and seawater. J. Chem. Eng. Data 21:78-80.

2. Drilling Fluids Toxicity References

Atema, J., D.F. Leavitt, D.E. Barshaw, and M.C. Cuomo. 1982. Effects of drilling fluids on behavior of the American lobster, Homarus americanus in Water column and substrate exposures. Can. J. Fish. Aquat. Sci. 39:675-690.

Bookhout, C.G., R. Monroe, R. Forward, and J.D. Costlow, Jr. 1982. Effects of soluble fractions of drilling fluids and hexavalent chromium on the development of the crabs, Rhithropanopeus harrisii and Callinectes sapidus. EPA-600/S3-82-018. Final report to U.S. EPA Environmental Research Laboratory, Gulf Breeze, Florida.

Carls, M.G., and S.D. Rice. 1980. Toxicity of oil well drilling fluids to Alaskan larval shrimp and crabs. Research unit 72. Final report. Project No. R7120822. Outer Continental Shelf Energy Assessment Program. Bureau of Land Management? U.S. Department of the Interior. 29 pp.

Carr, R.S., L.A. Reitsema, and J.M. Neff. 1980. Influence of used chrome-lignosulfonate drilling fluids on the survival, respiration, growth, and feeding activity of the opossum shrimp Mysidopsis almyra. In: Proceedings of a Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Washington, D.C.: Courtesy Associates, pp. 944-963.

Chaffee, C., and R.B. Spies. 1982. The effects of used ferrochrome lignosulfonate drilling fluids from a Santa Barbara Channel oil well on the development of starfish embryos. Mar. Environ. Res. 7:265-277.

Conklin, P.J., D.G. Doughtie, and K.R. Rae. 1980. Effects of barite and used drilling fluids on crustaceans, with particular reference to the grass shrimp, Palaemonetes pugio. In: Proceedings of a Symposium on Research on Environmental Fate amd Effects of Drilling Fluids and Cuttings. Washington, D.C.: Courtesy Associates, pp. 723-738.

Conklin, P. J., D. Drysdale, D. G. Doughtie, K. R. Rae, J. P. Kakareka, T. R. Gilbert, and R. F. Shokes. 1983. Comparative toxicity of drilling mods: role of chromium and petroleum hydrocarbons. Mar. Environ. Res. 10:105-125.

Crawford, R.B., AND J.D. Gates. 1981. Effects of drilling fluid on the development of a teleost and an echinoderm. Bull. Environ. Contain. Toxicol. 26:207-212.

Derby, C. D., and J. Atema. 1981. Influence of drilling fluids on the primary chemosensory neurons in walking legs of the lobster, Homarus americanus. Can. J. Fish Aquat. Sci. 38:268-274.

Dodge, R.E. 1982. Effects of drilling fluids on the reef -building coral Montastrea annularis. Mar. Biol. 71: 141-147.

ERCO. 1980. Results of joint bioassay monitoring program. Final report to the Offshore Operators Committee under direction of Exxon Production Research Co., Houston, Tex. ERCO, Inc., Cambridge, Mass.

Gerber, R.P., E.S. Gilfillan, J.R. Hotham, L.J. Galletto, and S.A. Hanson. 1981. Further studies on the short and long-term effect of used drilling fluids on marine organisms. Unpublished. Final Report, Year II to the American Petroleum Institute, Washington, D.C. 30 pp.

Gerber, R.P., E.S. Gilfillan, B.T. Page, D.S. Page, and J.B. Hotham. 1980. Short- and long-term effects of used drilling fluids on marine organisms. In: Proceedings of a Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Washington, D.C.: Courtesy Associates, pp. 882-911.

Gilbert, T.R. 1981. A study of the impact of discharged drilling fluids on the Georges Bank environment. New England Aquarium. H.E. Edgerton Research Laboratory. Progress Rept. No. 2 to U.S. EPA, Gulf Breeze, Fla. 98 pp.

Houghton, J.P., D.L. Beyer, and E.D. Thielk. 1980. Effects of oil well drilling fluids on several important Alaskan marine organisms. In: Proceedings of a Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Washington, D.C.: Courtesy Associates, pp. 1017-1043.

Hudson, J.H., and D.M. Robbin. 1980. Effects of drilling fluids on the growth rate of the reef-building coral, Montastrea annularis. In: Proceedings of a Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Washington, D.C.: Courtesy Associates, pp. 1101-1122.

Krone, M.A., and D.C. Biggs. 1980. Sublethal metabolic responses of the hermatypic coral Madracis decactis exposed to drilling fluids, enriched with ferrochrome lignosulfonate. In: Proceedings of a Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Washington, D.C.: Courtesy Associates, pp. 1079-1100.

Marine Bioassay Labs. 1982. Drilling fluids bioassays. Texaco Habitat Platform Well A-1 Pitas Point Lease Sale Unit: Acanthomysis sculpts and Macoma nasuta. Report submitted to Texaco, Inc., Los Angeles, CA., and IMCO Services, Houston, Tex., by Marine Bioassay Labs., Watsonville, CA.

National Academy Press. 1983. Drilling Discharges in the Marine Environment. Washington, D.C. 180pp.

Neff, J.M. 1980. Effects of used drilling fluids on benthic marine animals. Publ. No. 4330. American Petroleum Institute, Washington, D.C. 31 pp.

Petrazzuolo, G. 1981. Preliminary report. An environmental assessment of drilling fluids and cuttings released onto the Outer Continental Shelf. Vol. 1: Technical assessment. vol. 2: Tables, figures and Appendix A. Draft report prepared for Industrial Permits Branch, Office of Water Endorsement and Ocean Programs Branch, Office of Water and Waste Management, Us. Environmental Protection Agency, Washington, D.C.

Powell, E.N., M. Kasschau, E. Che, M. Loenig, and J. Peron. 1982. Changes in the free amino acid pool during environmental stress in the gill tissue of the oyster, Crassostrea virginica. Comp. Biochem. Physiol. 71A: 591-598.

Rubenstein, N.I., R. Rigby, and C.N. D'Asaro. 1980. Acute and sublethal effects of whole used drilling fluids on representative estuarine organisms. In: Proceedings of a Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Washington, D.C.: Courtesy Associates, pp. 828-846.

Sharp, J.R., R.S. Carr, and J.M. Neff. 1982. Influence of used chrome lignosulfonate drilling and fluids on the early life history of the mummichog Fundulus heteroclitus. In: Proceedings of Ocean Dumping Symposium. New York: John Wiley & Sons.

Szmant-Froelich, A., V. Johnson, T. Hoen, J. Battey, G.J. Smith, E. Fleishmann, J. Porter, and D. Dallmeyer. In press. The physiological effects of oil-drilling fluids on the Caribbean coral Montastrea annularis. In: Proceedings of the 4th International Coral Reef Symposium, Manila. vol. 1.

Thompson, J.H., Jr. 1980. Responses of selected scleractinian corals to drilling fluid used in the marine environment. Ph.D. Dissertation. Texas A&M University. 130 pp.

Thompson, J. H., Jr. , and T.J. Bright. 1977. Effects of drilling fluids on sediment clearing rates of certain hermatypic corals. In: Oil Spill Conference. Washington, D.C.: American Petroleum Institute, pp. 495-498.

Thompson, J.H., Jr. , and T.J. Bright. 1980. Effects of an offshore drilling fluid on selected corals. In: Proceedings of a Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Washington, D.C.: Courtesy Associates, pp. 1044-1078.

Thompson, J.H., Jr., E.A. Shinn, and T.J. Bright. 1980. Effects of drilling fluids on seven species of reef -building corals as measured in the field and laboratory. In: R.A. Geyer (cd.), Marine Environmental Pollution. vol. 1. Hydrocarbons. Elsevier Oceanography Series.' Vol. 27A. New York: Elsevier/North-Holland.

White, D.C., J.S. Nickels, M.J. Gehron, J.H. Parker, R.F. Martz, and N.L. Richards. In Press. Effect of well-drilling fluids on the physiological status and microbial infection of the reef-building coral Monastrea annularis. Arch. Environ Contain. Toxicol.

APPENDIX A

DESCRIPTION OF KEY SPECIES

HARBOR SEAL

Introduction

The harbor seal (Phoca vitulina) is one of several species of phocid seals which occurs at least seasonally within the waters of Bristol Bay and along the Alaska Peninsula.

Distribution. Harbor seals are found within the nearshore zone all the way from Unimak Pass around to Cape Newenham. Approximately 80 percent of the population, however, hauls during the summer for moulting and pupping on beaches at Port Moller, Port Heiden, and Cinder River. Other major hauling sites along the coast are Egegik Bay, Ugashik Bay, Seal Islands, Izembek Lagoon, and Bechevin Bay (Braham et al, 1977; Everitt and Braham, 1980). During the onset of winter ice, the population seems to disperse, probably shifting somewhat to the south or moving into the edge of the winter ice (F.H. Fay, personal communication) .

Commercial Importance. Like all marine mammals, harbor seals are currently protected by federal law, with no commercial harvest allowed. Some seals are taken by Alaskan natives for subsistence use, though apparently not enough to significantly impact the population. Though quantitative data are generally lacking, harbor seals are known to feed on several commercial fish species, including salmon, pollock, and herring.

Population Status. The resident population of harbor seals in the area is estimated at 28,000 to 30,000 (Everitt and Krogman, 1979; Everitt and Braham, 1980), though this estimate may be overly conservative (F.H. Fay and J.J. Burns, personal communication). The population appears more or less stable.

Life History

Reproduction. Females normally produce a single 'pup every year. Pups are born on the beach in June or July. As described by Johnson (1977), this is a critical period in that disturbance, particularly from boats and low-flying aircraft, frequently results in separation of pups and mothers, and starvation of the latter. Practically the entire adult population occupies the beaches of the region at this time and would be particularly vulnerable to oil spills.

Feeding, Age and Growth. Harbor seal pups nurse for a period of from 3 to 6 weeks, during which time they normally double in weight (Lowry et al, 1982). Pups weigh about 12 kg at birth. They continue to grow after weaning, though at a reduced rate, until about 10 years of age when average

weights are 85 kg for males and 76 kg for females (Lowry et al, 1982). Food requirements range from 13 percent of total body weight per day during the first year to 3 percent per day at age nine (Ashwell-Erickson et al, 1978).

Harbor seals are top predators, feeding on a wide range of fish, cephalopods and crustaceans. Major prey items from this area seem to include pollock, sandlance, smelt, greenling, sculpins and various flatfishes (Lowry et al, 1982). It is likely that they also take, during certain times of year, salmon juveniles and adults, herring, capelin, yellowfin sole, shrimp, and crabs.

STELLER SEA LION

Introduction

The Steller sea lion (Eumetopias jubatus) is the only otarid seal common in the nearshore zone of the region. The other otarid of the Bering Sea, the northern fur seal, generally remains further offshore.

Distribution. Sea lions occur throughout the Bristol Bay and northern Aleutian region. During the breeding season, approximately 80 percent of the population is concentrated at rookeries in the Fox Islands, with most of the remainder of the breeding population located at the Amak Island rookery. Minor, non-breeding rookeries have been observed on Hagemeister Island, Cape Newenham, Crooked Island, and the Twins. Sea lions are absent from the area during winter months when they probably frequent the ice edge of the central Bering Sea (Braham et al, 1977; Lowry et al, 1982).

Commercial Importance. Sea lions are protected under federal law with no commercial harvest allowed at present. They are known to feed on several species of commercially harvested fish, though their impact on these populations is unknown.

Population Status. At present, the population in the north Aleutian-Bristol Bay region is estimated to be between 15,000 and 25,000 (Braham et al, 1977, 1980; Braham and Rugh, 1978). For reasons which are uncertain, this population seems to have declined significantly (perhaps by as much as 50 percent) since the late 1950's and early 1960's (Braham et al, 1980).

Life History

Reproduction. Females normally give birth to a single pup each year at rookeries in the Fox Islands and on Amak Island. Pups are born between May and early July, and nurse for about one year.

Feeding, Age and Growth. Sea lion pups weigh about 23 kg at birth. Most females attain their average adult weight of 263 kg by age six, while males continue to grow until their eleventh year, when they weigh an average of 566 kg. Daily consumption rates probably range between six and ten percent of total body weight (Lowry et al, 1982). They are opportunistic feeders on a wide range of finfish, squid and octopus.

PACIFIC WALRUS

Introduction

The Pacific walrus (Odobenus rosmarus divergens) is the sole representative of the family Odobenidae in the Bering Sea.

Distribution. During winter months, large numbers of walruses of mixed sex and age composition frequent the ice edge in northern and central Bristol Bay. During summer, a population of between 12,000 and 20,000 males remains in northern Bristol Bay. The principal hauling ground for this summer population is Round Island, though animals range widely during feeding forays and are known to haul at other locations in northern Bristol Bay and along the coast of the Alaska Peninsula (Fay, 1982; Fay and Lowry, 1981).

Commercial Importance. Walruses are currently protected under federal law, with no commercial harvest allowed. Significant numbers are harvested each year by Alaskan natives for subsistence use and for ivory, though this hunting has apparently not had any adverse impact on the population.

Population Status. The present population of walrus in the Bering and Chukchi Seas is estimated at over 250,000 animals. This population has increased rapidly over the past several decades and is still growing, though at a reduced rate (Fay, 1982; Fay and Stoker, 1982a,b). The number of animals frequenting Bristol Bay during winter is highly variable, depending on ice conditions.

Life History

Reproduction. Females normally produce a single calf every other year. Calves are born on the ice from late April through early June. Recent studies (Fay and Stoker, 1982a,b) indicate that reproductive success has declined over the past few years, probably indicating population stress.

Feeding, Age and Growth. Calves weigh 45-75 kg at birth, and triple their weight during the first year when they are solely dependent on nursing. Females attain their average adult weight of 880 kg by 12 to 14 years of age, while males continue to grow until about 16, when they weigh an average of 1,200 kg (Fay, 1982). Walrus feed on a wide variety of benthic infaunal and epifaunal invertebrates, sandlance and occasionally other seals (Fay et al. 1977). In Bristol Bay walruses are known to take at least 22 general of benthic invertebrates, though the vast bulk (90%) is contributed by bivalve mollusks of the genera Serripes, Tellina, Spisula, siliqua and Mya (Fay and Lowry, 1981). There are some indications that they are stressing their food resource, at least in the northern Bering Sea (Fay and Stoker, 1982a,b).

GRAY WHALE

Introduction

The gray whale (Eschrichtius robustus) is the sole member of the family Eschrichtidae. It is one of the most common cetaceans in the region, is certainly the one most frequently encountered in the nearshore zone of the shelf, and is the most numerous baleen whale in the Bering Sea (Lowry et al, 1982).

Distribution. Gray whales are migratory, entering the Bering Sea through Unimak Pass from March until June and departing in the fall. The entire population follows around Bristol Bay close inshore during the spring migration, with some animals remaining in the area throughout the summer months (Braham et al, 1977; Gill and Hall, 1983).

Commercial Importance. Gray whales are protected by federal law, with no commercial harvest allowed. A few are taken each year for subsistence by Alaskan natives, and there is a limited subsistence harvest in Siberian waters.

Population Status. The present population of gray whales is estimated to be at least 15,000 (Rugh and Braham, 1979). This population has increased rapidly over the past few decades, and is probably still growing.

Life History

Reproduction. Females give birth, usually, to a single calf every other year. Calves are born while the population is overwintering in the lagoons of Baja California.

Feeding, Age and Growth. Calves are born between December and early February, averaging 4.75 m in length at birth. They grow to 7-8 m by the-time they are weaned in August, and are about 9 m in length by the end of their first year. After the first year they continue to grow, though more slowly, attaining an average adult length of 12 m and weighing as much as 34,000 kg (Lowry et al, 1982). Gray whales feed on benthic epifauna and infauna, with most of their diet consisting of gammarid amphipods of the genera Ampelisca, Lembos, Anonyx, and Pontoporeia. Daily consumption is estimated to be about 1,200 kg per animal per day (Lowry et al, 1982).

BELUGA (BELUKHA) WHALE

Introduction

The beluga is the sole member of the family Monodontidae in the Bering Sea, and is the most common toothed whale (suborder Odontoceti) in the nearshore zone.

Distribution. Belugas are widespread in northern Alaska waters, occurring from Cook Inlet on the north Pacific coast 'around to the Beaufort Sea. In the Bristol Bay-Alaska Peninsula region, they occur primarily in the upper part of Bristol Bay, concentrating in the vicinity of the Nushagak and Kvichak River mouths during summer months (Brooks, 1955) .

Commercial Importance. Belugas are protected under federal law with no commercial harvest allowed. Some are taken each year for subsistence use by Alaskan natives. Belugas are also known to feed on several commercial stocks of finfish, including salmon, herring, and pollock, though their impact upon these populations is unknown at present.

Population Status. The total Bering-Chukchi-Beaufort beluga population is estimated at 15-18,000 animals, 1,000 to 1,500 of which frequent Bristol Bay (Lowry et al, 1982). This Bristol Bay population varies considerably from year to year and seasonally (Brooks, 1955). So far as is known, the population is stable at this time.

Life History

Reproduction. Females normally give birth every third year. Most calves are born in July or early August, and nurse for a period of 2 years (Lowry et al, 1982).

Feeding, Age and Growth. Beluga calves average 150 cm in length at birth and weigh 80 kg. By age ten they have normally attained their maximum adult size of 3.2-4.4 meters (520-1,200 kg) for males, 3.1-3.6 meters (480-700 kg) for females (A.D.F. & G., unpublished data). Belugas consume a wide variety of fish and invertebrates, though smelt and salmon seem to comprise a major part of their diet in the Bristol Bay region from May through August (Lowry et al, 1982). During the winter months, when they move out to the edge of the winter ice, they probably rely heavily on pollock (Seaman et al, 1982). Records from captive belugas indicate a consumption rate of four to seven percent of body weight per day (Lowry et al, 1982).

SEA OTTER

Introduction

The sea otter (Enhydra lutris) is the only marine member of the family Mustelidae and, along with the polar bear, is one of only two members of the orde-r Carnivora classified as marine mammal.

Distribution. Sea otters occur, in the Bristol Bay-Alaska Peninsula region, from Unimak Island to about Port Heiden, with the population density decreasing toward the northern part of this range. The bulk of the population is found between Cape Mordvinof on Unimak Island to about Cape Leontvich on the Alaska Peninsula (Schneider and Fare, 1975).

Commercial Importance. Once hunted intensely for their valuable fur, sea otters are now protected by federal law with no commercial harvest allowed. They feed on several commercially valuable species of invertebrates, including king and tanner crab, and may affect these populations in the nearshore zone.

Population Status. The current population estimate is from 11,700 to 17,200 sea otters residing in the Bristol Bay-Unimak Island area (Lowry et al, 1982). This population is probably still expanding slowly.

Life History

Reproduction. Normally, a single pup is born to females in the spring of every other year in the Bristol Bay region (Lowry et al, 1982).

Feeding, Age and Growth. Average weights of pups at birth are 1.75 kg for males, 1.96 kg for females. Sea otters reach sexual maturity at three or four years of age, with adult weights of 28.3 kg (mean) for males and 21.1 kg for females. The preferred prey of otters seems to be sea urchins, though they will consume practically any invertebrate species. When these are depleted, they will feed on slow-moving fish. In the Bristol Bay region, the principal prey species may be yellowfin sole, augmented by bivalve and gastropod mollusks and various crabs. Adult otters consume between 20 and 25 percent of their body weight daily (Estes and Palmisano, 1974) .

COMMON MURRE

Introduction

The common murre (Uris aalge) is one of many members of the family Alcidae common to the eastern Bering Sea. Other members of the family present include the thick-billed murre (Uris lomvia), pigeon guillemot (Cepphus columba), and several species of murrelets, auklets, and puffins.

Distribution. Within the Bristol Bay-Alaska Peninsula region, the vast majority of breeding murres are confined to large cliff-rookeries at Cape Newenham, Cape Peirce, the islands of northern Bristol Bay, Amak Island, and a few minor colonies on Unimak Island and along the Alaska Peninsula. Overwintering populations of murres seem to congregate along the coast of the Alaska Peninsula from about Port Moller outward, and in Unimak Pass (Hunt et al, 1981). Summer distributions are probably controlled by the availability of both nesting habitat (sea cliffs) and food supply; winter distributions are probably dictated largely by availability of food and by weather and sea conditions.

Commercial Importance. Murres are of no direct commercial importance. Some eggs, fledglings and adult birds are taken for subsistence use, but apparently not in quantities sufficient to impact the population. Indirectly, murres feed heavily on several species of commercially important fish, though their impact on these populations is unknown.

Population Status. At least one million common murres nest in this region (Sowls et al, 1978; Bartonek and Sealy, 1979). During fall and winter the number of murres in the region is probably reduced by at least half, with the remainder moving for the winter to south of the Alaska Peninsula. So far as is known, the population is more-or-less stable in this area, though significant fluctuations have been known to occur in this and adjacent areas due to hostile weather and/or fluctuations in food resources (Bailey and Davenport, 1972; D.G. Roseneau, personal communication) .

Life History

Reproduction. A single egg is laid on cliff ledges in late spring. Reproductive success is apparently dependent on weather patterns during the nesting period and on availability of prey species (often related to weather patterns) during nesting and fledging. In some colonies, predators such as foxes and gulls also affect reproductive success.

Feeding, Age and Growth. Fish probably form the mainstay of murre diets in the Bristol Bay region. Analyses from other areas (Hunt et al, 1981) indicate that walleye pollock are the most frequent species taken, followed by

other available fish species, cephalopods, and crustaceans. In the Bristol Bay vicinity, it seems probable that murres also consume juvenile salmon when available.

SHORT-TAILED SHEARWATER

Introduction

The short-tailed shearwater (Puffinus tenuirostris) is one of several seabirds of the family Procellariidae which frequent the eastern Bering Sea. Other members of this family in the area include sooty shearwaters (Puffinus griseus) and fulmars (Fulmarus glacialis).

Distribution. Short-tailed shearwaters nest in the southern hemisphere, returning to the North Pacific and Bering Sea to feed during summer months (Hunt et al, 1981). While in the Bering Sea, feeding concentrations of shearwaters occur within inner Bristol Bay, along the nearshore zone of the Alaska Peninsula, and in Unimak Pass. Distribution is, presumably, determined by availability of prey.

Commercial Importance. None. .

Population Status. Estimates of shearwater populations present in the region during summer vary considerably from author to author, with estimates ranging from seven million (Sanger and Baird, 1977) to a minimum of nine million (Hunt et al, 1981). This latter estimate may even be considerably low, since Hunt et al (1981) seem to feel that a more realistic estimate for normal years is probably around 20 million birds. When present, shearwaters commonly occur in huge flocks exceeding 100,000 birds, and form aggregations of a million or more. So far as is known, the population is stable.

Life History

Reproduction. Shearwaters breed on islands off southern Australia.

Feeding, Age and Growth. While in the Bering Sea, the preferred prey of shearwaters seems to be euphausiids during summer (over 70 percent; "Hunt et al, 1981-), and hyperiid amphipods (particularly Parathemisto libellula) during fall (Hunt et al, 1981). They also consume, in lesser proportions, fish, cephalopods, and carrion.

BLACK-LEGGED KITTIWAKE

Introduction

The black-legged kittiwake (Rissa tridactyla) is one of many species of the family Larinae which frequent the eastern Bering Sea.

Distribution. Most of the nesting population of blacklegged kittiwakes in the Bristol Bay-Alaska Peninsula region is confined, probably by habitat restrictions, to rocky islands and headlands in the vicinity of Cape Newenham, Cape Peirce, the islands of northern Bristol Bay and Amak Island. Due probably to habitat rather than to food requirements? the nesting locations of this and other seabird species, particularly murres, often coincide. Kittiwakes usually arrive in the Bering Sea between late April and mid-May, and depart in the fall.

Commercial Importance. No commercial importance is presently attached to kittiwakes, other than perhaps the fact that they seem to feed on juveniles of some commercially important fish species. Their impact upon these species is unknown. In the past, kittiwake eggs, young, and adults contributed significantly to local Eskimo and Aleut subsistence economies of the region.

Population Status. Between 300,000 and 500,000 blacklegged kittiwakes probably nest and feed in Bristol Bay and along the coastal zone of-the Alaska Peninsula (Sowls et al, 1978; Bartonek and Scaly, 1979). This population is probably somewhat unstable in that surface-feeding seabirds, in which category kittiwakes fall, seem in general to be more subject to recruitment failures as the result of inclement weather and/or fluctuating prey availability. "

Life History

Reproduction. Kittiwakes, like murres, nest in dense rookeries on cliffs of rocky islands and headlands. Two eggs are normally produced between late June and early July, with young birds fledging by early September (Petersen and Sigman, 1977). Kittiwake reproductive success appears to be highly unstable, probably as the result of weather patterns and food availability.

Feeding, Age and Growth. The diet of kittiwakes is somewhat variable seasonally and from area to area. In the Pribilof region they feed heavily on amphipods and euphausiids prior to nesting, then switch to fish during incubation. They are known to feed heavily on pollock, sandlance, myctophids , cod, probably several other species of small fish, and on squid to some extent (Hunt et al, 1981).

B LACK BRANT

Introduction

The black brant (Branta bernicla nigricans) is one of many species of the family Anatidae (swans, geese, and ducks), which frequent the lagoons, estuaries, and nearshore zone of Bristol Bay and the Alaska Peninsula.

Distribution. During their spring and fall migrations to and from nesting grounds on the Yukon-Kuskokwim Delta, the entire world population of black brant visits Izembek and adjacent lagoons.

Commercial Importance. Brant are hunted for sport, and provide part of the subsistence diet of Alaskan natives along the coast of the Bering and Chukchi Seas.

Population Status. The black brant population is currently estimated at 150,000-200,000 birds (King and Dau, 1981; U.S. Fish and Wildlife Service, 1982). So far as is known, the population is stable.

Life History

Reproduction. About half of the brant population nests on the Yukon-Kuskokwim Delta (King and Dau, 1981), with the remainder nesting in the vegetated intertidal along the coast of the northern Bering and Chukchi Seas. The productivity of black brant is fairly low, estimated at about 25 percent annually (U.S. Fish and Wildlife Service, 1980). Jones (1970) estimates that between 31 percent and 69 percent of the adults are non-breeders.

Feeding, Age and Growth. Brant feed on eelgrass and other marine and intertidal vegetation. At Izembek Lagoon, where the entire population stages during the fall migration, brant rely almost exclusively on eelgrass to put on needed fat reserves after the breeding and moulting season (C.P. McRoy, personal communication). Brant normally arrive at Izembek from September until early October, and remain until late October or early November (Jones, 1970) .

EMPEROR GOOSE

Introduction

The emperor goose (Philacte canagica) is one of many species of the family Anatidae which frequents the nearshore zone of the Alaska Peninsula and Bristol Bay during its spring and fall migrations.

Distribution. During spring and fall migrations, emperor geese stage at various lagoons and estuaries along the Alaska Peninsula and Bristol Bay. Principal areas are Izembek Lagoon, Port Moller, Port Heiden, and Cape Peirce (U.S. Fish and Wildlife Service, 1981; Petersen and Sigman, 1977; Petersen and Gill, 1982).

Commercial Importance. Emperor geese are hunted for sport, and comprise part of the subsistence diet of Alaskan natives along the Bering Sea coast.

Population Status. The current population is estimated at about 80,000-150,000 (King and Dau, 1981; Petersen and Gill, 1982), all of which reside in the Bering Sea. So far as is known, the population is stable.

Life History

Reproduction. Emperor geese nest primarily on the Yukon-Kuskokwim Delta in the vegetated intertidal.

Feeding, Age and Growth. Emperor geese feed primarily on intertidal invertebrates. Recent studies (Petersen, 1983) indicate that they also supplement this diet with marine and intertidal vegetation? including eelgrass where available. Emperor geese winter in the Aleutian Islands.

STELLER'S EIDER

Introduction

Steller's eider, (Polysticta stelleri) is one of many members of the family Anatidae which frequents the coast of Bristol Bay and the Alaska Peninsula.

Distribution. During the spring and fall migrations, huge flocks of Steller's eiders stage and moult at lagoons and estuaries of Bristol Bay and along the Alaska Peninsula. During the fall migration, birds normally arrive in the area in August or early September feed and moult in lagoons and estuaries and depart in early October (Petersen, 1980) . In some years, however, they do not arrive in the area until after the moult, sometimes as late as November (Jones, 1965). Steller's eiders winter from Kodiak Island west along the south side of the Alaska Peninsula and into the eastern Aleutians. Significant numbers also overwinter in open-water areas of the northern Alaska Peninsula and Bristol Bay coasts (Jones, 1965).

Commercial Importance. Steller's eiders are hunted for sport, and are used as a subsistence resource by Alaskan natives.

Population Status. The present population is estimated at about 400,000, all of which frequent the Bering Sea during migration (King and Dau, 1981). The population appears to be stable.

Life History

Reproduction. Most Steller's eiders nest along the Chukchi coast of Alaska and Siberia.

Feeding, Age and Growth. During their fall migration and moult, Steller's eiders are known to feed almost exclusively on 0-1 age class mussels (Mytilus edulis) and amphipods (Anisogammarus pugettensis) in the intertidal and shallow subtidal zone of "lagoons and estuaries along the coast of Bristol Bay and the Alaska Peninsula (Petersen, 1980).

DUNLIN

Introduction

Dunlins (Calidris alpina) are one of many members of the family Charadriidae (plovers, turnstones, and surfbirds) which seasonally frequent the coast of Bristol Bay and the Alaska Peninsula.

Distribution. Dunlin occupy the littoral areas of Bristol Bay and the Alaska Peninsula during the spring migration (May), while on their way to the nesting grounds, and as post-nesting foraging habitat prior to the fall migration (late June-mid October). During this post-breeding period, they undergo moult and put on fat reserves in preparation for the fall migration to wintering grounds in the Pacific Northwest and California (Gill and Handel, 1981). Major dulin concentrations occur in the estuary-lagoon systems of the region such as Port Heiden, Nelson Lagoon, Port Moller, Izembek Lagoon, and so on.

Commercial Importance. None.

Population Status. No estimates of the total population are currently available. Dunlin are by far the most common and numerous shorebird in the area, comprising about 80 percent of the total shorebird population. Gill and Jorgensen (1979) estimate summer populations of 260,000 in the Nelson Lagoon area alone. So far as is known, the population is stable.

Life History

Reproduction. 'The major nesting area for Dunlin in the region is the Yukon Delta, though some nesting does occur along the Alaska Peninsula (Gill and Handel, 1981) . No productivity estimates are available.

Feeding, Age and Growth. Dunlins feed in the region, during the summer and fall post-breeding period, on the littoral beaches and exposed flats of estuaries and lagoons along the Alaska Peninsula and Bristol Bay. Presumably, their diet consists primarily of infaunal and epifaunal crustaceans.

WESTERN SANDPIPER

Introduction

Along with dunlin, western sandpipers (Calidris mauri) are one of numerous members of the large Charadiidae family which frequents the Bristol Bay-Alaska Peninsula region.

Distribution. Western sandpipers occupy littoral zones of estuaries and lagoons in the region during both the spring migration, from early to mid-May, and during the postbreeding season prior to the fall migration (late June to early September).

Commercial Importance. None.

Population Status. No estimates of total population are currently available. It is, following dunlin, the most common and numerous shorebird found along the Bristol Bay-Alaska Peninsula coast during summer and early fall. It is estimated that at least 36,000 sandpiper use the Nelson Lagoon area during the post breeding period (Gill and Jorgensen, 1979) . The population appears stable at present.

Life History

Reproduction. Though the major nesting grounds of the region is the Yukon Delta, large numbers of sandpiper are known to nest along the coast of the Alaska Peninsula as well (Gill and Handel, 1981). No productivity estimates are available.

Feeding, Age and Growth. Like dunlins, western sandpipers feed on intertidal beaches and exposed flats of lagoons and estuaries along the Alaska Peninsula and Bristol Bay coast. Their major prey probably consists of infaunal and epifaunal crustaceans.

SOCKEYE (RED SALMON)

Introduction

Sockeye salmon (Oncorhynchus nerka) are one of five salmon species which spawn in streams and lakes of the Alaska Peninsula-Bristol Bay region.

Distribution. Though sockeye salmon enter at least 30 streams of the Bristol Bay and Alaska Peninsula coast during their spawning migration, about 90 percent of the average total run is associated with 5 river systems of inner Bristol Bay (Nushagak, Kvichak-Naknek, Egegik, Ugashik, and Togiak). Adult salmon enter the Bering Sea from the North Pacific enroute to spawning grounds in early May, arrive in Bristol Bay starting about mid-June and peaking between the first and the tenth of July, and by late July or early August have all entered the stream systems and nursery lakes. Juvenile salmon outmigrate into Bristol Bay in late May and early June of most years, with maximum concentrations found northeast of Port Heiden from late May through early July (Straty and Jaenicke, 1980). Juveniles outmigrate close inshore along the Alaska Peninsula coast to about the vicinity of Port Moller, where they swing out to sea and, eventually, pass through Unimak Pass into the North Pacific. Adult salmon on their return migration stay well out to sea until they are within proximity of their home rivers, where they then swing inshore (Favorite et al, 1977).

Commercial Importance. Historically, the Bristol Bay sockeye salmon fishery has been the most important salmon fishery in North America (Stern et al, 1976). Since 1963, an average of 10.1 million fish have been landed annually in Bristol Bay, for an average ex-vessel value of $29.719 million. In 1983, 37.226 million sockeye were landed, for an ex-vessel value of $138.8 million (A.D.F. & G. files, Anchorage) .

Population Status. Though sockeye salmon runs occur every year in Bristol Bay, they are strongly cyclical in that much higher numbers of fish seem to occur, on the average, every 5th year. Returning runs of sockeye vary greatly, from about 2.2 million to in excess of 56 million fish (A.D.F. & G. files, Anchorage). The average run of adult sockeye into Bristol Bay is about 16.5 million fish (Stern et al, 1976), while escapement of juvenile salmon is estimated to average 313.3 million fish annually (Stern et al, 1976).

Life History

Reproduction. Sockeye salmon spawn in the lakes adjacent to the Alaska Peninsula and Bristol Bay. Adults spawn on gravel beds of these lakes in late summer, after which all of them die. Alevins hatch during the winter and remain in the gravel until spring, by which time their yolk

sacs are absorbed. They remain feeding in the lake systems for one to two years, then outmigrate into Bristol Bay and eventually, the Bering Sea and North Pacific, where they spend from two to three years before returning (Rogers, 1977).

Feeding, Age and Growth. The size of outmigrating sockeye smelt ranges from 89 to 149 mm (5.4-33 g) for 1.0 year old fish, and from 109 to 184 mm (8-71 g) for 2.0 year old fish (Ogi, 1973). Growth during the early part of the outmigrating, when juveniles remain close inshore, is fairly slow. Once they move offshore, into the apparently richer oceanic waters, growth rates increase significantly. Both juveniles and adults feed on zooplankton and smaller fishes. Preferred prey items seem to be euphausiids, copepods, cladocerans, and sandlance (Straty and Jaenicke, 1980).

BOREAL (RAINBOW) SMELT

Introduction

Boreal or rainbow smelt (Osmerus eperlanus) is one of several small forage fish (including herring, capelin, sandlance, and eulachon) which inhabit the estuaries and nearshore zone of Bristol Bay.

Distribution. Little is known about the distribution of smelt other than that they are very common in the estuary and river systems of Bristol Bay.

Commercial Importance. Though there is presently no commercial smelt fishery in the region, smelt are taken for subsistence use.

Population Status. Virtually nothing is known concerning the abundance or population status of smelt in this area. Warner and Shafford (1981) estimate that it is the most common forage fish in the Meshik-Port Heiden area from late May through June.

Life History

Reproduction. In most regions, smelt overwinter in freshwater streams, spawn in tributaries soon after the ice goes out,. and return to the coastal estuaries to feed for the summer (Warner and Shafford, 1981). In the Port Heiden vicinity, however, it is conjectured (Barton et al, 1977) that smelt may remain in the estuary year-round, ascending the streams to spawn during the day and returning at night to feed.

Feeding, Age and Growth. Little is known other than that smelt fed on mysids, amphipods, fish, polychaete worms, and other invertebrates. Adults spawn at age two or three, and continue to spawn for two to three years (Warner and Shafford, 1981).

RED KING CRAB

Introduction

The red king crab, Paralithodes camtschatica, belongs to the family Lithodidae and is one of two Paralithodes Spp. in the eastern Bering Sea; the other is the blue king crab, P. platypus.

Distribution. Red king crab are distributed on both sides of the North Pacific Ocean. In Asian waters, it is found from the Sea of Japan northward into the Sea of Okhotsk and along the shores of the Kamchatka Peninsula; the northern limit on the Asiatic coast at approximately 60° N. latitude. The species occurs throughout the Aleutian Islands and the southeastern Bering Sea where large fisheries exist. On the west coast of North America, the northern limit appears to be the southeastern Chukchi Sea. Red king crab are distributed in the Gulf of Alaska from the Aleutian Islands south to Vancouver Island, British Columbia. The commercial fishery is generally confined to depths less than 200 meters. King crab migrate from offshore feeding grounds to coastal spawning areas from January to April, then stay in coastal waters through the summer before returning to greater depths offshore. Before the recent decline in stock, greatest concentrations of pre-recruit and legal-sized male crabs were located in 50-100 meters of water in the eastern Bering Sea. Red king crab are found in 0-5.5° C temperatures. Maximum concentrations of males are caught near the 1.5° C isotherm; females are found in 3-6° C. Spawning and mating occur in the shallow waters. Larvae settle out in waters less than 50 meters. Juveniles remain in the shallow waters along the North Aleutian Shelf and northern and inner Bristol Bay (Armstrong et al, 1981, 1982; Haynes, 1974; VTN Oregon, 1983 a,b,c).

After the eggs are hatched in the shallow waters along the North Aleutian shelf, the larvae mainly reside in the upper 30 meters. The larvae molt through four zoeal and one glaucothöe stages and become juveniles from mid-July to mid-August. First-year juveniles reside among coarse substrate bottom in patchy locations. Recent surveys have identified patches of juveniles in Kvichak Bay, off Port Moller and Cape Seniavin and around the Walrus Islands (VTN Oregon, 1983 a,b,c). Juveniles remain in the shallow waters for approximately three years until they begin the similar offshore migrations as adults.

Man affects the distribution and abundance of red king crab through commercial fishing, either directly upon the crab or upon their competitors, e.g., Pacific cod, yellowfin sole, and Pacific halibut. Water temperature, predators, and parasites are the natural factors which affect red king crab distribution and abundance.

Commercial Importance. King crab have been exploited in the southeastern Bering Sea since the 1940's. Until 1960, U.S., Soviet, and Japanese fisherman caught king crab with otter trawl, tangle net, and pots; thereafter only pots were used. In 1971 the Soviets ceased fishing for king crab in this region; Japan ceased operation after 1973. Only domestic fishermen now fish king crab in this region. The 1980 and 1982 seasons were historic high and low seasons, respectively. In 1980, the red king crab harvest reached 59.1 thousand mt in the southeastern Bering Sea. The catch in 1981 and 1982 plummeted to 15.4 thousand mt and 1.3 thousand mt, respectively (Powell and McCrary, 1982). In 1982 fishermen received $3.50/lb (Forrest Blau, A.D.F. & G., personal communication, 1982). The projected red king crab harvest is expected to remain low for several years.

Population Status. The 1983 red king crab population is the lowest since the onset of the commercial fishery in 1958. Recent NMFS crab surveys in the southeastern Bering Sea have revealed that in addition to finding few pre-recruit and legal-sized males, large numbers of adult females were found clutchless (Dr. Robert Otto, NMFS, personal communication, 1983). A 1983 NMFS survey of the Bristol Bay region revealed that 54.8 million males and 33.8 million females (86.6 total) were present. This estimate is almost one third of the 1982 estimate. This decline in abundance from 1982 to 1983 is reflected in both sexes (Otto, personal communication, 1983).

Life History

Reproductive Mode. Female red king crab carry their eggs beneath their abdominal flap for approximately eleven months. Once the crab has arrived in the shallow waters of the North Aleutian Shelf egg hatching begins. After egg hatching and molting, mating and spawning ensue while still in shallow water.

Feeding, Age and Growth. Adult king crab in the eastern Bering Sea are opportunistic feeders, mainly feeding on polychaete worms, pelecypods, gastropod, sand dollars, and brittle stars (Feder and Jewett, 1981). Similar prey is assumed to be taken by juveniles. An OCSEAP study is currently underway to address juvenile crab feeding.

King crab reach maturity between seven and eight years of age. Males and females have a carapace length between 99-120 mm at maturity. Male crab may live for approximately 15 years. (Guy Powell, A.D.F. & G., personnal communication, 1982).

YELLOWFIN SOLE

Introduction

yellowfin sole, Limanda aspera, belongs to the family Pleuronectidae, and is one of two species of Limanda found in the eastern Bering Sea.

Distribution. Yellowfin sole is limited in distribution to continental shelf and slope waters of the North Pacific Ocean, the Bering Sea and, to a limited extent, the Chukchi Sea. It ranges along the Pacific coast of North America from Barclay Sound, Vancouver Island, British Columbia, northward into the Chukchi Sea and along the Asian coast from the Gulf of Anadyr southward to the east and west coasts of Hokkaido Island, Japan, and along the Asian mainland in the Okhotsk Sea and the Sea of Japan to about 35°N off South Korea. Its bathymetric range is from about 5 to 360 meters, although in some regions (e.g., the Gulf of Alaska) it is limited to continental shelf waters of generally 100 meters or less. The deepest recorded occurrence (360 meters) is in the eastern Bering Sea (Bakkala, 1981a).

Yellowfin sole form dense concentrations on the outer continental shelf of the eastern Bering Sea in winter. The largest of these is formed in the vicinity of Unimak Island, and the second largest is west of St. Paul Island. Other lesser winter concentrations have been recognized. One may be south or east of St. George Island, and the other, consisting of small fish, in Bristol Bay. Unimak Island/St. George Island populations migrate toward shore in winter and early spring, concentrating along the North Aleutian Shelf and Bristol Bay. The large wintering concentration located west of St. Paul Island may remain relatively independent of the Unimak Island/St. George concentrations throughout the year. Spawning occurs in waters less than 100 meters in the summer. More than a million eggs may be produced by each spawning female. The young remain in shallow nearshore areas throughout their first few years of life. They begin to disperse to more offshore waters at three to five years of age. The observed age range of yellowfin sole since the early 1970's has been 2-19 years for males and 2-21 years for females; however, about 97% of the sampled population were younger than 13 (Bakkala, 1981a).

Man influences yellowfin sole through the commercial fishing activity either directly on yellowfin sole or on their competitors and/or prey.

Indices of relative abundance and biomass estimates from trawl surveys in the southeastern Bering Sea have shown that abundance continued to increase through 1978 and presumably is still increasing today. The primary reason for the increase has been the recruitment of a series of relatively strong year-classes originating in the years 1966-70. These were years of relatively warm climatic condition; year-classes produced in cold years had relatively low abundance. Evidence also suggests that extensive ice cover may delay the start of spring inshore migrations, and residual cold water in central shelf regions may alter patterns of summer migrations and distributions (Bakkala, 1981a).

Commercial Importance. This species was heavily fished by the USSR and Japan in the late 1950's and early 1960's, with peak harvests reaching approximately 500,000 ret/year. After 1962, harvests dropped drastically (Bakkala, 1981a; Haflinger and McRoy, 1983). Signs of improvement in the general yellowfin sole stock appeared in the early 1970's and have continued to present (Pereyra et al, 1976). In 1980, a joint US/USSR fishery for yellowfin sole in the eastern Bering Sea was successful. Five American catcher boats caught 8,638 mt of food-grade yellowfin sole, 1,421 mt of Pacific cod, and 3,118 mt of fishmeal-grade product for a grand total of 13,177 mt, valued a approximately $1.6 million during this period. The product was transported to the USSR and then marketed in the USSR and Africa (Fisher, 1980).

Population Status. Perhaps in response to the easing of fishing pressure, fish populations have, since the mid-1970's, steadily approached and perhaps exceeded pristine stock levels. Current biomass estimates for this species are in the two to four million mt range, making it the most common flatfish found on the shelf of the eastern Bering Sea, second only to Alaska pollock in biomass (Bakkala, 1981a; Haflinger and McRoy, 1983).

Life History

Reproductive Mode. Yellowfin sole are oviparous spawners. Little else is know about their reproductive mode.

Feeding, Age and Growth. Recent findings on the food of yellowfin sole in the southeastern Bering Sea along the Alaska Peninsula revealed that newly recruited surf clams Spisula polynyma (l-2 mm) were often encountered in the range of 100-500 per stomach of yellowfin caught in the deeper waters (>30 meters) off Port Moller, while various groups of polychaete worms, benthic amphipods, and the sand dollar Echinarachnius parma dominated the shallow water and Bristol Bay samples (Haflinger and. McRoy, 1983). King crab glaucothöe larvae and Tanner crab (Chionoecetes bairdi) zoea were also taken as food; however, only two of 557 fish examined accounted for nearly all the crab consumption

reported here. The overall incidence of king crab was 0.69/stomach. Overall incidence of Tanner crab was 0.27/ stomach. Extrapolations from these rates to total numbers of crab consumed for one month in this area are 11.5 x 10^9 king crab and 4.5 x 10^9 Tanner crab.

` A characterization of yellowfin sole food and feeding habits is presented in Bakkala (1981a) and summarized here. Yellowfin sole are capable of feeding on a variety of animals, from strictly benthic forms such as clams and polychaete worms to zooplankton (mysids and euphausiids) to pelagic fishes (capelin and smelt). About 50 different taxa have been found in stomachs of yellowfin sole in the eastern Bering Sea. The kinds of organisms consumed vary by season, area, and size of fish. Although feeding generally stops in winter, instances of fairly intense winter feeding have been recorded. During the onshore migrations in May and June 1971, 73 percent of the fish that had wintered near Unimak Island were feeding, but feeding intensities were low for fish that had wintered near St. George Island (0.05 percent), St. Paul Island (19 percent), and in Bristol Bay (zero percent). They fed more intensively as they moved onto the central shelf. Diet varies by region, apparently dependent on the availability of food organisms.

Contents of 2,357 stomachs taken over a broad area of the eastern Bering Sea showed that the primary food items, representing 65 percent of stomach contents by weight, were bivalves, amphipods, polychaete worms, and echiuroid worms. Polychaetes and amphipods were the principal food items in smaller fish (10-20 cm). Polychaetes and bivalves and then echiuroids and amphipods were the principal food in larger fish (20-30 cm), and bivalves and echiuroids in fish longer than 30 cm.

Male" yellowfin sole in the southeastern Bering Sea begin to mature at a length of 10.5 cm. The length at which 50 percent of the population is mature is 12.8 cm for males and 25.2 cm for females. All males mature at 25 cm and most females at '30 cm. Yellowfin sole first become recruited to the fishery at 13 or 14 cm, which corresponds to an age of four or five years (Bakkala, 1981a).

PACIFIC HERRING

Introduction

Pacific herring, *Clupea harengus pallasi*, is a member of the family Clupeidae and is the only member of the genus *Clupea* in the North Pacific Ocean.

Distribution. In the North Pacific Ocean, herring are distributed along the Asiatic and North American continental shelves; in Asia they range from Taksi Bay, near the mouth of the Lena River, to the Yellow Sea; and in North America from Cape Bathurst in the Beaufort Sea to San Diego Bay, California. Pacific herring spawn between the intertidal zone and about 20 meters (Wespestad and Barton, 1981).

Herring wintering northwest of the Pribilof Islands migrate to the Alaska coast in spring and spawn in Bristol Bay and between the Yukon and Kuskokwim Rivers. Although some may also spawn in the eastern Aleutian Islands, Alaska Peninsula, and Norton Sound, herring in these areas may also winter inshore near spawning grounds. Herring spawn in coastal waters between late April and mid-May. Eggs hatch in two or three weeks as planktonic larvae and metamorphose to juveniles after six to ten weeks (Wespestad and Barton, 1981). Little is known of larval and juvenile stages in the eastern Bering Sea.

Commercial fishing may affect the distribution and abundance of Pacific herring. Temperature may influence seasonal distributions more than anything else. In a major wintering area northwest of the Pribilof Islands, dense schools have been found during the day a few meters off the bottom at depths of 105-137 meters and at water temperatures of 2-3.5° C. In spring they migrate to warmer coastal waters, where they remain during the summer because of heavy phytoplankton blooms (1-3 g/m^3); poor feeding conditions exist on the outer shelf (Wespestad and Barton, 1981).

Commercial Importance. Following inception of the inshore herring sac roe fisheries in the eastern Bering Sea in the mid—1960's, herring catches and fishing effort remained low until recent years. Due to favorable market conditions and high prices for sac roe herring, both catch and effort have dramatically increased since 1977. A domestic harvest of nearly 12,000 mt of herring and 200 mt of spawn-on-kelp with a combined ex-vessel value of nearly $8.5 million was landed in 1979 (Wespestad and Barton, 1981). In 1981, 28 companies paid more than 200 permit holders and their crews an estimated $4 million for over 11,000 mt of herring and another $300,000 for 172 mt of spawn-on-kelp (Fried and Skrade, 1982). The total harvest for the eastern Bering Sea for 1983 was 30.7 mt; 24.5 mt were harvested from the Togiak District (Craig Whitmore A.D.F. & G., personal communication, 1983).

Population Status. Abundance of herring in the eastern Bering Sea appears to have increased since 1978 in all major coastal areas. Total spawning biomass is estimated to have ranged from 187,210 to 334,723 mt in 1978, and from 258,079 to 637,583 mt in 1979, an indicated 27 percent increase at the lower range (Wespestad and Barton, 1983). Studies have shown that Bristol Bay contains the largest assemblage of spawning herring within the entire State of Alaska: in 1981 about 144,000 mt of herring arrived to spawn within Bristol Bay (Fried and Skrade, 1982).

Life History

Reproductive Mode. Herring liberate their eggs in the coastal environment on substrates consisting primarily of rocks covered with rockweed kelp (*Fucus* sp.). However, almost any substrate is used under conditions of dense spawning.

Feeding, Age and Growth. Herring are planktivorous. The first food of herring larvae is usually limited to small and relatively immobile plankton organisms. Microscopic eggs often make up more than half of the earliest food; other items include diatoms and nauplii of small copepods. Herring do not have a strong preference for certain food species but feed on the comparatively large organisms that predominate in the plankton of a given year. Feeding generally occurs before spawning and intensifies afterwards. During winter, feeding declines, and ceases in late winter. Fall prey is dominated by euphausiids; spring prey is dominated by pelagic amphipods and chaetognaths. After spawning, the main diet is euphausiids, *Calanus* sp., and *Sagitta* sp. (Wespestad and Barton, 1981).

Herring have been found to live as long as 15 years, and generally occur in substantial numbers from ages three to six, but when strong year-classes occur, ages seven to ten may comprise a substantial portion of the catch. Bering Sea stocks grow at about the same rate as those in the Gulf of Alaska and British Columbia until ages three to four, but growth is greater in the Bering Sea for older fish which achieve a greater maximum length and weight than the more southern stocks (Wespestad and Barton, 1981).

CAPELIN

Introduction

The capelin, Mallotus villosus, is one of six members of the family Osmeridae. Both generic and specific names of the capelin mean hairy, the appearance of the rough extruded scales on spawning males.

Distribution. The capelin occurs circumpolar in the northern hemisphere. It occurs south to approximately 42° N. The only information on where the various life stages of capelin occur concerns their spawning. Capelin typically spawn along clean, fine gravel beaches; however, spawning has been documented at depths of up to 60 meters (Barton et al, 1977).

Man may only affect their distribution and abundance by way of commercial fisheries that target on other planktivorous species. Predation, water temperatures and severe storms during spawning are presumably the natural factors that affect capelin distribution and abundance.

Commercial Importance. The capelin has no commercial importance, although it has the potential of becoming a commercially valuable resource. It is taken in some areas for subsistence purposes.

Population Status. In 1976, capelin was the most geographically widespread forage fish species encountered in the eastern Bering Sea and constituted the second-most abundant species (next to herring) captured at onshore stations between Ugashik Bay and Unimak Island (Barton et al, 1977).

Life History

Reproductive Mode. Capelin liberate their eggs in the sand in intertidal regions.

Feeding, Age and Growth. Little is known about the food and feeding habits of the capelin from the eastern Bering Sea. Capelin are planktivorous. Smith et al (1978) examined the stomach contents of 135 feeding individuals from the southeastern Bering Sea. All specimens were captured during the period from late spring to early fall; therefore, no information is available on seasonality of feeding in Bering Sea capelin. Only two phyla were represented among the food organisms, the Arthropoda (all crustaceans) and the Chaetognatha. The most numerous prey organisms were calanoid copepods. The only identifiable genus was Calanus. Virtually all of the amphipods present were members of the pelagic Hyperiidae. Identifiable euphausiid specimens were all of the genus Thysanoessa. The smallest food item, copepods, had its greatest volumetric and relative importance in the smallest fishes. The same is true of the next smallest food item, the mysids.

Little is known about the age and growth of capelin.

GREAT ALASKA TELLIN

Introduction

The Great Alaska tellin clam, Tellina lutes, belongs to the family Tellinidae, and is the only member of the genus Tellina in the southeastern Bering Sea.

Distribution. Tellina populations in the southeastern Bering Sea occur mainly on the inner and middle continental shelf of Bristol Bay. 'Recent studies have shown that nearly 80 percent of all tellin clams caught came from depths less that 50 meters, although densities were greatest closer to the 50 meter depth (Hughes et al, 1977; McDonald et al, 1981). Seventy-eight percent of the clams occurred in medium to fine sand with 83 percent at sediment sorting from 39 to 44 percent (McDonald et al, 1981). Benthic and/or demersal commercial fishing operations may affect the distribution and abundance of the Great Alaska tellin clam. Alterations to their benthic habitat may result from trawling. Furthermore, removal of predator species (e.g., yellowfin sole) could also enhance their distribution and abundance. Water temperatures and predators are the two most important natural factors that may affect the distribution and abundance of this species.

Commercial Importance. This species currently is not commercially harvested, although it has been identified as a potential commercial species (Hughes et al, 1977).

Population Status. A clam survey done during 1977 in the southeastern Bering Sea estimated that the harvestable biomass inside the 50 meter contour between Port Moller and Ugashik Bay was conservatively placed at about 82,000 mt (Hughes et al, 1977) .

Life History

Reproductive Mode. The sexes are separate, and gametes are liberated into the water.

Feeding, Age and Growth. Tellina lutea is a filter-feeder.

Seventy-one Tellina clams from the southeastern Bering Sea ranged from 2 to 15 years old. Seventy-two percent were between 6 and 13 years old. The mean shell length of 15 year-old clams was 72.3 mm (McDonald et al, 1981).

ASTERIAS AMURENSIS

Introduction

The sea star, Asterias amurensis, has no common name. It is one of two members of the genus Asterias that occurs in the eastern Bering Sea.

Distribution. This species is distributed on both sides of the North Pacific. In Japan it occurs from Hokkaido in the north to Kii Peninsula in the south on the Pacific side and to Toyama Bay"on the Japan Sea side. In Alaska it occurs from the Alaska Peninsula north through the southeastern Chukshi Sea. It occurs mainly within depths of less than 50 meters (Jewett and Feder, 1981). Larval Asterias presumably settle near the spawning population. Once they attain post-larval existence their movement is minimal. The only human activity that may affect the distribution and abundance of this sea star is the commercial fishing that is directed at other benthic and demersal organisms. Natural factors that affect their distribution and abundance include water temperature, predators, and prey.

Commercial Importance. This species has no commercial importance.

Population Status. In 1975-76 Asterias amurensis was the most ubiquitous species in benthic trawl surveys, occurring at 69 percent 'of the stations in the southeastern Bering Sea. This sea star was more commonly found in shallow water (20 to 60 meters). It accounted for 84.4 percent of the biomass from the 0-40 meter stratum in the southeastern Bering Sea. The mean density of A. amurensis in these shallow waters was 157.6 sea stars/km (Jewett and Feder, 1981). These 1975-76 figures may reflect the current population status.

Life History

Reproductive Mode. The sexes are separate. Gametes are released into the sea and fertilization is external.

Feeding, Age and Growth. The sea star Asterias amurensis feeds on a variety of organisms in the southeastern Bering Sea (Feder et al, 1978). It has been estimated that food, primarily clams, consumed annually by A. amurensis in Japanese waters amounts to 8 x 10^3 mt, approximating the annual consumption of food (primarily clams) taken by bottom fishes (Hatanaka and Kosaka, 1958). Presumably, the large standing stock of A. amurensis in the shallow waters of the southeastern Bering Sea preys intensively on the bivalve resources of the region (i.e. , Tellina lutes, Cyclocardia ciliatum, Macoma calcarea, Spisula polynyma, and Serripes groenlandicus) . The food requirements for sea stars, crabs, and some species of bottom fishes in the coastal

regions of the southeastern Bering Sea are similar; thus, the size of sea-star populations must have an important bearing on the production of useful crabs and fishes.

The only means of determining the growth of *Asterias* is to examine the seasonal variation in the frequency distributions of the arm lengths. This has not been done for this species in the southeastern Bering Sea.

ALASKA SURF CLAM

Introduction

The Alaska surf clam, Spisula polynyma, belongs to the family Mactridae, and is also known as the pinkneck clam because of its pink-colored siphon.

Distribution. Major concentrations of Alaska surf clams occur southwest of Nunivak Island, northeast of the Pribilof Islands, and along the southeast portion of the shelf of the Alaska Peninsula (McDonald et al, 1981). Most juveniles are found in 50-100 m of water (McDonald et al, 1981). Adults are found in greatest concentrations at 30-32 m depths (Hughes and Bourne, 1981). They are found in waters with relatively high current velocities and poorly sorted sediments (McDonald et al, 1981). Benthic and/or demersal commercial fishing operations may affect the distribution and abundance of the Alaska surf clam. Alterations to their benthic habitat may result from trawling. Furthermore, removal of predator species (e.g., yellowfin sole) could also enhance their distribution and abundance. Water temperature and predators are the two most important natural factors that may affect the distribtuion and abundance of the Alaska surf clam.

Commercial Importance. No commercial fishery currently exists for this species. However, recent studies indicate potential for a commercial fishery in the region between Port Moller and Naknek (Hughes and Bourne, 1981) .

Population Status. A 1977 exploratory survey of subtidal clam resources in the southeastern Bering Sea revealed extensive concentrations of Alaska surf clams (Spisula polynyma) along the north coast of the Alaska Peninsula (Hughes and Bourne, 1981). An area of 6,800 km^2 between Port Moller and Ugashik Bay had an estimated exploitable whole clam biomass of 329,000 + or - 52,000 mt and potential annual yield of 17,800 mt of whole clams. This resource was most dense at depths of 30-32 m.

Life History

Reproductive Mode. The sexes are separate, and gametes are liberated into the water.

Feeding, Age and Growth. The Spisula polynyma clam is a filter-feeder, ingesting phytoplankton and particulate matter. This species is long-lived and slow-growing with a maximum age of 25 years. At the age of eight it is fully recruited into the spawning population (Hughes and Bourne, 1981).

APPENDIX B

TOXICITY SUMMARY TABLES

Table B-1. Toxicity of Petroleum to Marine Macrophytes

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Fucus edentatus Fucus vesiculosus Fucus distichus	Reproductive	12 days	No. 2 fuel oil JP-4 JP-5 Willamar Crude	0-2000 ppm 200 ppb critical dose	Length of Juvenile Plants Measured		112
Fucus vesiculosus	Acute and Chronic (Field Surveys)	5 yr Observation after spill	Light and heavy fuel oil	400 tons into a small bay (Sweden)	Growth (Recovery)	Resistant to light and heavy fuel oil. May relate to time of year spill occurs (fall/winter) followed by clean up effort.	86
Salicornia virginica	Acute and Chronic (Field Surveys)	2 wk 3 yr	No. 2 fuel oil spill in Bourne, Mass.	Oil in salt-marsh. oil remaining in peat.	Growth (Recovery)	Some recovery in "high" areas after 3 years, dwarfed plants in "low" areas.	51
Spartina alterniflora	Chronic (Field Surveys) Acute	2 wk and 3 yr	No. 2 fuel oil spill in Bour ne, Mass .	Oil in salt-marsh oil remaining in peat.	Growth (Recovery)	Marsh grass not able to reestablish after 3 years.	51

Table B-2. Toxicity of Petroleum to Annelids

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Abarenicola pacifica (lugworm)	Chronic	11 days	Prudhoe Bay Crude in Sediment	250 to 1000 ppm	Mortality and Behavior		8
Abarenicola pacifica	Chronic	60 days	Phenanthrene, Chrysene, & Benzo (a) pyrene	C^{14} labeled	Ratio of tissue cone. to sediment cone. measured.		9
Capitella capitata	Acute (TLm)	96 hr 28 days	Louisiana Crude	>19.8 ppm 17.8 ppm	Lethality		23
		96 hr 28 days	No. 2 fuel oil	>8.7 ppm 7.3 ppm			
Chenodrilus serratus	Acute (TLm)	96 hr 28 days	Louisiana Crude	>19.8 ppm 15.8 ppm	Lethality		23
		96 hr 28 days	No. 2 fuel oil	4.1 ppm 2.6 ppm			
Cirriformia spirabranchia	Acute (TLm)	96 hr 28 days	Louisiana Crude	>19.8 ppm 7.9 ppm	Lethality		23
		96 hr 28 days	No. 2 fuel oil	8.7 ppm 5.5 ppm			

Table B-2. Toxicity of Petroleum to Annelids

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-point	Remarks	Reference
Naiselinguis (oligochaete)	Acute ($\bar{x}$ survival time)	2-6 D	WSF Crude	4.0-14.0 ppm	Lethality		59
Neanthes arenaceodentata	Acute (LC_{50})	48 hr 96 hr	Crude oil	13.9 ppm 12.5 ppm	Lethality		83
Neanthes arenaceodentata	Acute (TLm)	48 hr 96 hr 48 hr 96 hr 48 hr 96 hr 48 hr 96 hr	No. 2 fuel oil Bunker C oil Crude oil (a) Crude oil (b)	3.2 ppm 2.7 ppm 4.6 ppm 3.6 ppm 13.9 ppm 12.5 ppm >10.4 ppm >10.4 ppm	Lethality		107
Neanthes arenaceodentata Gravid females 60 segments-54 days	Acute (TLm)	24 hr 48 hr 96 hr	Crude Crude Crude	>19.8 ppm 18.0 ppm 17.6 ppm	Lethality		106
Capitella capitata	Acute (TLm)	48 hr 96 hr 48 hr 96 hr 48 hr 96 hr 48 hr 96 hr	No. 2 fuel oil Bunker C oil Crude oil (a) Crude oil (h)	3.5 ppm 2.3 ppm 1.1 ppm 0.9 ppm 16.2 ppm 12.0 ppm 10.4 ppm 9.8 ppm	Lethality		107

Table B-2. Toxicity of Petroleum to Annelids

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Neanthes arenaceodentata	Acute (Tim)				Lethality		106
Juvenile stages							
4 segments-9 days		24 hr	No. 2 fuel oil	>8.7 ppm			
		48 hr		>8.7 ppm			
		96 hr		8.4 ppm			
18 segments-21 days		24 hr		>8.7 ppm			
		48 hr		>8.7 ppm			
		96 hr		5.7 ppm			
32 segments-30 days		24 hr		>8.7 ppm			
		48 hr		7.8 ppm			
		96 hr		5.2 ppm			
40 segments-40 days		24 hr		>8.7 ppm			
		48 hr		6.2 ppm			
		96 hr		4.0 ppm			
4 segments-9 days		24 hr	Crude	>19.8 ppm			
		48 hr		>19.8 ppm			
		96 hr		>19.8 ppm			
18 segments-21 days		24 hr		>19.8 ppm			
		48 hr		>19.8 ppm			
		96 hr		>19.8 ppm			
32 segments-30 days		24 hr		>19.8 ppm			
		48 hr		>19.8 ppm			
		96 hr		17.8 ppm			

Table B-2. Toxicity of Petroleum to Annelids

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Neanthes arenaceodentata	Acute (TLm)				Lethality		106
Juvenile stages							
40 segments-40 days		24 hr	Crude	>19.8 ppm			
		48 hr		17.0 ppm			
		96 hr		15.2 ppm			
Adult stages							
Immature		24 hr	No. 2 fuel oil	>8.7 ppm			
48 segments-46 days		48 hr		3.2 ppm			
		96 hr		2.7 ppm			
Mature males		24 hr		>8.7 ppm			
60 segments-54 days		48 hr		3.0 ppm			
		96 hr		2.6 ppm			
Gravid females		24 hr		>8.7 ppm			
60 segments-54 days		48 hr		5.6 ppm			
		96 hr		4.2 ppm			
Immature		24 hr	Crude	18.0 ppm			
48 segments-46 days		48 hr		13.9 ppm			
		96 hr		12.5 ppm			
Mature males		24 hr		18.0 ppm			
60 segments-54 days		48 hr		13.6 ppm			
		96 hr		12.0 ppm			
Nereis branti trochophore stage	Acute	48 hr	No. 2 diesel oil	0.5% in seawater	100% Mortality		24

Table B-2. Toxicity of Petroleum to Annelids

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Nereis diversicolor	Acute ($\bar{X}$ Survival time)	2-6 days	WSF Crude	5.0-15.0 ppm	Lethality		59
Nereis succinea	Acute (TLm)	48 hr	WSF Bunker C fuel oil	5.53 ppm	Lethality (0)		14
Nereis vexillosa	Acute (TLm)	96 hr	Cook Inlet Crude No. 2 fuel oil	mg/l(gc) >10.58 >3.36	Lethality	Alaskan sp.	101
Nereis vexillosa (larva)	Acute ($\bar{X}$ Survival time)	48 hr	No. 2 fuel oil	0.5 %	Lethality		24
Ophryotrocha puerilis	Acute (TLm)	96 hr 28 days 96 hr 28, days	Louisiana Crude No. 2 fuel oil	17.2 ppm 2.2 ppm 1.4 ppm	Lethality		23
Ophryotrocha sp.	Acute (TLm)	96 hr 28 days 96 hr 28 days	Louisiana Crude No. 2 fuel oil	12.9 ppm 10.9 ppm 2.9 ppm 2.4 ppm	Lethality		23

Table B-2. Toxicity of Petroleum to Annelids

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Platynereis dumerilii	Acute (LC_{50})	48 hr 96 hr	WSF Crude	12.3 ppm 9.5 ppm	Lethality		83
Serpula vermicularis (larva)	Acute ($\bar{x}$ Survival time)	3 hr	No. 2 fuel oil	0.5%	Lethality		24

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Acmaea scutum Veliger stage	Acute	48 hr	No. 2 diesel oil	0.5% in seawater	100% Mortality		24
Acmaea scutum	Chronic (EC50)	24 hr 48 hr	No. 2 diesel oil	41.0 ppm 23.5 ppm	Behavior		3 9
	Acute (EC50)	24 hr 48 hr	WSF of No. 2 diesel oil	17.0 ppm 1506 ppm	Lethality		22
Arenicola marina	Chronic (Field study)	4 to 150	No. 2 fuel Bunker C-a Bunker C-b SLA Crude Kuwait Crude	35-2086 µg/g oil to sediment concentration	Biochemistry (tissue con.) Chemistry (cast con.)	sediment working of sediment-bound oil	46
Argopecten irradians Adult	Acute (% mort)	91 days 91 days 91 days 7 days	WSF No. 2 fuel oil	ppm 0.006 0.067 0.54 10.6	Lethality 17.3% 24.6% 87.9% 100.0%		125
Argopecten irradians (bay scallop)	Acute	6 hr dosing 5 day depuration	Kuwait Crude oil & Corexit 9527 oil dispersant	Various concentrations of oil, dispersant & a mixture of the two	Mortality Behavior		87

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Cardium edule (8-15 mm)	Acute (LC_{50})	96 hr	Crude	<1,000 ppm	Lethality		116
Cardium edule	Acute (LC_{50})	48 hr	Phenol	500 ppm	Lethality		85, 94
Cerastoderma lamarcki	Acute (Survival days)	3 days 5 days	WSF Crude	4.0 14.0	Lethality		59
Chlamys lericus	Acute (TLm)	96 hr	Cook Inlet Crude No. 2 fuel oil	mg/1 (GC) 3.94 >3.36	Lethality	Alaskan sp.	101
Chlamys rubida	Acute (TLm)	96 hr 96 hr 96 hr 96 hr 96 hr 96 hr	WSF Prudhoe Bay Crude Cook Inlet Crude Cook 'Inlet untreated Crude No. 2 fuel oi 1 OWD of Prudhoe Bay Crude Cook Inlet Crude	ppm (uv) 168 162 146 199 155 148	Lethality	Arctic and subarctic Species	102

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Collisella scutum	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) 8.18	Lethality	Alaskan sp.	101
			No. "2 fuel oil	>3.36			
Colus halli	Acute (TLm)	96 hr	Cook Inlet Crude	mg/1 (GC) >8.98	Lethality	Alaskan sp.	101
Crassostrea angulata (larva)	Acute (% mort)	6 hr (exposure)	Crude	1,000 ppm	Lethality 30.7%		95
			No. 2 fuel oil	1,000 ppm	Lethality 26.0%		
Crassostrea gigas (larva)	Acute (ED_{50})	48 hr		ppm	Lethality	Pr udhoe Bay oil	69
			crude	523			
			extract	323,600			
			WSF :				
			pentane	46,000			
			hexane	41,000			
			heptane	11,000			
			cyclohexane	69,000			
			benzene	9.4			
			toluene	5.9			
			o-xylene	0.4			
			m-xylene	1.2			
			p-xylene	0.4			
			PH :				
			napthalene	194			
			cyclooctane	233			
			isopropyl benzene	236			
			o-xylene	338			

Table '-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Mater ial Tested	Concen-tration	TeSt End-Point	Remarks	Reference
Crassostrea gigas (larva) (continued)	Acute (ED_{50})	48 hr		ppm	Lethality	Pr udhoe Bay oil	69
			PH (continued):				
			m-xylene	626			
			p-xylene	695			
			benzene	1,052			
			ethyl benzene	1,182			
			toluene	1,209			
			cyclohexane	1,701			
			cyclopentane	3,753			
Crassostrea gigas (larva) (veliger stage)	Acute (% survival)	24 hr	No. 2 diesel oil	0.5%	Lethality		24
Crassostrea gigas (larva)	Acute (% mort)	6 hr exposure	Crude	1,000 ppm	Lethality 31.4%		95
			No. 1 fuel oil	1,000 ppm	Lethality 27.0%		
Crassostrea virginica (gamete, embryo, larva)			WSF of 3 Crude oils	1 ppm		Prudhoe Bay oil	96
	Life History	1 hr			Reproduction		
	Chronic	1 hr			Growth		
	Acute	1 hr (exposure)			Lethality		
Crassostrea virginica (adult)	Acute (% survival)	13 days	Diesel	5,291 ppm	Lethality 33%		25
		13 days	Diesel + sand	5,291 ppm	Lethality 75%		
		12 days	Crude	2,000 ppm	Lethality 75%		
		12 days	Crude + sand	2,000 ppm	Lethality 75%		

Table '-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Mater ial 'rested	Concen- tration	Test End-Point	Remarks	Reference
Cryptochiton stelleri	Acute (TLm)	24 hr	No. 2 fuel oil	>1.13 ppm	Lethality		103
		96 hr	No. 2 fuel oil	1.24 ppm			
Gibbula umbilicals	Acute (% mort)	6 hr (exposure)	Crude	whole	Lethality 4%	17°C	30
			Crude (residue)	whole	o%	17°C	
Haminoea virescens veliger stage	Acute	31 hr	No. 2 Diesel oil	0.5% in seawater	100% Mortality		24
Harmothoe imbricata	Acute (TLm)	96 hr	Cook Inlet Crude	mg/1 (GC) > 1 0 . 5 8	Lethality	Alaskan sp.	101
Katharina tunicata trochophore stage	Acute	72 hr	No. 2 Diesel oil	0.5% in seawater	100% Mortality		24
Katharina tunicata	Acute (TLm)	96 hr	Cook Inlet Crude	mg/1 (GC) >8.46	Lethality	Alaskan sp.	101
			No. 2 fuel oil	>3.36			
Katharina tunicata	Acute (TLm)	24 hr	No. 2 fuel oil	1.03 ppm	Lethality		103
		96 hr	No. 2 fuel oil	0.44 ppm			

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Littorina littoralis (adult)	Acute (% mort)	5 days (exposed)	Crude (various)	Whole oil % asphaltenes	Lethality	Crude oils coded	88
			CT 10	5.8	1		
			CT 18	0.4	55		
			CT4	2.8	63		
			CT 14	5.0	57		
			CT 12	1.4	85		
			CT6	1.4	72		
			CT5	0.5	56		
			CT7	0.7	48		
			CT 11	0.5	52		
			CT9	0.7	21		
			CT 19	0.1	17		
			CT 8	0.17	32		
			CT 17	0.4	70		
			CT 16	0.0	29		
			CT 20	0.1	44		
			Ct 2	0.05	74		
			CT 1	0.05	89		
			CT 15	0.0	52		
			CT3	0.0	83		
			CT 13	0.0	64		
Littorina littorea (adult)	Acute (% mort)	(exposure)	Crude	whole oil	Lethality		30
		6 min			12%		
		30 min			10%		
		1 hr			20%		
		6 hr			62%		

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
[illegible]	[illegible]				[illegible]		30
Littorea	(% mort)	6 hr (exposure)	Crude	Whole	34%	14°C	
			Crude (residue)	Whole	0%	14°C	
Littorina littorea	Acute (TD_{50})	10 hr	Crude	11%	Lethality	4.6°C	48
		12 hr		12.5%		4.6°C	
		2 hr		11%		11.0°C	
		4 hr		12.5%		11.0°C	
[illegible] obtusata	[illegible] (% mort)	6 hr (exposure)	Crude	Whole	[illegible] 44%	10°C	30
			Crude (residue)	Whole	0%	10°C	
[illegible] saxatilis rudis	[illegible] (% mort)	6 hr (exposure)	Crude	Whole	[illegible] 80%	18°C	30
			Crude (residue)	Whole	0%	18°C	
[illegible] sitkana	[illegible] (TLm)	24 hr	Cook Inlet	(ppm) >20.97	Lethality		03
		96 hr	Crude	>20.97	Lethality		
Littorina sitkana	Acute (TLm)	9≤ hr	Cook Inlet Crude	mg/l (GC) >8.46	Lethality	Alaskan sp.	0

Table B.-3, Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Macoma balthica	Acute (ECM)	2 mo	Prudhoe Bay Crude	1.2, 2.4, 5 µl/cm² per day	lethality	Arctic species 8-18°C	123
	Chronic (Burrowing)	3 days	WSF static	0.436 ppm	Behavior		
		11 days		0.036 ppm	Lethality		
		3 days	WSF flow-through	0.367 ppm	Behavior		
				0.019 - 0.302 ppm	ϕ Lethality		
		1 day	Oil-contaminated sediment	0.5 µm	Lethality		
				0.669 µm	Behavior		
Macoma balthica (linnaeus)	Acute	exposures up to 60 days	Prudhoe Bay Crude		Lethality and Behavior		75
	Chronic		(Oil slicks, WSF, and Oil-treated sediment)				
Macoma balthica	Bio-accumulation	180 days	Prudhoe Bay Crude	0.03 0.3 3.0 mg/l	Accumulation & Deputation Measured		26
	Sublethal	180 days	Prudhoe Bay Crude	0.03 0.3 3.0 mg/l	Behavior		114
Macoma calcarea	Chronic (Field Survey)	2 days to 4 years	Aged crude (experimental spill)	variable	Biochemistry (Body burdens)	Subarctic species	15

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material. Tested	Concentration	Test End-Point	Remarks	Reference
Macoma inquinata	Chronic (Bioaccumulation)	7 days 40 days 60 days	Prudhoe Bay Crude and C^{14} polycyclic aromatic hydrocarbons	contaminated detritus at 2,000 µg/g	Biochemistry (Body burdens)	feeding type considered, deposit feeder	105
Macoma inquinata		54 days	Prodhoe Bay Crude in sediment	1237 ppm	Mortality & Morphology		10
Macoma inquinata	Chronic	60 days	phenanthrene, chrysene, & benzo(a)-pyrene	C^{14} labeled	Ratio of tissue cone. to sediment conc. measured		9
Margaritas pupillus	Acute (TLm)	96 hr	Cook Inlet crude	mg/l ((%) >8.46	Lethality	Alaskan sp.	101
Melibe leonina veliger stage	Acute	15 hr	No. 2 diesel oil	0.5% in seawater	100% Mortality		24
Mercenaria mercenaria (clam)	Chronic	24 hr	phenol	o, 1, 10, 100, 1000, 10000, 25000, & 50000 ppb	Histology		41

Table B3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Mercenaria mercenaria (juvenile)	Acute (% mort)	4 mo 4 mo 4 mo 20 days	WSF of No. 2 fuel oil	0.006 ppm 0.06 ppm 0.54 ppm 10.6 ppm	0 Lethality 0 Lethality 1.6 Lethality 100.0 Lethality		125
Mod iolus demissus (adult)	Acute		WSF Bunker C oil	5.53 ppm	Lethality (ϕ%)	12-18% sal.	14
Monodonta lineata	Acute (% mort)	6 hr exposure	Crude Crude (residue)	Whole Whole	Lethality ϕ/6% ϕ/ϕ%	14/17°C 14/17°C	30
Mopal ia cilliata	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) >8.46	Lethality	Alaska sp.	101
Mya arenar ia	Chronic (Field survey)	6 yr exposure	Bunker C oil (" Ar row" spill)	Dosing over period of recovery i.e. natural	Growth (Length and Weight)	Significantly lower at oiled stations	124
Mya arenaria	6 yr and Older	Chronic (bioaccumulation, biomagnification and field survey)	4 days and 6 yr	No. 2 Fuel oil ("Arrow" spill) . WSF of: Kuwait Crude & No. 2 fuel in lab study	Biochemistry (no induction of aryl hydrocarbon hydroxylase AHH)	Lack of AHH presents an opportunity for food chain transfer (unaltered)	127

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Mya arenaria (X, 25 mm)	Chronic (Bioaccumulation)	28 days	No. 2 Oil	ppm 10, 50, 100 single dose	Metabolism (Respiratory Rates)	Lowest dose (10 ppm) appeared to cause most significant and long-lasting effect.	111
Mya arenaria	Chronic (Field survey)	6 yr	Bunker C oil	Sediment loads as great as 3800 g/g	Growth (Shell and Tissue) Biochemistry (Body burdens)	Population under stress 6 yr after "Arrow" spill	45
Mya arendr ia	Sublethal Field	up to 4 years after exposure	No. 2 fuel oil mixed with JP5 jet fuel	Variable	Histopathological Study		11
Mya truncata	Chronic (Field study)	2 days to 4 yr	Aged Crude (experimental spill)	Variable	Biochemistry (Body burdens)	Subarctic species	15
Mytilus californianus (adult)	Acute (% mort)	48 to 56 days	Crude	10,000ppm	Lethality o-loo%		57

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Mytilus edulis	Chronic	1 wk and 5 wk	WSF of Northsea Crude	µg/l 20-35	Growth (Test for growth) Mussels Biochemistry (lysosomal latency)	Scope for 12 growth depressed in dosed in 1 and 5 weeks. Paper presents several good studies.	
Mytilus edulis (6 yr and older)	Chronic (Bioaccumulation, Biomagnification, & Field survey	4 days and 6 yr	No. 2 fuel oil 'Arrow' spill WSF of Kuwait Crude No.2 fuel	ppm variable 4.3-24.9 2.0-1.7	Biochemistry (No Induction of aryl hydrocarbon hydroxylase AHH)	Lack of AHH presents an opportunity for food chain transfer (unaltered)	127
Mytilus edulis	Acute (TLm)	96 hr	Cooke Inlet Crude No. 2 fuel oil	mg/l (GC) >8.97 >1.25	Lethality	Alaskan Sp.	101
Mytilus edulis (adult)	Acute (% mort)	6 hr exposure	Crude to Whole oil	N/A	Lethality (0%)	17°C	30
Mytilus edulis (adult)	Acute (TLm)	24 hr 96 hr 24 hr 96 hr	Crude Crude No. 2 fuel No. 2 fuel	>5.15 ppm >5.15 ppm >3.11 ppm >3.11 ppm	Lethality	Cook Inlet Crude Oil	103

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Mytilus edulis (9.8mm, $\bar{x}$)	Chronic (EC_{50})	24 hr 48 hr	No. 2 diesel oil	16.6 ppm 15.0 ppm	Behavior		39
Mytilus edulis (60-70mm)	Chronic (EC_{50})	96 hr	Crude	<1,000 ppm	Behavior		116
Mytilus edulis	Acute (TD_{50})	>10 hr	Crude	11% 12.5%	Lethality 0% Lethality 0%	Test at 4.6°C and 11°C	48
Mytilus edulis (adult)	Chronic (EC_{50})	24 hr 48 hr	WSF of No. 2 Diesel oil	17.0 ppm 15.6 ppm	Growth (Loss of Byssus Thread)		22
Mytilus edulis (blue mussel)	Chronic	7 days	Ekofish Crude oil WSF	3.5 ppm	Freezing Tolerance Measured		6
Mytilus edulis (blue mussel)	Chronic Field Observations	2 day exposure 86 day observation	No. 2 fuel oil	Exposed by oil slick	Deputation of various compounds measured		40

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Mytilus edulis (blue mussel)	Field Observations After spill	12 mo	Eleni V Oil spill	Variable	Accumulation		16
Mytilus edulis (blue mussel)	Chronic	4 wk to 5 mo	North Sea Crude oil WAF (WSF)	7 to 6% µg/l	Accumulation Patterns & Physiological Responses Measured		132
Mytilus gallo-provincialis (larva)	Acute (% mort)	6 hr exposure	Crude No. 1 Fuel oil	1,000ppm 1.000ppm	Lethality (28.4%) Lethality (24.4%)		95
Neptunea lyrata	Acute (Tim)	96 hr	Cook Inlet Crude	mg/l (GC) >10.58	Lethality	Alaskan Sp.	101
Notoacmaea pelta	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) >8.46	Lethality	Alaska Sp.	101
Notoacmaea Scutum	Acute (TLm)	96 hr 24 hr 96 hr	Cook Inlet Crude No. 2 fuel No.2 fuel	3.65 >4.19 5.04	Lethality Lethality Lethality		103

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Nucella lima	Acute (TLm)	24 hr 96 hr	Cook Inlet Crude oil	>20.97 ppm >20.97 ppm	Lethality		103
Ostrea edulis 6 yr or older	Chronic (Bioaccumulation, Biomagnification and Field survey)	4 days and 6 yr	No. 2 fuel ("Arrow" spill) WSF of Kuwait Crude No. 2 fuel	ppm variable 4.3 to 24.9 2.0 to 1.7	Biochemistry (No Induction of aryl hydrocarbon hydroxylase AHH)	Lack of AHH presents an opportunity for food chain transfer (unaltered)	127
Patella vulgata	Chronic	Exposure 6 hr 12 hr	Crude	Whole	Behavior 40-60% 30-55%	Detachment not a sign of mortality	36
Patella vulgata	Acute (Chronic)	6hr (exposure)	Crude Crude (Residue)	Whole Whole	Lethality 100% 0%	12°C 12°C	30
Pecten opercularis (45-70 mm)	Acute (LC_{50})	96 hr	Crude	<1,000 ppm	Lethality		116
Protothaca staminea	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) >6.84	Lethality	Alaska Sp.	101

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Protothaca staminea	Chronic (Bioaccumulation)	40 days 60 days	Prudhoe Bay Crude in Field Test	Contaminated Sediment	Biochemistry (Body burdens)	Feeding type considered, suspension feeder	105
Protothaca staminea	Acute (TLm)	96 hr 96 hr	Cook Inlet Crude No. 2 fuel oil	>14.7 ppm >2.11 ppm	Lethality		103
Protothaca staminea		54 days	Prudhoe Bay Crude in sediment	1237 ppm	Mortality & Morphology		10
Pyrgohydrodiadubia	Acute (Survival days)	12 days 6 days	WSF Crude	4.0 14.0	Lethality		59
Thais lamellosa	Chronic (EC_{50})	36 hr 48 hr	WSF of No. 2 diesel oil.	11.3 ppm 59.0 ppm	Unknown Unknown		22
Thais lima	Acute (TLm)	96 hr	Cook Inlet Crude No. 2 fuel oil	mg/l (GC) >8.46 >3.36	Lethality	Alaska Sp.	101

Table B-3. Toxicity of Petroleum to Mollusks

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Urosalpinx cinerea (oyster drill)	Acute	6 hr dosing 5 day deputation	Kuwait Crude oil & Corexit 9527 oil dispersant	Various concentrations of oil, dispersant and a mixture of the two	Mortality Behavior		87
	Chronic	up to 7 weeks	Nigerian Crude oil in clay	o to 10 mg/1	Growth and Feeding Measured.		38
Urosalpinx cinerea	Chronic (Field survey)	3 yr	No. 2 fuel oil	Results of spill	Histology (Genetic comparisons) Reproduction (Ecological reestablishment)		27
Venus mercenaria	Acute (mort)	12.5 days	Crude Diesel Lubricating Fuel	Unknown Unknown Unknown Unknown	ϕ Lethality ϕ Lethality ϕ Lethality ϕ Lethality		25

Table B-4. Toxicity of Petroleum to Echinoderms

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Asterias forbesi (common starfish)	Acute	6 hr dosing 5 day deputation	Kuwait Crude oil & Corexit 9527 oil Dispersant	Various concentrations of oil, dispersants & a mixture of both	Mortality Behavior		87
Crossaster papposus (larvae)	Acute	200 hr	No. 2 Diesel oil	0.5%	Lethality		24
Cucumaria vega	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) >6.84	Lethality	Alaska Sp.	101
Cucumaria vega cf.	Acute	96 hr	Crude	>14.7	Lethality	4-12°C	103
Dendraster excentricus (larvae)	Acute	21 hr	No. 2 Diesel oil	0.5%	Lethality		24
Eupentacta quinquesemita	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l ((%) >12.29	Lethality	Alaska sp.	101
Eupentacta quinquesemita	Acute	96 hr	No. 2 fuel & Crude oil	>6.9 ppm	Lethality	4-12°C	103
Leptasterias hexactis	Acute (TLm)	96 hr	Cook Inlet Crude No. 2 fuel oil	mg/l (GC) >10.58 >3.36	Lethality	Alaskan Sp.	101

Table B-4. Toxicity of Petroleum to Echinoderms

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Luidia foliata (larva)	Acute	15 hr	No. 2 Diesel oil	0.5%	Lethality		24
Patiria miniata embryos (bat starfish)	Chronic	up to 48 hrs	Prudhoe Bay Crude WSF	100% WSF	Growth measured vs time exposed		34
	Chronic effects of embryos from parental exposure	48 hrs	Prudhoe Bay Crude Vs Monterey Zone Vs Rincon Zone vs Isla Vista seep.	up to 100% WSF	Growth measured		109
Piaster ochraceous (larva)	Acute	12 hr	No. 2 Diesel oil	0.5%	Lethality		24
Strongylocen-trotas drobachiensis	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) >10.58	Lethality	Alaskan Sp.	101
Stongylocen-trotas purpyratus (eggs)	Acute	4 hr	Jet, Diesel, heating oil and Crude	12.5%	Lethality and Growth		2

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Acanthomysis psendomacropsis	Acute (TLm)	96 hr	Cook Inlet Crude No. 2 fuel oil	mg/l (GC) >9.02 2.31	Lethality	Alaska Sp.	101
Acanthomysis pseudomacropsis	Acute (TLm)	96 hr 96 hr	WSF/Cook Inlet Crude No. 2 fuel	ppm (IR) >8.99 >0.95	Lethality		103
Acartia clausi	Acute (Survival)	24 hr	Crude oil Black oil Solar oil	ppm 10-50 50-100	Lethality Little cliff. Great cliff. in Survival	Great variation in test results	79
Arisogammarus locustoides	Acute (mort)	96 hr 96 hr	Treated: Puget Sound ballast H20 Valdez ballast H20	ppm to 33 7.4 and 5.6	Lethality None None None		133
Anisogammarus sp.	Acute (LC_{50})	48 hr	WSF of: No. 2 Diesel oil	ppm 100.0	Lethality	Only one contested	39
Anonyx nugax (amphipod)	Acute (LC_{50})	8 days	Naphthalene @ 4.8+/-0.5 6.9+/-0.4 9.6+/-0.3 $\bar{x}$=7.1+/-2.4 'C	 1.95 1.20+/-0.07 1.52+/-0.07 1.56+/-0.11 ppm	Lethality	Arctic	99

Table B-5., Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Anonyx nugax (Amphipod)	Acute (LC_{50})	8 days	Cook Inlet Crude WSF @ 3.5+/-0.3 "C	2. 26+/- 0.093 ppm	Lethality	Auke Bay Collected	99
Anonyx nugax (amphipod)	Acute (LC_{50})	4 days	Naphthalene @ 4.8+/-0.5 6.9+/-0.4 9.6+/-0.3 $\bar{x}$=7.1+/-2.4 "C	2.7+/-0.10 2.06+/-0.05 1.84 2.20+/-0.13 ppm	Lethality		99
Atylus Carinatus	Acute (% mort)	96 hr	Dispersion (Normal wells)	ppm 3oo-1000	"Lethality 15%	Crude	93
Balanus cariosus (larva)	Acute ($\bar{x}$ Survival)	12 hr	No. 2 Diesel oil	0.5%	Lethality		24
Balanus crenatus	Acute (% mort)	96 hr	Crude (Normal wells)	ppm 30-1000	Lethality 73%	Arctic Sp .	93
Balanus glandula	Acute (TLm)	24 hr 96 hr	WSF of: Cook Inlet Crude	ppm(IR) >8.51 >8.51	Lethality		103

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Boeckosimus (=onisimus) alfinis	Long-term Chronic & Acute	3 days to 16 wk	Prudhoe Bay Crude WSF	1 ppm 1 p/hund thou 1 p/ten thou 1 p/thou 1 p/ten	Mortality Behavior	Arctic	19
Boeckosimus nanseni (amphipod)	Acute (LC_{50})	4 days	Cook Inlet Crude WSF @ 3.4°C	5.462+/-0.533 ppm	Lethality	Pr udhoe Bay (Arctic)	99
		8 days	"	4.879+/-0.33 ppm	"	"	99
Boeckosimus nanseni (amphipod)	Acute (LC_{50})	4 days	Naphthalene @ 6.9+/-0.4 9.6+/-0.3 $\bar{x}$=6.6+/-2. 2	 4.02+/-0.12 2.88+/-0.09 3.45+/-0.57	Lethality	Arctic	99
		8 days	Naphthalene @ 4.8+/-0.5 5.0+/-1.8 6.9+/-0.4 9.6+/-0.3 $\bar{x}$=6.6+/-2. 2	 5.26+/-0.12 3.36 2.49+/-0.05 2.88+/-0.09 3.45+/-0.24			
Calanus hyperboreas	Acute (% mort)		Dispersion of :	ppm	Lethality	Crude oi 1s	93
		96 hr	Atkinson Pt	300-1000	0		
		96 hr	Venezuelan	300-1000	0		
		96 hr	Norman Wells	300-1000	10		
		96 hr	Pembina	300-1000	37.5		

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Callinectes sapidus (blue crab)	Chronic	120 sec exposure	Prudhoe Bay Crude WSF	0.15 mg/l max.	Behavior Perception of WSF was measured		90
Calliopius laeviusculus	Acute (LT_{50})	Minutes exposure 103 531	 No. 2 Diesel Mineral oil	Whole	Lethality	Temp. °C 15.5+/-0.4 13.3+/-0.4	22
Carcinus maenas	Acute (LC_{50})	48 hr	Phenol	ppm 56.0	Lethality		84, 94
Cancer magister (larva)	Acute (TLm) (ECm) (TLm) (ECm)	 48 hr 48 hr 48 hr 48 hr	 Cook Inlet Crude oil Prudhoe Bay Crude oil	ppm >7.1 1.6 >5.5 2.14	Lethality	Alaskan	102
Cancer magister dana (dungeness crab) larval stages	Acute	48 hr and 96 hr	Prudhoe Bay Crude (WSF) Naphthalene Benzene	.0083 mg/1 max. 0.17 mg/l max. 7.0 mg/l max.	Lethality	Alaskan	20

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Cancer magister dana (dungeness crab) larval stages	Chronic	60 days	Prudhoe Bay Crude (wSF)	.0083 mg/l	Development	Alaskan	-20
			Naphthalene	0.17 mg/l			
			Benzene	.0083 mg/l			
Cancer magister	Acute (LC_{50})	96 hr	Ballast water treatment effluent.	ppm 1.7	Lethality		-4
Cancer magister (dungeness crab) larval stages	Acute	96 hr	Cook Inlet Crude	0.22 ppm total hydrocarbons	Lethality	Alaskan	2 1
	Chronic	60 days	Naphthalene	Lowest effective cone.	Growth		
Cancer magister	Acute (TLm)	96 hr	No. 2 fuel oil	ppm 4778 +/-1071	Lethality	Alaskan	'129
Cancer productus "(larva)	Acute (TLm)	96 hr	No. 2 fuel oil	ppm 4	Lethality		129
		96 hr	Crude (a)	200			
		96 hr	Crude (b)	250			
Cancer productus	Acute (LT_{50})	min 730	No. 2 Diesel oil	Whole	Lethality	13.1°C	22

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Centropages ponticus	Acute (Survival)	24 hr	Black oil	ppm 10-50 50-100	Lethality Little cliff. Great cliff. in Survival	Large variation in results	79
Chionoecetes bairdi (juvenile)	Acute (TLm)		Prudhoe Bay Crude	ppm	Lethality	Subarctic Species	58
pr emolt		24 hr		560			
		96 hr		560			
post molt		24 hr		830			
		96 hr		560			
Chionoecetes bairdi (larva)	Acute (TLm)	96 hr	Cook Inlet Crude (treated)	ppm >10.8	Lethality	Subarctic Species	102
	(ECm)	96 hr		1.7			
Corophium clarencense	Acute (% mort)	96 hr	Dispersion Normal wells	ppm 300-1000	Lethality 67. 5%	Crude oil	93
Crangon alaskensis	Acute (Tim)	96 hr	Cook Inlet Crude	µg/l (GC) 0.87	Lethality	Alaskan Sp.	101
			No. 2 fuel oil	0.36			
Crangon crangon (brown shrimp)	Chronic	42 days	Eleni V. Oil spill oi 1	up to 500 µg/l	Mortality Behavior Accumulation Growth		16
Crangon crangon	Acute (LC_{50})	48 hr	Phenol	ppm 23.4	Lethality		84, 94

Table B5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Eliminius modestus (spat)	Chronic		Crude oil surf. film	ppm			28
		4 hr		100	>50% normal cirral beat		
		48 hr		100	28% normal cirral beat		
		4 hr		100	50% normal cirral beat		
		48 hr		100	10% normal cirral beat		
Eliminius modestus (Stage II nauplius)	Chronic	24 hr	Suspension in Crude	ppm 1000	Behavior: Loss of Swimming		28
				100	NO change		
Eliminius modestus (larva)	Acute (LC_{50})	1 hr	Fresh Crude	ppm 100	Lethality		84, 94
Eualus fabricii (larva)	Acute		WSF of	ppm (IR)	Lethality	Subarctic	102
	(TLm)	96 hr	Cook Inlet	5.89		Sp.	
	(ECm)	96 hr	Crude (treated)	0.95			
	(TLm)	96 hr	Prudhoe Bay	6.36			
	(ECm)	96 hr	Crude	1.29			
Eualus fabricii	Acute (Tim)		WSF of	ppm (IR)	Lethality	Subarctic	103
		24 hr	Cook Inlet	2.52		Sp.	
		96 hr	Crude	1.46			
		24 hr	No. 2	0.91			
		96 hr	fuel oil	0.53			

Table B-5, Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Eualus fabricii	Acute (TLm)	96 hr	WSF of: Prudhoe Bay Crude	ppm (IR) 1.94	Lethality	Subarctic	102
		96 hr	Cook Inlet (treated)	3.17			
		96 hr	Cook Inlet Crude	4.34			
		96 hr	No. 2 fuel oil	0.53			
		96 hr	OWD of: Prudhoe Bay Crude	13.91			
		96 hr	Cook Inlet (treated)	10.06			
Eulalus suckleyi	Acute (LC_{50})	96 hr	Ballast water treatment effluent	ppm 0.4 1.2	Lethality	April 17 April 22	98
Eualus suckleyi	Acute (TLm)	96 hr	Cook Inlet Crude No. 2 fuel oil	mg/l (GC) 1.86 1.10	Lethality	Alaska sp .	101
Gammaracanthus loricatus (amphipod)	Acute (LC_{50})	4 days	Naphthalene @ 2.05+/-0.5	2.29 ppm	Lethality	Arctic	99
		8 days	Naphthalene @ 2.05+/-0.5	2.09 ppm			

Table B-5 Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Gammaracanthus loricatus (amphipods)	Acute (LC_{50})	8 days	Cook Inlet Crude WSF @ 2.0+/-0.5 °C	>1.729	Lethality	Pr udhoe Bay Collected (Arctic)	99
Gammarus macronatus	Acute (TL_{50})	48 hr	WSF of Bunker C	ppm 0.42	Lethality		14
Gammarus mar ino gammarus olivii (adult)	Acute (% Survival)	10 days	Crude	ppm 1000	Lethality 0		77
				100	100		
				10	80		
				1	100		
(juvenile)				1000	0		
				100	0		
				10	20		
				1	50		
Ghorimosphaeroma oregonesis oregonesis	Acute (LT_{50})	Minutes exposure	No. 2 Diesel oil	Whole	Lethality	Temp. "C	22
		1360				10.9+/-0.7	
		1040				13.8+/-0.7	
		403				20.2+/-0.5	
		392				25.0+/-0.4	
		119				30.0+/-0.6	
		3400	Mine ,al			12.9+/-0.7	
		2120	oil			18.5+/-1.7	

Table B 5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Hemigrapsis nudus	Acute (TLm)	96 hr	Cook Inlet crude	mg/l (GC) 8.45	Lethality	Alaskan sp.	101
Hemigrapsus nudus	Acute (LT_{50})	Min. exposure 1,770 835	Mineral oil	Whole	Lethality	Temp. (°C) 12.8+/-0.7 20.2+/-0.3	22
Hemigrapsus nudus	Acute (LT_{50})	Min. exposure 812 364 149 42	No. 2 diesel oil	Whole	Lethality	Temp. (°C) 14.0+/-1.0 20.5+/-0.4 2.50+/-0.1 30.5+/-0.8	22
Hemigrapsus oregonensis	Acute (Mortality)	96 hr	Treated Valdez ballast water	Percent 1 3 10 30 100	Lethality .0 0 0 0 0		133
Hemigrapsus oregonensis	Acute (LT_{50})	Min. exposure 1,795 1,305 835 295 675 235 57	No. 2 diesel oil	Whole	Lethality	Temp. (°C) 12.0+/-0.4 14.5+/-1.1 17.4+/-0.7 20.3+/-0.5 20.3+/-0.5 25.0+/-0.5 30.2+/-0.5	22

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Hemigrapsus oregonensis	Acute (LC_{50})	48 hr	WSF No. 2 diesel	ppm 3,000	Lethality		39
Homarus americanus (lobster]	Chronic		Crude oil	0.9 ml/ 100 liters seawater	Behavior Chemo-sensory		7
Homar us americanus	Chronic		WSF	50 ppb			7
Homar us americanus (larva)	Acute (LC_{50})		Crude (Dispersion)	ppm	Lethality		131
Ist stage		96 hr		0.86			
3rd & 4th stage		96 hr		4.90			
1st stage		30 days		0.14			
Homarus americanus (larva)	Acute (LC_{50})		Crude (Emulsions)	ppm	Lethality		130
		24 hr		100	100%		
		96 hr		10	variable		
		96 hr		1	low		
		96 hr		0.1	low		
		96 LC_{50}		2-30	LC_{50}		
Idothea baltica baster i (adult)	Acute (Survival)	10 days	Crude	ppm 1,000	Lethality 75%		77
				100	90%		
				10	100%		
				1	100%		

Table B-5, Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Idothea baltica basteri (adult)	Acute (Survival)	10 days	Crude	ppm 1,000 100 10 1	Lethality 0 25 60 75		77
Idothea fewkesi	Acute (mort.)	96 hr	Treated Valdez ballast water	Percent 1 3 10 30 100	Lethality 0 0 0 0 0		133
Idothea tribola	Acute (TL_{50})	48 hr	WSF of Bunker C	ppm 5.53	Lethality No effect		14
Idothea wosnesenskii	Acute (TLm)	96 hr 96 hr	WSF of Cook Inlet Crude No. 2 fuel oil	ppm (IR) >8.99 >5.59	Lethality		103
Leander adspersus	Acute (TL_{50})	96 hr	Oil	50 ppm	Lethality		80
Leander adspersus var. Fabricii Rathke	Acute (LC_{50}) Chronic	96 hr	Crude Crude	ppm <1,000 350	Lethality Behavior (locomotion)		166

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Leander terruicornis	Acute (LC_{50})	48 hr 96 hr	WSF of: S. LA Crude	ppm (IR) 10.2 6.0	Lethality		83
Limulus polyphemus (horseshoe crab) Eggs & larvae	Acute Chronic	Through first 3 Instar Development	No. 2 fuel oil	0 to 50% WSF	Lethality, development rate, and respiration		68
Mesidatea entomon	Chronic	160 days	WSF of: Norman Wells Crude Pembina Crude Norman Wells (weathered)	% of stock 100, 50, 10 100, 50, 10 100, 50, 10	Growth (length & molting times, includes intermolt period). Small effect on growth (length). High concentration increased intermolt period.	Arctic sp.	92
Mesidotea entomon	Acute (LT_{50})	41 days	WSF of: Norman Wells Crude Pembina Crude Norman Wells (weathered)	ppm 1.71 0.50 1.01	Lethality 17 days 17 days 41 days	Arctic sp.	92
Mesidotea entomon	Acute (% mort.)	96 hr	Dispersion Norman Wells	ppm 300-1,000	Lethality 0	Crude	93

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Mesidotea sabini	Acute (% mort.)	96 hr	Dispersion Norman Wells	ppm 300-1,000	Lethality 0	Crude oil	93
Mesidotea sibirica	Acute (% mort.)	96 hr	Dispersion Norman Wells	ppm 300-1,000	Lethality 0	Crude	93
Mysidopsis almyra	Acute (LC_{50})	48 hr 96 hr	WSF of: S. LA Crude	ppm 8.7	Lethality		83
Mysidopsis almyr a	Acute (TLm)	48 hr 48 hr 48 hr 48 hr 48 hr 48 hr 48 hr 48 hr	S. LA Crude OWD NSF Kuwait OWD WSF No. 2 fuel OWD WSF Bunker C WSF	ppm 37.5 8.7 63.0 6.6 1.3 0.9 0.9	Lethality		5
Mysis relicia (mysid)	Acute (LC_{50})	4 days	Naphthalene @ 4.4°C	2.0 ppm	Lethality	Arctic	99
		4 days	Cook Inlet Crude WSF @ 4.4°C	2.60 +/-0.52 ppm	Lethality	Pr udhoe Bay (Arctic)	99

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Neohaustorius biarticulatus	Acute (LD_{50})		No. 2 fuel	ppm	Lethality		108
		36 hr	Turbulent stirring	25			
		72 hr	slow stirring	25			
		24 hr	Clean sand & oil	50			
Neomysis awatschensis	Acute (LC_{50})		Emulsion	ppm (IR)	Lethality		22
		24 hr	No. 2	327			
		48 hr	diesel oil	112			
Neomysis sp.	Acute (LC_{50})		WSF of:	ppm	lethality		39
		24 hr	No. 2	350.0			
		48 hr	diesel oil	95.0			
Neopanope texana (larva)	Acute (LC_{50})		WSF of:	ml/L	Lethality	(Taken	60
		96 hr	Crude	10		from graph)	
Oithona nana	Acute (Survival)		Black	ppm	Lethality	Large	79
		24 hr	oil	10-50	Little cliff.	variation	
				50-100	Great cliff. in survival	in results	
Onisimus affinis (Boekisimus)	Chronic	96 hr	Crude oil WSF (Pembina, Atkinson Point, Norman Wells, & Venezuelan)	o to 10,000 ppm	Respiration		91

Table B-5 . Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Onisimus affinis	Acute (% mort.)			ppm	Lethality	Oil and SW dispersion of Crudes	93
		96 hr	Norman Wells	300-1,000	95		
		96 hr	Venezuelan	300-1,000	100		
		96 hr	Atkinson Pt.	300-1,000	88		
		96 hr	Pembina	300-1,000	25		
		96 hr	Venezuelan	20-200	18		
		96 hr	Norman Wells	20-200	33		
Orchestia traskiana	Acute (LT_{50})	Min. exposure	No. 2 diesel oil	Whole	Lethality	temp (°C)	22
		152				12.2+/-0.3	
		134				13.4+/-0.4	
		104				19.7+/-0.7	
		106				24.8+/-0.5	
		2,900	Mineral oil			13.7+/-0.6	
		1,650				20.4+/-0.7	
Orchomene pinguis	Acute (Tim)		Cook Inlet	mg/l (gc)	Lethality	Alaskan sp.	101
		96 hr	Crude	>7.98			
			No.2 fuel oil	>1.74			
			WSF of:	ppm (IR)	Lethality		103
		24 hr	Cook Inlet	>7.40			
		96 hr	Crude	>7.40			
		96 hr	No. 2 fuel oil	>1.34			

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Pachygrapsus marmoratus (larva)	Acute (% survival)	Min. exposure		ppm	Lethality		80
		5	oil	100	25%		
		5	Bunker C	100	15%		
		5	Solar oil	100	10%		
		30	oil	100	10%		
		30	Bunker C	100	20%		
		30	Solar oil	100	0%		
		60	oil	100	0%		
		60	Bunker C	100	0%		
		60	Solar oil	100	0%		
Pagurus granosimanus	Acute (LT_{50})	Min. exposure 350	No. 2 diesel oil	Whole	Lethality		22
Pagurus hirsutinsculus	Acute (LT_{50})	Minutes 159	No. 2 diesel oil	Whole	Lethality	temp. (°C) 10.1+/-0.1	22
		49				20.3+/-1.7	
		34				24.9+/-0.5	
		1,118	Mineral oil			12.0+/-0.7	
		435				16.6+/-0.7	
	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) >10.58	Lethality	Alaskan sp.	101
			No. 2 fuel oil	>3.36			
	Acute (TLm)	96 hr	Cook Inlet Crude	ppm 3.1	Lethality		103
		96 hr	No. 2 fuel oil	>5.59			

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Pagurus longicarpus	Acute (LD50)	12 hr	No. 2 fuel oil	ppm 50	Lethality		108
	(LT80)	48 hr	WSF of Bunker C	0.62			14
Palaemonetes pugio (grass shrimp)	Life history	72 hr	No. 2 fuel oil, naphthalene	1.44 ppm hydrocarbon	Respiration, hatching success, growth		120
	Acute (% mort.)	control 4 mo. 4 mo. 100 days 6 days	WSF No. 2 fuel oil	ppm (IR) 0.006 0.067 0.54 10.6	Lethality 0.8% 6.2% 73.8% 100%		125
	Acute (LC50)	48 hr 96 hr	WSF of S. LA Crude	ppm >16.8 >16.8	Lethality		83
	Chronic	32 days (exposure) 16 days (recovery)	Dimethylnaphthalene and Fluctuating temperature and reduced salinity	µg/g of food 0.24	Metabolism under stressed conditions (temp., reduced 02 and salinity)	Increased resistance to hyooxia by shrimp fed contaminated food.	37

Table B-5 , Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Palaemonetes pug io (grass shrimp)	Acute (TLm)	48 hr	WSF of:	ppm	Lethality	temp. (°C)	121
			S. LA Crude	<16.80		21	
			Kuwa it	<10.20		21	
			No. 2 fuel	5.50		21	
			Bunker C	3.43		21	
			S. LA Crude	15.70		24	
			S. LA Crude	10.70		32	
			benzene	33.00		21	
			naphthalene	2.35		21	
			methylnaphthalene	1.00		21	
			dimethylnaphthalene	0.70		21	
			phenol	20.0		21	
	Acute (TLm)		s. LA Crude	ppm	Lethality		5
		48 hr	OWD	1,650			
		96 hr	OWD	200			
		48 hr	WSF	>16.8			
		96 hr	WSF	>16.8			
			Kuwait				
		48 hr	OWD	9,000			
		96 hr	OWD	6,000			
		48 hr	WSF	>10.2			
		96 hr	WSF	>10.2			
			No. 2 fuel				
		48 hr	OWD	3*4			
		96 hr	OWD	3.0			
		48 hr	WSF	4.1			
		96 hr	WSF	3.5			
			Bunker C				
		48 hr	WSF	2.8			
		96 hr	WSF	2.6			

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Pandalus borealis	Acute (TLm)	96 hr 96 hr	WSF of: Prudhoe Bay Crude Cook Inlet Crude (treated)	ppm (IR) 2.11 2.43	Lethality	Arctic/ subarctic Sp.	102
	Acute (TLm)	24 hr 96 hr 24 hr 96 hr	WSF of: Cook Inlet Crude No. 2 fuel oil	ppm (IR) 2.89 2.43 0.38 0.21	Lethality	Arctic/ subarctic Sp.	103
	Acute (Tim)	96 hr	Cook Inlet Crude	mg/l (GC) 4.94	Lethality	Alaskan sp.	101
Pandalus danae	Acute (Toxicity Index -- ppm-days)	Index 15.7+/-5.2 3.5+/-1.8 18.0+/-7.8 8.1+/-0.8	Prudhoe Bay Crude Prudhoe Bay Crude with a dispersant	ppm 2.6-5.4 1.5-5.9 2.8-12.6 2.3-7.6	Lethality	winter & fall spring & summer winter & fall spring & summer	4
	Acute (% mort.)	24 hr	Filtered SW extract Prudhoe Crude	ppm (IR) 0.6 1.2 2 . 3 3.3	Lethality 0 20 100 100	Alaskan	13

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Pandalus danae	Acute (% mort.)	24 hr	Unfiltered SW extract Prudhoe Bay Crude	ppm (IR) 0.6 1.2 2.3 3.3	Lethality 0 80 100 100	Alaskan	13
			Filtered SW extract S. LA Crude	0.6 1.2 2.3 3.3	0 0 60 100		
			Unfiltered SW extract S. LA Crude	0.6 1.2 2.3 3.3	0 100 100 100		
			WSF Prudhoe Bay Crude oil	1.86 1.02 0.56	100 10 10		
	Acute (Tim)	24 hr 96 hr 24 hr 96 hr	Cook Inlet Crude No. 2 fuel oil	ppm 0.95 0.81 1.68 1.11	Lethality	Alaskan	103
	Acute (LC_{50})	72 hr 96 hr	OWD No. 2 fuel oil	ppm 1.3 0.8	Lethality	Alaskan sp.	126

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Pandalus goniurus (larva)	Acute TLm	96 hr	Cook Inlet Crude	1.72	Lethality	Subarctic	102
	ECm	96 hr	(treated)	1.69			
Pandalus goniurus	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) 1.79	Lethality	Alaskan sp.	101
	Acute (Tim)	96 hr	WSF of: Prudhoe Bay Crude	ppm (IR) 1.26	Lethality	Subarctic sp.	102
		96 hr	Cook Inlet Crude (treated)	1.98			
		96 hr	Cook Inlet Crude	1.85			
		96 hr	No. 2 fuel	1.69			
		96 hr	OWD of: Prudhoe Bay Crude	2.31			
		96 hr	Cook Inlet Crude (treated)	4.13			
	Acute (TLm)	24 hr	WSF of: Cook Inlet	ppm (IR) 2.31	Lethality		103
		96 hr	Crude	1.98			
		96 hr	No. 2 fuel oil	1.69			

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Te steal	Concen-tration	Test End-Point	Remarks	Reference
Pandalus hypsinotus (post-larval)	Bioaccumu-lation	144 hr exposure 48 hr deputation	Tritiated naphthalene	6ppb	Accumulation and deputation measured		71
Pandalus hypsinotus	Acute (TLm)	96 hr 96 hr	WSF of: Prudhoe Bay Crude Cook Inlet Crude	ppm (IR) 1.96 2.72	Lethality	Arctic/ subarctic Sp .	102
Pandalus hypsinotus (coonstrip shrimp) (larvae)	Acute (LC_{50})	96 hr	Cook Inlet Crude WSF	7.94 ppm (stage 1) 4.06 (stage 2)	Lethality		75
	Chronic	144 hr			Percent molt-ing success		75
Pandalus hypsinotus	Acute (LC_{50})	96 hr	Ballast water treatment effluent	ppm 1.8 2.1 1.9 1.6 1.5	Lethality	April 22 April 27 May 23 May 27 June 2	98

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Pandalus hypsinotus (larva)	Acute (Tim)	96 hr	WSF of: Cook Inlet	ppm (IR) 7.94	Lethality	Arctic/ subarctic Sp.	102
	(ECm)	96 hr	Crude (treated)	1.83			
	(TLm)	96 hr	Prudhoe Bay crude	8.53		test @ 3.5°C	
	(ECm)	96 hr		0.75			
Pandalus hypsinotus	Acute (TIM)	24 hr	WSF of Cook Inlet	ppm (IR) 2.87	Lethality	Arctic/ subarctic sp.	42
		96 hr	Crude	2.72			
Pandalus montagui	Acute (LC_{50})	48 hr	phenol	17.5 ppm	Lethality		84, 94
Pandalus platycerus (spot shrimp)	Bioaccumulation	7 days	Prudhoe Bay Crude (WSF)	0.11 ppm	Accumulation	Alaskan	71
Paracalanus parvus	Acute (survival)	24 hr	Black oil	ppm 10-50 50-100	Lethality little cliff. Great cliff. in survival	Large variation in results	79
Paralithodes camtschatica	Acute (TLm)	24 hr	WSF of: Cook Inlet	ppm 5.16	Lethality	Arctic/ Alaskan	103
		96 hr	Crude	4.21			
		96 hr	No. 2 fuel oil	5.10			

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Paralithodes camtschatica (king crab) (larva)	Acute (LC_{50})	96 hr	Cook Inlet Crude WSF	2.00 ppm (stage I) 1.33" (molting larvae)	Lethality	Alaskan	21
	Chronic	144 hr	Cook Inlet Crude WSF	o to 1.87 ppm	Percent molting success	Alaskan "	75
	Acute		WSF of:	ppm (IR)	Lethality	Arctic Alaskan	102
	TLm	96 hr	Cook Inlet	3.0			
	ECm	96 hr	Crud e (treated)	3.0			
	TLm	96 hr	Prudhoe Bay	>6.4			
	ECm	96 hr	Crud e	1.4			
Paralithodes camtschatica	Acute (TLm)		WSF of: Prudhoe Bay	ppm (IR)	Lethality	Arctic Alaskan	102
		96 hr	Crude	2.35			
		96 hr	Cook Inlet Crud e	4.2i			
		96 hr	No. 2 fuel oil	5.10			
	Acute (TLm)	96 hr	Cook Inlet Crud e	mg/l (GC) 3.69	Lethality	Alaskan sp.	101
			No. 2 fuel oi 1	1.02			
	Acute (LC_{50})	96 hr	Ballast wate r treatment effluent	ppm 2.4 1.4 2.5	Lethality	April 17 April 22 April 27	98

Table B-5. Toxicity of Petroleum to Arthropods

Organi em	Type of Toxicity Test	Test Duration	Mater ial Tested	Concen-tration	Test End-Point	Remarks	Reference
Penaeus aztecus (larva)	Acute (LC50)	48 hr 96 hr	WSF of S. LA Crud e	ppm >19.8 >19.8	Lethality		83
Penaeus aztecus	Acute (TLm)	48 hr 96 hr 48 hr 96 hr 48 hr 96 hr	S. LA Crude OWD OWD No. 2 fuel oil OWD OWD Bunker C! WSF WSF	ppm >1,000 >1,000 9.4 9.4 3.5 1.9	Lethality		
Penillia avirostris	Acute (survival)	24 hr	Black oil	ppm 10-50 50-100	Lethality little cliff. Great cliff. in survival	Large variation in results	79
Pilumnus hirtellus	Acute (TL50)	96 hr	oil	10 ppm	Lethality		80
Porcellana platycheles	Acute (% survival)	20 days 20 days	Crude	ppm 10,000 1,000	Lethality		32
Pugettia products (megalops)	Acute (TLm)	96 hr 96 hr 96 hr	No. 2 fuel oil Crude (a) Crude (b)	ppm >10 <100 <1,000	Lethality		70

Table B-5. Toxicity of Petroleum to Arthropods

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Pugettia products (larva)	Acute (TLm)	96 hr 96 hr 96 hr	No. 2 fuel oil Crude (a) Crude (b)	ppm 10 500 450	Lethality		129
Trigriopus californicus	Acute (days to 100% mortality)	3 days 5 days	Crude Crude	1.5 mm thick slick	Lethality 100% 100%	no aeration aeration	61
Uca pugnax	Acute Chronic (life cycle, life history, and field survey)	7 years	Fuel oil spill in salt-marsh west of Falmouth, MA	ppm high 6,000 in sediment. >1,000 toxic to adults; 100-200 toxic to juveniles	Lethality reproduction; behavior; biochemistry	Good long term salt-marsh contamination study. Recovery not complete after 7 years.	65, 64

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Alosa sapidissima (juvenile)	Acute (TLm)	24 hr 48 hr 24 hr 48 hr 48 hr 96 hr	WSF of gasoline Diesel fuel Bunker #6	91 ppm 91 ppm 204 ppm 167 ppm 2,417 ppm 1,952 ppm	Lethality		119
Alosa sapidissima (young)	Acute (LC_{50})	48 hr 48 hr 48 hr	Gasoline Fuel oil Diesel oil	91 ppm 2,417 ppm 167 ppm	Lethality		84, 44
Ammodytes hexapterus	Acute (TLm)	96 hr	#2 fuel oil	4,326 ppm	Lethality		129
Anoplarchus purpurescens	Acute (Tim)	96 hr	Cook Inlet Crude	mg/l (GC) >11.72	Lethality	Alaskan sp.	101
Aulorhynchus flavidus	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) 2.55	Lethality	Alaskan Sp.	101

Table B-6 . Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Aulorhynchus flavidus	Acute (TLm)	96 hr	WSF of: Cook Inlet Crude	1.34 ppm (IR) .	Lethality		103
Boreogadus saida (Arctic cod)	Acute LC_{50}	4 days	Cook Inlet Crude WSF @ 2.0+/-0.5	1.569 +/- 00040	Lethality	Prudhoe Bay collected (Arctic)	99
Borreogadus saida (Arctic cod)	Acute LC_{50}	4 days	naphthalene @ 1.5+/-0.2 2.0+/-0.5 6.4+/-1.1 8.5+/-1.3 X4.6+/-3.4 °C	 1.52+/-0.04 1.24+/-0.09 1.55 1.22+/-0.17 1.38+/-0.05 ppm		Arctic	99
Boreogadus saida (Arctic cod)	Acute LC_{50}	8 days	naphthalene @ 1.5+/-0.2 2.0+/-0.5 6.4+/-1.1 8.5+/-1.3 X4.6+/-3.4 "C	 1.46+/-0.04 1.24+/-0.09 1.46+/-0.05 1.22+/-0.17 1.35+/-0.04 ppm	Lethality	Arctic	99

TableB-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen- tr at ion	Test End-Point	Remarks	Reference
Clupea harengus (egg)	Acute (% mort)	140 days	Crude:	ppm:	Lethality	Age at start	66
			Venezuelan	100-10,000	100%	3.5 days	
			Iranian	100-10,000	100%	3.5 days	
			Libyan	100-10,000	90%	4.5 days	
			Libyan	100-10,000		5.5 days	
Clupea harengus pallasii (larva)	Acute (TLm)	96 hr	WSF of Cook Inlet Crude (treated)	3.0 ppm (IR)	Lethality	Arctic Subarctic Sp.	102
Clupea harengus **pallasi**	Acute (LC_{50})	96 hr	Ballast water treatment effluent	1.4 ppm 2.6 ppm	Lethality	May 27 June 2	4
Clupea pallasii	Acute				Lethality		115
(egg)	(TL_{50})	96 hr	benzene	40-45 ppm			
(larva)		48 hr	benzene	20-25 ppm			
Clupea pallasii	Acute (Tim)	96 hr	#2 fuel oil	20 ppm	Lethality		129

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Clupea pallasii	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) 1.22	Lethality	Alaska Sp.	101
Clupea Sp. (egg)	Chronic	45 hr	"Total hydrocarbons" (North Sea oil)	240 µg/l	Growth (hatching) extended hatching period if concentration > 100 g/1		33
Coryphopterus heptacanthus (marine goby)	Sublethal Feeding	4 days			Threshold limit to appetite decline	Feeding behavior noted	117
				phenol	3 ppm		
				Suspended lamp oil	0.3 ppm		
				Suspended heavy oil	2 ppm		
				Suspended "Mobil" oil	4 ppm		
				Crude oil	0.2 ppm		
Cymatogaster aggregata	Acute (TLm)			ppm (IR)	Lethality		129
(adult)		96 hr	#2 fuel	500+/-80			
(adult)		72 hr	S.LA Crude	1,200			
(adult)		96 hr	Kuwait Crude	1,300+/-260			
(juvenile)		72 hr	S.LA Crude	840+/-80			

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	TeSt End-Point	Remarks	Reference
Cyprihodon var iegatatus	Acute (TLm)		OWD of:	ppm:	Lethality		5
		48 hr	S.LA Crude	33,000			
		96 hr	S.LA Crude	29,000			
		48 hr	Kuwait Crude	80,000			
		96 hr	Kuwait Crude	80,000			
		48 hr	#2 fuel oil	200			
		96 hr	#2 fuel oil	93			
			WSF of:				
		48 hr	S.LA Crude	19.8			
		96 hr	S.LA Crude	19.8			
		48 hr	#2 fuel oil	>6.9			
		96 hr	#2 fuel oil	6.3			
		48 hr	Bunker C oil	4.4			
		96 hr	Bunker C oil	3.?			
Cyprinodon variegates (sheepshead minnow) (eggs)	Acute Hatching success	8 days	#2 fuel oil WSF	10 ppm total hydrocarbons 2 ppm naphthalenes	Mortality Hatching		3
Cyprinodon variegates	Acute (LC_{50})	48 hr	WSF of	>19.8 ppm	Lethality		83
		96 hr	S.LA Crude	>19.8 ppm			
Eleginus gracilis	Acute (TLm)		WSF of:	ppm (IR)	Lethality		103
		24 hr	Cook Inlet	2.48			
		96 hr	Crude	2.28			
		24 hr	#2 fuel	>4.56			
		96 hr	oil	2.93			

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Engraulis mardax	Acute				Lethality		129
(egg)	(TL_{50})	48 hr	Benzene	20-25 ppm			
(larva)		48 hr	Benzene	20-25 ppm			
Esox lucius	Acute		WSF of Russian Crude oil	ppm	Lethality		50
I (eyed egg)	(TLm)	24 hr		>10,000	approx. 0	Dissolved fractions of this Crude seem to have no effect	
		48 hr		>10,000	approx. 0		
II (yolk sac)		24 hr		>10,000	approx. 0		
		48 hr		>10,000	approx. 0		
III (free swimming)		24 hr		>10,000	approx. 0		
		48 hr		>10,000	approx. 0		
IV (1 mo. old)		24 hr		>10,000	approx. 0		
		48 hr		>10,000	approx. 0		
Fundulus heteroclitus	Chronic (Field Survey)	8 yr	#2 fuel oil spill "Florida"		Biochemistry	Mixed function oxygenase activity indicates marsh not recovered after 8 years	113
Fundulus heteroclitus (mummichog)	Acute	8 day	#2 fuel oil WSF	10 ppm total hydrocarbons 2 ppm naphthalenes	Mortality		3
(eggs)	Hatching Success				Hatching		

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Fundulus similis (longnose killifish) (eggs)	Acute Hatching Success	8 days	South Louisiana Crude WSF	20 ppm total hydrocarbons 0.3 ppm naphthalenes	Mortality Hatching Success		3
Fundulus similus	Acute (LC_{50})	48 hr 96 hr	WSF of S.LA Crude	16.8 ppm 16.8 ppm	Lethality		83
Fundulus similus	Acute (TLm)		OWD of:	ppm	Lethality		5
		48 hr	S.LA Crude	6,000			
		96 hr	S.LA Crude	6,000			
		48 hr	Kuwait	14,800			
		96 hr	Crude	14,800			
		48 hr	#2	36			
		96 hr	fuel oil	33			
			WSF of:				
		48 hr	S.LA	16.8			
		96 hr	Crude	16.8			
		48 hr	Kuwait	10.4			
		96 hr	Crude	10.4			
		48 hr	#2	4.7			
		96 hr	fuel oil	3.9			
		48 hr	Bunker	2.27			
		96 hr	C. oil	1.69			
Gadus macrocephalus (cod)	Acute	2 hr		4 ppm	100% Mortality	Alaskan	35

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Gadus morhua (egg)	Acute (% mort)	00 hr	WSF of:	ppm	Lethality	10^4 ppm is approx. 10 ppm dissolved hydrocarbon	67
			Venezuelan Crude	10,000	40%		
			Iranian Crude	10,000	30%		
				100	10-17%		
			Libyan Crude	$2.1-10^6$	approx. 0		
Gadus morhua	Chronic (Lifecycle)	Age of eggs	WSF of:	ppm	Hatching success	10^4 ppm is approx. 10 ppm dissolved hydrocarbon	67
		0.5 days	Venezuelan	10,000	20%		
		0.5 days	Iranian	10,000	20%		
		0.5 days	Libyan	10,000	40%		
		4 days	Venezuelan	10,000	25%		
		4 days	Iranian	10,000	40%		
		4 days	Libyan	10,000	95%		
		10 days	Venezuelan	10,000	50%		
		10 days	Iranian	10,000	50%		
		10 days	Libyan	10,000	50%		
morhua	(LC_{50}	96 hr	Oman Crude	ppm >1,000	Lethality		[illegible]

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Gadus morhua	Acute	N/A	WSF of:	ppm	Lethality	Age at transfer	67
(larva)	(X Critical Time)		Iranian	100	14 days	1 day	
			Crude	100	10 days	3 days	
				100	8.2 days	5 days	
				100	5.5 days	10 days	
			Agha	1,000	8.4 days	1 day	
			Crude	1,000	7.5 days	3 days	
				1,000	5.9 days	5 days	
				1,000	4.5 days	10 days	
			Jari	10,000	4.2 days	1 day	
			Crude	10,000	3.5 days	3 days	
				10,000	2.5 days	5 days	
				10,000	0.5 days	10 days	
Gadus morhua	Acute	140 days	WSF of:	ppm '-"	Lethality	Age at start	66
(egg)	(% mort)		Venezuelan	10,000	30%	0-1 days	
			Crude	10,000	40%	3.5 days	
				10,000	20%	10 days	
				1,000	40%	0-1 days	
				1,000	25%	3.5 days	
				1,000	2.5%	10 days	
				100	approx. 0	1-0 days	
				100	approx. 0	3.5 days	
				100	approx. 0	10 days	
			Libyan	10,000	approx. 0		
			Crude	1,000	approx. 0		
				100	approx. 0		

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen- tr at ion	Test End-Point	Remarks	Reference
Gadus morhua (continued) (egg)	Acute (% mort)	140 days	WSF of: Iranian Crude	ppm 100 100 1,000 1,000 1,000 10,000 10,000 10,000	Lethality 60% approx. 0 45% 35% 12% 70% 60% 5%	Age at start 0-1 days 3.5-10 days 0-1 days 3.5 days 10 days 0-1 days 3.5 days 10 days	66 cont.
Hypomesus pretiosus (surf smelt) (eggs & larvae)	Develop- mental	Through development	Prudhoe Bay Crude SWSF	various: depending on life stage	Physiology		73
Leptocottus armatus	Acute (TLm)	96" hr	Kuwait Crude	5,600+/- 1,400 ppm	Lethality		129
Lepidopsetta bilineata (rock sole)	Chronic	2 weeks to 4 months	Prudhoe Bay Crude oil contaminated sediments	0.2 to 1.0% (v/v)	Pathology	Arctic	73

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Lepidopsetta bilineata (rock sole)	Acute	20 hr	naphthalene	4 ppm	100% Mortality	Alaskan	35
Mallotus villosus	Acute (Tim)	72 hr	S*LA Crude	1 50+/- 360 ppm	Lethality	Subarctic Sp.	129
Menidia beryllina	Acute (TLm)	48 hr 96 hr	WSF of: S.LA Crude	8.7 ppm 5.5 ppm	Lethality		83
Menidia beryllina	Acute (Tim)		OWD of:	ppm	Lethality		5
		48 hr	S*LA	5,000			
		96 hr	Crude	3,700			
		48 hr	Kuwait	15,000			
		96 hr	Crude	9,400			
		48 hr	#2 fuel	125			
			WSF of:				
		48 hr	S.LA	8.7			
		96 hr	Crude	5.5			
		48 hr	Kuwait	6.6			
		96 hr	Crude	6.6			
		48 hr	#2	5.2			
		96 hr	fuel oil	3.9			
		48 hr	Bunker	2.7			
		96 hr	C oil	1.9			

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Menidia menidia	Acute (LC_{50})	48 hr	Waste crankcase oil	2,200 ppm	Lethality		42
		96 hr		1,700 ppm			
	(% mort)	7 days		250 ppm	100%		
	(% mort)	36 days		100 ppm	0%		
	(% mort)	60 days		20 ppm	0%		
Morone saxatilis (juvenile)	Acute (LC_{50})	72 hr	benzene	10.9 ppm	Lethality		78
		96 hr		10.9 ppm			
Morone saxatilis (striped bass)	Sublethal	96 hr	benzene in freshwater	5 & 10 ppm	Oxygen Consumption Maxed at 24 hr for 5 ppt. No cliff. in 10 ppt.		17
Myoxocephalus polyacanthocephalus	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) 3.96	Lethality	Alaskan Sp.	101
		96 hr	#2 fuel oil	1.31			

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Myoxocephalus verrucosus (sculpin)	Acute	20 hr	Naphthalene	4 ppm	100% Mortality	Alaskan	35
	Sublethal		Naphthalene	1 ppm	Morphology Physiology	Alaskan	35
Onocottus hexacornis (arctic sculpin)	Acute (LC_{50})	8 days	Cook Inlet Crude WSF @ 2.0+/-0.5 °C	>1.729 ppm	Lethality	Prudhoe Bay collected (Arctic)	99
		4 days	Naphthalene @				
			1.5+/-0.2	1.06 ppm	Lethality	Arctic	
			2.0+/-0.5	1.07 ppm			
			6.4+/-1.1	1.63 ppm			
			8.5+/-1.3	1.82 ppm			
			$\bar{X}$=4.6+/-3.4	1.40+/-0.11			
			°C				
		8 days	Naphthalene @				
			1.5+/-0.2	1.00 ppm	Lethality	Arctic	
			2.0+/-0.5	1.07 ppm			
			6.4+/-1.1	1.63 ppm			
			8.5+/-1.3	1.74 ppm			
			$\bar{X}$=4.6+/-3.4	1.36+/-0.11			

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Oligocottus maculosus (tidepool sculpin)	Acute Delayed Mortality	66 hr exposure 5 day deputation	No. 2 fuel oil	0.100 to 0.398 ml/1	Delayed Mortality Measured		22
Oligocottus maculosus	Acute (LC_{50})	48 hr	No. 2 Diesel Oil	400 ppm	Lethality		39
Oncorhynchus gorbuscha	Acute (Tim)	48 hr 96 hr	Prudhoe Bay Crude	550 ppm 148 ppm	Lethality	30 ppt salinity	22
		96 hr	Cook Inlet Crude	mg/l (GC) 1.69	Lethality	Alaskan Sp .	101
		96 hr	No. 2 fuel oil	0.97			
Oncorhynchus gorbuscha (fry) (pink salmon) (fry)	Acute (TLm)	96 hr 96 hr	Prudhoe Bay Crude	213 ppm 110 ppm	Lethality	7.5°C 11.5°C	97
	Acute Delayed Mortality	66 hr exposure 5 day deputation	No. 2 fuel oil	0.100 to 0.398 ml/1 in seawater	Delayed Mortality Measured	Alaskan	22

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Oncorhynchus gorbuscha (0.22g, $\bar{X}$) (0.47g, X)	Acute (% mort)	48 hr	100% Treated	4.5 ppm	Lethality	Simulated Valdez Ballast water	133
		96 hr	30% Treated	<1.0			
	Acute (TLm)	96 hr	OWD of Prudhoe Bay Crude	ppm (IR) 4.50	Lethality	Arctic/ Subarctic Sp.	102
		96 hr	Cook Inlet Crude, treated	3.41			
Oncorhynchus gorbuscha (pink salmon)	Sublethal	22 hr	Prudhoe Bay Crude WSF	0.35 to 2.22 ppm total Hydro-carbons	Coughing Response- Peaked within 3 hr	Alaskan	104
			Cook Inlet Crude WSF	"	"		
			No. 2 fuel oil	"	"		

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Oncorhynchus gorbuscha	Acute (TLm)	96 hr	WSF of Pr udhoe Bay Crude	ppm(IR) 1.41	Lethality	Arctic/ Subarctic Sp .	102
		96 hr	Cook Inlet Crude	2.92			
		96 hr	Cook Inlet Crude, treated	1.47			
		96 hr	No. 2 fuel oil	0.81			
		24 hr	Cook Inlet Crude	4.13	Lethality	Arctic/ Subarctic sp	103
		96 hr		2.92			
		24 hr	No. 2 fuel oil	0.89			
		96 hr		0.81			
			Prudhoe Crude	ml/l	Lethality	Arctic/ Subarctic spp.	100
Egg		96 hr		3.20	no deaths	mechanically mixed fresh-water	
Early-alevin		96 hr		0.62			
Mid-alevin		96 hr		0.55			
Late-alevin		96 hr		0.70			
Emergent fry		96 hr		0.40			
Migrant fry		96 hr		0.042		Mechanically mixed seawater	

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Oncorhynchus gorbuscha							100
Egg		96 hr		3.20	no deaths (<50% mort)	Water agitation fresh-water	
Early-alevin		96 hr		3.20			
Mid-alevin		96 hr		3.20			
Late-alevin		96 hr		1.85			
Emergent fry		96 hr		1.25			
Migrant fry		96 hr		0.075		Water agitation seawater	
Oncorhynchus keta fry (chum salmon)	Behavior	1 wk	Cook Inlet Crude oil SWSF	0.4 ppm	Altered Behavior	Arctic	73
	Acute (LC_{50})	48 hr 96 hr	Emulsion No. 2 Diesel fuel	ppm 538 312	Lethality	25 ppt salinity	22
	Acute (TLm)	96 hr	No. 2′ fuel oil	1040+/-260 ppm	Lethality		129

Table B-6, Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Oncorhynchus keta							
Unstressed (0.9, $\bar{X}$) (Simulated ballast water)	Acute (% mort)	7 days 14 days	50% treated 30% treated	3.4 ppm 2.0 ppm	Lethality 75% 63%		133
Unstressed (.35g, $\bar{X}$)	Acute (% mort)	<16 hr <48 hr	100% treated 100% treated	6.4 4.6	100% 100%	Simulated Valdez ballast water made from Prudhoe Crude	
Unstressed (1.83g, $\bar{X}$)		16 hr 70 hr	100% untreated 10% untreated	7.9 1.0	1 00% 100%		
Stressed (0.38g, $\bar{X}$) real ballast water		78 hr	50% untreated	<1.0 to 3.5	98%		
Unstressed (5.36g, $\bar{X}$) simulated ballast water		7.5 hr 7.5 hr	Puget Sound water and 100% treated	13.3	100%		
unstressed (5.36g, $\bar{X}$)		7.5 hr	Valdez water and treated	12.8	100%		
Unstressed (1.90g, $\bar{X}$)		96 hr	Valdez water and 20%, 30%, 50% treated	<1.0 to 1.2	0		

Table B-6. Toxicity of Petroleum to Fish

organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-trat ion	Test End-Point	Remarks	Reference
Oncorhynchus kisutch (coho salmon)	Physiology	2 t 0 6 weeks	Prudhoe Bay Crude WSF	0.8 ppm	Accumulation Deputation	Alaskan	71
	Chronic	40 days	Toluene in freshwater	0.4, 0.8, 1.6, 3.2, 5.8 pi/l	Growth	Alaskan	81
			Naphthalene in freshwater	0.2, 0.4, 0.7, 1.4, 3.0 mg/l			
Oncorhynchus kisutch (coho salmon) Oncorhynchus tschawytscha (chinook salmon)	Behavior	24 to 28 hr	Prudhoe Bay Crude WSF	600 ppb	Homing Behavior	Alaskan	71
Oncorhynchus kisutch (advanced 11 mo. old)	Acute (% mort) parr/ "	96 hr exposure	Prudhoe Bay Crude poured on surface	ppm	Lethality	Temp.°C	8 2
				control	10%	8	
				3,500	50%	8	
				control	0%	13	
				3,500	62.5%	13	
				cent rol	9.1%	8	
				3,500	80. 5%	8	

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Oncorhynchus nerka (advanced parr/10 mo. old)	Acute (% mort)	96 hr	Prudhoe Bay Arude poured on surface	ppm	Lethality	Temp. C	82
				control	10%	8	
				500	39.3%	8	
				1,000	44.8%	8	
				1,750	6.7%	8	
				3,500	40 .0%	8	
				cent rol	0%	3-5	
				500	55%	3-4	
				1,750	100%	3	
				3,500	90%	4-5	
				control	0%	13	
				500	0%	13	
				1,000	6.9%	13	
				1,750	5%	13	
				3,500	20%	13	
Oncorhynchus tschawytscha (chinook salmon)	Sublethal	96 hr	Benzene in freshwater	5 and 10 ppm	Oxygen consumption maxed at 48 hr then decreased to 96 hr	Alaskan	17
Oncorhychus tschawytscha (fingerling)	Acute (% mort)	24 hr	WSF Of: Prudhoe Bay Crude	ppm (IR)	Lethality		109
				1.86	100%		
				1.02	70%		
				0.56	0%		

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Oncorhynchus tschawytscha	Acute (LC_{50})	48 hr 96 hr	Emulsion No. 2 diesel oil	ppm 1,190 349	Lethality	Arctic/ Subarctic Sp.	22
Opsanus tau (larvae)	Acute (% survival)	48 hr	Crude oil and carbonized sand	ppm 5,000 12,500 25,000 50,000 100,000	Lethality 100% 100% 40% 0% 0%		25
		52 hr	Diesel oil and carbonized sand	ppm approx. 25,000 approx. 50,000 approx. 100,000	 100% 40% 0%		
		50 hr	Lubricating oil (SAE 20) and carbonized sand	approx. 25,000 approx. 50,000 approx. 100,000	80% 100% 80%		

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Parophrys vetulus (English sole) eggs and larvae	Developmental	Through development	Prudhoe Bay Crude SWSF	various, depending on life stage	Physiology		73
	Chronic	2 weeks to 4 months	Prudhoe Bay crude oil contaminated sediments	0.2 to 1.0% (v/v)	Pathology	Arctic	73
	Biochemical	24 hr to 160 hr exposure	[^{3}H]benzo[d]-pyrene and [^{14}C]naphthalene in sediment with 1% Prudhoe Bay Crude	[^{14}C]NPH 0.83 mCi/mmol [^{3}H]B[a]P 167 mCi/mmol	Metabolism accumulation	Alaskan	128
Pholis laeta	Acute (Tim)	96 hr	Cook Inlet Crude No. 2 fuel oil	mg/l (at) >11.72 >0.97	Lethality	Alaskan Sp.	101
Platichthys **stellatus**	Chronic (bioaccumulation)	9 days	2,6 dimethylnaphthalene	0.3-0.4 mg/kg body wt per day force feed	metabolism	Pre-exposure to chemicals may alter the metabolism of different chemicals & affect their toxicity.	49

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Platichtys stellatus	Acute (TLm)	96 hr	Cook Inlet Crude #2 fuel oil	mg/l ((%) >5.34 >0.97	Lethality	Alaskan Sp.	101
Platichthys stellatus (starry flounder)	Physiology	2 to 6 weeks	Prudhoe Bay Crude WSF	0.8 ppm	Accumulation Deputation	Alaskan	71
Platichthys stellatus	Acute (Tim)	72 hr	S.LA Crude	1,400+/- 110 ppm	Lethality		129
Platichthys stellatus (starry flounder)	Chronic	2 weeks to 4 months	Prudhoe Bay Crude contaminated sediments	0.2 to 1.0 % (v/v)	Pathology	Arctic	73
Prophrys vetulus (145-242 mm)	Chronic (bioaccumulation)	4 months	North Slope Crude in sediment	700 ppm	Histology (severe hepatocellular lipid vacuolization) Growth (weight loss)	Induction of aryl hydrocarbon hydroxylase may be occurring with this fish.	74

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Psettichthys melanosticus (sand sole) (eggs and larva)	Development	Through development	Prudhoe Bay Crude SWSF	Various depending on life stage	Physiology	Arctic	73
Psettichthys melanostictus (eggs and larva)	Acute (% mort)			ppm	Lethality		129
		6 days	S. LA Crude	10	100		
				30	100		
				50	100		
				100	100		
				500	100		
		4 days	No. 2 fuel oil	1	0		
				5	0		
				10	0		
				25	0		
				50	20		
		5 days	Kuwait Crude	10	50		
				30	20		
				50	10		
				100	60		
				500	90		
Pseudopleuronectes americanus	Acute (LC_{50})		Bunker C fuel oil	ppm	Lethality	Temp 'C	110
		96 hr		>10,000		15	
		96 hr		>10,000		5	

Table B-6 . Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Pseudopleuronectus sp. (larva 8 hr)	Acute (% mort)	24 hr	Bunker C oil	% oil 0 0.1	Lethality 0% 6.8%		56
Psychrolutes paradoxus (tadpole sculpin)	Acute delayed mortality	66 hr exposure 5 day deputation	#2 fuel oi 1	0.100 to 0.398 ml/1	Delayed mortalities measured		22
Psychrolutes paradoxus	Acute (LC_{50})	48 hr	#2 diesel oil	400 ppm	Lethality		39
Rhombus maeoticus (larva)	Chronic (life cycle)	5 days	Bunker C fuel oil Solar oi 1 Malgobeck oil	ppm 0.1 0.01 1.0 0.1 0.01 1.0 0.1 0.01 0.0	% hatch 100 100 100 100 100 0 100 100 100	% abnormal 100 37 all dead all dead 23 100 40 7	78
Rhombus maeoticus	Acute (% mort)	2 days	WSF of: Bunker C	1.0	Lethality 100%		78

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Rhombus maeoticus (egg)	Acute (% viable eggs)	1 day	Bunker C	ppm	Lethality	Concludes that 0.01-1 ppm may be toxic to flat fish eggs	78
				100	82		
				10	84		
				1	76		
				0.1	87		
				0.01	8 9		
				0.0	83		
		2 days		100	0		
				10	0		
				1	71		
				0.1	81		
				0.01	89		
				0.0	83		
		3 days		100			
				10			
				1	0		
				0.1	81		
				0.01	89		
				0.0	83		
		1 day	Solar oil	100	81		
				10	82		
				1	89		
				0.1	87		
				0.01	94		
				0.0	83		
		2 days		100	0		
				10	10		
				1	78		
				0.1	87		
				0.01	81		
				0.0	83		

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration ppm	Test End-Point	Remarks	Reference
Rhombus maeoticus (egg)	Acute (% viable eggs)	3 days	Solar oil	100	Lethality		78
				10	0		
				1	78		
				0.1	67		
				0.01	81		
				0.0	83		
		1 day	Malgobeck oil	100	80		
				10	87		
				1	81		
				0.1	72		
				0.01	67		
				0.0	83		
		2 days		100	0		
				10	74		
				1	81		
				0.1	67		
				0.01	67		
				0.0	83		
		3 days		100			
				10	0		
				1	81		
				0.1	55		
				0.01	67		
				0.0	83		

Table B-6 . Toxicity of Petroleum to Fish

Organi em	Type of Toxicity Test	Test Duration	Material Tested	Concen- tration	Test End-Point	Remarks	Reference
Salmo clarki (cutthroat trout)	Chronic	90 days	Wyoming Crude oil	Up to 520 µg/liter	Growth and Morphology		134
Salmo gairdneri (yearling)	Acute (LC_{50})	48 hr	Phenol	ppm 5.25 7.25 7.90 8.00 9.3	Lethality	% Sw 60 40 30 15 0	18
Salmo gairdneri (rainbow trout)	Sublethal reproductive capability	6 to 7 months	Prudhoe Bay Crude incorporated into food	2 gm oil/ 2 kg Oregon moist pellets 2% body wt. fed per day	Reproductive Success measured no significant difference		53
Salmo gairdneri (rainbow trout)	Morphological	>1 year fed oil treated food	Prudhoe Bay Crude	1 gm oil/ 1 kg pellet food	Lens Morphology investigated	Alaskan	71, 72
Salmo salar (parr)	Acute (LC_{50})	96 hr 96 hr	Bunker C fuel oil	ppm >10,000 >10,000	Lethality	Temp °C 15 5	110

Table B 6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Salvelinus malma (smelt)	Acute (TLm)		WSF of:	ppm (IR)		Alaskan Sp.	103
		24 hr	Cook Inlet	3.25			
		96 hr	Crude	2.94			
		96 hr	#2 fuel	2.29			
Salvelinus malma	Acute (TLm)	96 hr	Cook Inlet Crude	mg/l (GC) 1.55	Lethality	Alaskan sp.	101
			#2 fuel oil	0.15			
Salvelinus malma	Acute (TLm)		WSF of:	ppm (IR)	Lethality	Alaskan Sp.	102
		96 hr	Prudhoe Bay Crude	1.10			
		96 hr	Cook Inlet Crude treated	2.94			
		96 hr	Cook Inlet Crude untreated	1.54			
		96 hr	#2 fuel oil	2.29			
			owl) of:				
		96 hr	Pr udhoe Bay Crude	16.41			
		96 hr	Cook Inlet Crude treated	7.30			
Scorpaenichthys marmoratus (larva)	Acute (Tim)	approx. 96 hr	OWD of: #2 fuel oil	ppm <10	Lethality		70
		approx. 96 hr	L.A. Crude	>100			

Table B-6. Toxicity of Petroleum to Fish

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Syngnathus griseolineatus	Acute (TLm)	96 hr	Kuwait Crude	ppm <675	Lethality		129
Tautogolabrus adsperus	Chronic	6 months	Venezuelan Crude oil	not measured	Growth (differences in: testis somatic index, lens diameter and plasma chloride. No histopathological changes were observed.)	Mixed function oxygenase present	89
Theragra chalcogramma (pollack)	Acute	2 hrs		4 ppm	100% Mortality	Alaskan	35
Theragra chalcogrammus	Acute (Tim)	96 hr	Cook Inlet Crude	mg/l (GC) 1.73	Lethality	Alaskan Sp.	101

Table B-7. Toxicity of Petroleum to Birds

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Arias platyrhynchos (mallard duck) eggs	Reproduction	Until hatched	Mineral oil	Total shell coverage	Hatching success		52
Anas platyrhynchos (mallard duck) eggs	Reproduction	Until hatched	No. 2 fuel oil	Port ion of shell coverage	l-latching success Sig. mortal. with 1 /1 oil applied to 2% of shell		1
Anas platyrhynchos (mallard duck) Adult	Acute	100 days	Kuwait and South Louisiana Crude	Mixed with dry poultry food - 3.0 and 2.4 ml oil/kg body weight	Lethality after cold stress.		55
Anas platyrhynchos (mallard duck) Adults	Chronic	90 days	Santa Barbara Crude Kuwait Crude No. 2 fuel oil	5 ml one time daily doses ingested	Pathological effects observed		54
Anas platyrhynchos (mallard duck) Juvenile	Chronic	Single oral dose	Santa Barbara Crude	0.2 ml	Rates of mu cos al transfer in small intestine measured.		31

Table B-7. Toxicity of Petroleum to Birds

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Anas platyrhynchos (mallard duck) juvenile	Acute	6 days	south Louisiana Crude oil in food	5, 10 and 20% (v/w)	Lethality		54
Coturnix coturnix Japanese quail Adult	Reproductive	Single dose	Mineral and Safflower oil		Egg Production and Matchability Measured		47
			Bunker C fuel oil	100, 200 & 500 mg			
			Kuwait Crude	800 mg			
			Prudhoe Bay Crude	800 mg			
			Cook Inlet Crude	800 mg			
Somateria mollissima (eider duck) eggs	Reproductive	Until Hatched	No. 2 fuel oil	Portion of shell coverage			118

Table B-8. Toxicity of Petroleum to Marine Mammals

Organism	Type of Toxicity Test	Test Duration	Material Tested	Concentration	Test End-Point	Remarks	Reference
Callorhinus ursinus (fur seal)	Pelt Conductance	N/A	Prudhoe Bay Crude	.02 ml/cm^2 Brushed into Pelt			62, 63
Callorhinus ursinus (fur seal)	Physiology	12 hours	Prudhoe Bay Crude	100 ml Brushed into Pelt	Physiological Measurements		62, 63
Enhydra lutris (sea otter)	Pelt Conductance	N/A	Prudhoe Bay Crude	.02 ml/cm^2 Brushed into Pelt			62, 63
Enhydra lutris (sea otter)	Physiology	8 days	Prudhoe Bay Crude	60 ml Brushed into Pelt	Physiological Measurements		29
Erignathus barbatus (bearded seal)	Pelt Conductance	N/A	Prudhoe Bay Crude	.02 ml/cm^2 Brushed into Pelt			62, 63
Leptonychotes weddelli (weddell seal)	Pelt Conductance	N/A	Prudhoe Bay Crude	.02 ml/cm^2 Brushed into Pelt			62, 63
Odobenus rosmarus (walrus)	Pelt Conductance	N/A	Prudhoe Bay Crude	.02 ml/cm^2 Brushed into Pelt			62, 63

Table B-8, Toxicity of Petroleum to Marine Mammals

Organism	Type of Toxicity TeSt	Test Duration	Material Tested	Concen-tration	Test End-Point	Remarks	Reference
Phoca groenlandica (harp seals)	Chronic	4 days	Norman Wells Crude	Pelt Totally Coated	Behavior, Physiology, Pathology		43
Phoca hispida (ringed seals)	Acute	24 hours	Crude oil	1 cm Surface Thickness in Enclosed Pen	Lethality, Behavior, Physiology, Pathology		43
Zalophus californicus	Pelt Conductance		Prudhoe Bay Crude	.02 ml/cm^2 Brushed into Pelt	Thermal Conductance Measured		62

Toxicity Summary Table References

1. Albers, P. H. 1977. Effects of external applications of fuel oil on matchability of mallard eggs. In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms. Proceedings of a symposium. (D. A. Wolfe, cd.) Pergamon Press, pp. 158-163.

2. Allen, H. 1971. Effects of petroleum fractions on the early development of a sea urchin. Mar. Pollut. Bull. 2:138-140.

3. Anderson, J. W., D. B. Dixit, G. S. Ward, and R. S. Foster. 1977. Effects of petroleum hydrocarbons on the rate of heartbeat and hatching success of estuarine fish embryos. In: Physiological responses of marine biota to pollutants. (F. J. Vernberg, A. Calabrese, F. P. Thruberg, and W. B. Vernberg, eds.). Academic Press, pp. 241-258.

4. Anderson, J. W., S. L. Kiesser, R. M. Bean, R. G. Riley, and B. L. Thomas. 1981. Toxicity of chemically dispersed oil to shrimp exposed to constant and decreasing concentrations in a flowing system. In: Proceedings of the 1981 oil spill conference. American Petroleum Institute Publ. No. 4334, pp. 69-75.

5. Anderson, J. W., J. M. Neff, B. A. Cox, H. E. Tatem, and G. M. Hightower. 1974. Characteristics of dispersions and water-soluble extracts of crude and refined oils and their toxicity to estuarine crustaceans and fish. Mar. Biol. (Berl.) 27:75-88.

6. Araset, A. V. and K. E. Zachariassen. 1982. Effects of oil pollution on the freezing tolerance and solute concentration of the blue mussel Mytilus edulis. Mar. Biol. 72:45-51.

7. Atema, J. and L. Stein. 1972. Sublethal effects of crude oil on lobster, (Homanus americanus) behavior. WHOI Tech Report No. 72-74.

8. Augenfeld, J. M. 1980. Effects of Prudhoe Bay crude oil contamination on sediment working rates of Abarenicola pacifica. Mar. Environ. Res. 3:307-313.

9. Augenfeld, J. M., J. W. Anderson, R. G. Riley, and B. L. Thomas. 1982. The fate of polyaromatic hydrocarbons in an intertidal sediment exposure system: bioavailability to Macoma inquinata (Mollusca:Pelecypoda) and Abarenicola pacifica (Annelida:Polychaeta) . Mar. Environ. Res. 7:31-50.

10. Augenfeld, J. M., J. W. Anderson, D. L. Woodruff, and J. L. Webster. 1980. Effects of Prudhoe Bay crude oil-contaminated sediments on Protothaca staminea (Mollusca: Pelecypoda): hydrocarbon content, condition index, free amino acid level. Mar. Environ. Res. 4:135-143.

11. Barry, M. and P. P. Yevich. 1975. The ecological, chemical, and histopathological evaluation of an oil spill site. Part III. Histopathological studies. Mar. Pollut. Bull. 6:164-173.

12. Bayne, B. L., K. R. Clarke, and M. N. Moore. 1981. Some practical considerations in the measurement of pollution effects on bivalve molluscs, and some possible ecological consequences. Aqu. Tox. 1:159-174.

13. Bean, R. M., J. R. Vanderhorst, and P. Wilkinson. 1974. Interdisciplinary study of the toxicity of petroleum to marine organisms. Battelle Pacific Northwest Laboratories, Richland, WA, 31 p.

14. Bender, M. E., J. L. Hyland, and T. K. Duncan. 1974. Effect of an oil spill on benthic animals in the lower York River, Virginia. In: Marine pollution monitoring (petroleum). Natl. Bur. Stand. Spec. Publ. 409, p. 257-259.

15. Blackall, P. J. and G. Sergy. 1983. BIOS Project-Preliminary Results. In: Baffin Island Oil Spill Project, working report series. Environmental Protection Service. Environment Canada. Edmonton, Alberta spring 1983, p. 292-295.

16. Blackman, R. A. A. and R. J. Law. 1980. The Eleni V oil spill: fate and effects of the oil over the first twelve months. Part II. Biological effects. Mar. Pollut. Bull. 11:217-220.

17. Brooksen, R. W. and H. T. Bailey. 1973. Respiratory response of juvenile chinook salmon and striped bass exposed to benzene, a water-soluble component of crude oil. In: Proceedings of Joint Conference n Prevention and Control of Oil Spills. American Petroluem Institute Publ., pp. 783-791.

18. Brown, V. M., D. G. Shurben, and J. K. Fawell. 1967. The acute toxicity of phenol to rainbow trout in saline waters. Water Res. 1:683-685.

19. Busdosh, M. 1981. Long-term effects of the water soluble fraction of Prudhoe Bay crude oil on survival, movement, and food search success of the Arctic amphipod Boeckosimus (=onisimus) affinis. Mar. Environ. Res. 5:167-180.

20. Caldwell, R. S., E. M. Caldarone, and M. H. Mallon. 1976. Effects of a seawater-soluble fraction of Alaskan crude oil and its major aromatic components on larval stages of the Dungeness crab, Cancer magister Dana. In: Environmental assessment of the Alaskan continental shelf. Principal investigators' reports, Oct.-Dec. 1976. Vol. 3, pp. 157-168.

21. Caldwell, R. S., E. M. Caldarone, and M. H. Mallon. 1977. Effects of a seawater-soluble fraction of Cook Inlet crude oil and its major aromatic components on larval stages of the, Dungeness crab, Cancer magister Dana. In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms. Proceedings of a symposium. (D.A. Wolfe, cd.) Pergamon Press, p. 210-220.

22. Cardwell, R. D. 1973. Acute toxicity of No. 2 diesel oil to selected species of marine invertebrates, marine sculpins, and juvenile salmon. Ph.D. Thesis, University of Washington, Seattle, 124 p.

23. Carr, R. S. and D. J. Reish. 1977. The effect of petroleum hydrocarbons in the survival and life history of polychaetous annelids. In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms. Proceedings of a symposium. (D.A. Wolfe, cd.) Pergamon Press, p. 168-173.

24. Chia, F.-S. 1973. Killing of marine larvae by diesel oil. Mar. Pollut. Bull. 4:29-30.

25. Chipman, W. A. and P. S. Galtsoff. 1949. Effects of oil mixed with carbonized sand on aquatic animals. U.S. Bur. Sport Fish. Wildl., Spec. Sci. Rep. 1, p 1-52.

26. Clement, L. E., M. S. Stekoll, and D. G. Shaw. 1980. Accumulation, fractionation, and release of oil by the intertidal clam Macoma balthica. Mar. Bio. 57:41-50.

27. Cole, T. J. 1978. Preliminary ecological-genetic comparison between unperturbed and oil-impacted Urosalpinx cinerea (Prosobranchia: Gastropoda) populations: Nobska Point (Woods Hole) and Wild Harbor (West Falmouth), Massachusetts. J. Fish. Res. Board Can. 35:624-629.

28. Corner, D. S., A. J. Southward, and E. C. Southward. 1968. Toxicity of oil spill removers ('detergents') to marine life. An assessment using the intertidal barnacle, Elminius modestus. J. Mar Biol. Assoc. U.K. 38:29-47.

29. Costa, D. P. and G. L. Kooyman. 1981. Effects of oil contamination in the sea otter, Enhydra lutris. In: Environmental assessment of the Alaskan continental shelf. Final reports of principal investigators, Vol. 10. Biological Studies, p. 65-107.

30. Crapp, G. B. 1971. The ecological effects of stranded oil. In: Proceedings of the ecological effects of oil pollution on littoral communities (E. B. Cowell, cd.). Institute of Petroluem, London, p. 181-186.

31. Crocker, A. D., J. Cronshaw, and W. N. Holmes. 1974. The effect of the crude oil intestinal absorption in ducklings (Anus platyrhynchos) . Environ. Pollut. 7:165-178.

32. Davenport, J. 1973. A comparison of the effects of oil, B.P.1100 and oleophilic fluff upon the porcelain crab, Porcellana platycheles. Chemosphere 1:3-6.

33. Davies, J. M., R. Hardy, and A. D. McIntyer. 1981. Environmental effects of North Sea oil operations". Mar. Pollut. Bull. 12(12):412-416.

34. Davis, P. H., T. W. Schultz, and R. B. Spies. 1981. Toxicity of Santa Barbara seep oil to starfish embryos. Part 2 - The growth bioassay. Mar. Environ. Res. 5:287-294.

35. Devries, A. L. 1977. The physiological effects of acute and chronic exposure to hydrocarbons on near-shore fishes of the Bering Sea. In: Environmental assessment" of the Alaskan continental shelf. Annual reports of principal investigators for the year ending March 1977. vol. 12. Effects.

36. Dicks, B. 1973. Some effects of Kuwait crude oil on the limpet Patella vulgata. Environ. Pollut. 5:219-229.

37. Dillon, T. M. 1981. Effects of dimethylnaphthalene and fluctuating temperature on estuarine shrimp. In: 1981 Oil Spill Conference (Prevention, Behavior, Control, Cleanup): Proceedings, p. 79-85, March 2-5 1981. EPA, API, USCG.

38. Edwards, S. F. 1980. Crude oil effects on mortality, growth, and feeding of young oyster drills, Urosalpinx cinerea (Say). Veliger 23(2):125-130.

39. Ehrsam, L. C, Jr., T. S. English, J. Matches, D. Weitkamp, R. Cardwell, R. S. LeGore, R. W. Steele, and R. Orhiem. 1972. Biological assessment of diesel oil spill, Phase II, Anacortes, Washington, September 971 . Final report prepared for EPA, Contr. No. 68-01-0017, Texas Instruments, Inc., 82 p.

40. Barrington, J. W., A. C. Davis, N. M. Frew, and K. S. Rabin. 1982. No. 2 fuel oil compounds in Mytilus edulis. Retention and release after an oil spill. Mar. Bio. 66:15-26.

41. Fries, C. R. and M. R. Tripp. 1977. Cytological damage in Mercenaria mercenaria exposed to phenol. In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms. Proceedings of a symposium. (D.A. Wolfe, cd.) Pergamon Press. 1977. pp. 174-181.

42. Gardner, G. R., P. P. Yevich, and P. F. Rogerson. 1975. Morphological anomalies in adult oyster, scallop, and Atlantic silversides exposed to waste motor oil. In: Proceedings of 1975 Conference on Prevention and Control of Oil Pollution, p. 473-477. American Petroleum Institute, Washington, D.C.

43. Geraci, J. R. and T. G. Smith. 1977. Consequences of oil fouling on marine mammals. In: Effects of petroleum on arctic and subarctic marine environments and organisms. vol. 2. Biological Effects (D.C. Malins, cd.). Academic Press, pp. 399-410.

44. Gilet, R. 1960. Water pollution in Marseilles and its relation with flora and fauna. In: Proceedings of the First International Conference for Waste Disposal in the Marine Environment, Berkeley, California, 1959. Pergamon Press, New York, p. 39-56.

45. Gilfillan, E. S. and J. H. Vandermeulen. 1978. Alterations in growth and physiology of soft-shell clam Mya arenaria, chronically oiled with Bunker C from Chedabucto Bay, Nova Scotia, 1970-76. J. Fish. Res. Board Can. 35:630-636.

46. Gordon, D. C., Jr., J. Dale, and P. D. Keizer. 1978. Importance of sediment working by the deposit-feeding polychaete Arenicola marina and the weathering rate of sediment-bound oil. J. Fish. Res. Board Can. 35: 591-603.

47. Gray, C. R., T. Rondybush, J. Dobbs, and J. Wathen. 1977. Altered yolk structure and reduced matchability of eggs from birds fed single doses of petroleum oils. Science 195:779-781.

48. Griffith, D. de G. 1970. Toxicity of crude oil and detergents to two species of edible molluscs under artificial tidal conditions. In: FAO Technical Conference on Marine Pollution and Its Effect on Living Resources and Fishing. FAO Fish. Rep. 99, FIRM/R99. Food and Agriculture Organization of the United Nations, Rome, 188 p.

49. Gruger, E. H., Jr. , J. V. Schnell, P. S. Fraser, D. W. Brena, and D. C. Malias. 1981. Metabolism of 26-dime thylnaphthalene in starry flounder (Platichthys stellatus) exposed to naphthalene and p-cresol. Aqu. Tox. 1:37-48.

50. Hakkila, K. and A. Niemi. 1973. Effects of oil and emulsifiers on eggs and larvae of Northern pike (Esox lucius) in brackish water. Aqua Fenn., p. 44-59.

51. Hampson, G. R. and E. T. Moul. 1978. No. 2 fuel oil spill in Bourne, Massachusetts: immediate assessment of the effects on marine invertebrates and a 3-year study of growth and recovery of a salt-marsh. J. Fish. Res. Board Can. 35:731-744.

52. Hartung, R. 1965. Some effects of oiling on reproduction of ducks. J. Wildlife Manag. 29(4):872-874.

53. Hodgins, H. O., W. D. Gronlund, J. L. Mighell, J. W. Hawkes, and P. A. Robisch. 1977. Effects of crude oil in trout reproduction. In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms. Proceedings of a symposium. (D.A. Wolfe, cd.) Pergamon Press, pp. 143-150.

54. Holmes, W. N. and J. Cronshaw. 1977. Biological effects of petroleum on marine birds. In: Effects of petroleum on arctic and subarctic marine environments and organisms. vol. 2. Biological effects. (D.C. Malins, cd.) Academic Press, pp.359-398.

55. Holmes, W. N., J. Cronshaw, and J. Gorsline. In prep. The effects of cold stress on seawater-maintained ducks given food contaminated with petroleum.

56. James, M. C. 1926. Preliminary investigation of the effect of oil pollution on marine pelagic eggs, April 1925. In: Preliminary Conference on Oil pollution of Navigable Waters, June 8-16, 1926, Appendix 6, P. 85-92. U.S Bureau of Fisheries Interdepartmental Committee, Washington, D. C.

57. Kanter, R. 1974. Susceptibility to crude oil with respect to size, season, and geographic location in Mytilus californianus (Bivalvia). University of Southern California, Sea Grant Program (USC-SG-4-74), Los Angeles, Calif., 43 p.

58. Karinen, J. F. and S. D. Rice. 1974. Effects of Prudhoe Bay crude oil on molting tanner crabs, Chionoecetes bairdi. Mar. Fish. Rev. 36:31-37.

59. Kasymov, A. G. and A. D. Aliev. 1973. Experimental study of the effect of oil on some representatives of benthos in the Caspian Sea. Water Air Soil Pollut. 2:235-245.

60. Katz, L. M. 1973. The effects of water soluble fraction of crude oil on larvae of the decapod crustacean, Neopanope texana (Sayi). Environ. Pollut. 5:199-204.

61. Kontogiannis, J. E. and C. J. Barnett. 1973. The effect of oil pollution on survival of the tidal pool copepod, Tigriopus californicus. Environ. Pollut. 4:69-79.

62. Kooyman, G. L., R. W. Davis, and M. A. Castellini. 1977. Thermal conductance of immersed pinniped and sea otter pelts before and after oiling with Prudhoe Bay crude. In: Fate and effects of petroleum hdyrocarbons in marine ecosystems and organisms. Proceedings of a symposium. (D.A. Wolfe, cd.). Pergamon Press, p. 151-157.

63. Kooyman, G. L. and R. L. Gentry. 1976. Physiological impact of oil on pinnipeds. In: Environmental assessment of the Alaskan continental shelf. Principal investigators report. October-December 1976. vol. 3, p. 3-26.

64. Krebs, C. T. and K. A. Burns. 1977. Long-term effects of an oil spill on populations of the salt marsh crab Uca pugnax. Science. 197:484-487.

65. Krebs, C. T. and K. A. Bruns. 1978. Long-term effects of an oil spill on populations of the salt-marsh crab Uca pugnax. J. Fish. Res. Board Can. 35:648-649.

66. Kuhnhold, W. W. 1969. Effect of water soluble substances of crude oil on eggs and larvae of cod and herring. Fisheries Improvement Committee Int. Count. Explor. Sea (CM 1969/E 17), Copenhagen, 15 p.

67. Kuhnhold, W. W. 1970. The influence of crude oils on fish fry. In: FAO Technical Conference on Marine Pollution and Its Effects on Living Resources and Fishing. MP/70/E-64. Food and Agriculture Organization of the United Nations, Rome, 10 p.

68. Laughlin, R. B., Jr. and J. M. Neff. 1977. Interactive effects of temperature, salinity shock, and chronic exposure to No. 2 fuel oil on survival, development rate and respiration of the horseshoe crab, Limulus polyphemus. In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms. Proceedings of a symposium (D.A. Wolfe, cd.). Pergamon Press, p. 182-191.

69. LeGore, R. S. 1974. The effect of Alaskan crude oil and selected hdyrocarbon compounds on embryonic devel - opment of the pacific oyster, Crassostrea gigas. Ph.D. Thesis, University of Washington, Seattle, 186 p.

70. Lichatowich, J. A., J. A. Strand, and W. L. Templeton. 1972. Development of toxicity test procedures for marine zooplankton. Am. Inst. Chem. Eng. Symp. Ser. 68: 372-378.

71. Malins, D. C., E. H. Gruger, Jr, H. O. Hodgins, and D. D. Weber. 1976. Sublethal effects as reflected by morphological, chemical, physiological, behavioral, and pathological indices. In: Environmental assessment of the Alaskan continental—shelf. Principal investigators' reports. Oct. - Dec. 1976. Vol. 3, pp. 46-85.

72. Malins, D. C. and H. O. Hodgins. 1976. Sublethal effects as reflected by morphological, chemical, physiological, and behavioral indices. In: Environmental assessment of the Alaskan continental shelf, Principal investigators' reports. July-Sept. 1976. Vol. 3, pp. 23-60.

73. Malins, D. C., H. O. Hodgins, B. B. McCain, D. D. Weber, U. Yaranasi, and D W. Brown. 1980. Sublethal effects of petroleum hydrocarbons and trace metals, including biotransformation, as reflected by morphological, chemical, physiological, pathological and behavioral indices. In: Environmental assessment of the Alaskan continental—shelf. Annual reports of principal investigators for the year ending March 1980. vol. 3* Effects, pp. 13-79.

74. McCain, B. B., H. O.Hodgins,W.D.Gronland, J. W. Hawkes, D. W. Brown, M. S. Myers, and J. H. Vandermeulen. 1978. Bioavailability of crude oil from experimentally oiled sediments to English sole (Parophrys vetulus) and pathological consequences. J. Fish. Res. Board Can. 35:657-664.

75. Mecklenburg, T. A., S. D. Rice, and J. F. Karinen. 1977. Molting and survival of king crab (Paralithodes camtschatica) and coonstripe shrimp (Pandalus hypsinotus) larvae exposed to Cook Inlet crude oil water-soluble fraction. In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organi sms. Proceedings of a symposium. (D.A. Wolfe, cd.) pergamon Press, 1977, pp. 221-228.

76. Meyerhoff, R. d. 1975. Acute toxicity of benzene, a component of crude oil, to juvenile striped bass (Morone saxatilis). J. Fish. Res. Board Can. 32:1864-1866.

77. Milovidova, N. Y. 1974. The effect of oil pollution on some coastal crustaceans of the Black Sea. Hydrobiol. J. (Eng. Transl. Hidrobiol. Zh.) 4:76-79.

78. Mironov, O. G. 1967. Effect of low concentrations of oil and oil products upon the developing eggs of the Black Sea flatfish-Kalkan (Rhombus maeoticus (Pallas)). Vopr. Ikhtio. 7:577-580.

79. Mironov, O. G. 1969. The effect of oil pollution on some representatives of the Black Sea zooplankton. Zool . Zh. 48:980-984.

80. Mironov, O. G. 1969. The viability of larvae of some crustaceans in marine water polluted with oil products. Zool . Zh. 48:1734-1737.

81. Moles, A., S. Bates, S. D. Rice, and S. Kern. 1981. Reduced growth of coho salmon fry exposed to two petroleum components, toluene and naphthalene, in fresh water. Trans. Amer. Fish. Sot. 110:430-436.

82. Morrow, J. E. 1973. Oil-induced mortalities in juvenile coho and sockeye salmon. J. Mar. Res. 31: 135-143.

83. Neff, J. M., J. W. Anderson, B. A. Cox, R. B. Laughlin, Jr., S. S. Rossi, and H. E. Tatem. 1976. Effects of petroleum, on survival, respiration, and growth of marine animals. In: Symposium on Sources, Effects, and Sinks of Hydrocarbons in the Aquatic Environment. AIBS, 9-11 August 1976. American University, Washington, D.C., 12 p.

84. Nelson-Smith, A. 1970. The problem of oil pollution of the sea. Adv. Mar. Biol. 8:215-306.

85. Nelson-Smith, A. 1971. Effects of oil on marine plants and animals. In: Water Pollution by Oil (P. Hepple, cd.), p. 273-291. In: Proceedings of a Seminar held at Aviemore Inverness-Shire, Scotland, 4-8 May 1970. Institute of Petroleum, London.

86. Notini, M. 1978. Long-term effects of an oil spill on Fucus macrofauna in a small Baltic bay. J. Fish. Res. Board Can. 35:745-753.

87. Ordzie, C. J. and G. C. Garofalo. 1981. Lethal and sublethal effects of short-term acute doses of Kuwait crude oil and a dispersant corexit 9527 on bay scallops, Argopecten irradians (Lamarck) and two predators at different temperatures. Mar. Environ. Res. 5: 195-210.

88. Ottway, S. 1971. The comparative toxicities of crude oils. In: Proceedings of the Ecological Effects of Oil Pollution on Littoral Communities (E. B. Cowell, cd.). Institute of Petroleum, London, p. 172-180.

89. Payne, J. F., J. W. Kiceniuk, W. r. Squires, and G. L. Fletcher. 1978. Pathological changes in a marine fish after a 6-month exposure to petroleum. J. Fish. Res. Board Can. 35:665-667.

90. Pearson, W. H., S. E. Miller, J. W. Blaylock, and B. L. Olla . 1981. Detection of the water-soluble fraction of crude oil by the blue crab, Callinectes sapiolus. Mar. Environ. Res. 5:3-11.

91. Percy, J A. 1977. Effects of dispersed crude oil upon the respiratory metabloism of an arctic marine amphipod, Onisimus (Boekisimus) affinis. In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organism. Proceedings of a symposium. (D. H. Wolfe, cd.). Pergamon Press, pp. 192-200.

92. Percy, J. A. 1978. Effects of chronic exposure to petroleum upon the growth and molting of juveniles of the arctic marine isopod crustacean Mesiodotea entomon. J. Fish. Res. Can. 35:650-656.

93. Percy, J. A. and T. C. Mullin. 1975. Effects of crude oils on arctic marine invertebrates. Beaufort Sea Tech. Rep. No. 11, Environment Canada, Victoria, B.C., 167 p.

94. Portmann, J. E. 1969. Report of the ICES working group on pollution of the North Sea. Int. Count. Explor. Sea. Coop. Res. Rep. Ser. A13, 61 p.

95. Renzoni, A. 1975. Influence of crude oil derivatives and dispersants on larvae. Mar. Pollut. Bull. 4:9-13.

96. Renzoni, A. 1975. Toxicity of three oils to bivalve gametes and larvae. Mar. Pollut. Bull. 6:125-128.

97. Rice, S. D. 1973. Toxicity and avoidance tests with Prudhoe Bay oil and pink salmon fry. In: Proceedings of 1973 Joint Conference on Prevention—and Control of 011 Spills, p. 667-670. American Petroleum Institute, Washington, D.C.

98. Rice, S. D., S. Kern, C. C. Brodersen, S. A. Lindsay, and S. Andrews. 1981. Toxicity of ballast-water treatment effluent to marine organisms at Port Valdez, Alaksa. In: Proceedings of the 1981 Oil Spill Conference. American Petroleum Institute Pub. No. 4334, pp. 55-61.

99. Rice, S. D., S. Kern, and J. F. Karinen. 1980. Lethal and sublethal effects on selected Alaskan marine species after acute and long-term exposure to oil and oil components. In: Environmental asssessment of the Alaskan continental shelf. Annual reports of principal investigators for the year ending March 1980. vol. 3. Effects, pp. 1-12.

100. Rice, S. D., D. A. Moles, and J. W. Short. 1975. The effects of Prudhoe Bay crude oil on survival and growth of eggs, alevins, and fry of pink salmon, Oncorhynchus gorbuscha. In: Proceedings of 1975 Conference on Prevention and Control of Oil Pollution, p. 502-507.

101. Rice, S. D., D. A. Moles, T. L. Taylor, and J. F. Karinen. 1979. Sensitivity of 39 Alaskan marine species to Cook Inlet crude oil and No. 2 fuel oil. In: Proceedings of the 1979 Oil Spill Conference, pp. 549-554. American Petroleum Institute Publ. No. 4308.

102. Rice, S. D., J. W. Short, C. C. Broderson, T. A. Mecklenburg, D. A. Moles, C. J. Misch, D. L. Cheatham, and J. F. Karinen. 1975. Acute toxicity and uptake-depuration studies with Cook Inlet crude oil, Prudhoe Bay crude oil, No. 2 fuel oil and several subarctic marine organisms. Dec. 1, 1975. Northwest and Alaska Fisheries Center, NMFS, NOAA, Auke Bay Fisheries Laboratory Processed Report, 144 pp.

103. Rice, S. D., J. W. Short, and J. F. Karinen. 1976. Toxicity of Cook Inlet crude oil and No. 2 fuel oil to several Alaskan marine fishes and invertebrates. In: Symposium on Sources, Effects, and Sinks of Hydrocarbons in the Aquatic Environment, AIBS, 9-11 August 1976. American University, Washington, D.C., 12 p.

104. Rice, S. D., R. E." Thomas, and J. W. Short. 1977. Effects of petroleum hydrocarbons on breathing and coughing rates and hydrocarbon uptake-depuration in pink salmon fry. In: Physiological responses of marine biota to pollutants. (F. J. Vernberg, A. Calabrese, F. P. Thurberg, and W. B. Vernberg, eds.) Academic Press, p. 259-277.

105. Roesijadi, G., J. W. Anderson, and J. W. Blaylock. 1978. Uptake of hydrocarbons from marine sediments contaminated with Prudhoe Bay crude oil: influence of feeding type of test species and availability of polycyclic aromatic hydrocarbons. J. Fish. Res. Board Can. 35:608-614.

106. Rossi, S. S. and J. W. Anderson. 1976. Toxicity of water-soluble fractions of No. 2 fuel oil and Louisiana crude oil to selected stages in the life history of the polychaete, Neanthes arenaceodentata. Bull. Environ. Contain. Toxicol. 16:18-24.

107. Rossi, S. S., J. W. Anderson, and G. S. Ward. 1976. Toxicity of water-soluble fractions of four test oils for the polychaetous annelids, Neanthes arenaceodentata and Capitella capitata. Environ. Pollut. 10:9-18.

108. Sandberg, D. M., A. D. Michael, B. Brown, and R. Beebe-Center. 1972. Toxic effects of fuel oil on haustoriid amphipods and pagurid crabs. Biol. Bull. 143:475-476.

109. Spies, R. B. and P. H. Davis. 1982. Toxicity of Santa Barbara seep oil to starfish embryos: Part 3 - Influence of parental exposure and the effects of other crude oils. Mar. Environ. Res. 6:3-11.

110. Sprague, J. B. and W. G. Carson. 1970. Toxicity tests with oil dispersants in connection with oil spill at Chedabucto Bay, Nova Scotia. Fish. Res. Board Can. Tech. Rep. 201, 30 p.

111. Stainken, D. M. 1978. Effects of uptake and discharge of petroluem hydrocarbons on the respiration of the soft-shell clam, Mya arenaria. J. Fish. Res. Board Can. 65:637-642.

112. Steele, R. L. 1977. Effects of certain petroleum products on reproduction and growth of zygotes and juvenile stages of the alga Fucus edentatus de la phl (Phaeophycaene: Fucales). In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms. Proceedings of a symposium. (D.A. Wolfe, cd.) Pergamon Press, pp. 138-142.

113. Stegeman, J. J. 1978. Influence of environmental contamination on cytochrome P-450 mixed-function oxygenates in fish: implications for recovery in the Wild Harbor Marsh. J. Fish. Res. Board Can. 35:668-674.

114. Stekoll, M. S., L. E. Clement, and D. G. Shaw. 1980. Sublethal effects of chronic oil exposure on the intertidal clam Macoma balthica. Mar. Biol. 57:51-60.

115. Struhsaker, J. W., M. B. Eldridge, and T. Echeverria. 1974. Effects of benzene (a water-soluble component of crude oil) on eggs and larvae of Pacific herring and northern anchovy. In: Pollution and physiology of marine organisms (J.F. Vernberg and W. B. Vernberg, eds.), p. 253-284. Academic Press, New York.

116. Swedmark, M., A. Granmo, and S. Kollberg. 1973. Effects of oil dispersants and oil emulsions on marine animals. Water Res. 7:1649-1672.

117. Syazuki, K. 1964. Studies on the toxic effects of industrial wastes on fishes and shell-fishes. J. Shimonoseki Coil. Fish. 13:157-211.

118. Szaro, R. C. and P. H. Al bers. 1977. Effects of external applications of No. 2 fuel oil on common eider eggs. In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms. Proceedings of a symposium. (D.A. Wolfe, cd.). Pergamon Press, pp. 164-167.

119. Tagatz, M. E. 1961. Reduced oxygen tolerance and toxicity of petroleum products to juvenile American shad. Chesapeake Sci. 2:65-71.

120. Tatem, H. E. 1977. Accumulation of naphthalenes by grass shrimp: effects on respiration, hatching, and larval growth. In: Fate and effects of petroleum hydrocarbons in 'marine ecosystems and organisms. Proceedings of a symposium. (D. A. Wolfe, cd.). Pergamon Press, pp. 201-209.

121. Tatem, H. E. and J. W. Anderson. 1973. The toxicity of four oils to Palaemonetes pugio (Holthuis) in relation to uptake and retention of specific petroleum hydrocarbons. Am. Zool. 13:1307-1308.

122. Taylor, T. L. and J. F. Karinen. 1977. Response of the clam Macoma balthica (Linnaeus), exposed to Prudhoe Bay crude oil as unmixed oil, water-soluble fraction, and oil-contaminated sediment in the laboratory. In: Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms. Proceedings of a symposium. (D. A. Wolfe, cd.). Pergamon Press, pp. 229-237.

123. Taylor, T. L, J. F. Karinen, and H. M. Feder. 1976. Responses of the clam Macoma balthica (Linnaeus) exposed to Prudhoe Bay crude oil as unmixed oil, water-soluble fraction and sediment-absorbed fraction in the laboratory. Northwest and Alaska Fisheries Center, NMFS, NOAA, Auke Bay Fisheries Laboratory Processed Report, 27 p.

124. Thomas, M. L. H. 1978. Comparison of oiled and unoiled intertidal communities in Chedabucto Bay, Nova Scotia. J. Fish. Res. Board Can. 35:707-716.

125. U*S. Environmental Protection Agency. 1975. Semi-annual Report, January to July 1975. Environmental Research Laboratory, Narragansett, Rhode Island, 137 p.

126. Vanderhorst, J. R., C. I. Gibson, and L. J. Moore. 1976. Toxicity of No. 2 fuel oil to coon stripe shrimp. Mar. Pollut. Bull. 7:106-108.

127. Vandermeulen, J. H. and W. R. Penrose. 1978. Absence of aryl hydrocarbon hydroxylase (AHH) activity in three marine bivalves. J. Fish. Res. Board Can. 35:643-647.

128. Varanasi, U, and D. J. Gmur. 1981. Hydrocarbons and metabolizes in English sole (Parophrys vetulus) exposed simultaneoulsy to (^{3}H)benzo(a)pyrene and (^{14}C) naphthalene in oil-contaminated sediment. Aquatic Toxicology 1:49-67.

129. Vaughan, B. E. 1973. Effects of oil and chemically dispersed oil on selected marine biota. Laboratory study . Am. Pet. Inst. Publ. 4191, 32 p.

130. Wells, P. G. 1972. Influence of Venezuelan crude oil on lobster larvae. Mar. Pollut. Bull. 3:105-106.

131. Wells, P. G. and J. B. Sprague. 1976. Effects of crude oil on American lobster (Homarus americanus) larvae in the laboratory. J. Fish. Res. Board Can. 33:1604-1614.

132. Widdows, J., T. Bakke, B. L. Bayne, P. Donkin, D. R. Livingstone, D. M. Lowe, M. N. Moore, S. V. Evans, and S. L. Moore. 1982. Responses of Mytilus edulis on exposure to the water-accommodated fraction of North Sea oil. Mar. Bio. 67:15-31.

133. Wolf, E. G. and J. A. Strand. 1973. Determination of acute and chronic effects of treated ballast water on selected aquatic biota from Port Valdez, Alaska. Final report to Alyeska Pipleine Service Co., Bellevue, Washington. Prepared by Battelle Pacific Northwest Laboratories, Richland, WA, 37 p.

134. Woodward, D. F., P. M. Mehrle, Jr., and W. L. Mauck. 1981. Accumulation and sublethal effects of a Wyoming crude oil in cutthroat trout. Trans. Amer. Fish. Sot. 110:437-445.