Environmental Assessment of the Alaskan Continental Shelf

Final Reports of Principal Investigators
Volume 12. Biological Studies

U.S. DEPARTMENT OF COMMERCE
National Oceanic & Atmospheric Administration
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FINAL REPORT

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Reproductive Ecology, Foods and Foraging Areas of Seabirds Nesting on The Pribilof Islands, 1975 - 1979

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ACKNOWLEDGEMENTS

Throughout the years of this project, we have become indebted to many people, without whose help our task would have been impossible. We thank the Aleut communities of St. Paul and St. George who allowed us to work on their beautiful islands and assisted us greatly. We thank the Pribilof Island Program of the National Marine Fisheries Service for their support and assistance. These people provided help and logisitic support to our project: Jack Adams, Ken Dzimbel, Roger Gentry, Al Groves, Dick Hajny, John Holt, Mark Keyes, John R. Merculief, Ed Robb, Joe Scordino, Dick Straud and Harold Thayer. The success of our pelagic studies was aided and supported by the captains and crews of the Discoverer, Moana Wave, Surveyor and T. G. Thompson and the helicopter pilots assigned to the Surveyor. Others helped us gather data: Doug Forsell, John Francis, Jim Johnson, Jeanne Koelling, Alexis Prokopiof, Greg McGlashan, Dosy Merculief and Phyllis Merculief. Dr. Barney Easterday and his group provided carcasses of birds for stomach analysis after blood samples were taken for their project. His group also helped by capturing murres for sexing and individual marking for our behavior and attendance studies.

We wish to thank the members of our field crew: Bobbie Braun, Bobbie Mayer, Maura Naughton, Laurie Philemonoff, Bill Rodstrom, Melody Roelke, Doug Schwartz, Sam Sharr, Doug Siegal-Causey and especially Molly Warner who played a major role in organizing and directing our field program during its first two years. These people all put in unreasonably long hours of hard work under miserable conditions for low pay. The project would not have succeeded without their enthusiasm and support.

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We acknowledge the assistance provided by the Juneau NOAA-OCSEAP project office and particularly want to thank George Lapienne, Bob Myers and Rod Swope. We appreciate the discussions and comments of Lawrence Coachman, Ted Cooney, Bill Drury, Tom Kinder, Peter McRoy and Cathy Ramsdell. We wish to thank Denby Lloyd who visited the Pribilofs in 1980 for sharing his observations with us. We apologize to those who have suffered most from this project, Lucia Wisdom and the seabirds of the Pribilofs.

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

The objective of this project was to investigate the reproductive ecology of the seabird community nesting on the Pribilof Islands and to identify aspects of their biology sensitive to oil development activities. To this end, data on the seasonal timing of reproduction, productivity, growth rates of young, food habits and foraging areas were obtained.

The Bering Sea supports the largest aggregation of breeding seabirds in the northern hemisphere. Nesting seabirds are concentrated into a few very large colonies (Figure 1; Hunt et al. 1980b); the Pribilof Islands are one of these large colonies. The colony on St. George Island contains an estimated 2.7 million birds (Hickey and Craighead 1977), and is probably the largest Thick-billed Murre colony in the world. St. George is also the primary nesting area for most of the world's population (88%) of Red-legged Kittiwakes.

The breeding season at the Pribilofs begins with the arrival of many seabird species in April. Most species lay eggs in June and have young by August. The period from late June through early September is the most critical period for Pribilof seabirds; at this time the rigors of chick-rearing place maximum energetic stress on nesting birds. During chick-rearing, breeding adults are largely confined to foraging in areas near the colonies due to the frequent feeding required by young. Several species are finished nesting by the end of August, and by October the colonies are virtually empty.

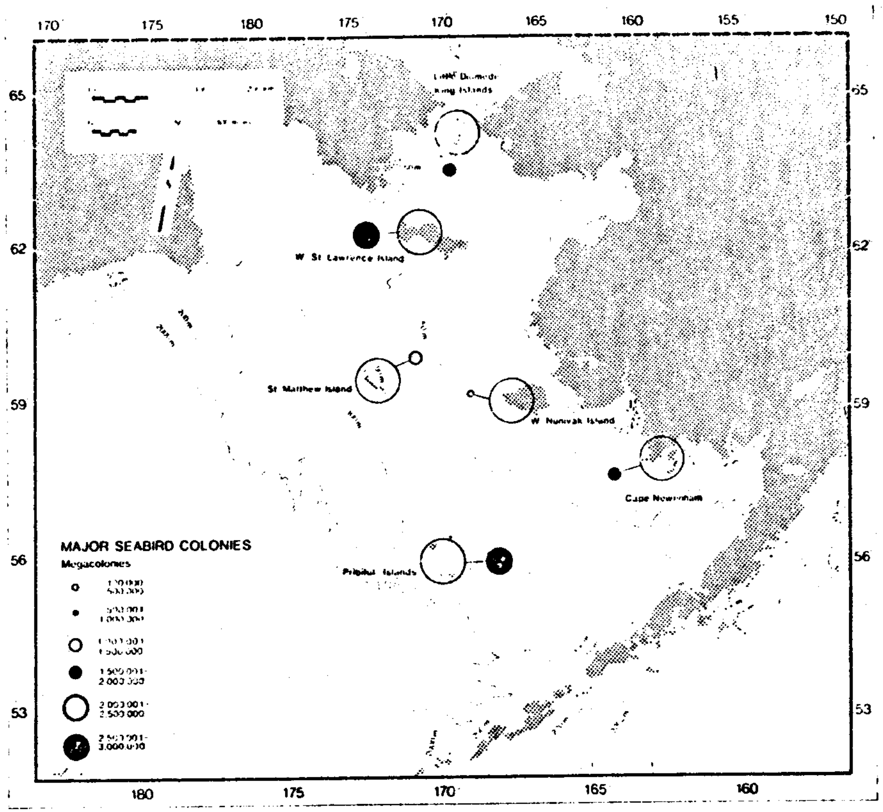

MAJOR SEABIRD COLONIES
Megacolonies
1,500,001-
2,000,000
2,000,001-
2,500,000
W. St Lawrence Island
St Matthew Island
W. Nunivak Island
Cape Newenham
Pribilof Islands

FIGURE 1

Little recent information is available on the winter distribution of seabirds around the Pribilofs, although early accounts (Coues 1874, Preble and McAtee 1923) suggest that a number of species overwinter near the islands. The lack of data on winter use is a serious gap in our knowledge of the biology of Pribilof seabirds.

Estimates of average productivity were made for Northern Fulmars (0.3 chicks fledged/mean no. adults), Red-faced Cormorants (1.3 chicks fledged/nest attempt), Black-legged Kittiwakes (0.5 chicks fledged/nest attempt), Red-legged Kittiwakes (0.4 chicks fledged/nest attempt), Common Murres (0.6 chicks fledged/egg laid) and Thick-billed Murres (0.6 chick fledged/egg laid) (Hunt et al. 1980c). Values found at the Pribilofs for most species were within the range of productivity found elsewhere in the Bering Sea, except that productivity of Black-legged Kittiwakes at the Pribilofs was higher, on average, than elsewhere in the Bering Sea. However, Bering Sea Black-legged Kittiwakes in general showed depressed productivity relative to kittiwakes nesting in the Chukchi Sea (Swartz 1966), Gulf of Alaska (Baird et al. 1979) and the North Atlantic (Coulson and White 1958).

Average growth rates of young were estimated for Red-faced Cormorants (60 gm/day), Black-legged Kittiwakes (14 gm/day), Red-legged Kittiwakes (12 gm/day), Common Murres (9.8 gm/day), Thick-billed Murres (11 gm/day) and Horned Puffins (11 gm/day). At the Pribilofs, Black-legged Kittiwake growth rates are similar to those found in the Chukchi Sea (Swartz 1966) and Gulf of Alaska (Baird et al. 1979) but appeared to be lower than values from the North Atlantic (Coulson and White 1958).

As a whole, the seabird community at the Pribilofs relies on a few prey species: juvenile walleye pollock (Theragra chalcogramma) are used most heavily, while amphipods (Parathemisto) and euphausiids (Thysanoessa) are also of considerable importance. Myctophid fishes and calanoid copepods, although not important to the seabird community as a whole, are a major part of the diet of particular seabird species.

Around the Pribilofs, foraging seabirds are concentrated within 50 km of the islands, although a few species (e.g. Northern Fulmar, Red-legged and Black-legged Kittiwakes) forage at greater distances from their colonies. Crucial foraging areas for Pribilof seabirds are located at the shelf break southeast of St. George, on the shelf 100 km east of St. Paul, and generally within 50 km of the islands. The reduction of food resources, or the occurrence of oil spills in these areas would affect a great number of birds.

The potential for an oil spill to have devasting effects on the Pribilof seabird community is greatest during the peak of the breeding season, particularly if important foraging areas near the islands are impacted (Wiens et al. 1979). Along with the dangers of oil spillage, oil development activities near the colonies may lower productivity through increased levels of disturbance. Aircraft disturbance is a primary concern; our limited experience suggests that both fixed wing aircraft and helicopters flying over colonies may cause major losses of eggs and young (Hunt et al. 1978). Murres, who lay their eggs on precarious ledges, are particularly vulnerable to disturbance. Chronic disturbance during the nesting season could significantly lower murre productivity in affected areas to the point where future recruitment to the population was affected.

Some species, by virtue of their life history strategies, are more vulnerable to spilled oil and disturbance than others (King and Sanger 1979). Fulmars and cormorants are intermediate in their sensitivity to oil. Alcids are particularly sensitive because of the time they spend on the water and their generally low productivity. It is likely that the gulls, including kittiwakes, are relatively insensitive to spilled oil because of the comparatively little time they spend on the water and their higher reproductive potential. The Red-legged Kittiwake is a possible exception due to its restricted breeding range and low reproductive potential.

Vulnerability of a species to oil spills or disturbance at the colonies is increased when a large proportion of the population is concentrated in a small area. Several species have a large proportion of their Bering Sea population concentrated at the Pribilofs: Northern Fulmar, Red-legged Kittiwake, Thick-billed Murre and Parakeet Auklet. Other species with large populations at the Pribilofs also have large colonies elsewhere in the Bering Sea: Black-legged Kittiwake, Common Murre, Crested Auklet and Least Auklet. Horned Puffins, Tufted Puffins and Glaucous-winged Gulls have only small populations at the Pribilofs. Storm-petrels and shearwaters occur in large numbers around the Pribilofs, but do not nest on the islands. Substantial numbers of storm-petrels are dispersed along the shelf break. Their large numbers and close association with the water surface make them vulnerable to oil.

However, their dispersion over a large area makes it unlikely that many would be affected by a single spill. Shearwaters occur in large flocks, occasionally numbering up to a million birds. These flocks are concentrated shoreward of the 50 m isobath during summer and over the shelf break in the fall. The large concentrations of shearwaters and the time they spend on the water make them particularly vulnerable to spilled oil. Shearwaters nest in the southern hemisphere during our winter, spending the summer in the Bering Sea. A spill in the Bering Sea affecting shearwaters would impact ecosystems in both the northern and southern hemispheres.

INTRODUCTION

Confronted with the prospect of oil exploration and its associated hazards, it is necessary to study and understand the status and natural fluctuations of populations which may be affected. Marine birds are an integral part of ecosystems in the Bering Sea. The seabird community of the Bering Sea is rivaled in numbers only by those in the Antarctic.

The Pribilof Islands lie in a rich oceanic community associated with upwelling at the outer front (Kinder and Schumacher 1980) and the continental slope. This region combines the abundant fisheries of the southeastern Bering Sea shelf with the complex invertebrate fauna of the shelf break and oceanic regions. The Pribilof Islands are known for their large populations of marine birds and mammals. The seabird colonies, with high species diversity and large numbers, are among the most important in the Northern Hemisphere. In addition, Red-legged Kittiwakes and Northern Fulmars, which have restricted breeding distributions in the Bering Sea, have large populations at the Pribilofs.

The goal in studying the reproductive biology of each species of seabird was to establish the timing of breeding, the number of eggs laid, productivity, growth rates of young, and the timing and reasons for reproductive failure. These factors are indicative of the health of seabird populations. Knowledge of when and why normal stresses in the breeding cycle occur facilitates predictions of the effects of oil spills or other perturbations on these systems. Nesting seabirds are particularly vulnerable because they are concentrated in colonies and are dependent on foraging areas within a limited distance of the colonies. Fledglings are unusually vulnerable to oil on the sea because of their inexperience in feeding and locomotion.

Data on the foods and foraging areas used by seabirds were collected in order to determine in which ocean areas oil spills would be particularly damaging to Pribilof seabird populations. Knowledge of the food chains on which seabirds depend is necessary to establish the role of seabirds in marine ecosystems, and to predict the direct and indirect effects of petroleum development on the availability of food organisms, and hence on seabird populations.

This report summarizes the knowledge of the numbers, distribution, reproductive biology and foods of seabirds nesting on the Pribilof Islands. Many of the previous years' data have been reanalyzed for this report to reflect our improved analysis schemes. Hence, this final report supercedes our previous reports.

CURRENT STATE OF KNOWLEDGE

Colony Studies

Baseline studies sponsored by OCSEAP have helped to identify regions of the Bering Sea that may be particularly vulnerable to oil spills. Multi-year colony studies (Drury 1976, Drury and Steele 1977, Biderman and Drury 1978, Ramsdell and Drury 1979, Hunt 1976, 1977, Hunt et al. 1978) have provided information on average productivity and natural fluctuations in population numbers. The Bering Sea synthesis projects (Hunt et al. 1980a, b, c) indicate which oceanic regions and prey species are of primary importance for seabirds, as well as the relative importance of different colonies in sustaining Bering Sea seabird populations.

Before 1973, information on seabirds breeding in the Bering Sea was derived from short visits to colonies, and consisted of narratives, brief species accounts, and population estimates. Only the northern auklets had received extensive study (Bédard 1967, 1969a and b; Sealy 1968; Sealy and Bédard 1973). Information on cliff-nesting species was more limited; Dick and Dick (1971) provided considerable comparative information on seabirds nesting at Cape Peirce, and Fay and Cade (1959) reported on the colonies of St. Lawrence Island.

Although the colonies at the Pribilofs are among the largest in Alaska, surprisingly little was known about them prior to this study. Preble and McAtee (1923) provided a summary of knowledge of the Pribilof avifauna, including fragmentary information on numbers, timing of breeding and food habits, and the only data on spring arrival and fall departure dates. In more recent studies, Kenyon and Phillips (1965), Sladen (1966) and Thompson and DeLong (1969) provided updates on the records of unusual species visiting the islands. The work of Kenyon and Phillips (1965) gave comparative information on the breeding biology and numbers of the two species of kittiwakes. DeLong and Thompson (1969) have scattered data on the numbers and phenology of some species nesting at the Pribilofs. In comparing estimates of current seabird populations at the Pribilofs (Hickey and Craighead 1977) to earlier accounts (Kenyon and Phillips 1965, Gabrielson and Lincoln 1959, p. 501), it appears that the numbers of some species have changed. In particular, Crested and Least Auklets and Common Murres may have declined, while Black-legged Kittiwakes may have increased in numbers.

Pelagic Studies

The pelagic distribution of seabirds is relevant to OCS oil production because their at-sea distribution will affect their potential vulnerability to oil spills. The relationship between the distribution of marine birds in the North Pacific/Bering Sea and the oceanographic features of these waters has been studied in recent years. Kuroda (1960) attempted to correlate numbers of seabirds with food availability and sea surface temperature, and Shuntov (1972) stressed the importance of upwelling near the shelf break, as well as the higher productivity and larger bird concentrations of the shelf waters. Swartz (1966) discussed bird distribution in the Chukchi Sea and Bering Strait regions.

Prior to OCSEAP cruises, knowledge of the pelagic distribution of seabirds over the eastern Bering Sea shelf was limited. Irving et al. (1970), Bartonek and Gibson (1972) and Wahl (1978) reported on birds seen in the course of single cruises, made for other purposes, which spent only brief periods in shelf waters. Wahl found a marked change in the density of birds and their species composition as he crossed from the deep oceanic waters to over the shelf break. In particular, storm-petrels were less common over the shelf, while murres and shearwaters increased in density. Wahl estimated a density fo 3.9 birds/km^2 for the oceanic waters compared to 14.9/km^2 for shelf waters. These values were similar to those obtained by Shuntov (1972) of 2.7/km^2 and 18/km^2, respectively. Sanger (1972) provided estimates of pelagic bird density over the Bering Sea shelf and oceanic basin based on extrapolations from other ocean regions. Most recently Iverson et al. (1979) have shown that seabird densities over the south-eastern Bering Sea shelf are related to frontal systems. In a series of cruises, bird densities were highest from the Outer Front (Figure 85), at the 200 m isobath, shoreward to the Middle Front, at the 100 m isobath.

Oil Effects

A vast literature exists on the effects of oil pollution on seabirds. Vermeer and Vermeer (1974) provide an annotated bibliography. More recently Holmes and Cornshaw (1977) have reviewed the biological effects of petroleum on birds with particular emphasis on physiological effects. OCSEAP sponsored studies have investigated the effects of oil on seabird reproduction (Patten and Patten 1977, 1978).

There are conflicting reports as to the behavior of seabirds when encountering oil slicks; Curry-Lindahl (1960) reported that

Oldsquaw were attracted to slicks. In contrast, Herring Gulls, Black-legged Kittiwakes and Common Murres are reported to leave slicks once they encounter one (Bourne 1968a). Differences in the reaction of birds to oil slicks affects the vulnerability of a species and the potential for population loss when oil is spilled.

Other studies have concentrated on the effects of oil spills on populations. Milon and Bougerol (1967, in Vermeer and Vermeer 1974) document changes in populations of seabirds on the Ile Rouzic in France subsequent to the Torrey Canyon disaster. Within a month the populations of Atlantic Puffins and Razorbills were reduced by 88% while the population of Common Murres was reduced by 75%. Populations of fulmars and gulls were affected to only a minor degree. Studies by O'Connor (1967), Phillips (1967) and Monnat (1967) report on the effect of the Torrey Canyon spill on alcids and gannets at other locations. The lack of a baseline hindered the study of effects of the Torrey Canyon spill on seabird numbers and reproductive success.

These studies, although fragmentary, show that alcids and sea ducks are particularly vulnerable to oil. King and Sanger (1979) developed an oil vulnerability index for marine birds for the North Pacific and Bering Sea regions. The sensitivity of alcids to oil pollution is a critical problem in relation to Alaskan oil recovery, as the large colonies are predominately populated by alcids. In fall and spring, sea ducks may occur in vast numbers, also creating the potential for the devastation of populations. Wiens et al. (1979) have modeled the effects of oil spills under various conditions on the Pribilof seabird colonies, and made predictions about the time for population recovery.

Sublethal doses of oil may affect reproduction; Patten and Patten (1978) found that injested oil caused aberrent incubation behavior in Herring Gulls, which included a failure to replace lost eggs. Grau et al. (1977) reported that injested oil caused inhibition of egg-laying or altered yolk structure, while oil transfered from the plumage of adults onto eggs greatly reduced their viability (Macko and King 1980).

Sublethal doses of oil may also lower the viability of adults by ruining the insulation provided by the feathers (Hartung 1967, McEwan and Koelink 1973). Since oiled birds usually stop eating (Hartung 1967), starvation, accelerated by depletion of fat reserves for thermoregulation, rapidly follows oiling.

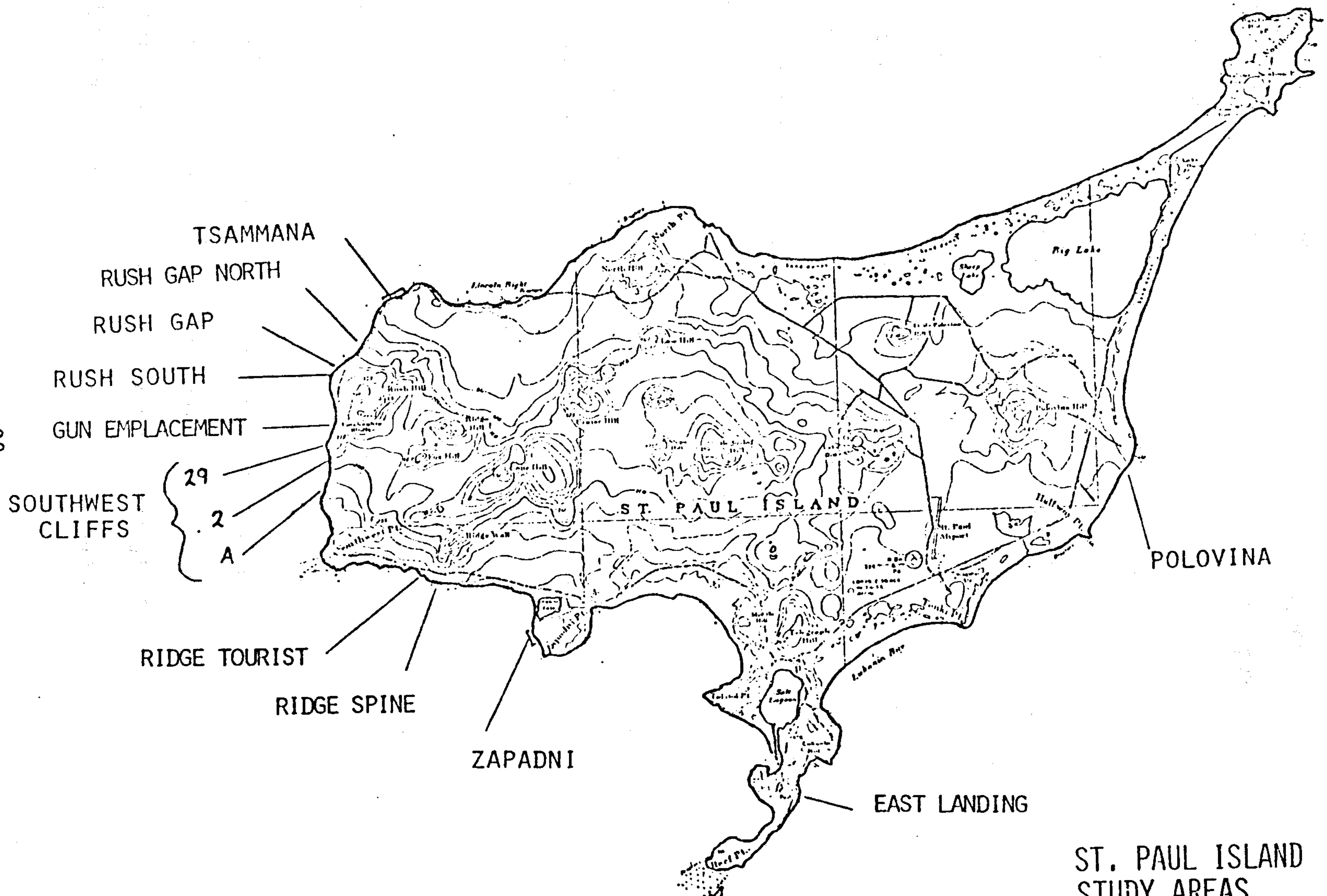
METHODS

STUDY AREAS

In our studies of the reproductive biology of Pribilof seabirds, we have focused on the two large islands, St. Paul and St. George, which support the largest seabird colonies. The two smaller islands which make up the Pribilof group, Walrus and Otter Islands, have only been briefly surveyed.

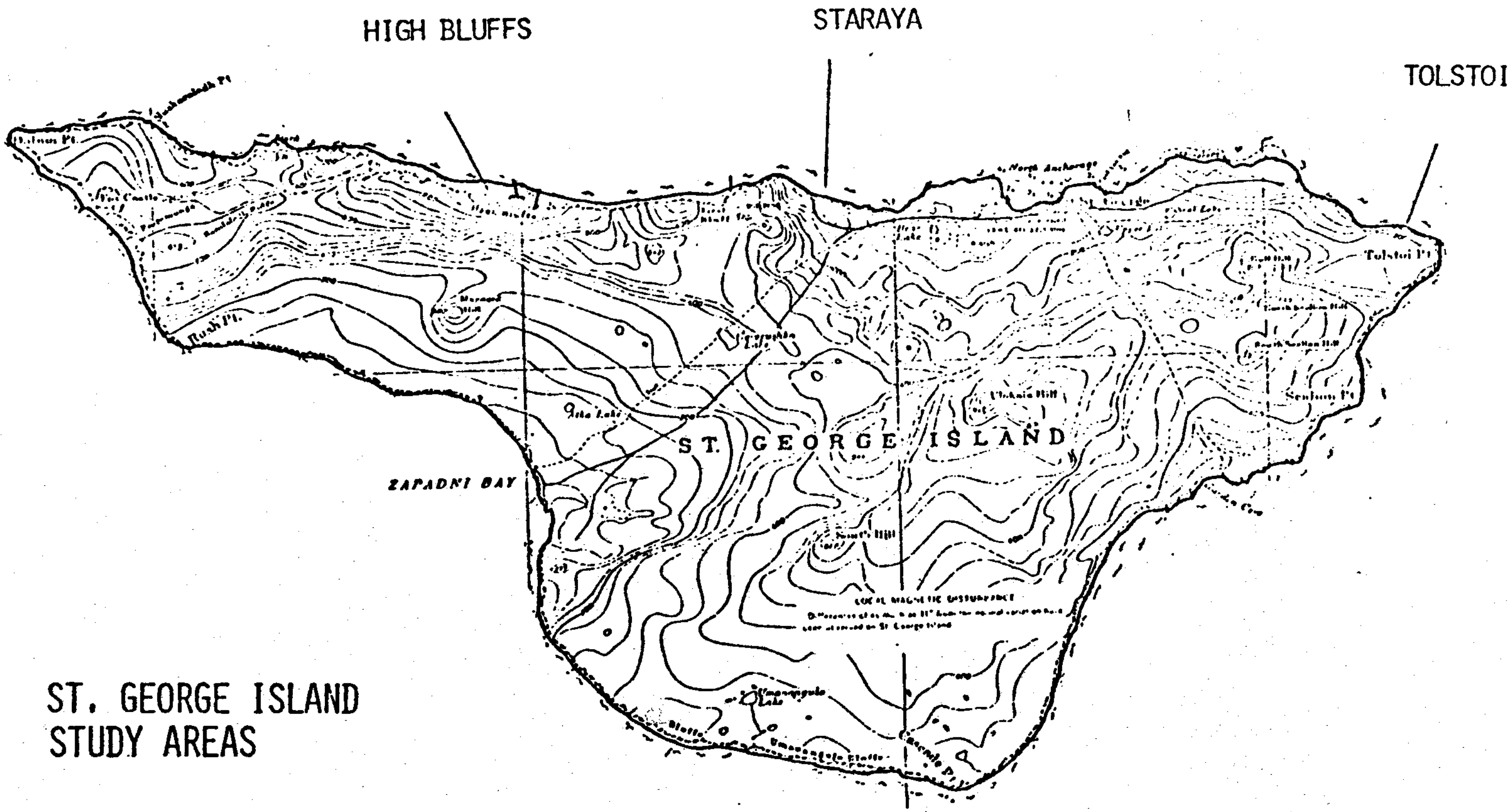
The productivity of Pribilof seabirds was investigated by following the progress of nesting from before egg-laying to fledging for a minimum of 100 nests for each species we studied. This goal was largely attainable for Black-legged Kittiwakes, Red-legged Kittiwakes and Thick-billed Murres, and to a lesser extent for Red-faced Cormorants and Common Murres. For these species, we had a number of study sites around the islands, each containing 15 to 20 nest sites (Figures 2-3). We were limited in our choice of sites by a requirement for good visibility from a safe vantage point on the cliff top within about 50 m of the nest. In addition, we required sites which could be reached within a few hours. This was a greater consideration on St. George Island where the road system is less extensive than on St. Paul Island. Despite these constraints on our choice of study sites, we believe our sites were sufficiently diverse so that no systematic bias was introduced.

For our investigation of chick growth and chick foods, we required concentrations of nests within reach of our ladders, that is, within 20 feet of the cliff base. On St. Paul Island, we located ladder-accessible sites for Black-legged Kittiwakes, Red-legged Kittiwakes and Red-faced Cormorants at Tsammana, for Thick-billed



ST. PAUL ISLAND
STUDY AREAS

FIGURE 2



ST. GEORGE ISLAND
STUDY AREAS

FIGURE 3

Murres and Horned Puffins at Ridge Wall and for Common Murres at Zapadni cliffs. On St. George Island, ladder sites were located at Tolstoi for Red-faced Cormorants, Black-legged Kittiwakes, Red-legged Kittiwakes and Thick-billed Murres, and at Staraya Artil for Red-legged Kittiwakes, Black-legged Kittiwakes, Thick-billed Murres and Common Murres.

We were not able to locate more than a few nests for many of the crevice-nesting species, including Least, Parakeet and Crested Auklets, Horned and Tufted Puffins. However, we were able to mist-net large numbers of Least Auklets at East Landing beach on St. Paul and Village Beach at St. George and made inferences about Least Auklet nesting phenology based on the presence of brood patches, gonadal state and the presence of food in the gular pouch.

To supplement our studies of the reproductive biology of Pribilof seabirds, we collected food samples. On St. Paul Island, birds were shot at Southwest Point and at the base of Zapadni cliffs, near Antone Lake, as they returned from foraging at sea. On St. George Island, birds were collected at Staraya Beach and at Zapadni Bay Beach.

In order to determine the important foraging areas for Pribilof seabirds, we surveyed the waters around the Pribilofs from ships and from aircraft. The cruise tracks were designed to determine the location of major concentrations of seabirds near the Pribilofs and to search for flight lines suggesting the existence of important foraging areas at greater distances from the islands. In addition, we surveyed the St. George Basin in order to assess the seabird use of this potential lease-sale area. For the most complete coverage of our study area, we have included transects near the Pribilofs from other investigators' work in our analysis. These other transects were obtained through the NOAA data base and came chiefly from U.S. Fish and Wildlife Service pelagic surveys as well as those of Juan Guzman.

PELAGIC STUDIES

The pelagic distribution of seabirds around the Pribilof Islands was studied on 15 shipboard cruises (Table 1). Additionally, data for the area around the Pribilofs gathered by other Research Units and available on the NOAA data base were used to supplement our data. Figures 4-13 illustrate the sampling distribution and the number of transects in each 10° by 10° block of latitude and longitude. A shipboard helicopter, available in 1977 and 1978, allowed us to further supplement our observations with aerial surveys, which are not subject to inflation of density estimates due to ship-following birds.

Table 1. Cruises made during RU 83 to study the pelagic distribution of seabirds.

Year	Dates	Cruise No.	Vessel
1975	20-23 Aug	UCI501	Discoverer
1976	2-4 June	UCI601	Moana Wave
1976	7-12 July	UCI602	Moana Wave
1977	7-11 July	UCI701	Surveyor
1977	7-11 July	UCI704	helicopter
1977	1-5 Aug	UCI702	Surveyor
1977	1-4 Aug	UCI703	helicopter
1978	9-28 April	UCI478	T.G. Thompson
1978	25 April-2 May	UCI801	Surveyor
1978	30 April-1 May	UCI808	helicopter
1978	26 May-12 June	UCI802	T.G. Thompson
1978	18-28 June	UCI804	T.G. Thompson
1978	3-10 July	UCI805	T.G. Thompson
1978	10-15 Aug	UCI803	Surveyor
1978	22-27 Sept	UCI806	Discoverer

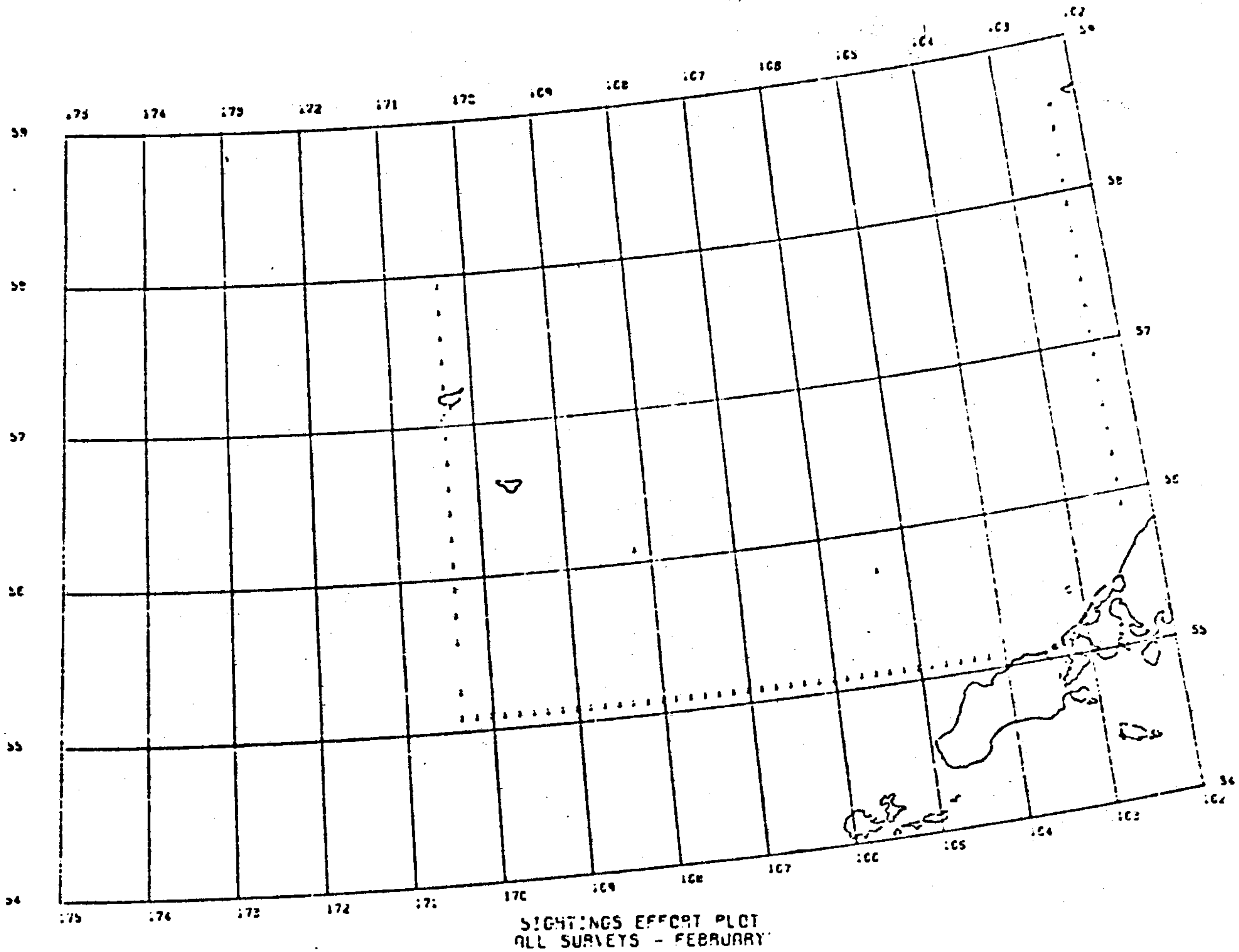


FIGURE 4

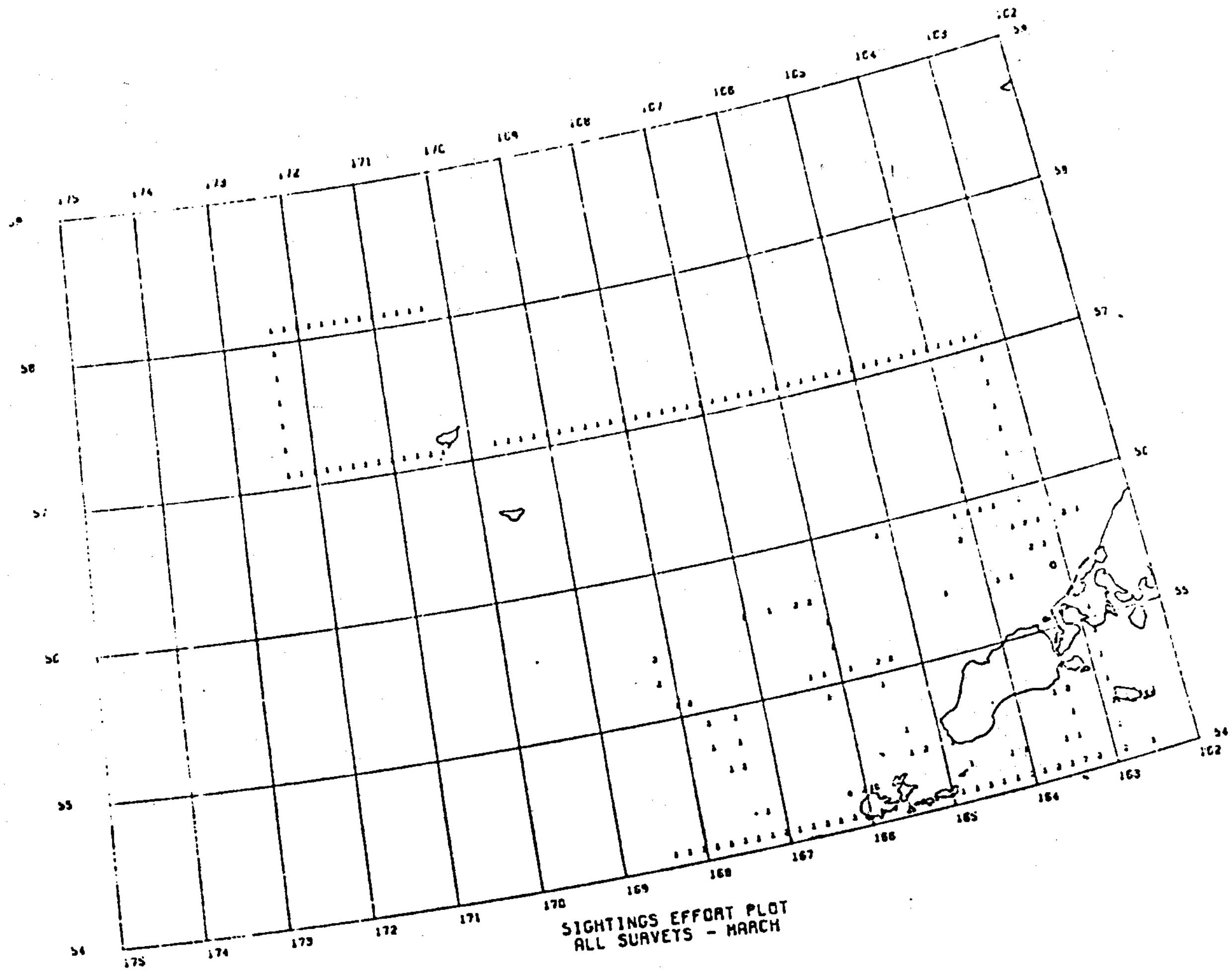
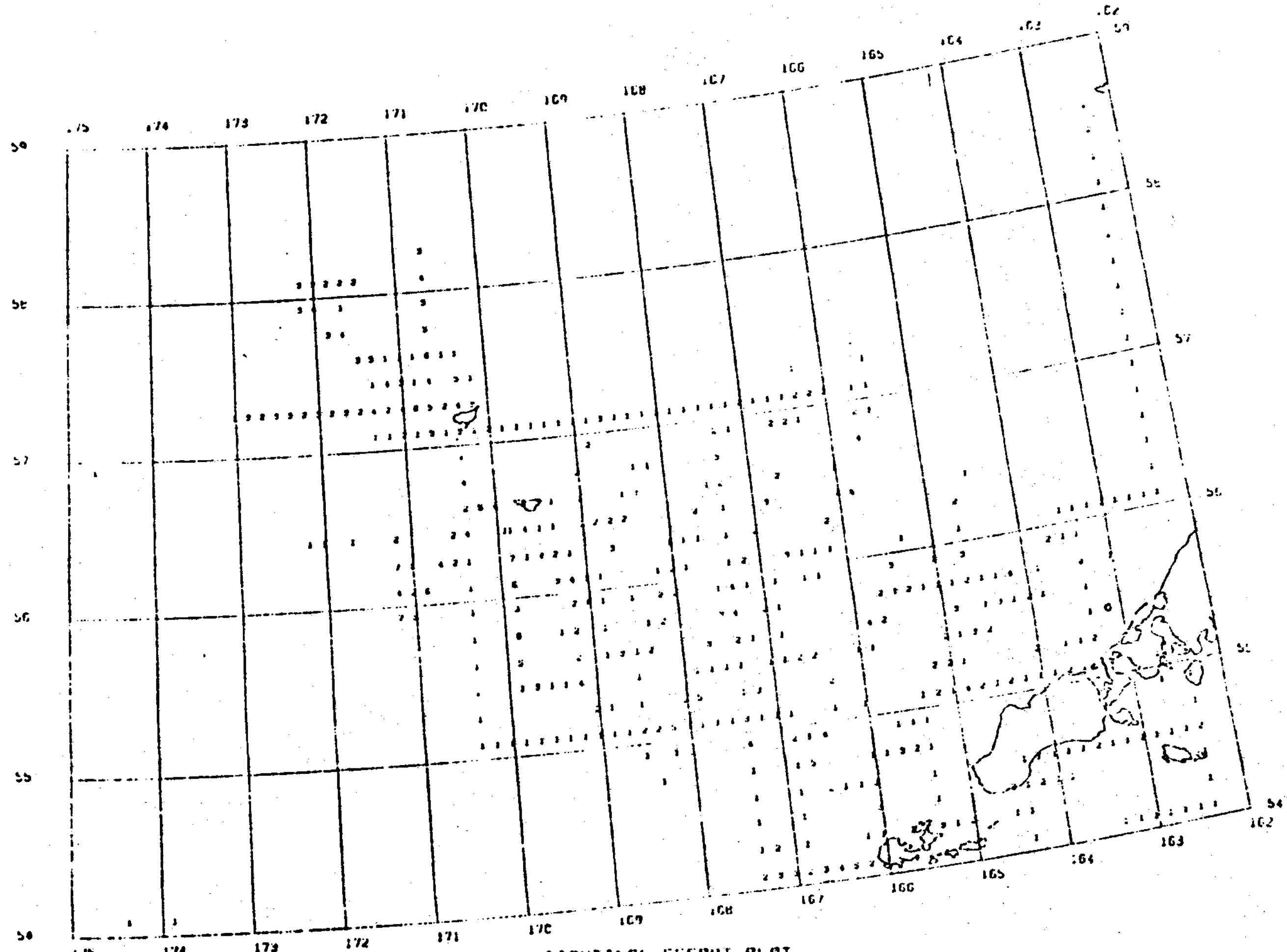


FIGURE 5



SIGHTINGS EFFORT PLOT
ALL SURVEYS - APRIL

FIGURE 6

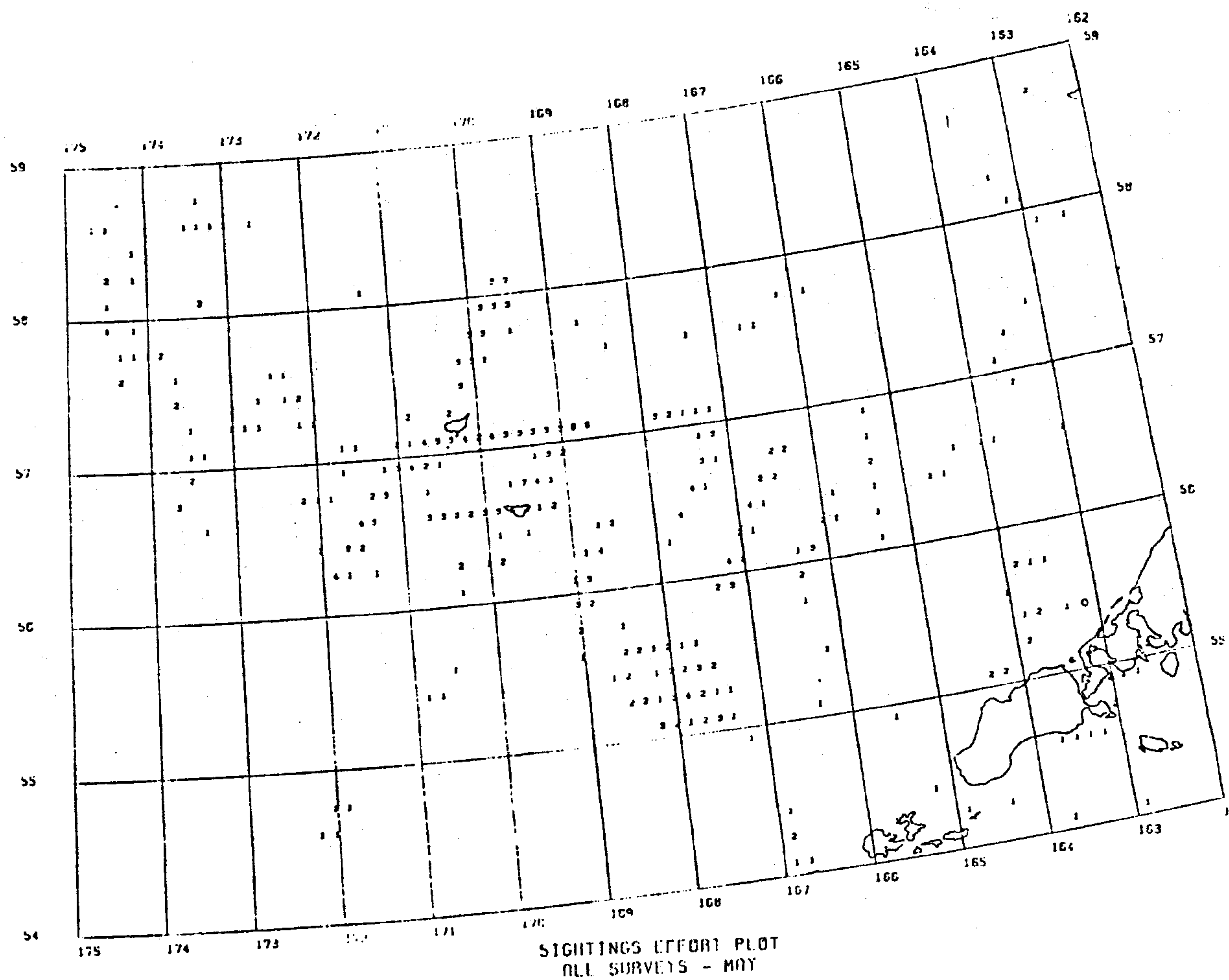
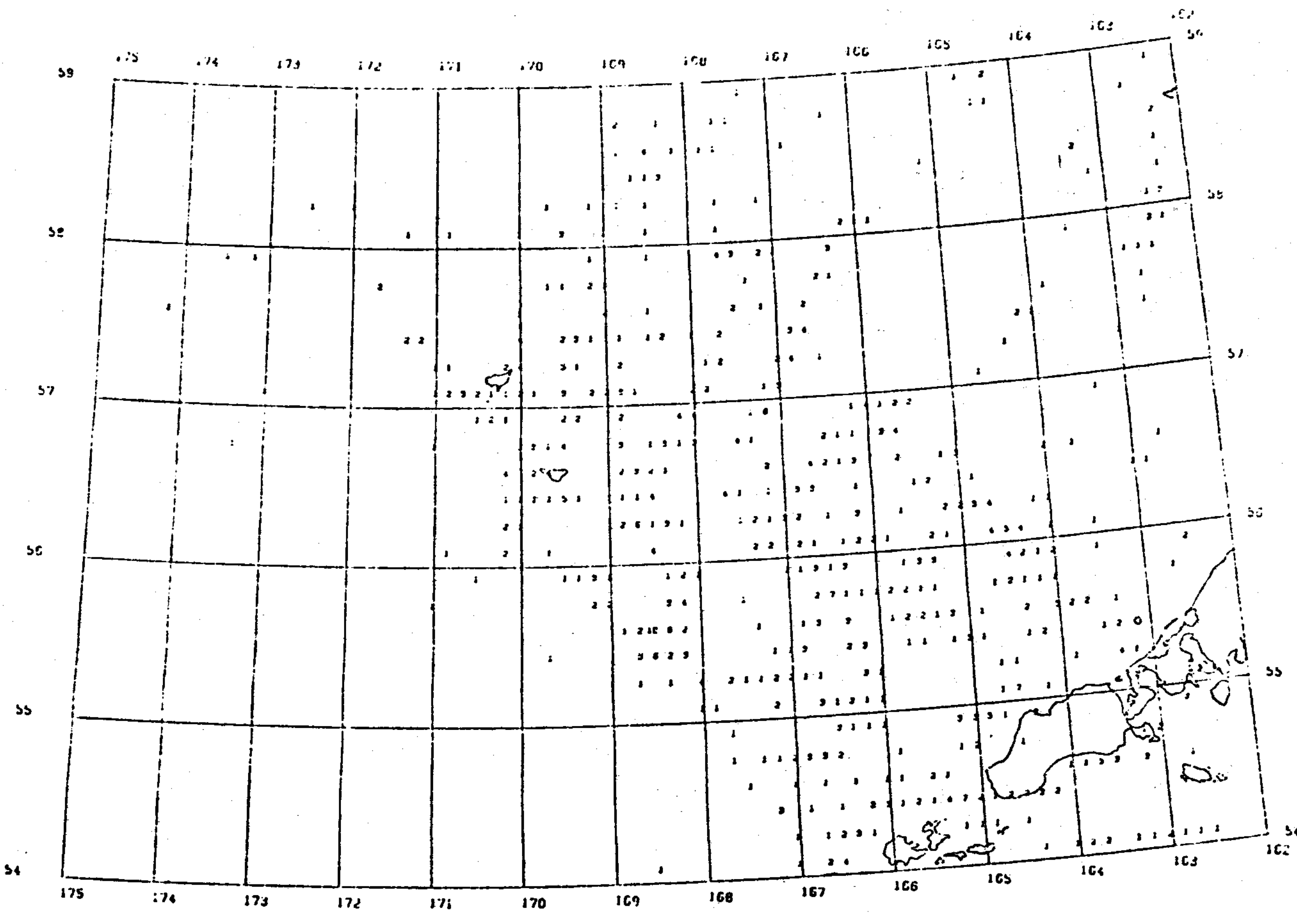
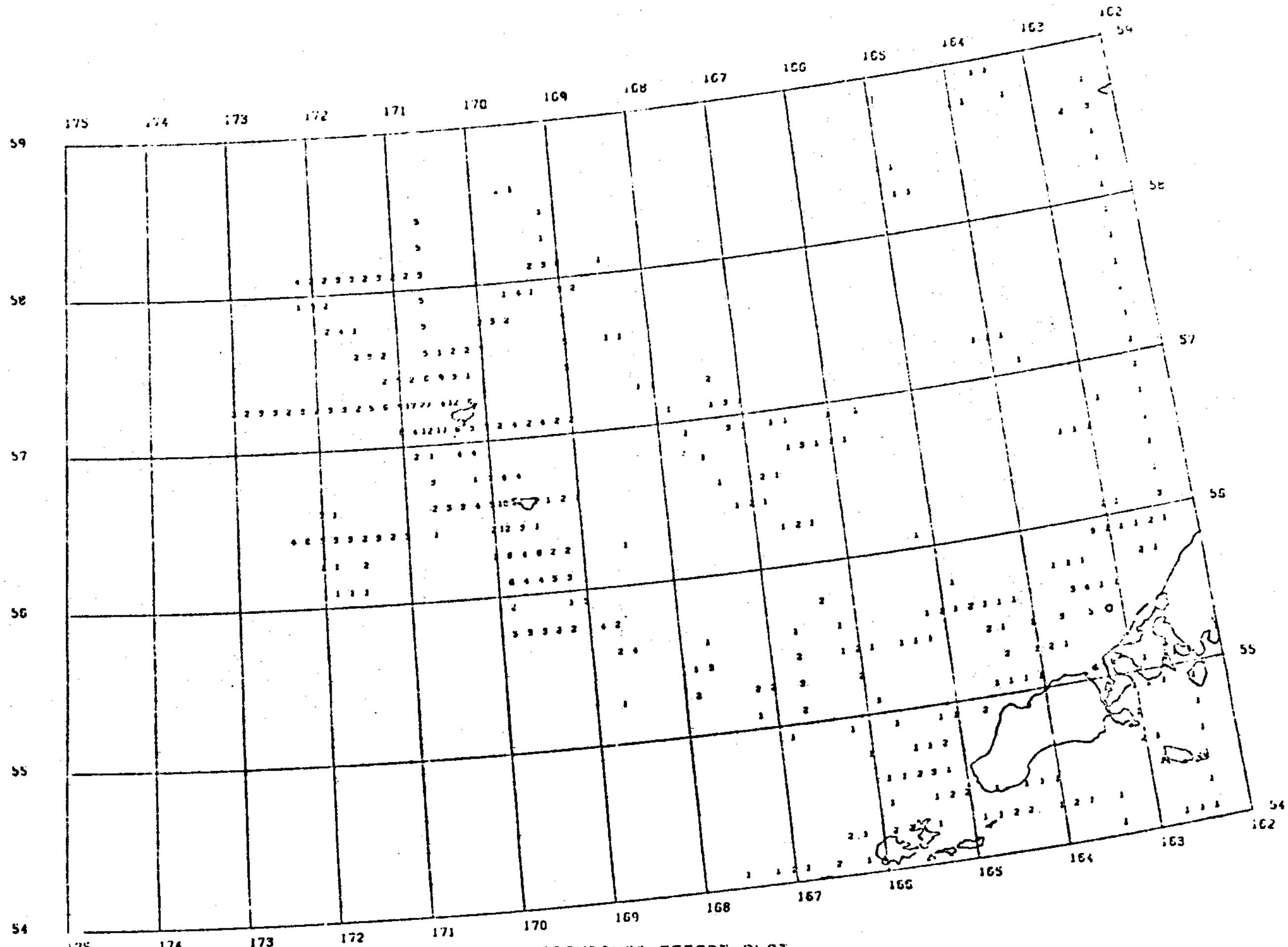


FIGURE 7



SIGHTINGS EFFORT PLOT
ALL SURVEYS - JUNE

FIGURE 8



SIGHTINGS EFFORT PLOT
ALL SURVEYS - JULY

FIGURE 9

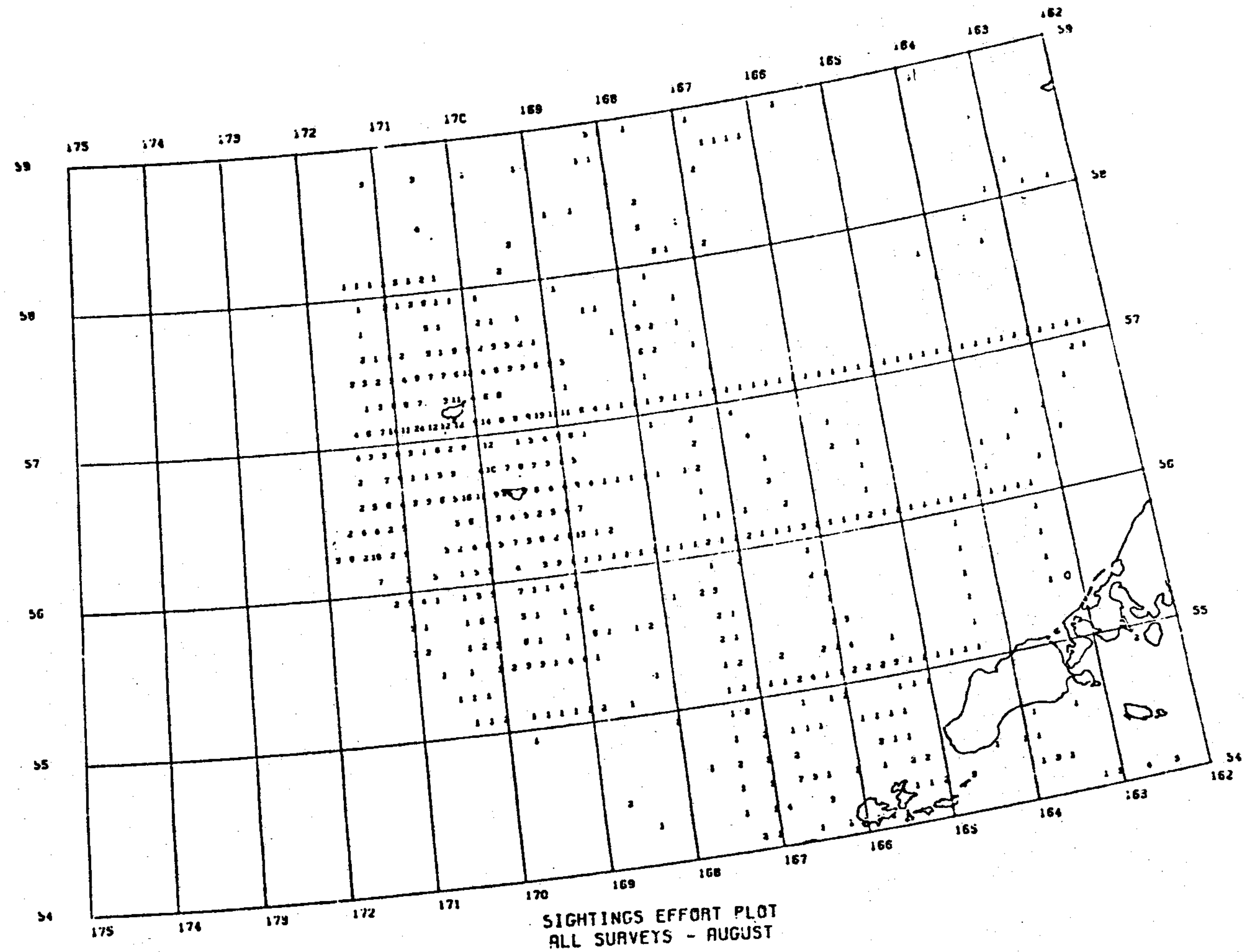
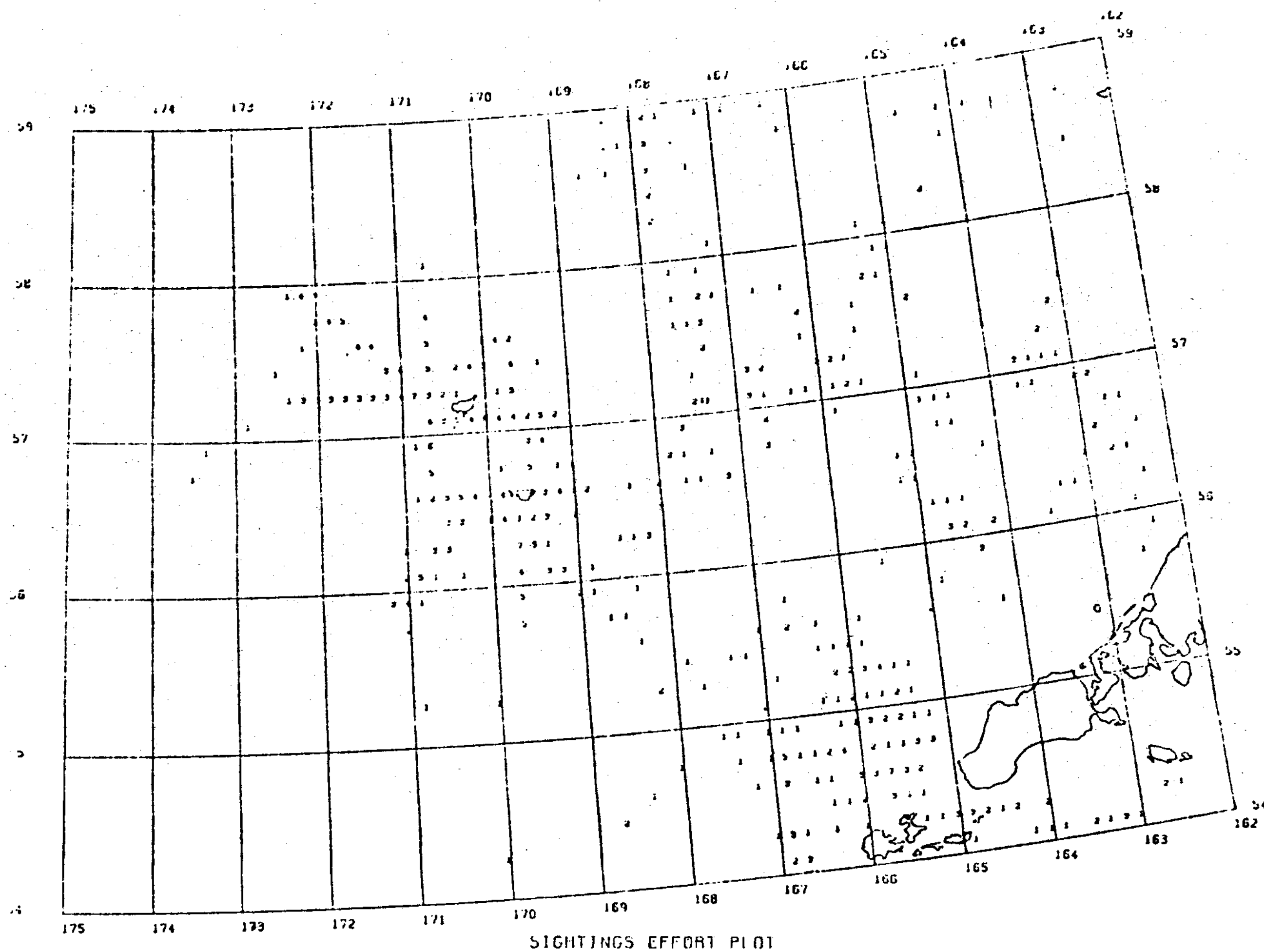
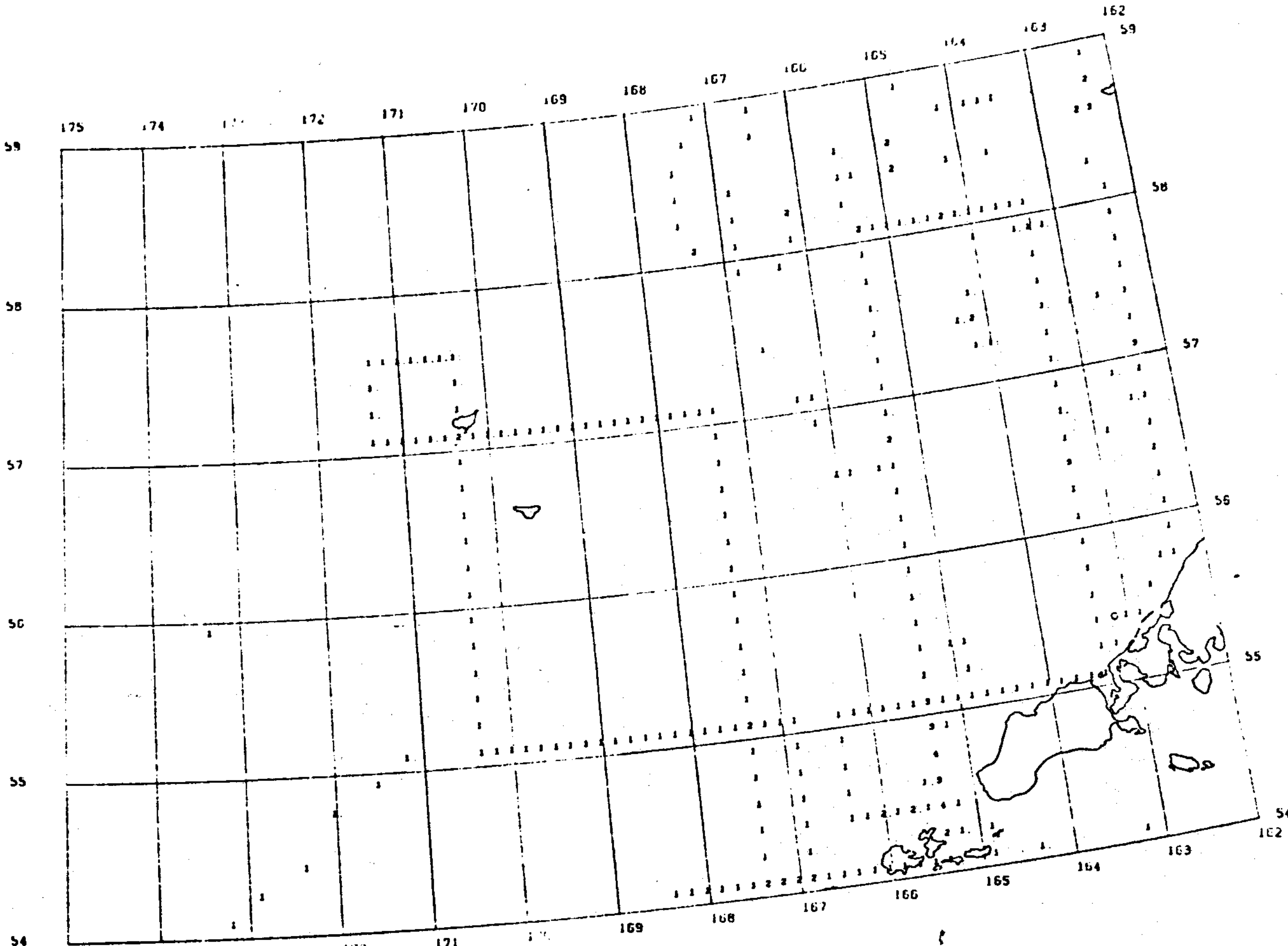


FIGURE 10



SIGHTINGS EFFORT PLOT
ALL SURVEYS - SEPTEMBER

FIGURE 11



SIGHTINGS EFFORT PLOT
ALL SURVEYS - OCTOBER

FIGURE 12

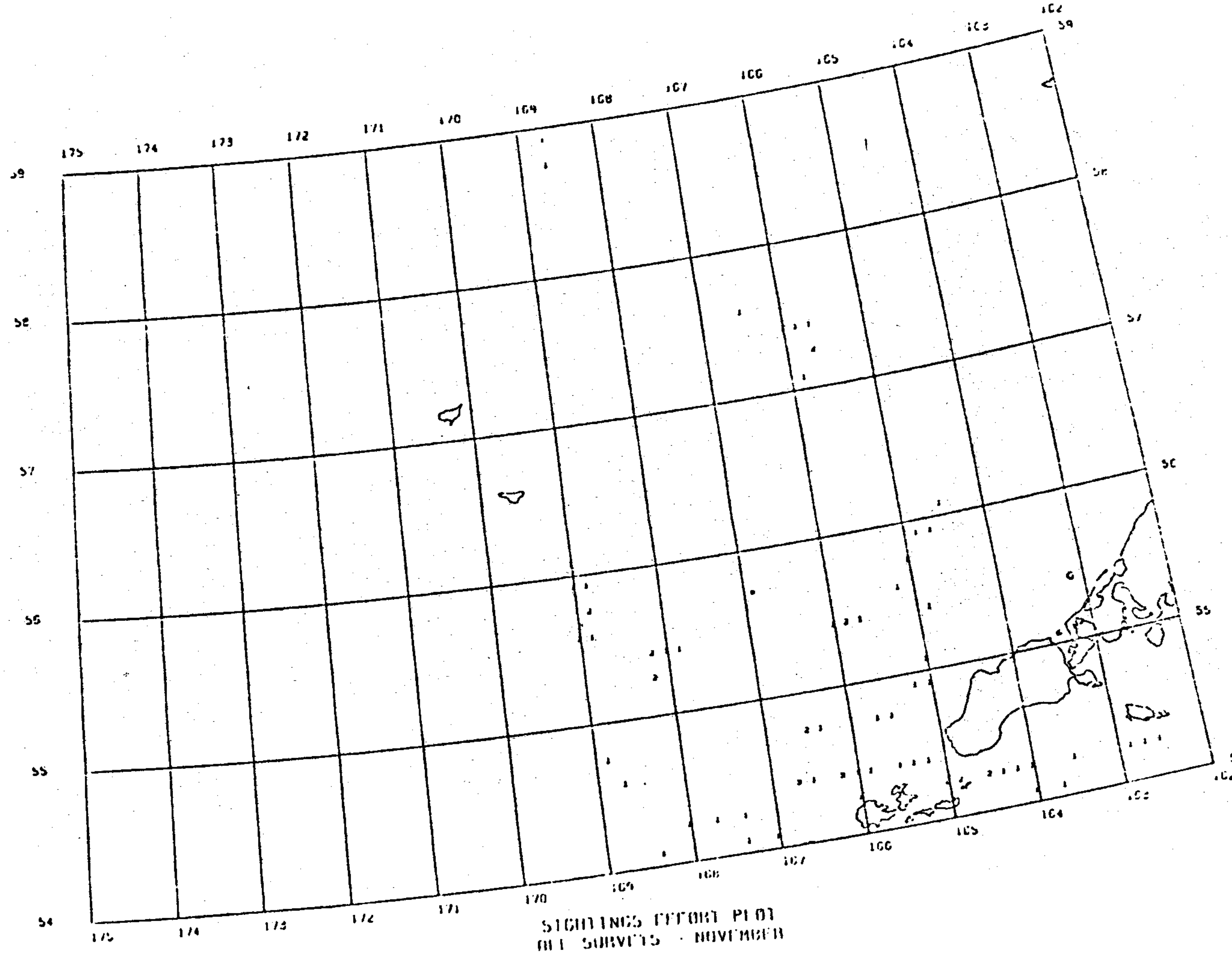


FIGURE 13

Sampling Technique

Seabird observations were taken almost continuously during daylight hours when the ship was near the Pribilof Islands. Our observations were made from the flying bridge (eyelevel 10 m above water for the Moana Wave and 13 m for the Discoverer and the Surveyor). Birds were counted within 100 m zones, out to 300 m from the ship. Counts were made on one side of the vessel only, from dead ahead to 90° to one side. At the time of observation, data were transcribed onto data forms. We recorded species, number, behavior, such as feeding, sitting on the water, flying and flight direction. At the start and end of each transect, time, ship's position, oceanographic and meterological data were recorded. To avoid inflating our estimates of seabird density, we attempted to count ship-followers only once; for the same reason, ship personnel were asked not to dump garbage over the side during transects.

Aerial transects were taken somewhat differently; birds were counted within a 50 m wide zone along the path of the helicopter. The helicopter maintained constant altitude, 40 m, and constant speed, 120 kph. Position readings were taken at the beginning and end of each transect; the helicopter's computer system provided constant position readings accurate to 1/10 nautical mile. Data were recorded at the time of observation onto a cassette tape and later transcribed onto data forms.

Data Reduction and Analysis

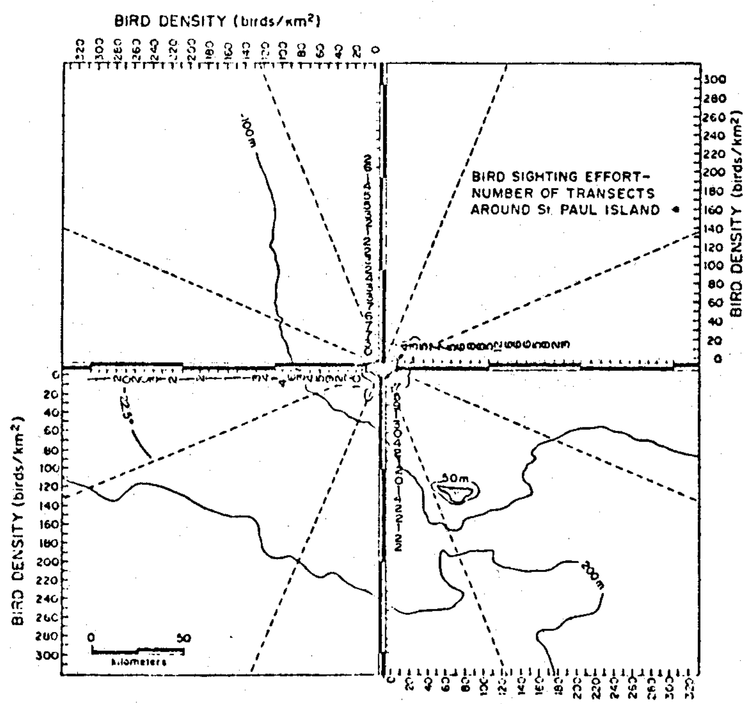
We entered our data onto floppy diskettes using a Texas Instrument 771 Intelligent Terminal and a Forms Program developed by the Data Projects Group, Pastore Laboratory, University of

Rhode Island (URI), which coded our data and made them compatible with NODC format. We sent our diskettes to URI where the data were range checked and any discrepancies were sent back to us for correction. The data were then added to a tape containing all previous RU 83 cruises for the year. Copies of the tape were forwarded to NOAA and to us.

At our request, the Data Projects Group developed a graphics program which plotted out mean seabird density, as a graduated symbol, within each 10° by 10° block, superimposed on a map of the Bering Sea. They were able to produce these maps for any species or species grouping, and for any time period. They were also able to produce similiar maps showing survey effort (Figures 4-13).

For our analysis of seabird distribution, we obtained a variety of seabird density maps from the Data Projects Group. Another URI product we used was a histogram plot of seabird density at 5 km intervals going out from the the two large Pribilof Islands, within a 45° region centered on each of the cardinal directions (Figure 14). Numbers of observations in each 5 km interval are indicated.

After inspecting the various URI products showing seabird distribution around the Pribilofs, we became interested in the apparent asymmetry of seabird distribution east and west of the islands. We designed a series of zones dividing the waters near the Pribilofs into shelf (east) and shelf break (west) regions. We further divided these zones into regions close to and distant from the islands (Figure 15). Our statistical consultant, Jerry Kaiwi, developed a program to extract observations from our data base and classify them by zone. This program computed means and


BIRD DENSITY (birds/km²)
BIRD SIGHTING EFFORT-
NUMBER OF TRANSECTS
AROUND St. PAUL ISLAND
100m
50m
200m
22.5°
kilometers

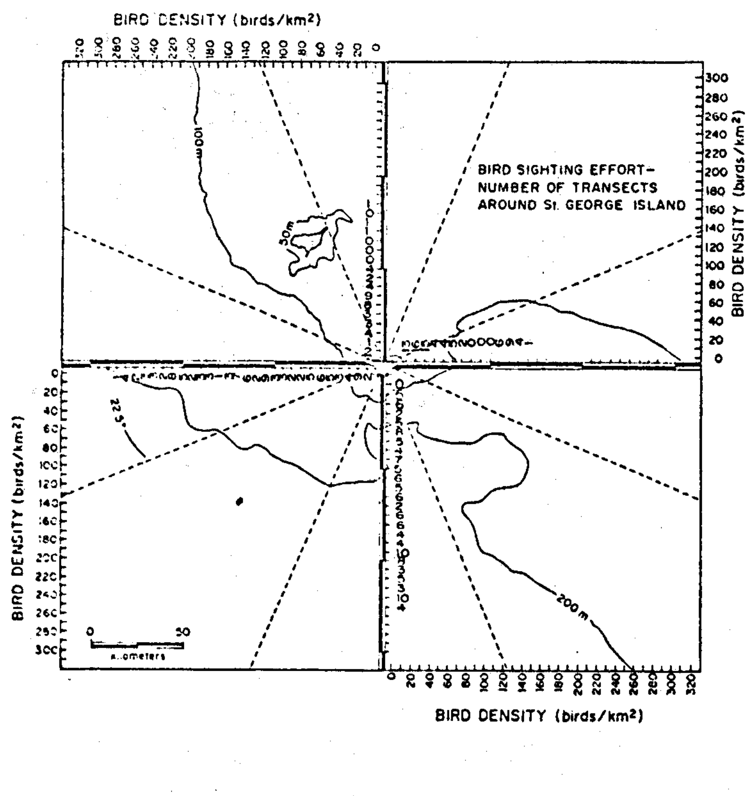

BIRD DENSITY (birds/km²)
BIRD SIGHTING EFFORT-
NUMBER OF TRANSECTS
AROUND St. GEORGE ISLAND
100m
50m
200m
22.5°
kilometers

FIGURE 14

Zonal Analysis of the pelagic distribution of seabirds near the Pribilof Islands. Number of observations per zone

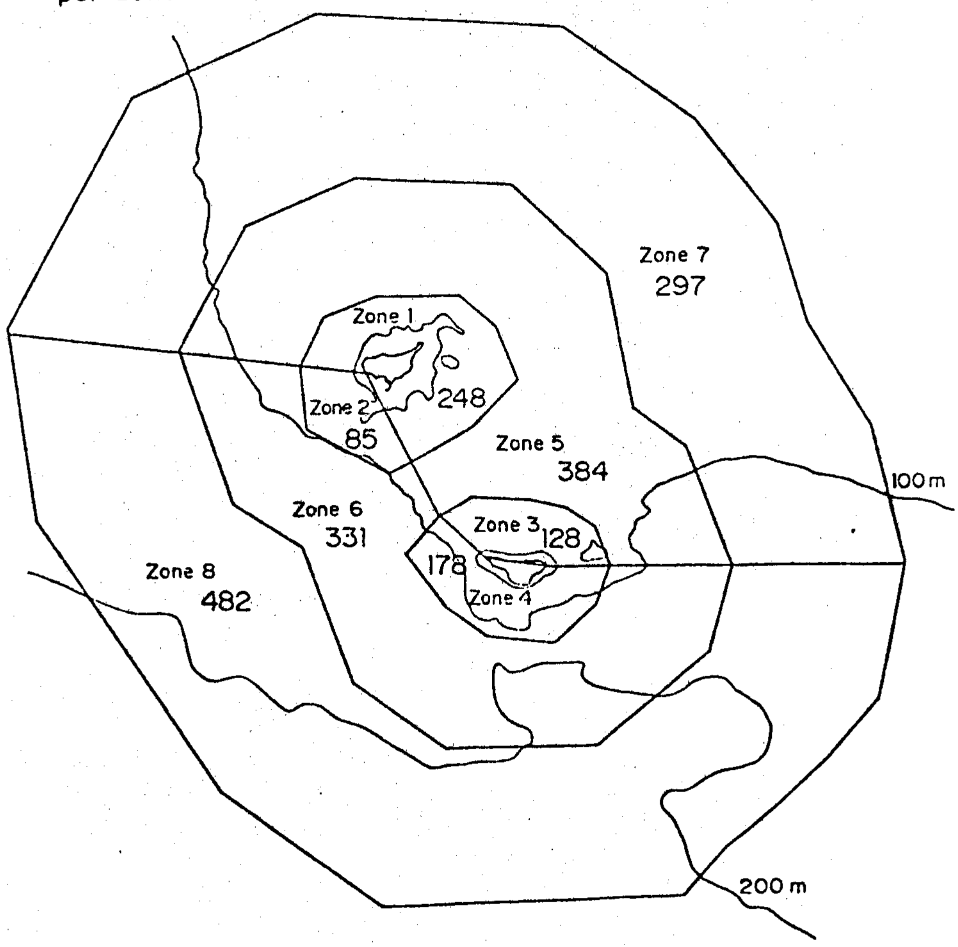


FIGURE 15

standard deviations of the densities of different species in each zone. A oneway ANOVA of seabird density across zones by each species determined if there were any statistically significant differences in seabird densities among the zones (Nie et al. 1975). Densities for each zone were compared using a modified LSD procedure (Nie et al. 1975), with α at 0.05 for the entire set of comparisons. When of interest, seabird densities in two zones were compared using a t test. Zones were set at 20 km, 40 km and 60 km from the periphery of the islands, and the number of observations made in each zone are indicated (Figure 15).

FOODS STUDIES

Sampling Technique

Our foods samples originated from two different sources: 1) shot adult or immature seabirds; 2) regurgitations of live birds handled for other reasons, i.e., for obtaining growth rates. We collected birds on an irregular basis throughout the summer. Early in the nesting season, most samples came from shot birds. Ethanol (70-80%) was injected down the throat of each bird and into the stomach to arrest digestion. Carcasses were occasionally frozen for later processing. The carcasses were weighed to the nearest 2% using a Pesola spring balance (300 g to 5 kg capacity). The carcasses were opened and all food from the proventriculus, gular pouch, and stomach was removed and placed in a whirl-pak bag in 70% ethanol. Food samples were labeled with the species, collection date, island and sample number. Bill-loads and gular pouch contents were kept separate from stomach samples, but were cross-indexed when samples originated from the same bird. Supplemental data frequently, but not consistently, taken on the carcasses included sex, brood patch state, molt, culmen length, flattened wing length, tarsus length, fat condition and gonad size. Most carcasses were made into study skins or skeletons and donated to San Diego Museum of Natural History or the Los Angeles County Museum of Natural History.

As the nesting season progressed, we were able to obtain food samples from the chicks of many species which regurgitated when handled, as happened when we weighed chicks to get growth rates.

Hence, we generally stopped shooting the following species when chick regurgitations were available: Red-faced Cormorant, Black-legged Kittiwake, and Red-legged Kittiwake. Alcid chicks did not regurgitate when handled, so we continued to shoot adult murres, puffins and auklets.

We obtained the following number of food samples: Northern Fulmar, 10; Red-faced Cormorant, 169; Black-legged Kittiwake, 605; Red-legged Kittiwake, 376; Common Murre, 117; Thick-billed Murre, 233; Parakeet Auklet, 55; Crested Auklet, 20; Least Auklet, 258; Horned Puffin, 39; Tufted Puffin, 23. The samples from Least Auklets were predominately regurgitations from adults caught in mist-nets and released.

Sample Analysis

In the laboratory, samples were sorted, identified to the lowest taxon possible, counted and displacement volumes were measured after draining, or estimated visually. Prey size was measured in eight organisms of each taxa, picked at random from each sample, unless there were less than eight whole prey, in which case all were measured. Copepods, cumacea, amphipods, euphausiids and shrimp were measured from the anterior tip to the back edge of the telson. In crabs, the width of the carapace was measured, and fish were measured from snout to the tip of the caudal fin. Otoliths were measured, and identified; for some species total fish length could be estimated from otolith length (Frost and Lowry in press). In estimating the number of prey taken, we counted the number of identifiable parts (eyes, beaks, heads, tails) and divided by the number of parts in an intact organism.

Voucher specimens for each species identified have been submitted to the California Academy of Sciences, San Franciso, California.

Data Reduction and Analyses

As with our pelagic data, foods data were entered on a floppy diskette using a Texas Instruments 771 Intelligent Terminal and a forms program developed by the Data Projects Group, University of Rhode Island, which coded our data and made them compatible with NODC format. We sent our diskettes to URI, where the data were range checked and any discrepancies were sent back to us for clarification. The data were transcribed onto tapes and filed with NOAA. We received computer generated tables of the diet of each species. Three different measures of importance of a food in the diet were calculated: percent occurrence is the percentage of samples in which a prey item occurs; percent volume is calculated by the dividing the sum of the volumes of a particular prey from all samples by the total volume for all samples combined, and converted to a percentage; percent number is the number of a given prey item divided by the total number of prey items and converted to a percentage. Percent occurrence may total more than 100 percent because of the occurrence of more than one prey type in a sample.

These three measures provide complementary information about seabird diets and allow comparison of our results with those of other investigators. Percent occurrence tends to overestimate prey with persistent hard parts. Percent volume overestimates the importance of large prey in the diet, as well as overestimating prey which are digested slowly. Percent number overestimates the importance of small organisms in the diet. For much of our analysis we have used percent volume, which we feel gives the most accurate picture of the relative importance of prey species in the diet.

We analyzed differences in the diet of seabirds throughout different phases of the nesting cycle, between the sexes, between adult (stomach) and chick (regurgitations) diets, and between birds nesting on St. Paul versus St. George Island. To determine whether differences in diet occurred, we ranked the major prey types (5% of the diet by volume or greater) and performed a median test (Chou 1969, p. 467). The median test, which is based on a x^2 statistic, has a number of degrees of freedom equal to the number of prey types minus one and is a conservative test. For many of our analyses, we had only 5 prey categories rendering the test relatively unpowerful. The solution to this problem is to retrieve the foods data by individual samples, rather than using a compilation, and to apply analysis of variance to determine whether there are differences in diet. We intend to reanalyze the data using this technique, but to date, time has not permitted this analysis.

REPRODUCTIVE BIOLOGY STUDIES

Sampling Techniques

In our studies of reproductive biology we used two basic types of study sites, visual sites and disturbed sites. Disturbance was due to either purposeful scaring of birds off their eggs, as in our early studies of murres and cormorants, or because we were climbing up to nests in order to weigh chicks. Although disturbed sites allowed the exact determination of the numbers of eggs and young and hatching dates, we were concerned about the exposure of eggs and chicks at sites where adults were scared off their nests. For murres, disturbance significantly lowered productivity and so disturbed sites were not used in determining productivity when data from non-disturbed areas were available.

We followed the fate of individual nest-sites from the first sign of nesting activity in late spring or early summer, until the nesting attempt had clearly failed, or chicks fledged. After 1975, we used 8 x 10 inch black and white photographs of the study sites as maps. On each, we marked the perimeter of the study area and identified the nest-sites we were studying. At ladder accessible sites, we also marked nest numbers on the cliff with paint.

At each site visit, we recorded time, weather conditions, the number of birds in the study area and information on individual nests. The time spent at each site varied considerably among observers and there was a trend for visits to become longer in succeeding years. For kittiwakes and cormorants, the optimum time spent at each site was around a half hour. However, this was not the case with murres and fulmars; a observer could spend up to 2.5

hours at a site and still not see under more than a few birds. We visited sites at 3 to 4 day intervals with some exceptions.

We used 30 foot extension ladders to reach nests at our ladder accessible study sites. We weighed chicks to the nearest 2% using bags and Pesola spring scales of 300 g to 5 kg capacity. The weight of the bag and any regurgitated food was subtracted from the gross weight of the chick. In nests with more than one chick, or on murre ledges, we banded chicks with a numbered plastic leg band. In 1978, chicks were weighed only until they showed the characteristic drop in weight that precedes fledging. In previous years, chicks were weighed until they flew off. We stopped this method, since we were concerned about causing premature fledging. In cormorants, chicks were weighed only until they reached 1000 grams, also to prevent premature fledging. Chicks were weighed approximately every 3 to 4 days, with the exception of Horned Puffins which were weighed at weekly intervals and some Black-legged Kittiwake chicks on St. George Island in 1978 which were weighed until they reached 100 grams and not again until their plumage indicated they were near their peak weight. This was done as a check to see whether our handling of chicks reduced their growth rates. We found no significant difference in weights between chicks given frequent weighings and those not handled so frequently (t test, $t_{14} = 2.04$, $P > .05$).

We also investigated patterns of adult nest attendance while attempting to estimate foraging time. Sites for attendance watches were chosen so that a reasonable number of nests at which adults could be marked were visible. Attendance watches were made for Black-legged Kittiwakes, Red-legged Kittiwakes, Thick-billed Murres and incidentally for Horned Puffins. Adults were marked with picric acid (yellow) or rhodamine-B dye (red) sprayed from a spray gun. Observers recorded times of arrival and departure of marked adults in addition to trade-off times and feeding of young. Attendance watches lasted from 31 to 46 hours. In 1978, we used a time-lapse camera (provided by G. Lapienne of NOAA) at two Black-legged Kittiwake nests; frames were taken every 20 seconds. We also studied the attendance patterns and the roles of male and female Thick-billed Murres in raising young. Several pairs of Thick-billed Murres at Ridge Bottom and at Zapadni cliffs on St. Paul Island were sexed by laporotomy, and foraging trip length and parental attendance data for each sex were gathered.

Data Reduction and Analysis

Phenology

Since we visited our sites only every 3 to 4 days, our phenology estimates contain an uncertainty of similiar length. For these estimates, we used eggs or young which showed a transition (laying, hatching) between one visit and the next. Nests where the contents could not be seen at a critical visit were not used for the phenology studies unless a known date of laying or hatching allowed us to calculate, or back-calculate, the predicted date of hatching or laying. For species which lay multiple egg clutches, we determined laying and hatching dates only for the first egg or chick.

In presenting our findings, we used two different graphical presentations. The figures, "Percent of active nests with eggs or young," reflects the nesting status of the population, and will be particularly useful for comparisons with spot checks of the birds in the future. The "Initiation of laying, hatching and fledging" figures show the peaks of initiation of laying, hatching and fledging in the population. In these figures, the histograms labeled "calculated" refer to the estimated date of laying based on a known hatching date or vice versa. Our phenology tables, "Mean dates of laying, hatching and fledging" assign dates and standard deviations to the peaks illustrated in the "Initiation" figure.

Incubation periods were calculated for eggs when both the laying and hatching dates were known. Similiarly, fledging age and the length of time spent in the nest were calculated for chicks when both hatching date and fledging date were obtained.

Productivity

Our measures of productivity include data from all study sites. We looked for differences in productivity between study sites using a one-way analysis of variance, but found no significant differences. Hence, we combined data from all sites for our analysis and presentation; we give productivity estimates for each island as a whole. We used two different subsets of our data in calculating our productivity parameters. In calculating mean clutch size, hatching success (chicks hatched/egg laid) and fledging success (chicks fledged/chick hatched), we used nests for which we knew the number of eggs, chicks or fledglings. We did not include nests without eggs in our estimation of mean clutch size. Ranges in our estimates of hatching and fledging success reflect our uncertainty about the fate of eggs which disappeared within 5 days of their estimated hatching date, and for young which disappeared close to their predicted fledging time. Although the ranges are inconvienent, we feel they present a more accurate picture of reproductive success than a single number. In estimating overall productivity we used the total number of chicks fledged in a study area divided by the total number of nesting attempts in that area. We defined a nest attempt as a pair holding a territory on the cliff, or any trace of nesting material from the current nesting season.

For some species, assessing productivity as we have defined it proved to be difficult, and for this reason, slightly different measures were used. For murres, the number of eggs within a study area was often unknown, due to the difficulty of seeing under sitting murres. To avoid biasing our estimates of hatching and fledging success, we excluded nest sites where a chick was seen, but not the egg from which it hatched. Since many non-breeding murres occupy the nesting ledges and murres do not build nests, we were unable to accurately estimate the number of nesting attempts in a study area. We estimated the number of breeding pairs by the mean number of adults on the study area and divided the total number of chicks fledged by this estimate to obtain a productivity estimate. This estimate is conservative for two reasons. It is possible for murre chicks to go to sea before we have seen them, since they stay on the cliffs for a minimum of 4 to 5 site visits, hence we probably underestimate the number of chicks fledged. In addition, there are probably fewer nesting pairs than the average number of adults in the study area; this again causes us to underestimate productivity. The same problem arose with fulmars, for which we applied the same solution as with murres.

Frequently, judgement was required to determine whether a chick had actually fledged. We used the following minimum criteria for fledging: fulmar, down present on the crown with only minor patches elsewhere, and/or the tips of the folded wings extend nearly to the tip of the tail; Red-faced Cormorant, flight and contour plumage complete with traces of down on the neck only; Black-legged Kittiwake, no down present except on the nape and possibly on the belly, and/or the chick is known to be older than 35 days; Red-legged Kittiwake, same as for Black-legged Kittiwakes except chick is known to be older than 30 days; murres, chicks are feathered and show white in the cheek and throat regions, and/or chick is known to be older than 15 days. Occasionally, kittiwake chicks had not fledged by our last check; we assumed they fledged if they had tail feathers, as we found that the mortality of chicks which had attained this stage was quite low.

Growth rates were computed for Red-faced Cormorants, Black-legged Kittiwakes, Red-legged Kittiwakes, Common Murres, Thick-billed Murres, Parakeet Auklets and Horned Puffins. Kittiwake, cormorant and puffin chicks showed a linear growth rates from shortly after hatching until reaching a peak weight just prior to fledging, after which weight decreased. We determined growth rates by subtracting the peak weight from the initial weight and dividing by the number of days between these two observations. For cormorants, and occasionally for kittiwakes, the last weight was used when the chicks had not attained their peak weights. Murre chicks at the Pribilofs show a two stage growth curve (Figure 16); for our analysis we used the growth rates from hatching to the

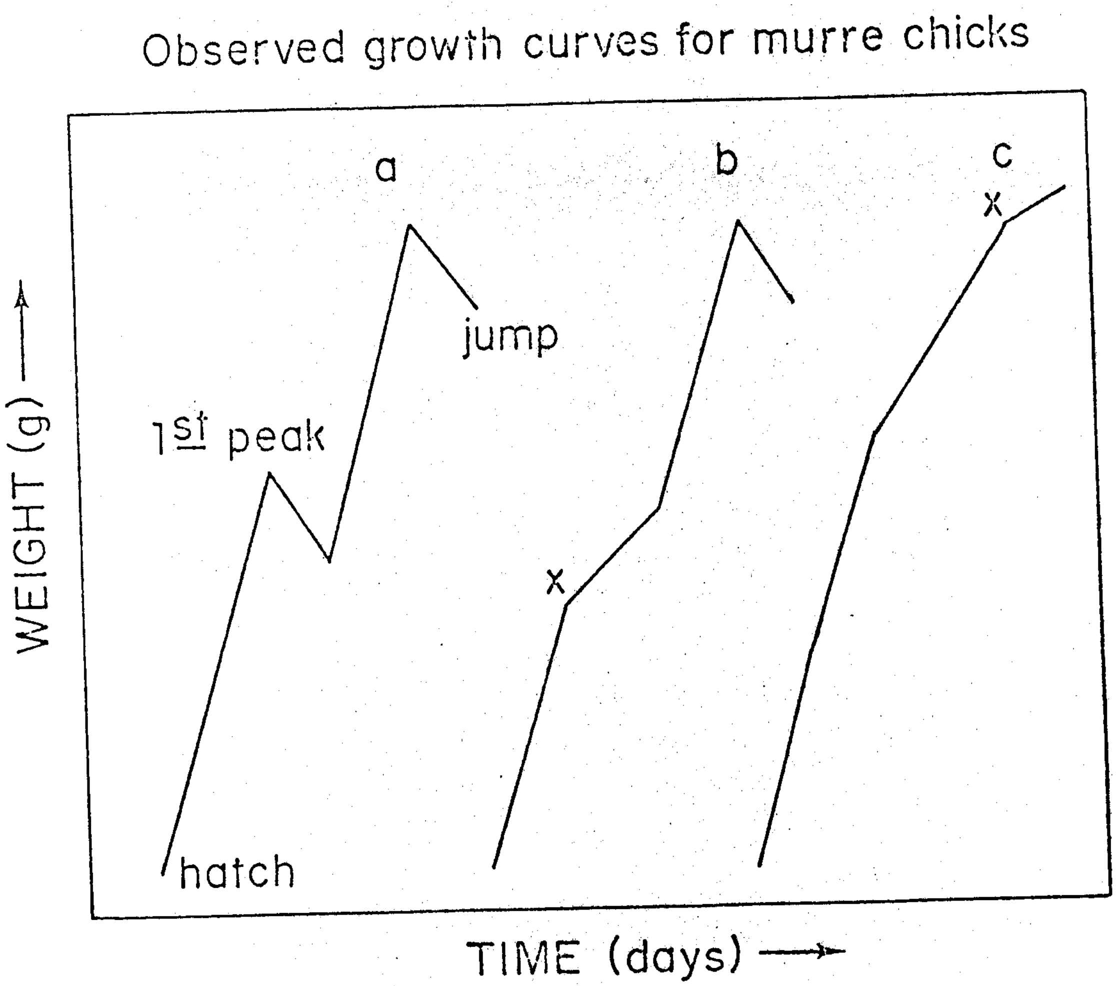

Observed growth curves for murre chicks
a
b
c
x
jump
1st peak
x
hatch
WEIGHT (g)
TIME (days)

FIGURE 16

first peak in the growth curve. Since we weighed chicks at 3 to 4 day intervals, we sometimes missed their peak weights, in which case, we approximated peak weight by using the weight marked x in Figure 16. Fledging weight was approximated by the last weight of a chick before fledging. Additionally, jumping weights were measured in serveral murre chicks caught on the water immediately after jumping from the cliffs.

Productivity and growth rates for species were compared among years and between the two islands using a two-way ANOVA and a mutliple classification analysis to obtain the amount of variation explained by the analysis and the main effects, island and year (Nie et al. 1975). Years were compared using an LSD procedure (Nie et al. 1975). When significant interaction was present, years were analyzed for each island. In comparing 3 years at a given island, the two years with similiar productivty or growth rates were compared using a t test. If no significant differences were found, then the two similiar years were combined and tested against the third using a t test.

PROCELLARIDAE

Species in the family Procellaridae are surface-feeders or pursuit-plungers, using only the upper portion of the water column for foraging (Ashmole 1971, Ainley and Sanger 1979). The Procellariids range farther from their colonies to obtain food than the diving seabirds. Long flight ranges and slow chick growth rates have evolved in this family as adaptations to patchily distributed food (Boersma and Wheelwright 1979). The center of distribution is in the southern hemisphere; the Northern Fulmar is the only representative of the family breeding in the Bering Sea. Short-tailed (*Puffinus tenuirostris*) and Sooty Shearwaters (*P. griseus*), which breed on islands off Australia, New Zealand, and South America, spend the austral winter over the Bering Sea. The biomass of the shearwaters in the Bering Sea during the northern summer warrants their consideration as the most important seabird species in the area (Sanger and Baird 1977).

Northern Fulmar (*Fulmarus glacialis*)

Numbers

Northern Fulmars occur throughout the northern regions of the North Atlantic and Pacific Oceans. In the Bering Sea, they nest at St. Matthew and the Pribilof Islands. The colonies on the Pribilofs contain an estimated 70,700 fulmars (Hickey and Craighead 1977), amounting to about 5% of the population in the eastern Bering Sea (Appendix 1).

Pelagic Distribution

The pelagic distribution of Northern Fulmars around the Pribilof Islands is given in Figures17-19. We have presented

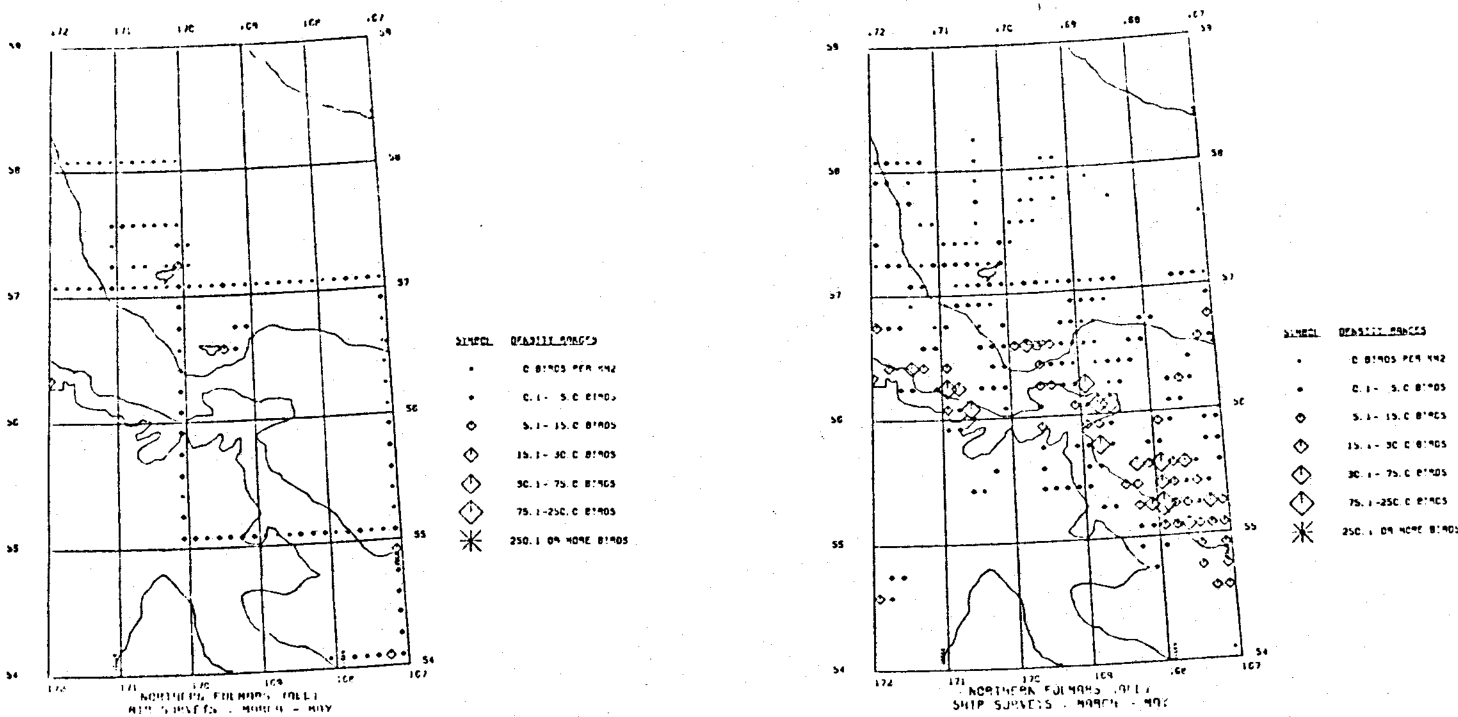


FIGURE 17

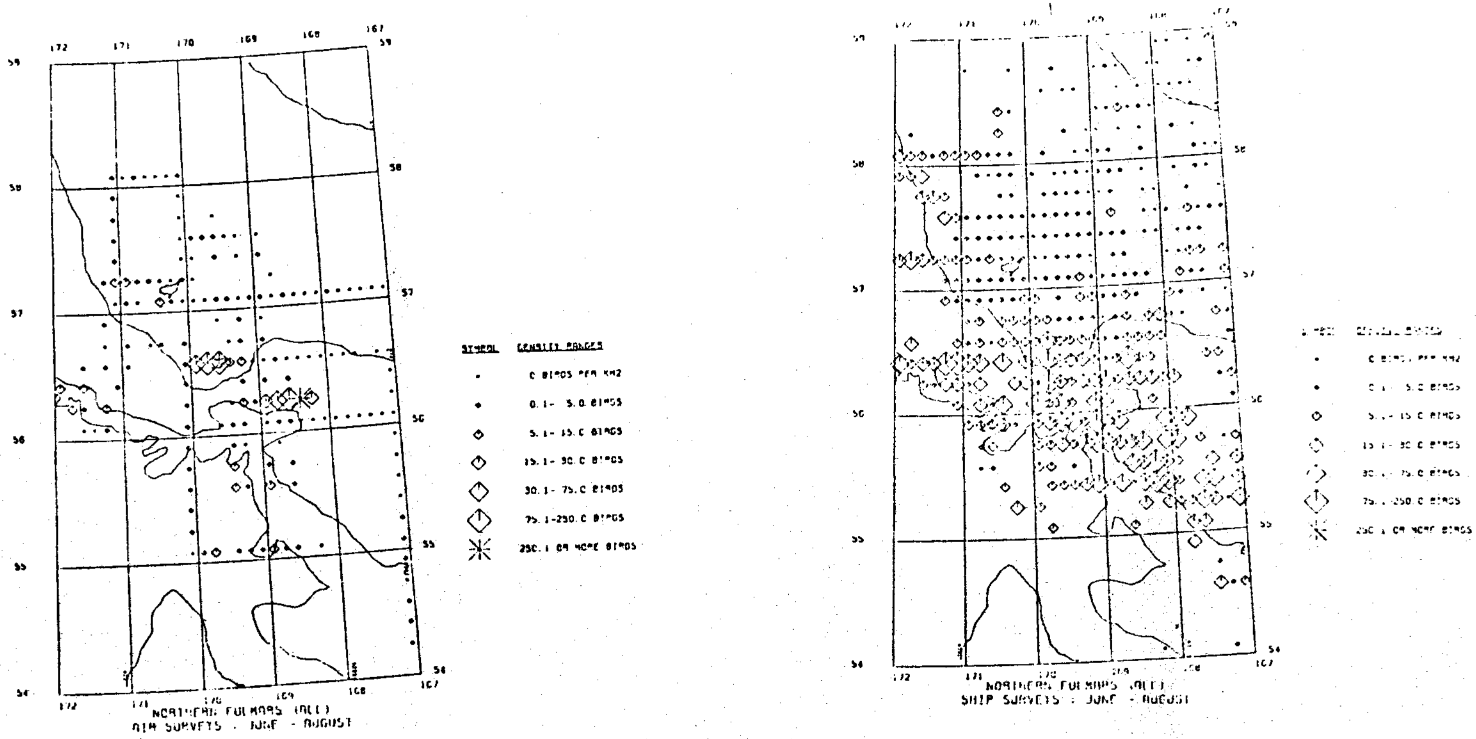

NORTHERN FULMARS (ALL)
AIR SURVEYS : JUNE - AUGUST
SYMBOL
DENSITY RANGES
0 BIRDS PER KM2
0.1- 5.0 BIRDS
5.1- 15.0 BIRDS
15.1- 30.0 BIRDS
30.1- 75.0 BIRDS
75.1-250.0 BIRDS
250.1 OR MORE BIRDS
NORTHERN FULMARS (ALL)
SHIP SURVEYS : JUNE - AUGUST

FIGURE 18

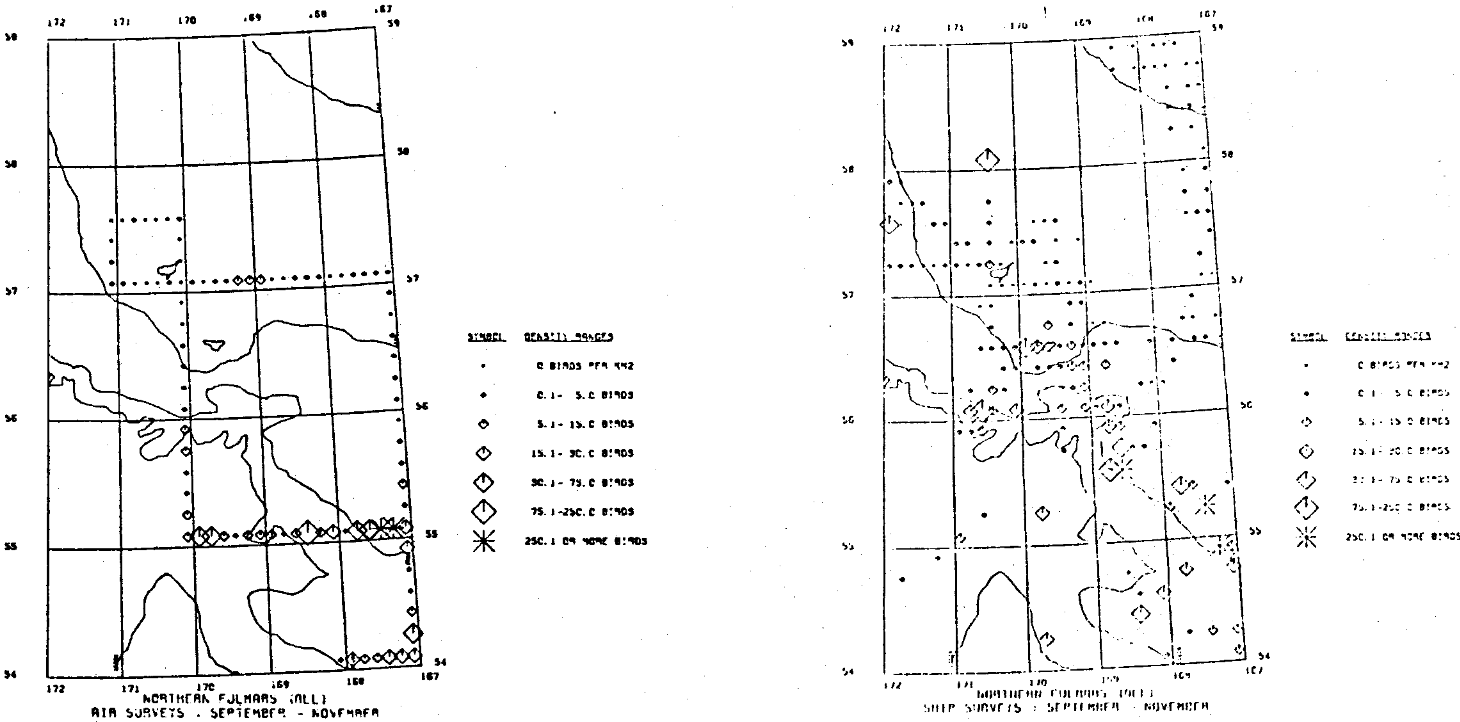

SYMBOL DENSITY RANGES
0 BIRDS PER KM2
0.1- 5.0 BIRDS
5.1- 15.0 BIRDS
15.1- 30.0 BIRDS
30.1- 75.0 BIRDS
75.1-250.0 BIRDS
250.1 OR MORE BIRDS
NORTHERN FULMARS (ALL)
AIR SURVEYS - SEPTEMBER - NOVEMBER
NORTHERN FULMARS (ALL)
SHIP SURVEYS - SEPTEMBER - NOVEMBER

FIGURE 19

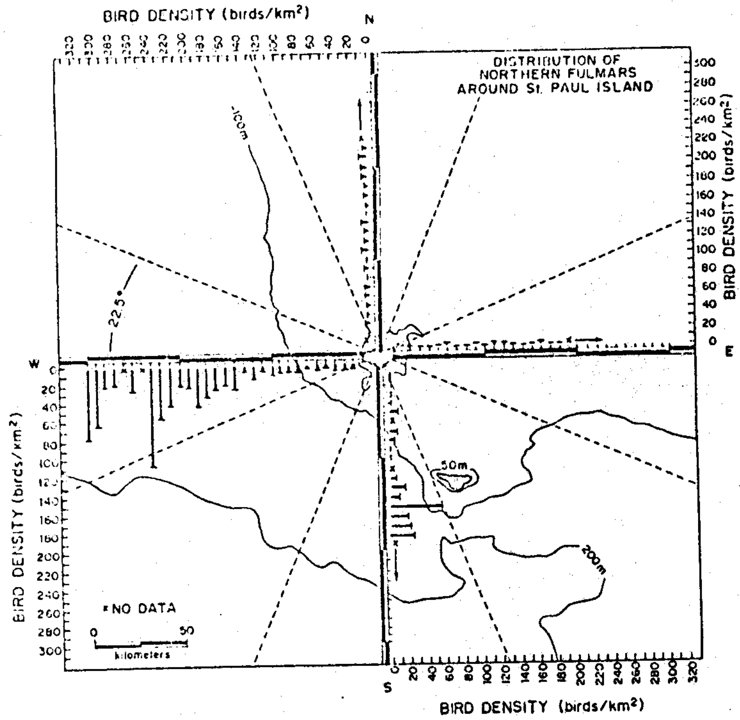
aerial and shipboard surveys separately since shipboard surveys tend to overestimate fulmar density due to the propensity of fulmars to join ships (Hunt et al. 1980c). Aerial surveys show that fulmars normally occur at low densities; high densities recorded on aerial surveys were always generated by large flocks associated with fishing vessels. Although ship surveys produce inflated density estimates, the patterns of pelagic distribution are similar for both ship and aerial surveys. These patterns are most readily seen in the shipboard surveys, due to the larger data base.

Information on the seasonal distribution of fulmars, particularly in early spring, has been gathered on PROBES cruises and will be presented in detail in future PROBES reports. Fulmars enter the Bering Sea in March and April with light phase birds predominanting at first. Numbers increase throughout the summer with peak densities in July and August, when dark phase birds are most common. Numbers decrease rapidly in fall.

Fulmar concentrations are greatest near the shelf break; relatively few are seen over shelf waters less than 100 m in depth, except in the immediate vicinity of the Pribilofs. North of the Pribilofs, over the shelf, fulmars were sighted less frequently and many transects recorded no fulmars at all. The concentration of fulmars along the shelf break may reflect the distribution of prey populations on which fulmars depend, or the distribution of the fishing fleets. Since fulmars take large amounts of offal from vessels, they may restrict their searching for food to those areas where they have a high probability of encountering fishing vessels.

Fulmar distribution in relation to their colonies on the Pribilofs are shown in Figure 20. These histograms reinforce the conclusion that fulmars are concentrated near the shelf break and are relatively scarce over shallow, shelf waters. Interestingly, there is no indication of an increase in density approaching the colonies at St. George and St. Paul. The implication is that foraging fulmars quickly leave the vicinity of the colonies and spend the major portion of their time near the shelf break. We analyzed the pelagic distribution of fulmars by zones around the islands (Figure 21), and found that densities were low near St. Paul Island while they were high near St. George Island, particularly on the southern side of the island nearest to the shelf break. Densities away from the islands were low over the shelf and high over the shelf break. The differences in mean density were statistically significant (Modified LSD Procedure, $P < .05$).

Light and dark phase fulmars appear to have different patterns of distribution (Figure 22). Light phase birds predominated near the Pribilofs, particularly near St. George, while dark phase birds predominated at the shelf break. However, light phase fulmars are more common relative to dark phase fulmars north of the Pribilofs than they are in the vicinity of the shelf break. These results suggest an increase in the proportion of dark birds in the study area since the surveys made by Shuntov (1972) in the 1960's. The dark phase fulmars are coming from colonies in or southeast of the Aleutian Islands, or represent non-breeding birds, since the fulmar colonies on the Pribilofs are over 99% light phase (Hickey and Craighead 1977).


DISTRIBUTION OF NORTHERN FULMARS AROUND St. PAUL ISLAND
BIRD DENSITY (birds/km²)
N
E
S
W
100m
50m
200m
22.5°
× NO DATA
kilometers

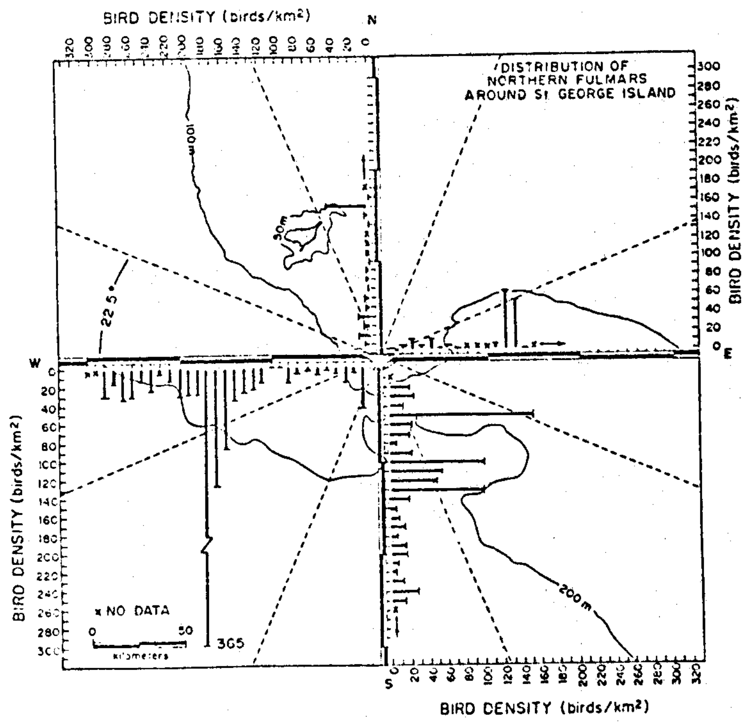
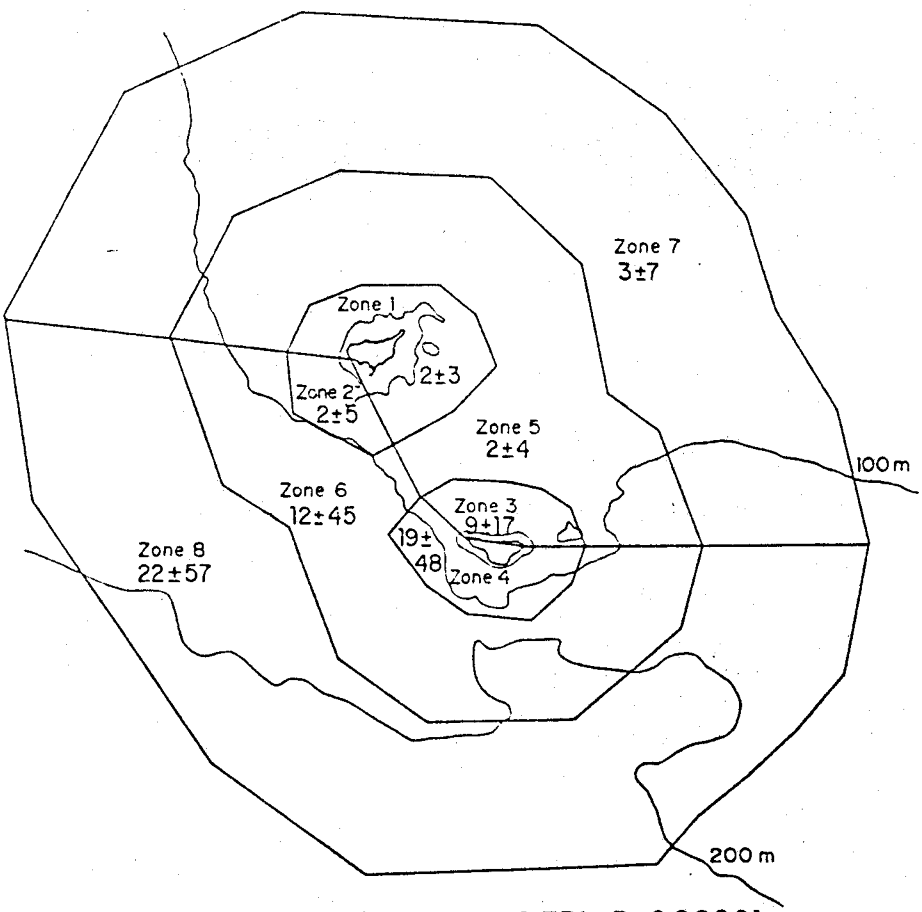

DISTRIBUTION OF NORTHERN FULMARS AROUND St. GEORGE ISLAND
BIRD DENSITY (birds/km²)
N
E
S
W
100m
50m
200m
22.5°
365
× NO DATA
kilometers

FIGURE 20

Distribution of Northern Fulmars by zones
near the Pribilof Islands 1975–1979 ($\bar{x} \pm s$)*



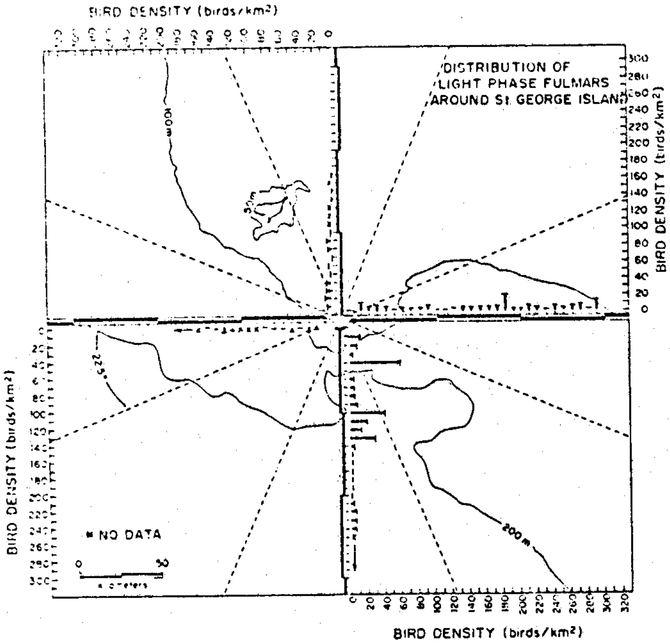
ANOVA across all zones, $F_{7,2132} = 16.731$, $P = 0.00001$

Homogeneous subsets by modified LSD Procedure, $\alpha = 0.05$

Subset 1 Zones 1,5,2,7,3
Subset 2 Zones 2,7,3,6
Subset 3 Zones 3,6,4
Subset 4 Zones 4,8

*rounded to whole numbers

FIGURE 21


BIRD DENSITY (birds/km²)
DISTRIBUTION OF LIGHT PHASE FULMARS AROUND St. GEORGE ISLAND
100m
30m
225
200m
* NO DATA
BIRD DENSITY (birds/km²)
BIRD DENSITY (birds/km²)
BIRD DENSITY (birds/km²)

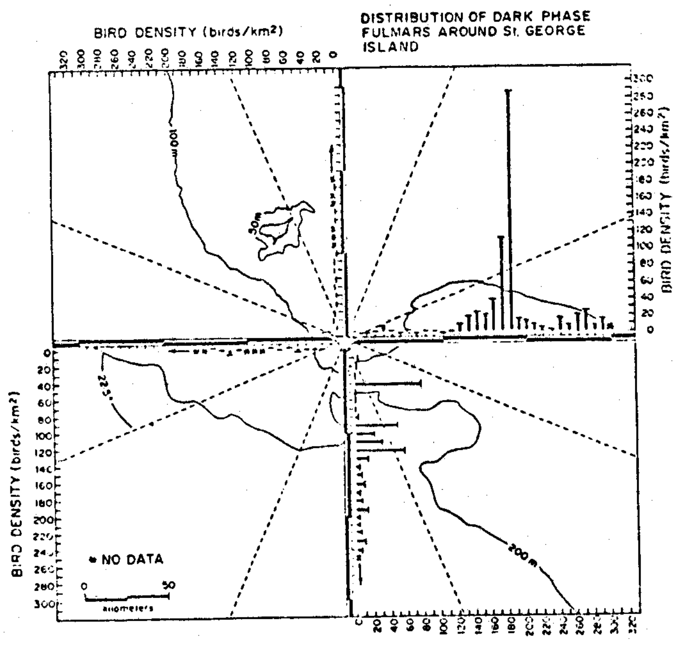

BIRD DENSITY (birds/km²)
DISTRIBUTION OF DARK PHASE FULMARS AROUND St. GEORGE ISLAND
100m
30m
225
200m
* NO DATA
0 50
kilometers
BIRD DENSITY (birds/km²)
BIRD DENSITY (birds/km²)
BIRD DENSITY (birds/km²)

FIGURE 22

Diet

Northern Fulmars have the potential to forage far from their colonies. In the North Atlantic, Fisher (1952) found nesting fulmars foraging 1200 miles from the nearest colony. In the Bering Sea, fulmars are widely distributed, but the greatest concentrations are found along the shelf break. At the Pribilofs, fulmars forage near the shelf break, which is 100 km from the colonies.

Fulmars obtain their food at or near the sea surface. We made little effort to collect this species because of their dependence on offal in the North Atlantic (Fisher 1952). The few birds we collected showed a variety of naturally occurring prey (Figure 23). Further study of fulmar diet in the Bering Sea is needed; our data represent only 10 individuals, of which only 5 are from the Pribilofs.

Although fulmars used cephalopods more extensively than other species studied, they also used a considerable amount of walleye pollock (*Theragra chalcogramma*) (Figure 23). The pollock may have been caught by fulmars or scavenged from fishing operations. The pelagic distribution of fulmars coincides with an area in which one might expect large numbers of pollock, based on fishing effort. We are left without a good idea of the natural diet of fulmars because there is no way of distinguishing food obtained in conjunction with fishing operations and that obtained independent of man.

MAJOR COMPONENTS OF THE DIET OF NORTHERN FULMARS

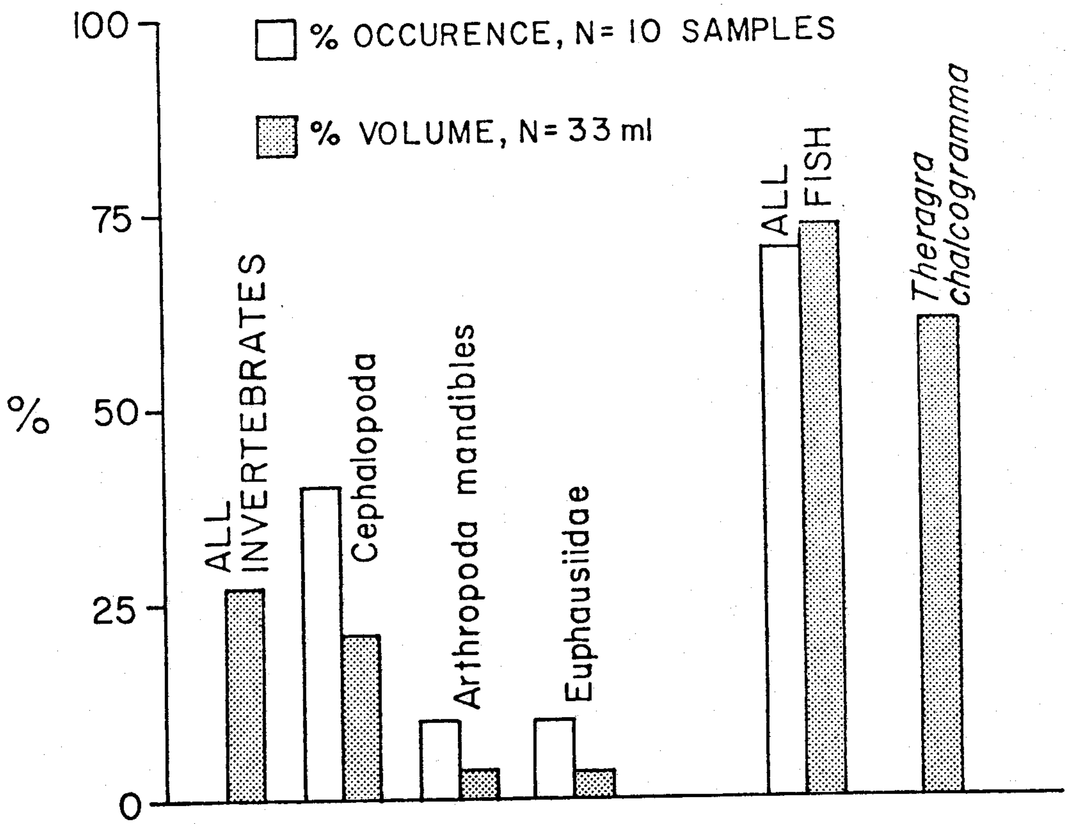


FIGURE 23

Nesting

Habitat

Fulmars nest on cliffs in association with other cliff-nesting seabirds, such as murres and kittiwakes. On fox-free islands, fulmars generally nest on the upper, vegetated slopes of cliffs, while on islands with mammalian predators, fulmars nest on nearly vertical portions in small caves or on bedrock ledges. At the Pribilofs, most fulmars nest at elevations greater than 61 m. St. George Island has a large number of high cliffs and this may explain their abundance on St. George relative to St. Paul Island.

Phenology

Our phenology estimates for fulmars are not as accurate as for other species. Fulmars build no nest and rarely moved off their nest site, hence, nesting fulmars were virtually indistinguishable from the numerous non-breeding birds on the cliffs.

Fulmars arrive at the Pribilofs in March or April (Preble and McAtee 1923), although arrival dates appear to be quite variable. Fulmars were not present on the islands when we arrived in May 1976 and none were seen until 26 May. However, egg-laying was well underway in 1977 when we arrived in late May. Fulmars lay a single egg and incubate it for an average of 48 days (Hatch 1979). Temporary desertion of eggs, apparently due to lack available food, was a common occurrence in fulmars nesting on the Semidi Islands in 1976 (Hatch 1977). The fact that egg neglect has not been observed in the Pribilof population may indicate a better food situation. Our earliest observations of chicks were in late July. Hatching continued into the second week of August. Young fulmars remain at the nest site for a mean of 53 days (Mougin 1967, Hatch 1979). Fledging normally began around 18 September, although we observed instances of fledging as early as 5 September. Once fledged, the young are independent.

Daily Activity Patterns

Hatch (1979) found large seasonal variation in colony attendance of fulmars at the Semidi Islands in the Gulf of Alaska. At the Pribilofs, colony attendance was regular once incubation had begun (Hickey and Craighead 1977). Numbers of fulmars on the cliffs rose rapidly in the morning and maximum numbers could be found between 1000 and 1900 hours (Hickey and Craighead 1977). We did not investigate patterns of nest attendance. Hatch (1979) found incubation shifts of 3.5 to 7.5 days at the Semidis.

Productivity

Table 2 shows fulmar productivity at the Pribilofs. A minimum value of reproductive success for population maintenance was estimated to be about 0.16 young fledged per nest (Hatch, pers. comm.). By this estimate, fulmars on the Pribilofs probably produce more than enough young to maintain their population. The figures for the Pribilofs represent a minimum estimate of reproductive output, since an unknown number of adults were undoubtably non-breeding birds. The index "young fledged/mean number of adults in the study area" was used to estimate "young fledged/nest" since the actual number of nests was unknown.

Productivity of fulmars at the Pribilofs averaged 0.28 (young fledged/mean number adults in the study area) between

1976 and 1978 (Table 2). The larger fulmar colony on St. George appeared to be more productive than the smaller colony on St. Paul.

Finally, although the Pribilof fulmar population is comprised of light phase birds, most fulmars on the southeastern Bering Sea are dark phase, the predominant color in the Aleutian Islands and Gulf of Alaska. If, as Fisher (1952) suggests, nesting fulmars have a foraging range of 2400 miles, then fulmars nesting in the Aleutians and Gulf of Alaska may be coming to the St. George Basin to forage. This would explain the occurrence of the long incubation shifts, low growth rates and egg neglect observed by Hatch (1977) in the Semidi fulmar population during 1976, features which are absent in the Pribilof population.

TABLE 2

Reproductive success of Northern Fulmars at the Pribilof Islands, 1976-1978

	ST PAUL ISLAND			ST GEORGE ISLAND		OVERALL
	1976	1977	1978	1977	1978	
MINIMUM NO. EGGS	14	22	21	46	42	
MINIMUM NO. CHICKS	13	20	17	38	40	
MINIMUM NO. FLEDGED	10	15	15	37	38	
CHICKS FLEDGED/ MEAN NO. ADULTS IN STUDY AREA	0.15	0.30	0.27	0.34	0.29	0.27

Shearwaters (*Puffinus* sp.)

Numbers

Short-tailed (*P. tenirostris*) and Sooty Shearwaters (*P. griseus*) both occur in the Bering Sea, with Short-tailed Shearwaters greatly predominating. Since these species are often difficult to distinguish in the field, many field investigators did not attempt to separate them and data for both species are combined for this account. Both species nest in the southern hemisphere during the austral summer and parts of their populations spend the southern winter in the Bering Sea. Shuntov (1972) estimated about 8.7 million shearwaters occur in the Bering Sea in summer. Sanger and Baird (1977) estimated a total of 10 million. Regardless of the estimate used, the Short-tailed Shearwater is the most abundant bird species in the Bering Sea from June through September.

The most striking feature of shearwater distribution is its patchy nature and the frequent occurrence of flocks of tremendous size. When foraging, the birds in these flocks churn the sea surface as they make shallow plunge-dives; at other times, they rest on the surface in densely packed flocks that may extend for many kilometers.

Shearwaters are most common over the continental shelf waters, particularly along and inside the 50 m isobath (Figure 24). Only moderate numbers were encountered along the shelf break. Shearwaters were rare over waters deeper than 2000 m.

Although shearwaters were generally not present in high concentrations near the Pribilofs, occasionally large flocks were encountered. Zonal analysis of shearwater distribution around

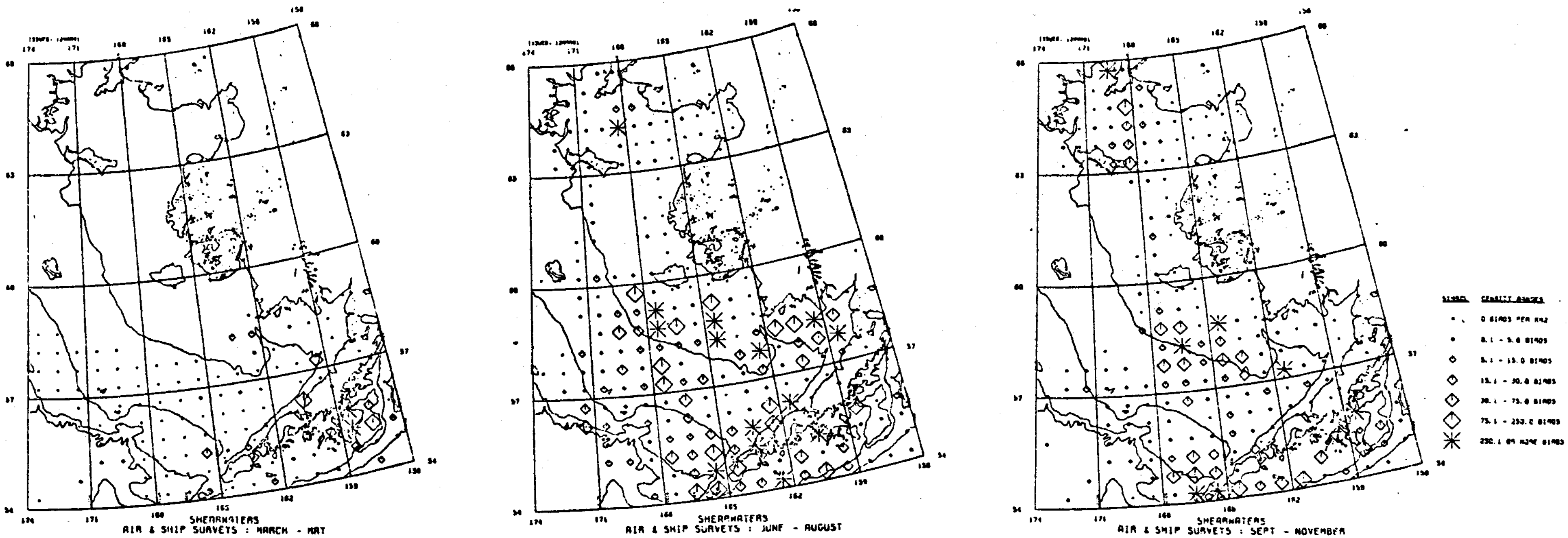
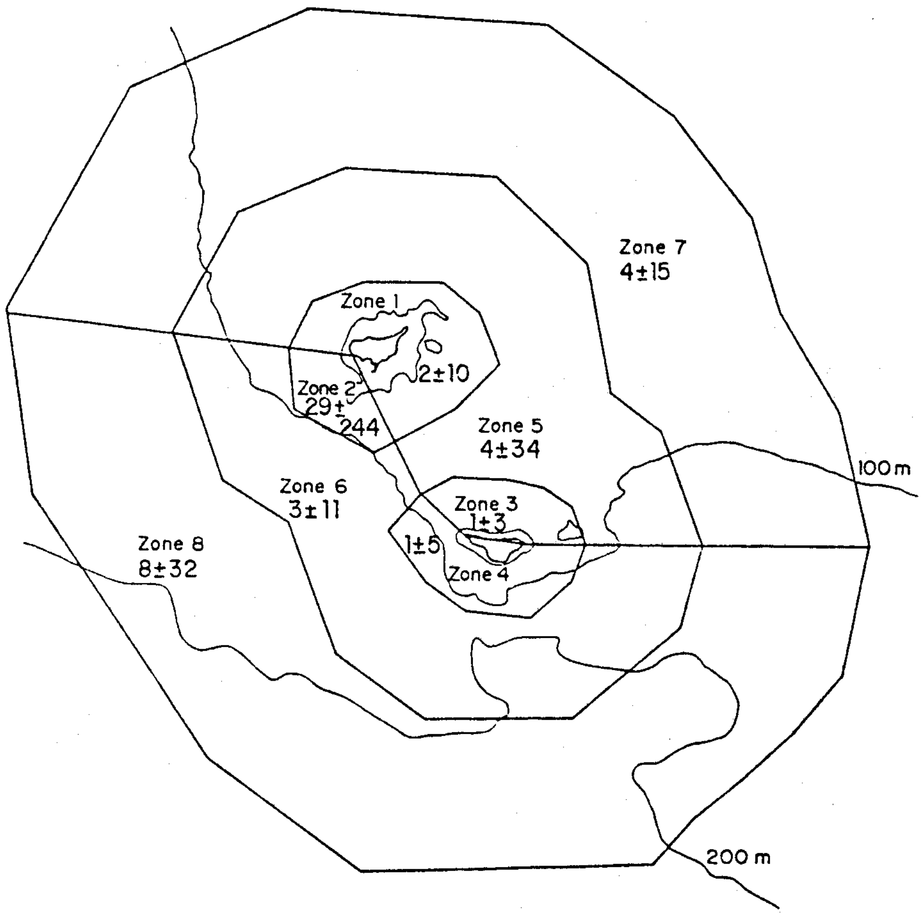

SHEARWATERS
AIR & SHIP SURVEYS : MARCH - MAY
SHEARWATERS
AIR & SHIP SURVEYS : JUNE - AUGUST
SHEARWATERS
AIR & SHIP SURVEYS : SEPT - NOVEMBER

FIGURE 24

Distribution of Shearwaters by zones
near the Pribilof Islands, 1975-1979 ($\bar{x} \pm s$)*



ANOVA across all zones, $F_{7,2131} = 3.078$, $P = 0.0031$
Homogeneous subsets by modified LSD Procedure, $\alpha = 0.05$
Subset 1 Zones 3,4,1,6,7,5,8
Subset 2 Zone 2
*rounded to whole numbers

FIGURE 25

the islands (Figure 25) showed low densities near the islands and no significant difference between zones, except that zone 2, where large flocks were encountered once in 1975, had higher mean values.

Diet

We obtained no data on the diet of shearwaters. Information on shearwater diet for the Bering Sea has been synthesized by Hunt et al. (1980a).

HYDROBATIDAE

The storm-petrels are small, pelagic seabirds that feed on small crustaceans or zooplankton at the sea surface. This family nests in polar and temperate areas of the Pacific from Antarctica north to the Aleutian Islands. Two species are known to breed in the Gulf of Alaska: the Fork-tailed Storm-Petrel (*Oceanodroma furcata*) and Leach's Storm-Petrel (*O. leucorhoa*). The northern limit of the known breeding range for this family in the Pacific is the Aleutian Islands; as yet there is no evidence that storm-petrels nest in the Bering Sea. Like the Procellariids, the storm-petrels have long incubation and nestling periods and have the potential to forage long distances from their colonies. It is not known why storm-petrels do not breed in the Bering Sea; Boersma and Wheelwright (1979) speculate that short nights and the frequent occurrence of storms in the southern Bering Sea may restrict their foraging and the ability of this nocturnal species to visit their colonies.

Fork-tailed Storm-Petrel (*Oceanodroma furcata*)

Fork-tailed Storm-Petrels breed on the Kommandorskie and Aleutian Islands, at the southern border of the Bering Sea. Hunt et al. (1980c) estimate 4 million storm-petrels forage over the eastern Bering Sea, predominately Fork-tailed Storm-Petrels. Leach's Storm-Petrels are relatively uncommon in the Bering Sea and hence will not be covered in this report. The estimates of Hunt et al. (1980c) are based on aerial and shipboard pelagic censuses.

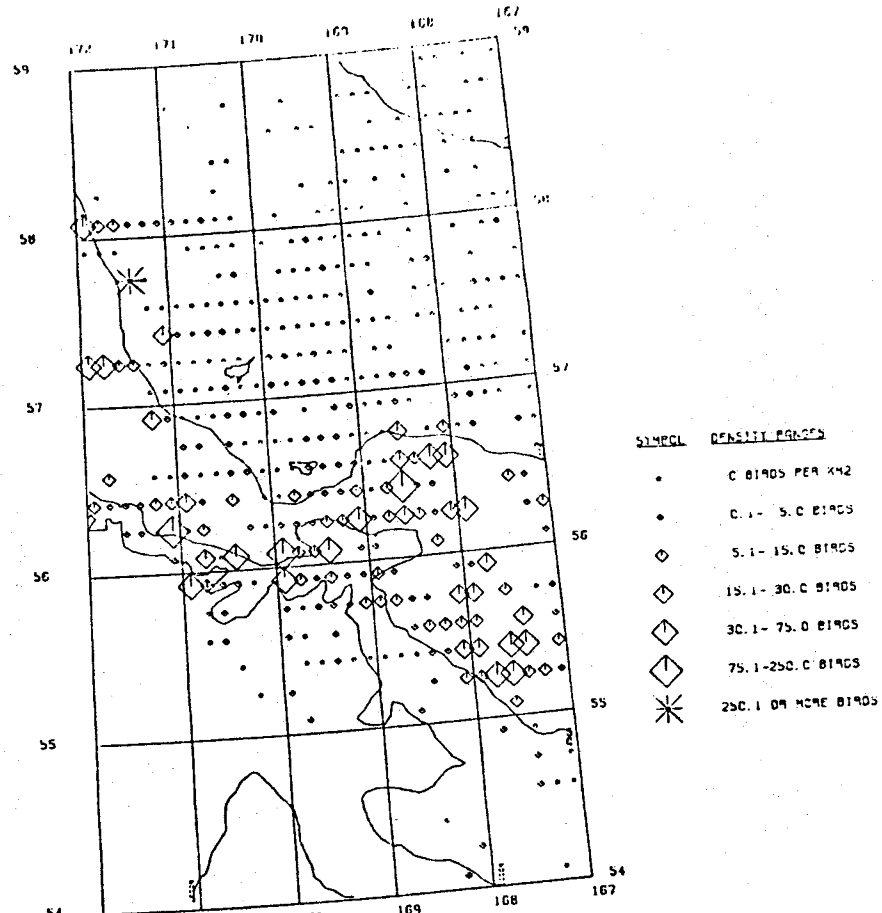
Pelagic Distribution

The pelagic distribution of Fork-tailed Storm-Petrels around the Pribilofs in summer is given in Figure 26. Although shipboard surveys of this species may produce elevated density estimates relative to aerial surveys because storm-petrels are attracted to ships, we could find no consistent differences in our data between the two survey methods. Hence, we have combined aerial and ship surveys in our analysis. Since Leach's Storm-Petrels are rare in the study area, Figure 26 and the following discussion applies almost exclusively to the Fork-tailed Storm-Petrel.

Storm-petrels do not appear in the study area from September through May. Fork-tailed Storm-Petrels apparently invade the Bering Sea rapidly in June and depart just as rapidly in late August.

During the summer months, the pelagic distribution of Fork-tailed Storm-Petrels is centered between the 100 and 2000 m isobaths. They apparently avoid the waters of the middle shelf domain (Figure 85; Hunt et al. 1980c). Relatively few are seen in shallower waters. Storm-petrels were encountered as solitary individuals or in small flocks, usually in transit, or in large flocks resting on the water.

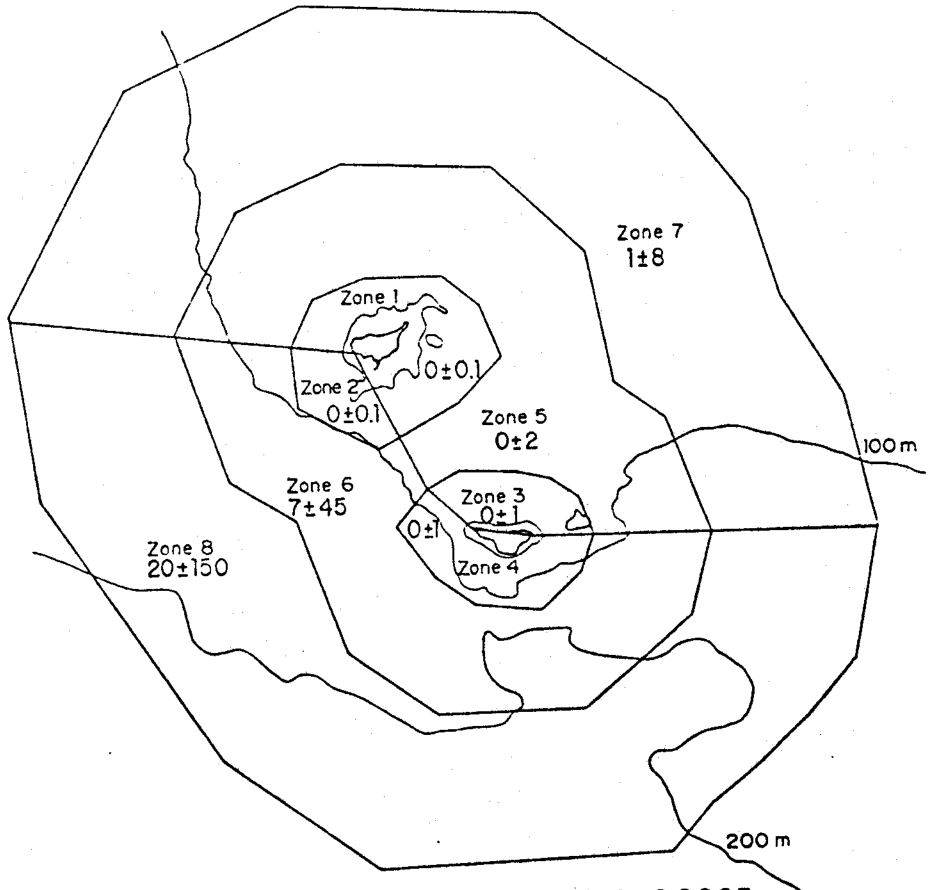
Examination of histograms of storm-petrel distribution around the Pribilofs provided little information of value. Zonal analysis showed that storm-petrels were rare near the islands, particularly on the north side (Figure 27). The differences in mean density between zones were not statistically significant (Modified LSD, $P > 0.05$).



STORM PETRELS (ALL)
SHIP & AIR SURVEYS . JUNE - AUGUST

FIGURE 26

Distribution of Storm Petrels by zones
near the Pribilof Islands 1975-1979 ($\bar{x} \pm s$)



ANOVA across all zones, $F_{7,2154} = 3.718$, $P = 0.0005$
Homogeneous subset by modified LSD Procedure, $\alpha = 0.05$
Subset 1 Zones 2,1,3,4,5,7,6,8

FIGURE 27

Diet

Fork-tailed Storm-Petrels forage by dipping and seizing prey while sitting on the water's surface. In the southeastern Bering Sea, they concentrate their foraging seaward of the 100 m isobath, and are seldom seen north of 57°N. One stomach sample of this species was taken during this study; the sample consisted entirely of squid. Preble and McAtee (1923) sampled another petrel at the Pribilofs and found traces of fish. Clearly we need more data on the diet of this species in the Bering Sea. Our observations of their ship-following tendencies suggest that they may take offal as well. Ainley and Sanger (1979) reviewed the literature for this species in the eastern North Pacific and added euphausiids to the items already mentioned.

PHALACROCORACIDAE

Three species of this family of diving seabirds breed in the Bering Sea: Pelagic, Double-crested and Red-faced Coromorants. The Red-faced Cormorant is the most numerous and is endemic to the Gulf of Alaska and southern regions of the Bering Sea. The Pelagic Cormorant has the widest distribution, reaching into the Chukchi Sea and south to the Channel Islands in California. Double-crested Cormorants in the eastern Bering Sea are confined to Bristol Bay. Cormorants make up a small portion of the large, multispecies colonies. They are numerous in coastal waters and bays and are rarely seen more than a few kilometers from land. Unlike the Procellariids and the Alcids, they lay several eggs and have a correspondingly high reproductive potential.

Pelagic Cormorant (*Phalacrocorax pelagicus*)

Numbers

Pelagic Cormorants occur in coastal waters throughout the Pacific, including the Bering Sea. There are an estimated 48,000 Pelagic Cormorants in the eastern Bering Sea (Appendix 1). Pelagic Cormorants do not nest on the Pribilof Islands, although they have been sighted there irregularly, and there are reports of nesting early in century (Preble and McAtee 1923).

Pelagic Distribution

This species was not observed during our pelagic surveys near the Pribilof Islands.

Diet

No samples of Pelagic Cormorant diet were obtained by OCSEAP investigators working in the Bering Sea. Preble and McAtee (1923) collected 21 Pelagic Cormorants at the Pribilof Islands during winter. Based on that sample, 74 percent of the diet was fish and 26 percent was crustaceans. Of the fish, Cottids were the most frequently taken. Shrimp were found in 86 percent of the stomachs. When compared to the diet of the Red-faced Cormorant, there appears to be some difference in the species of Cottids taken by the two cormorants at the Pribilofs (Preble and McAtee 1923), but without quantitative data it is impossible to assess the importance of these differences.

Fish and shrimp were the principal components of the diet of Pelagic Cormorants at Cape Thompson, based on two samples (Swartz 1966). In general, the findings from the Pribilofs and Cape Thompson agree with the summary of the foods of Pelagic Cormorants provided by Ainley and Sanger (1979).

Red-faced Cormorant (Phalacrocorax urile)

Numbers

The distribution of Red-faced Cormorants is centered in the Aleutian Islands and extends into the Gulf of Alaska (Gabrielson and Lincoln 1959). They nest on the Aleutian and Pribilof Islands and along the shore of Bristol Bay (Sowls et al. 1978). Like other cormorants, their distribution is typified by numerous small colonies. The eastern Bering Sea population of Red-faced Cormorants is estimated at 41,000 (Appendix 1). The cormorant colonies at the Pribilofs are among the largest in the Bering

Sea, and account for about 18 percent of the population in the eastern Bering Sea.

Pelagic Distribution

The pelagic distribution of Red-faced Cormorants around the Pribilofs is shown in Figure 28. Aerial and shipboard surveys produced similar results so both methods were combined in this analysis.

Red-faced Cormorants remain near the Pribilof Islands throughout the year when open water is available. We have few reports of this species away from the islands, except in fall when cormorants may have been migrating from northern waters. As expected, we found similar distribution patterns for this species in spring, summer and fall.

The pelagic distribution of Red-faced Cormorants is centered around the Pribilof Islands. Most cormorants are found within 1 to 2 km and rarely out to 5 km from the islands; cormorants were not encountered in water deeper than 100 m.

Diet

Red-faced Cormorants obtain their food by diving, capturing fish and crustaceans near the bottom. Cormorants usually forage in the immediate vicinity of their colonies or roosts, a result of their need to leave the water for frequent periods to dry their feathers (Rijke 1968).

Figure 29 summarizes the diet of Red-faced Cormorants at the Pribilofs between 1975 and 1978. Their primary source of food was fish, and of the remains identified, Cottids were taken most frequently. A wide variety of large decapods were taken,

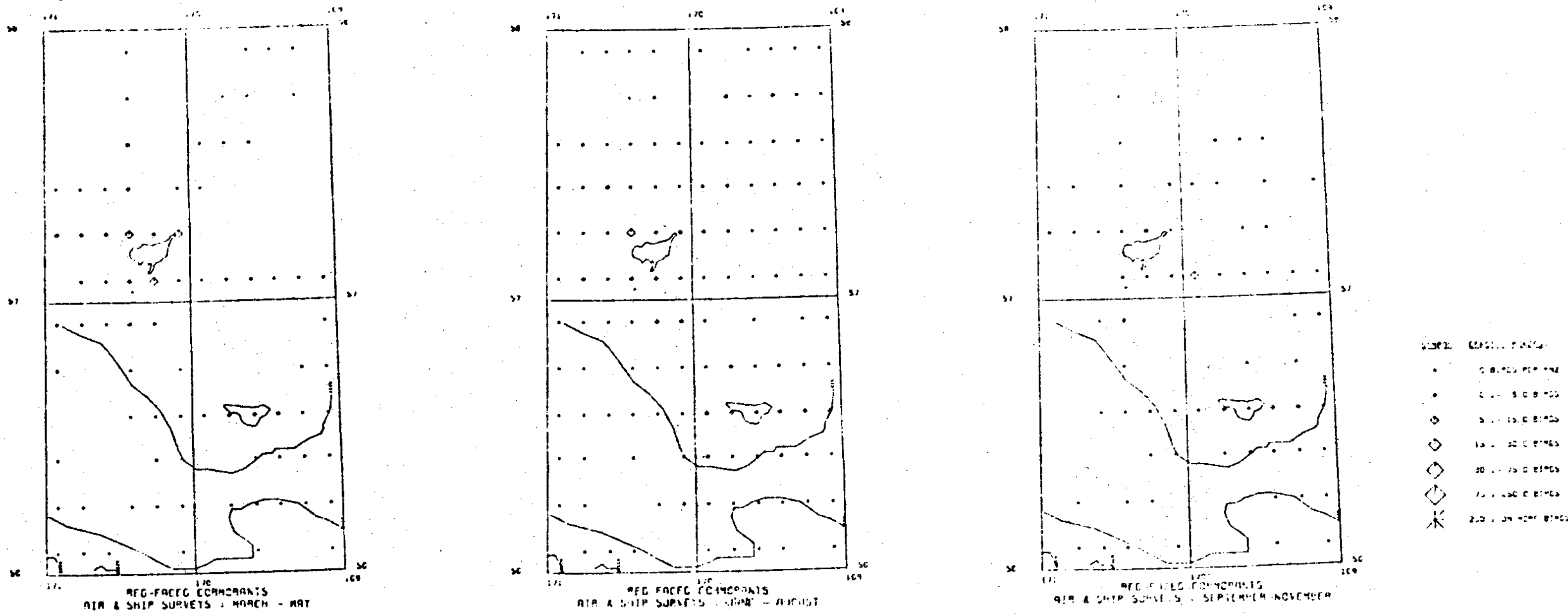

RED-FACED CORMORANTS
AIR & SHIP SURVEYS - MARCH - MAY
RED FACED CORMORANTS
RED-FACED CORMORANTS

FIGURE 28

MAJOR COMPONENTS OF THE DIET OF RED-FACED CORMORANTS

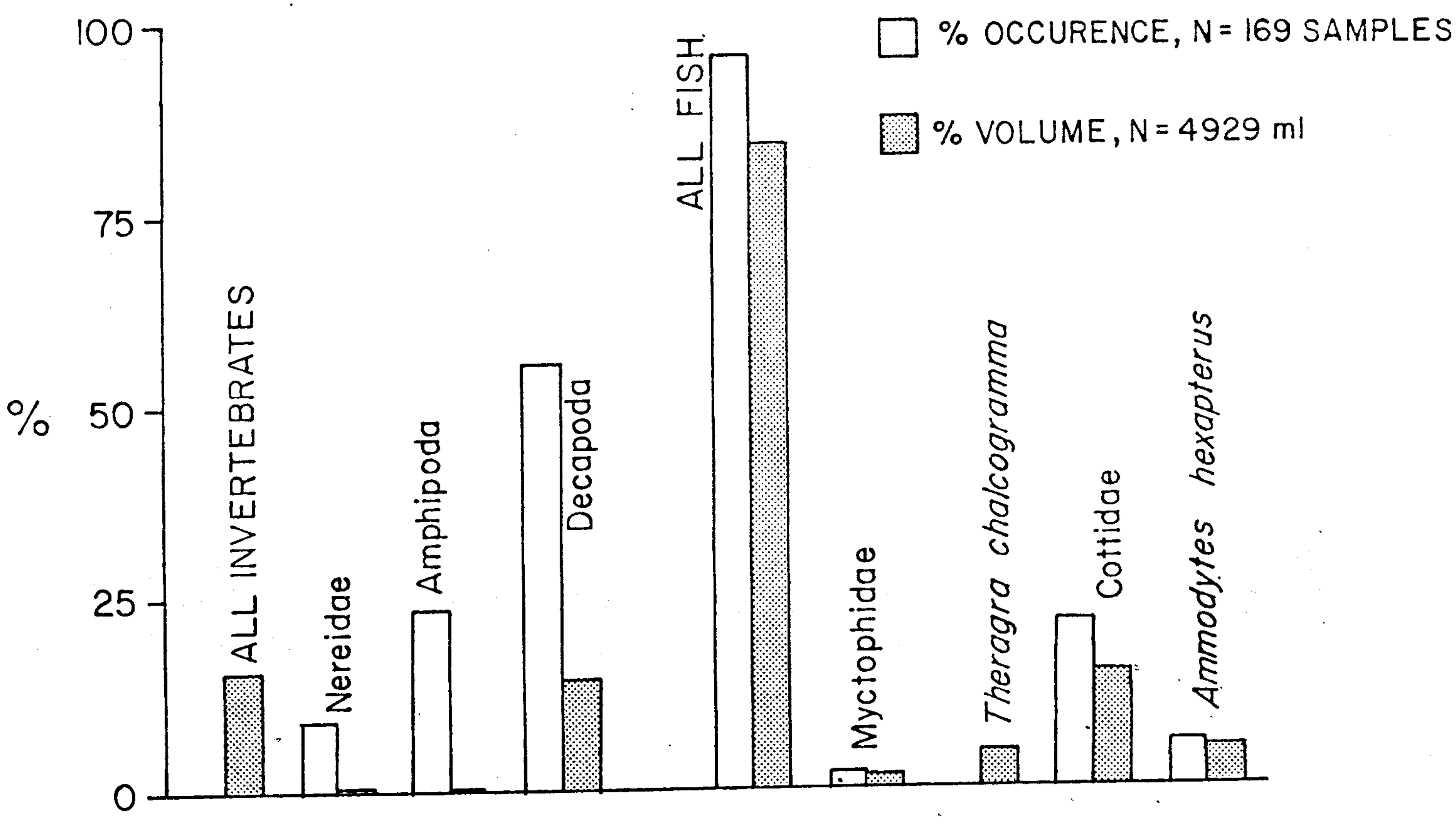


FIGURE 29

including shrimp and crabs. Preble and McAtee (1923) found in 5 stomachs collected at the Pribilofs, that 58 percent of the diet was fish, while shrimp were the most prevalent invertebrates. All indications are that Red-faced Cormorants forage near the sea bottom, close to land, and probably have little effect on the marine ecosystems of the Bering Sea as a whole.

Within the diet of Red-faced Cormorants, we found significant differences between the diets of adults (stomach samples) and of young (regurgitations) (Median test $\chi^2 = 6.0$, $P < 0.025$). Cottids were overrepresented in the diet of young, while adults subsisted on a larger percentage of invertebrates, mostly crabs. Belopol'skii (1957) and Hunt (1970, 1972) have suggested that invertebrates are nutritionally inferior to fish for the purposes of raising young.

Nesting

Habitat

Red-faced Cormorants nest in scattered pairs or small groups among other cliff-nesting seabirds. At the Pribilofs, they show a preference for the lower sections of cliffs and are rarely seen above 122 m (Hickey and Craighead 1977). It is common for Red-faced Cormorants to change the location of their nests from year to year. We found that many cormorant sites occupied in 1975 were abandoned in 1976 and new areas were colonized.

Phenology

Cormorants are year-around residents of the Pribilof Islands. They are also among the earliest seabirds to begin nesting. Only in 1977 and 1978 did we arrive at the island early enough to document egg-laying and even then we missed the first eggs. Egg-laying begins in early May, with the peak of laying occurring in mid-May (Tables 3 and 4). Incubation lasts an average of 31 $\pm$ 5 days (n = 5). The peak of hatching occurs in late June (Figure 30). Chicks remain in the nest for an average of 59 $\pm$ 5 days and fledge in late August (Figures 31 and 32). Cormorants on St. Paul Island consistently showed earlier phenology than cormorants nesting on St. George Island (Tables 3 and 4).

Daily Activity Patterns

The numbers of Red-faced Cormorants on the cliffs are quite variable throughout the season and throughout the day (Hickey and Craighead 1977). Since this species is present in comparatively small numbers, their patterns of colony attendance were not investigated.

Productivity

Productivity in Red-faced Cormorants did not differ significantly between islands despite the greater potential for competition on St. George Island. Since there seemed to be substantial variation in productivity from one year to the next, our analysis of island differences also had to take yearly variation into consideration. We analyzed productivity using a two-way analysis of variance to segregate the effects of islands and years on productivity and also to determine the degree to which island differences depend on years. Productivity in Red-faced Cormorants was largely independent of both island and year effects (r^2 = 0.13, P > 0.5). Reproductive success in cormorants averaged 1.25 chicks fledged per nest (Table 5). Average clutch size was 2.84 eggs per nest, with a range of 1 to 4 eggs (Table 5).

TABLE 3

Phenology of Red-faced Cormorants on St. Paul Island, 1975-1978

	1975	1976	1977	1978
FIRST EGG OBESERVED	22 June*	25 June*	21 May	5 May
CLUTCH INITIATION $\bar{X} \pm S$ (1st egg of clutch)	-------	13 M $\pm$ 2	30 M $\pm$ 8	19 M $\pm$ 11
N=		7	22	45
FIRST CHICK OBSERVED	23 June	5 July	21 June	7 June
HATCHING $\bar{X} \pm S$ (1st chick of brood)	-------	13 Jn $\pm$ 2	1 Jl $\pm$ 3	19 Jn $\pm$ 5
N=		7	11	7
FIRST FLEDGING OBSERVED	25 August	24 August	19 August	5 August
FLEDGING $\bar{X} \pm S$	21A $\pm$ 5**	1 S $\pm$ 9	25 A $\pm$ 5	22 A $\pm$ 8
N=	50	50	29	32

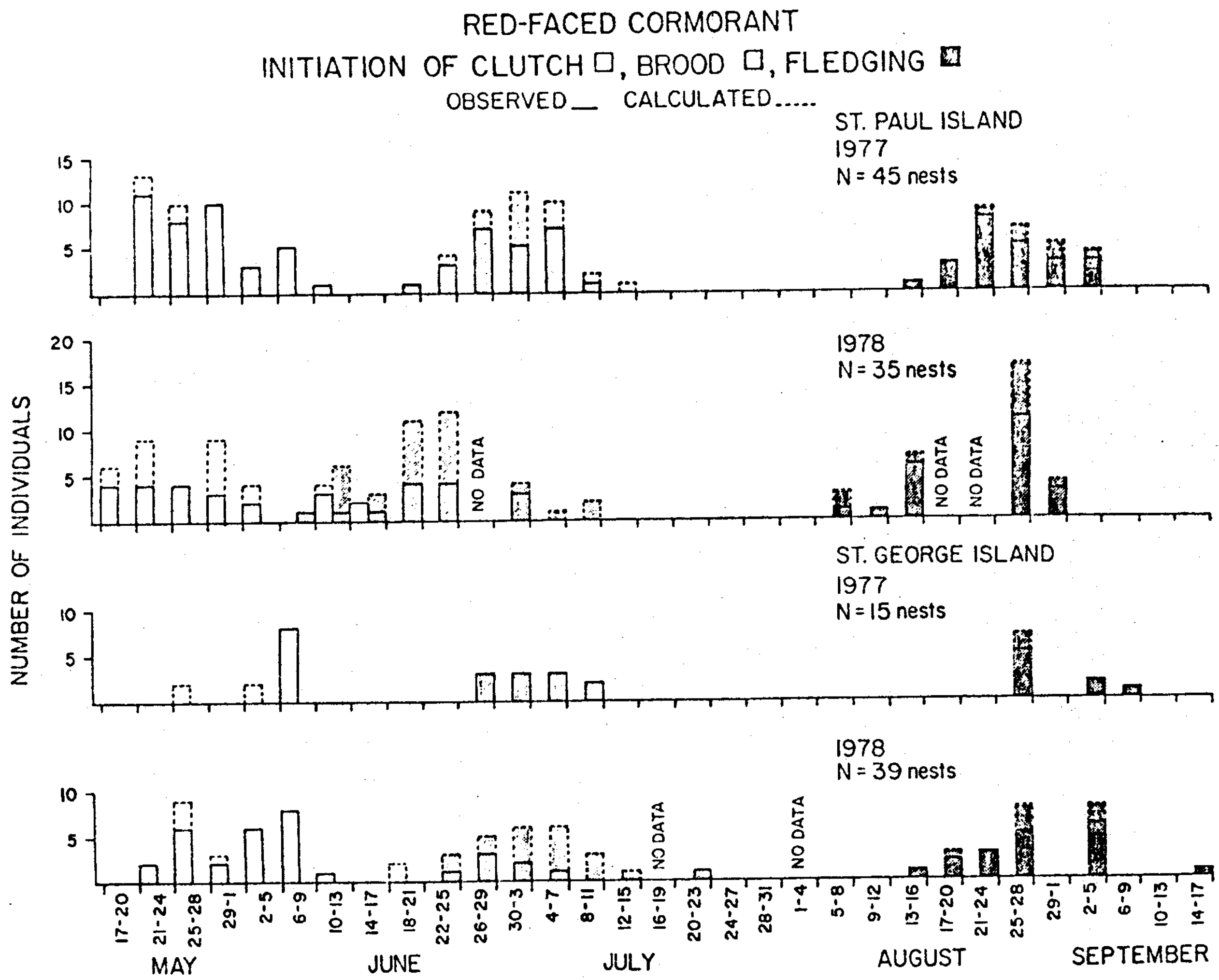
* first observation date
** missed late fledgings

TABLE 4

Phenology of Red-faced Cormorants on St. George Island, 1976-1978

	1976	1977	1978
FIRST EGG OBSERVED	----	27 May*	22 May*
CLUTCH INITIATION $\bar{X} \pm S$ (1st egg of clutch)	----	4 Jn $\pm$ 6	2 Jn $\pm$ 7
N=		15	28
FIRST CHICK OBSERVED	7 July	10 July	24 June
HATCHING $\bar{X} \pm S$ (1st chick of brood	----	3 Jl $\pm$ 6	4 Jl $\pm$ 7
N=		7	28
FIRST FLEDGING OBSERVED	25 August	25 August	16 August
FLEDGING $\bar{X} \pm S$	4 S $\pm$ 8	29 A $\pm$ 6	29 A $\pm$ 7
N=	5	13	44

* calculated from date of first hatching



RED-FACED CORMORANT
INITIATION OF CLUTCH, BROOD, FLEDGING
OBSERVED__ CALCULATED.....
ST. PAUL ISLAND
1977
N = 45 nests
1978
N = 35 nests
NO DATA
ST. GEORGE ISLAND
1977
N = 15 nests
1978
N = 39 nests
NUMBER OF INDIVIDUALS
17-20
21-24
25-28
29-1
2-5
6-9
10-13
14-17
18-21
22-25
26-29
30-3
4-7
8-11
12-15
16-19
20-23
24-27
28-31
1-4
5-8
9-12
13-16
17-20
21-24
25-28
29-1
2-5
6-9
10-13
14-17
MAY
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 30

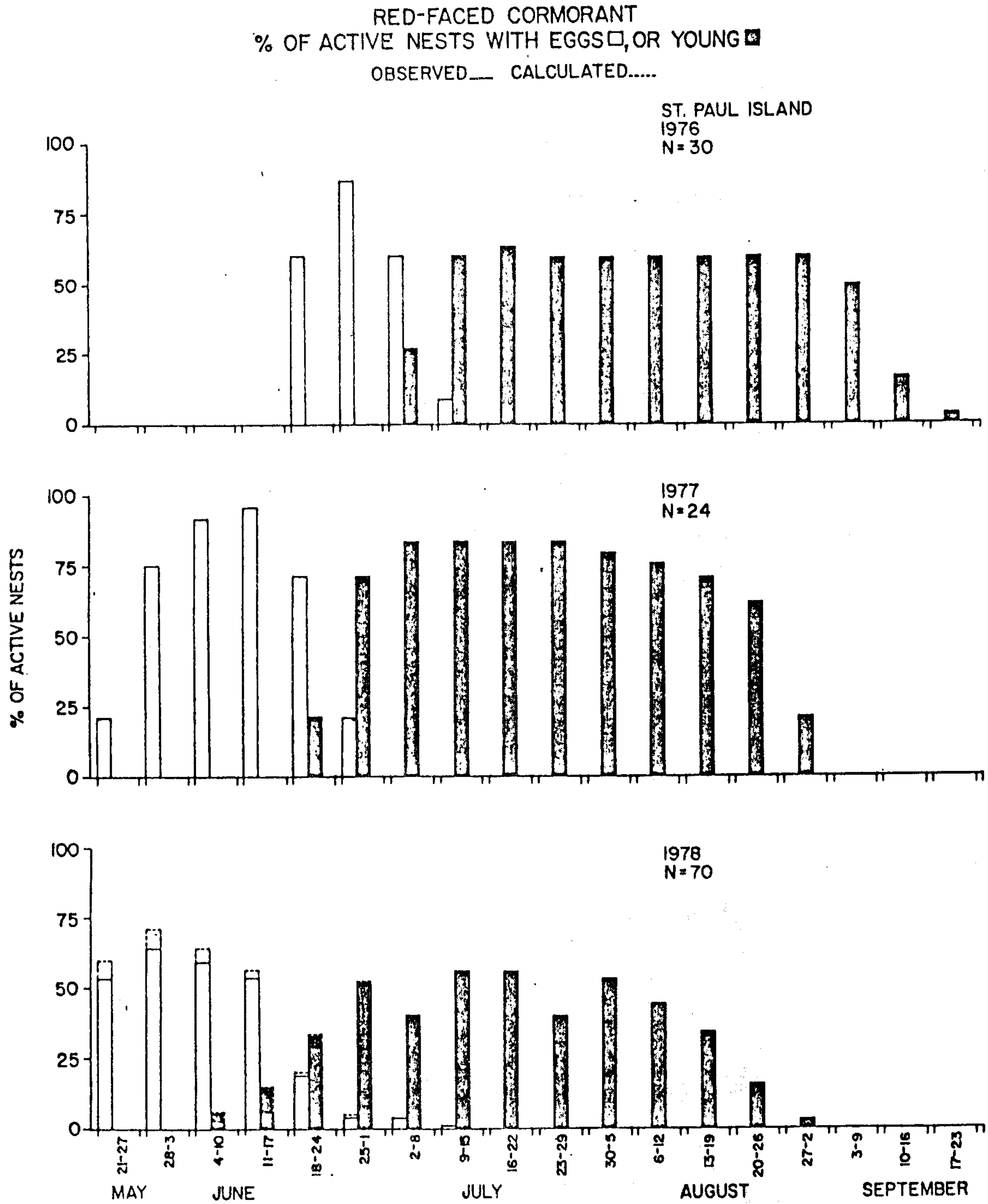

RED-FACED CORMORANT
% OF ACTIVE NESTS WITH EGGS, OR YOUNG
OBSERVED___ CALCULATED.....
ST. PAUL ISLAND
1976
N=30
1977
N=24
1978
N=70
% OF ACTIVE NESTS
100
75
50
25
0
21-27
28-3
4-10
11-17
18-24
25-1
2-8
9-15
16-22
23-29
30-5
6-12
13-19
20-26
27-2
3-9
10-16
17-23
MAY
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 31

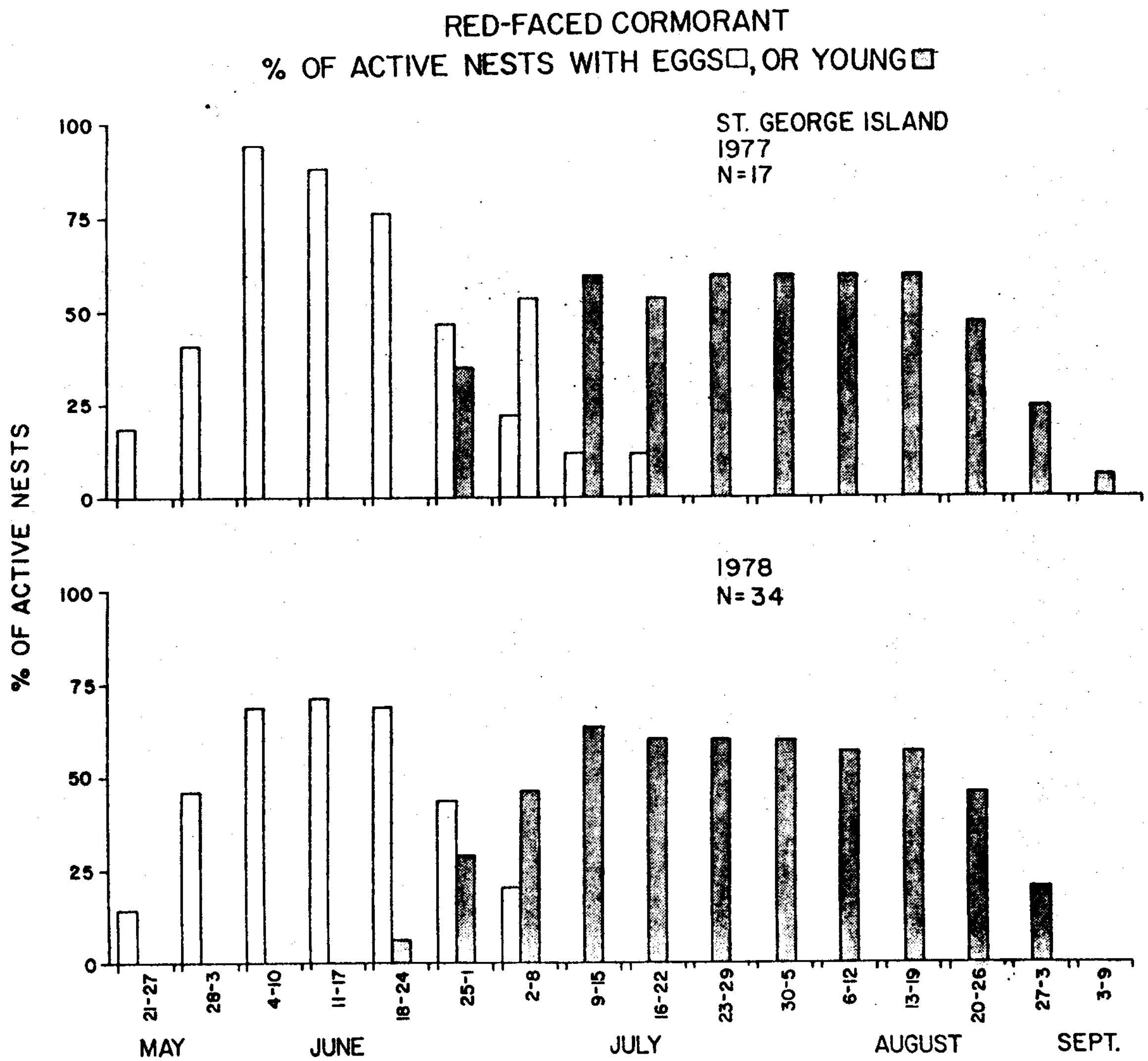

RED-FACED CORMORANT
% OF ACTIVE NESTS WITH EGGS, OR YOUNG
ST. GEORGE ISLAND
1977
N=17
1978
N=34
% OF ACTIVE NESTS
100
75
50
25
0
21-27
28-3
4-10
11-17
18-24
25-1
2-8
9-15
16-22
23-29
30-5
6-12
13-19
20-26
27-3
3-9
MAY
JUNE
JULY
AUGUST
SEPT.

FIGURE 32

TABLE 5

Reproductive biology of Red-faced Cormorants at the Pribilof Islands, 1975-1978

	ST. PAUL ISLAND				ST. GEORGE ISLAND		
	1975	1976	1977	1978	1976	1977	1978
X CLUTCH	3.00	2.89	2.75	2.62	3.00	2.83	2.78
N=	33	19	41	42	10	51	18
HATCHING SUCCESS (chicks hatched/ egg laid)	0.38-0.44	0.25-0.40	0.45	0.51	0.57	0.59	0.64
REPRODUCTIVE SUCCESS (chicks fledged/ incubated nest)	1.31-1.38	1.52	1.27	1.09	1.60	1.39	1.62
PRODUCTIVITY (chicks fledged/ nest attempt)	1.20-1.24	1.46	1.20	1.00	1.45	1.23	1.25
N=	88	82	54	90	11	27	53
CHICK GROWTH RATE (grams/day)	61.8 $\pm$ 10.2	60.2 $\pm$ 14.7	61.7 $\pm$ 8.1	72.0 $\pm$ 2.8	48.5 $\pm$ 13.2	59.8 $\pm$ 6.9	56.1 $\pm$ 5.1
N=	8	17	4	8	11	14	6

Losses of eggs and chicks were primarily due to desertion by the parents; the causes of abandonment are not known. Gull predation, an important cause of mortality in other Alaskan cormorant colonies is negligible on the Pribilof Islands. Other causes of mortality include fox predation and hunting by Aleuts. Death of young in the nest was encountered with some frequency, but the causes are unknown.

Cormorant chicks on St. Paul consistently showed higher growth rates than cormorant chicks on St. George Island (Table 5). We applied the same analysis of variance procedure to growth rates as was applied to productivity. The analysis was significant ($r^2 = 0.51$, $P < 0.005$). However, the difference between mean growth rates on the two islands depended on the years (significant interaction component, $P = 0.05$). Hence, we analyzed yearly differences for each island separately. On St. Paul Island, growth rates averaged 63.8 gm/day (T test, 1976 to 1977, $P > 0.5$), except for 1978 when rates were significantly higher (T test, 1976 and 1977 combined, compared to 1978, $P < 0.005$). On St. George Island, growth rates averaged 53.5 gm/day for 1976 and 1978 (T test, 1976 compared with 1978, $P = 0.5$), but growth rates were significantly higher in 1977 (T test, 1976 and 1978 combined compared with 1977, $.01 < P < .005$). In 1977, St. George growth rates rivaled those from St. Paul (T test, St. Paul 1977 compared with St. George 1977, $P = 0.2$). The fact that the highest growth rates for cormorants on the two islands camein different years suggests that populations of this species on the two islands are behaving independently.

LARIDAE

Eight species of Larids nest in the eastern Bering Sea; these are the Herring, Mew, Glaucous and Glaucous-winged Gulls, the Black-legged and Red-legged Kittiwakes, and the Arctic and Aleutian Terns. Only the two kittiwakes and the Glaucous-winged Gull nest at the Pribilofs, hence only these species will be discussed in this report.

Two types of feeding strategies are exemplified by the members of the Laridae: the gulls are scavengers, egg predators, or coastal foragers; while the pelagic kittiwakes feed at the surface of oceanic waters. The Black-legged Kittiwake is the most numerous Larid in the Bering Sea, while the large gulls comprise only a small percentage of large seabird colonies. Although the status of Bering Sea populations of the large gulls is unknown, we may expect their populations to increase as waste food from man becomes more available with continued coastal development.

Glaucous-winged Gull (*Larus glaucescens*)

Numbers

Glaucous-winged Gulls nest throughout the North Pacific, from Washington State north to Nunivak Island in the Bering Sea (Gabrielson and Lincoln 1959). The populations of Glaucous-winged Gulls in the eastern Bering Sea is estimated at 84,000 birds (Appendix 1). A few hundred, mostly immature gulls, are present at the Pribilofs throughout the summer. Two to four pairs were found nesting on Shag Rock in 1977 and 1978, 500 m east of Garden Cove, St. George Island, and one pair was seen nesting on a low cliff ledge at the west end of St. Paul Island in 1976.

Pelagic Distribution

We did not investigate the pelagic distribution of Glaucous-winged Gulls around the Pribilofs since they occurred in such low numbers. In general, they were concentrated near the islands or around ships in the area.

Diet

We made no effort to investigate the diet of Glaucous-winged Gulls at the Pribilofs; however they were frequently seen foraging in the dumps, at the fur seal killing fields and in the fur seal rookeries on St. Paul and St. George Islands. We refer the reader to Patten and Patten (1977) for a discussion of the diet of Glaucous-winged Gulls.

Black-legged Kittiwake (*Rissa tridactyla*)

Numbers

The Black-legged Kittiwake occurs throughout the northern oceans. In the Bering Sea, their breeding colonies are widespread: the largest of these is located at Cape Peirce (Sowls et al. 1978). The Pribilof Islands support as estimated 108,000 Black-legged Kittiwakes (Hickey and Craighead 1977). This amounts to approximately 12 per cent of the estimated population in the eastern Bering Sea (Appendix 1). The Black-legged Kittiwake colonies at the Pribilofs are probably insignificant in terms of world numbers, although they may be important in sustaining Bering Sea numbers (Hunt et al. 1980b).

Pelagic Distribution

The pelagic distribution of Black-legged Kittiwakes is presented in Figure 33. This analysis combines the results of

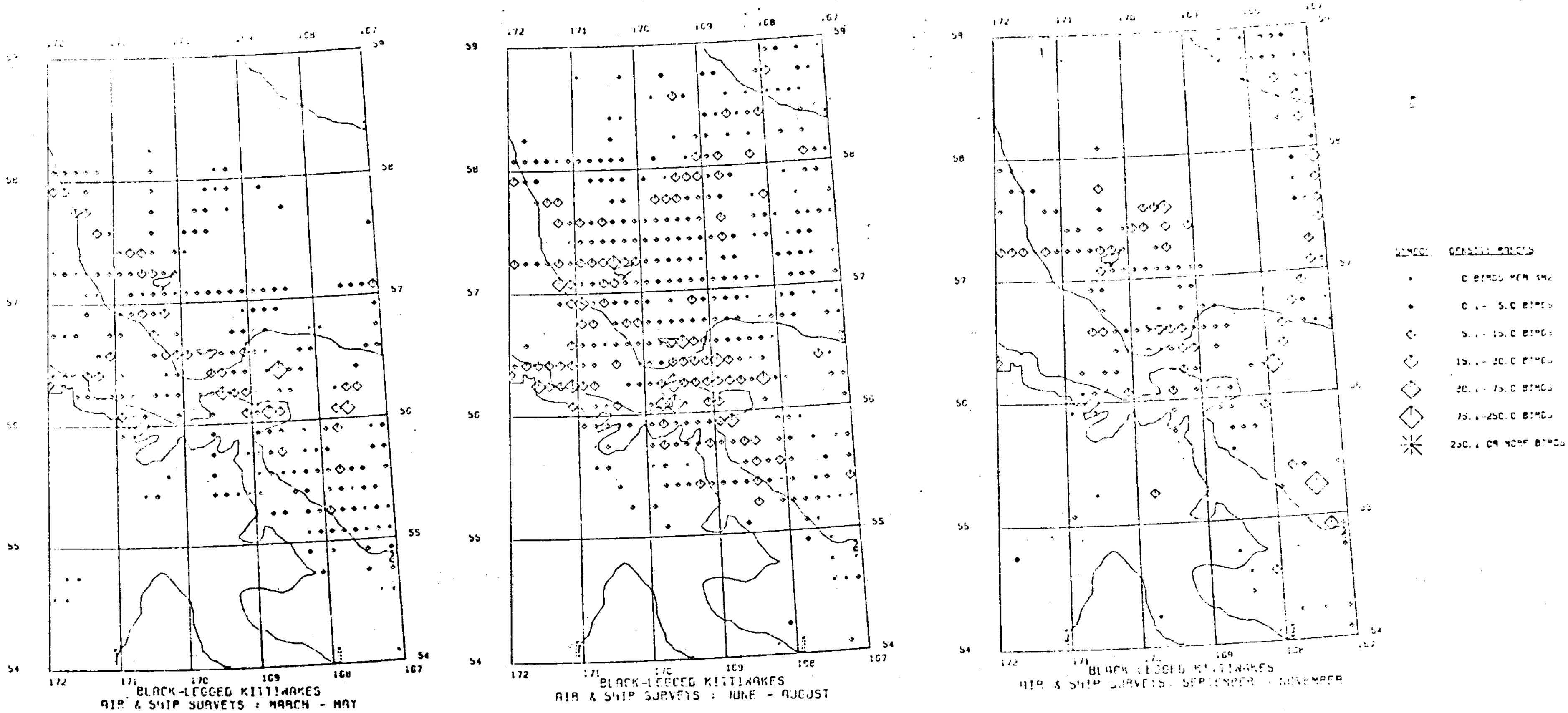

172
171
170
169
168
167
59
58
57
56
55
54
BLACK-LEGGED KITTIWAKES
AIR & SHIP SURVEYS : MARCH - MAY
BLACK-LEGGED KITTIWAKES
AIR & SHIP SURVEYS : JUNE - AUGUST
BLACK-LEGGED KITTIWAKES

FIGURE 33

ship and aerial surveys since the two methods produced similar results. We have included unidentified kittiwakes under Black-legged Kittiwakes, although near the Pribilofs, where observers familiar with the two species did most surveys, very few kittiwakes were not identified to species.

We found little variation in Black-legged Kittiwake distribution or densities between spring, summer and fall. In all three seasons, this species was generally found in low concentrations, with occasional large flocks associated with fishing vessels. Generally, Black-legged Kittiwakes were widely dispersed over the area surveyed. Small flocks frequently formed around local concentrations of food, but quickly dispersed as food was depleted. Black-legged Kittiwakes are the major catalysts for the formation of mixed species feeding flocks in Alaskan waters (Wiens et al. 1978). In our study area there appeared to be a trend toward higher densities of Black-legged kittiwakes over waters from 100 to 2000 m, particularly in spring and summer, although we are not certain why this occurs.

Histograms of Black-legged Kittiwake densities around the Pribilofs show virtually no increase in density close to the islands (Figure 34). Density increases near the shelf break, but is consistently low in all other areas. Examination of Black-legged Kittiwake densities by zonal analysis also shows consistently low densities (Figure 35).

Diet

Except for their occasional participation in feeding flocks, Black-legged Kittiwakes generally forage in low densities. Kittiwakes are restricted to foraging within about 0.5 m of the surface.

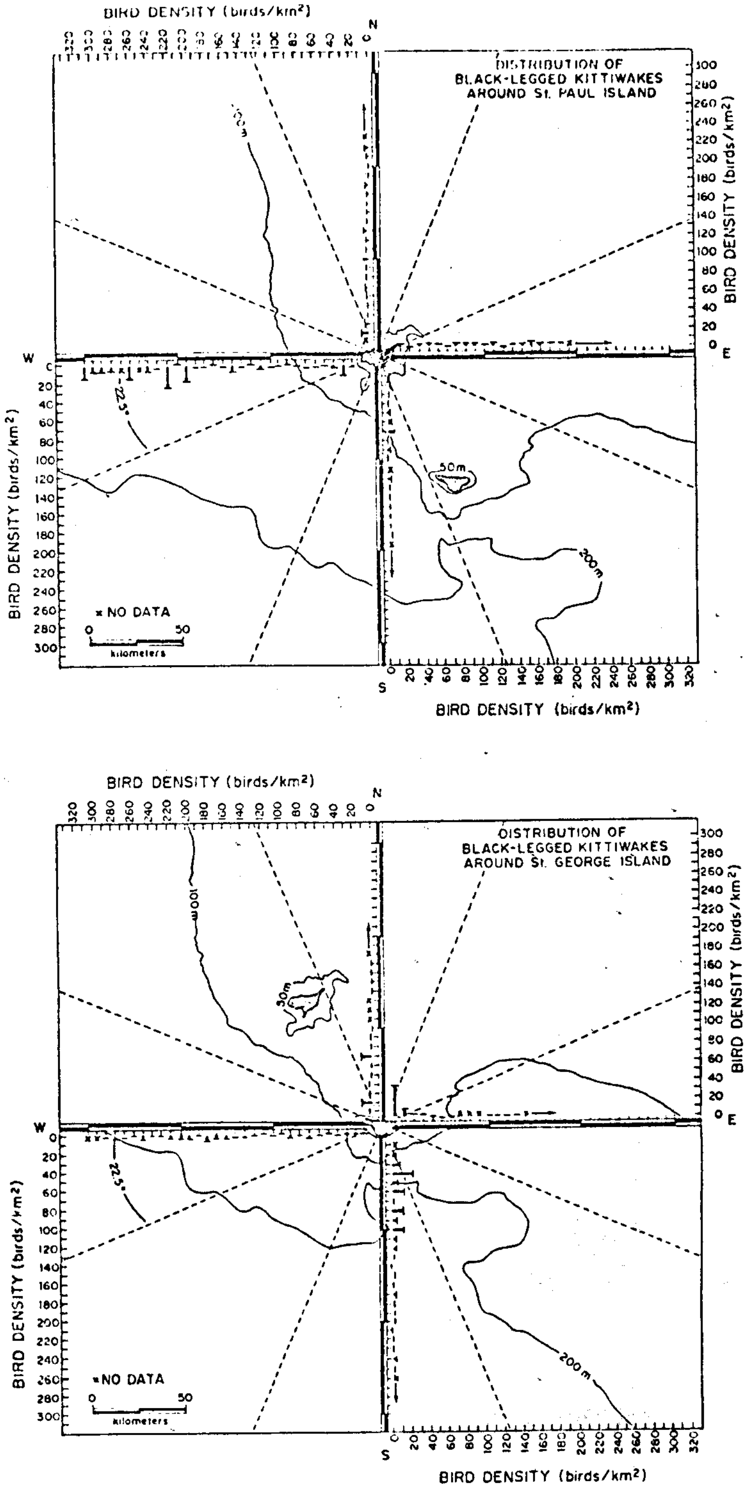
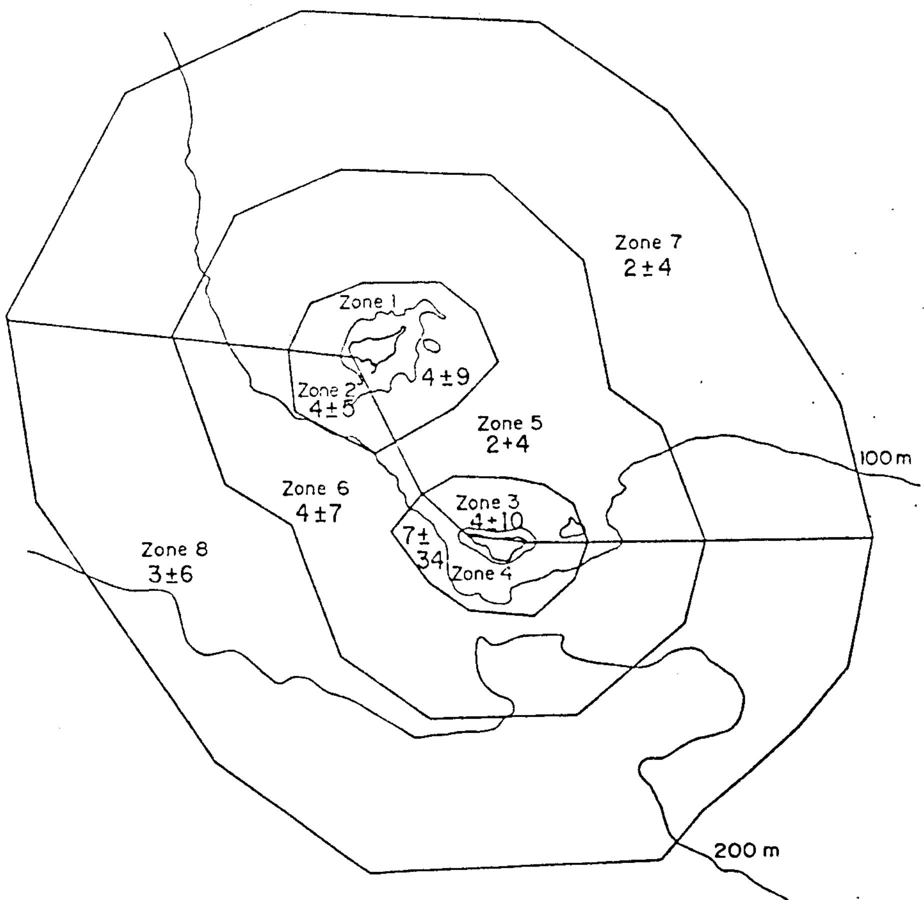

BIRD DENSITY (birds/km²)
N
S
E
W
DISTRIBUTION OF
BLACK-LEGGED KITTIWAKES
AROUND St. PAUL ISLAND
× NO DATA
0
50
kilometers
22.5°
50m
200m
100m
DISTRIBUTION OF
BLACK-LEGGED KITTIWAKES
AROUND St. GEORGE ISLAND

FIGURE 34

Distribution of Black-legged Kittiwakes by zones near the Pribilof Islands, 1975-1979 ($\bar{x} \pm s$)*



ANOVA across all zones, $F_{7,2150} = 3.120$, $P = 0.0029$

Homogeneous subsets by modified LSD Procedure, $\alpha = 0.05$

Subset 1 Zones 5,7,8,3,6,2,1

Subset 2 Zones 3,6,2,1,4

*rounded to whole numbers

FIGURE 35

MAJOR COMPONENTS OF THE DIET OF BLACK-LEGGED KITTIWAKES

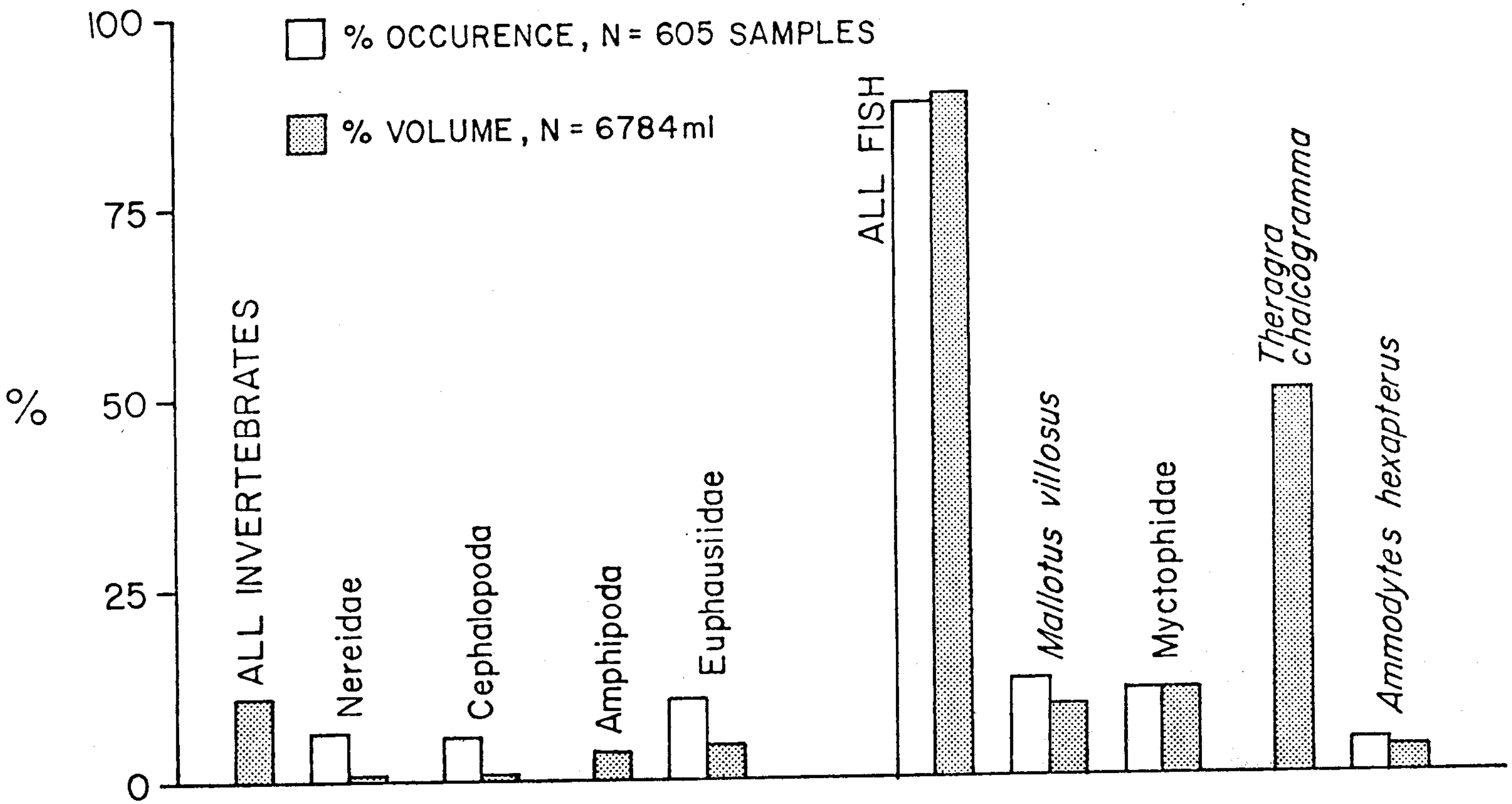


FIGURE 36

Figure 36 summarizes the major components of the Black-legged Kittiwake diet at the Pribilofs between 1975 and 1978. Fish were by far the most important food source, and walleye pollock was the predominant fish in the diet. Capelin (Mallotus villosus) and myctophids were also taken, but less frequently than pollock. Preble and McAtee (1923) collected only 3 Black-legged Kittiwake stomachs at the Pribilofs and one at St. Matthew Island, and provide few data of value.

There was a marked seasonal variation in Black-legged Kittiwake diet at the Pribilofs (Median Test $\chi^2 = 8.94$, $P < 0.05$). The diet showed a heavy dependence on invertebrates early in the breeding season, but switched to fish later (Figure 37). In June, before eggs were laid, amphipods (Parathemisto) and euphausiids (Thysanoessa) were the primary food source for Black-legged Kittiwakes. In July, once incubation had begun, walleye pollock was the primary food source, with myctophids and euphausiids contributing to a lesser degree. In August and September, when most food samples were obtained as regurgitations from chicks, walleye pollock and capelin predominated.

One explanation for the shift from invertebrates to fish is that kittiwakes may preferentially feed their young on fish, which are thought to be nutritionally superior to invertebrates for raising young (Belopol'skii 1957, Hunt 1970, 1972). Another explanation is that the diet reflects the changing abundance of prey types in the foraging areas. A third explanation is that Black-legged Kittiwake forage in different areas early and late in the breeding season. Initially, Black-legged Kittiwakes

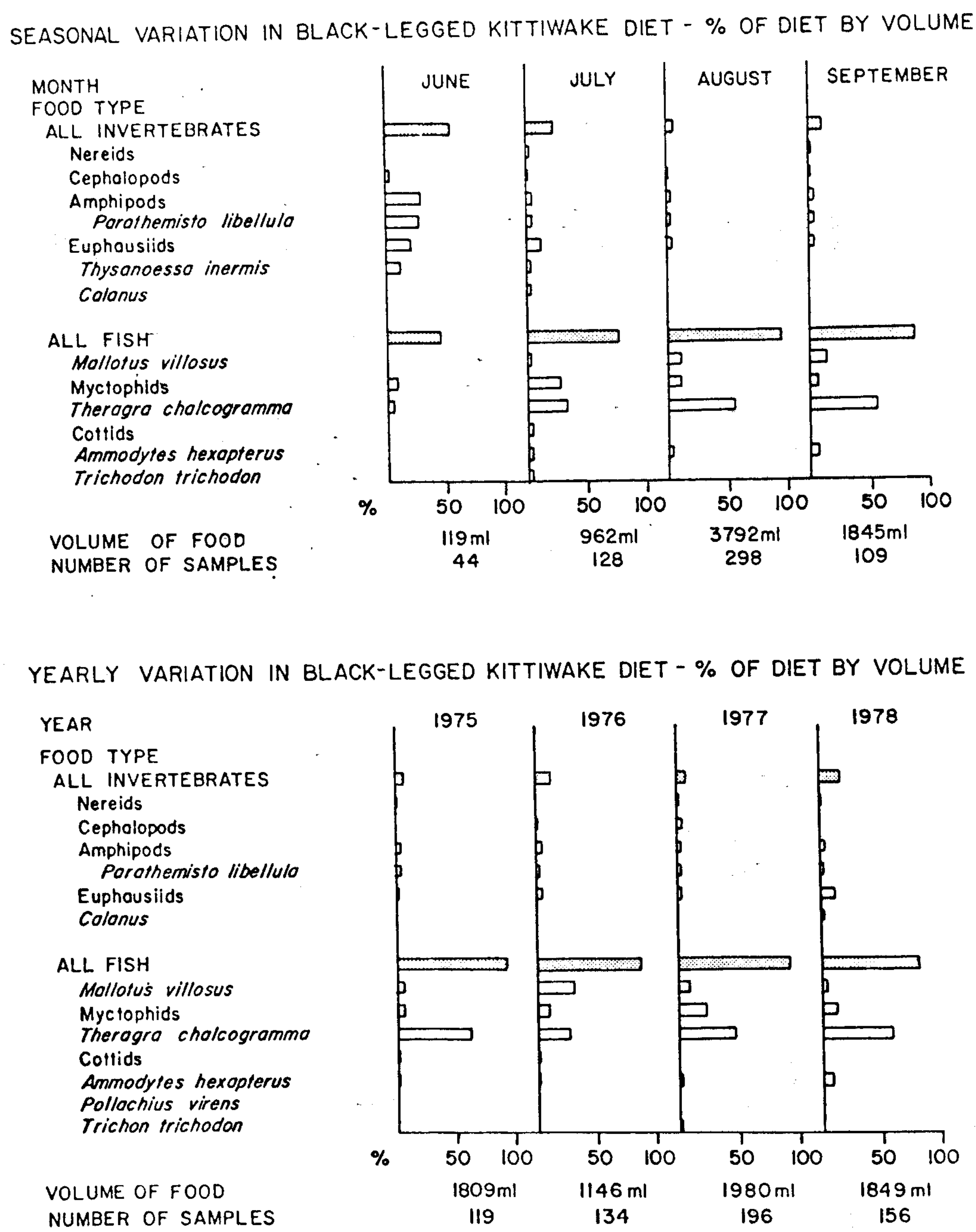

SEASONAL VARIATION IN BLACK-LEGGED KITTIWAKE DIET - % OF DIET BY VOLUME
MONTH
JUNE
JULY
AUGUST
SEPTEMBER
FOOD TYPE
ALL INVERTEBRATES
Nereids
Cephalopods
Amphipods
Parathemisto libellula
Euphausiids
Thysanoessa inermis
Calanus
ALL FISH
Mallotus villosus
Myctophids
Theragra chalcogramma
Cottids
Ammodytes hexapterus
Trichodon trichodon
%
50
100
VOLUME OF FOOD
119ml
962ml
3792ml
1845ml
NUMBER OF SAMPLES
44
128
298
109
YEARLY VARIATION IN BLACK-LEGGED KITTIWAKE DIET - % OF DIET BY VOLUME
YEAR
1975
1976
1977
1978
FOOD TYPE
ALL INVERTEBRATES
Nereids
Cephalopods
Amphipods
Parathemisto libellula
Euphausiids
Calanus
ALL FISH
Mallotus villosus
Myctophids
Theragra chalcogramma
Cottids
Ammodytes hexapterus
Pollachius virens
Trichon trichodon
%
50
100
VOLUME OF FOOD
1809ml
1146 ml
1980 ml
1849 ml
NUMBER OF SAMPLES
119
134
196
156

FIGURE 37

forage near the shelf break, feeding on oceanic species such as myctophids and the euphausiids _T. inermis_ and _T. longipes_. In August and September, the oceanic species are replaced by shelf species such as walleye pollock and _T. raschii_, suggesting that long foraging trips are avoided due to the time constraints of chick rearing.

The size of walleye pollock taken by Black-legged Kittiwakes changes throughout the breeding season (Figure 38). In July, fish 13 - 18 cm in length were common in the food samples and were probably year old fish (Cooney et al. 1978), although smaller fish seemed to be taken preferentially. In August and September, the small fish predominated in the diet. These fish belonged to the current year class, which had now attained a length of 6 - 8 cm. The shift to yonger and smaller fish probably reflects the increased availability of young pollock in August and September.

It is not known why pollock and other fish were not used more extensively in June; it is possible that they were not available. An alternative explanation is that the invertebrates, _Parathemisto_ and euphausiids were easier to obtain, or that there was less competition for this type of prey. Alternatively, invertebrates may be taken in preference to fish until a point in the breeding cycle when the higher nutritional values of fish are required for feeding growing young.

In discussing the competitive relations between species in seabird colonies, Belopol'skii (1957) comments that invertebrates were less valuable than fish for raising young. He found that when kittiwakes in Barents Sea colonies were forced to rely heavily

CHANGES IN SIZE OF WALLEYE POLLOCK (*Theragra chalcogramma*) TAKEN BY BLACK-LEGGED KITTIWAKES ON THE PRIBILOF ISLANDS

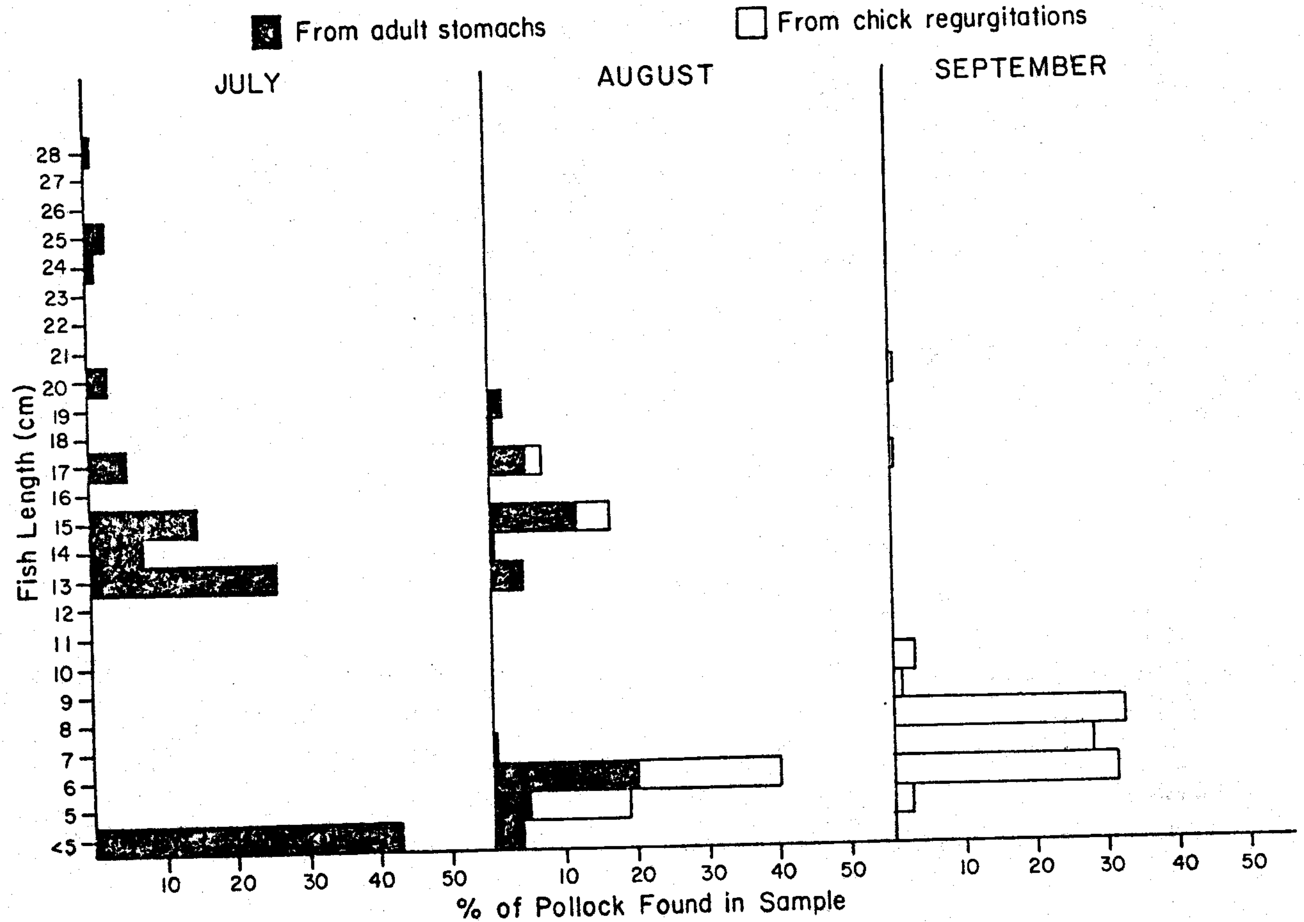


FIGURE 38

on invertebrates, they laid smaller clutches (p. 267) and had lower chick survival rates (p. 262). Thus, although Black-legged Kittiwakes take a great variety of foods, they may also be some important restrictions on the types of foods they must have if they are to reproduce successfully.

Nesting

Habitat

Black-legged Kittiwakes nest on small ledges on the vertical portions of cliffs. On the Pribilof Islands, they prefer the lower sections of the cliff-face and are rarely found above 180 m. Black-legged Kittiwakes are strictly cliff-nesters at the Pribilofs, but elsewhere they are reported to be somewhat flexible in their habitat requirements. There are reports that in predator-free areas, Black-legged Kittiwakes will nest on gradual slopes (Sowls et al. 1978) or on deserted buildings (Coulson 1974).

Phenology

Residents of the Pribilof Islands estimate that Black-legged Kittiwakes arrive in mid-April. Preble and McAtee (1923) report arrival dates of Black-legged Kittiwakes as early as 8 April and as late as 24 April. When we arrived, as early as 2 May, the kittiwakes were already holding territories on the cliffs. Although some nest-building occurs in May, it does not begin in earnest until the second week of June. The first eggs were laid about a week later (Tables 6 and 7) and the peak of clutch initiation is in late June (Figures 39 and 40). The eggs are incubated for approximately 27 days. The peak of hatching occurs around 29 July (Tables 6 and 7). Chicks are nestbound for 43 days,

TABLE 6

Phenology of Black-legged Kittiwakes on St. Paul Island, 1975-1979

	1975	1976	1977	1978	1979	OVERALL
FIRST EGG OBSERVED	15 June	18 June	21 June	18 June	----	18 June
CLUTCH INITIATION $\overline{X} \pm S$ (1st egg of clutch)	5 Jl ± 4.4	29 Jn ± 3.9	30 Jn ± 4.7	30 Jn ± 4.8	----	1 July
N=	43	46	49	73		211
FIRST CHICK OBSERVED	24 July*	22 July	20 July	21 July	21 July	22 July
HATCHING $\overline{X} \pm S$ (1st chick of brood)	2 A ± 4.7	29 Jl ± 2.8	28 Jl ± 4.9	28 Jl ± 5.0	29 Jl ± 4.3	29 July
N=	33	23	60	39	19	174
FIRST FLEDGING OBSERVED	1 Sept	1 Sept	31 Aug	26 Aug	----	30 Aug
FLEDGING $\overline{X} \pm S$	9 S ± 5.9	15 S ± 5.2	7S ± 5.6	12 S ± 4.7	----	11 Sept
N=	47	48	126	33		254

* actual first date of hatching probably earlier than reported

TABLE 7

Phenology of Black-legged Kittiwakes on St. George Island, 1976-1978

	1976	1977	1978	OVERALL	OVERALL BOTH ISLANDS
FIRST EGG OBSERVED	18 June	20 June	15 June	21 June	22 June
CLUTCH INITIATION $\bar{X} \pm S$ (1st egg of clutch	1 Jl ± 6.6	30 Jn ± 5.2	3 Jl ± 6.0	1 Jl ± 6.6	1 Jl
N=	21	53	45	119	330
FIRST CHICK OBSERVED	23 July	14 July	21 July	19 July	21 July
HATCHING $\bar{X} \pm S$ (1st chick of brood)	28 Jl ± 6.1	27 Jl ± 4.6	1 A ± 5.0	29 Jl ± 6.1	29 Jl
N=	17	63	32	112	286
FIRST FLEDGING OBSERVED	3 Sept	10 Sept	28 Aug	3 Sept	1 Sept
FLEDGING $\bar{X} \pm S$	11 S ± 6.2	7 S ± 4.6	15S ± 4.6	11 Sept	11 Sept
N=	20	52	34	106	360

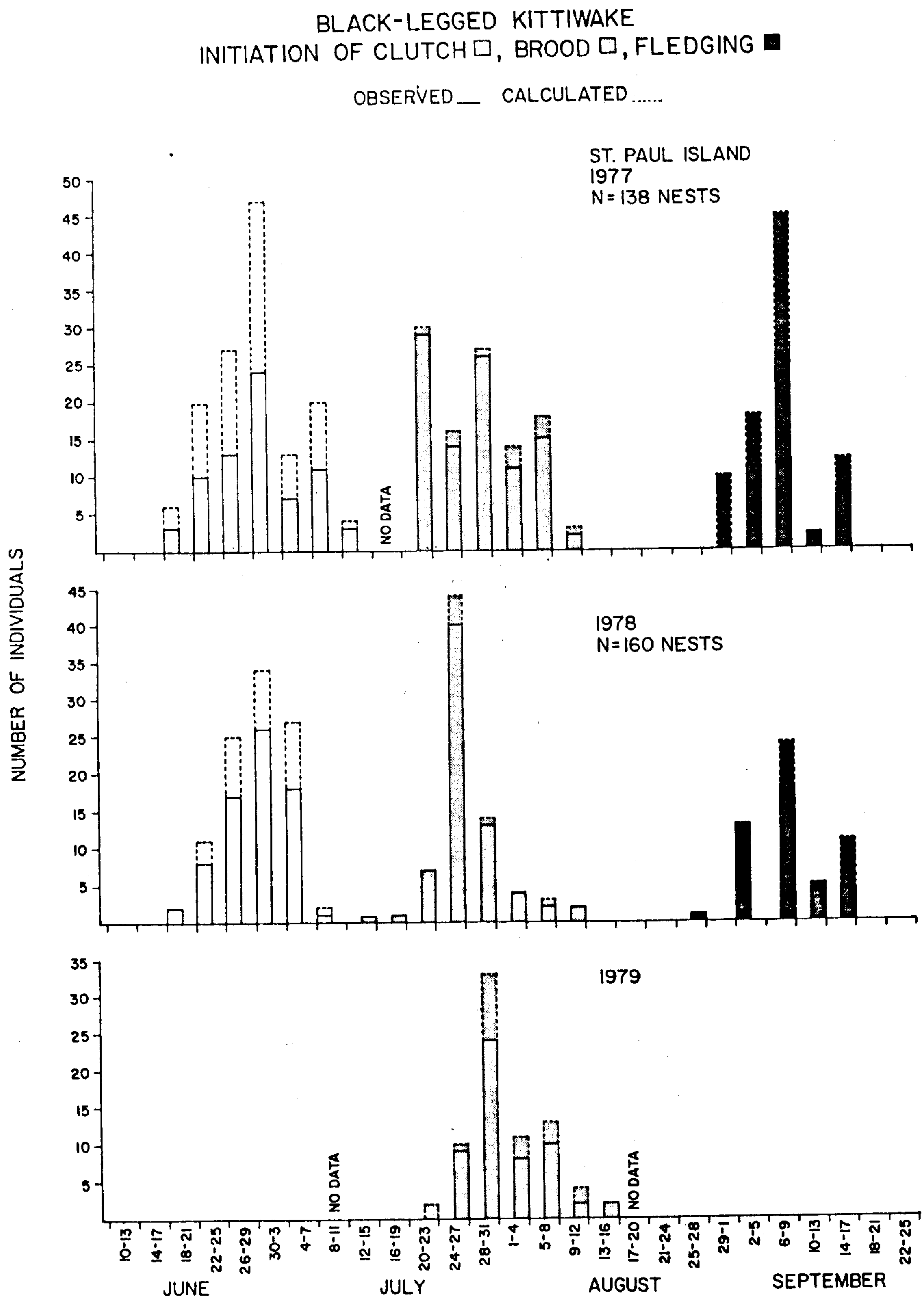

BLACK-LEGGED KITTIWAKE
INITIATION OF CLUTCH □, BROOD □, FLEDGING ■
OBSERVED __ CALCULATED ......
ST. PAUL ISLAND
1977
N= 138 NESTS
1978
N=160 NESTS
1979
NO DATA
NUMBER OF INDIVIDUALS
10-13
14-17
18-21
22-25
26-29
30-3
4-7
8-11
12-15
16-19
20-23
24-27
28-31
1-4
5-8
9-12
13-16
17-20
21-24
25-28
29-1
2-5
6-9
10-13
14-17
18-21
22-25
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 39

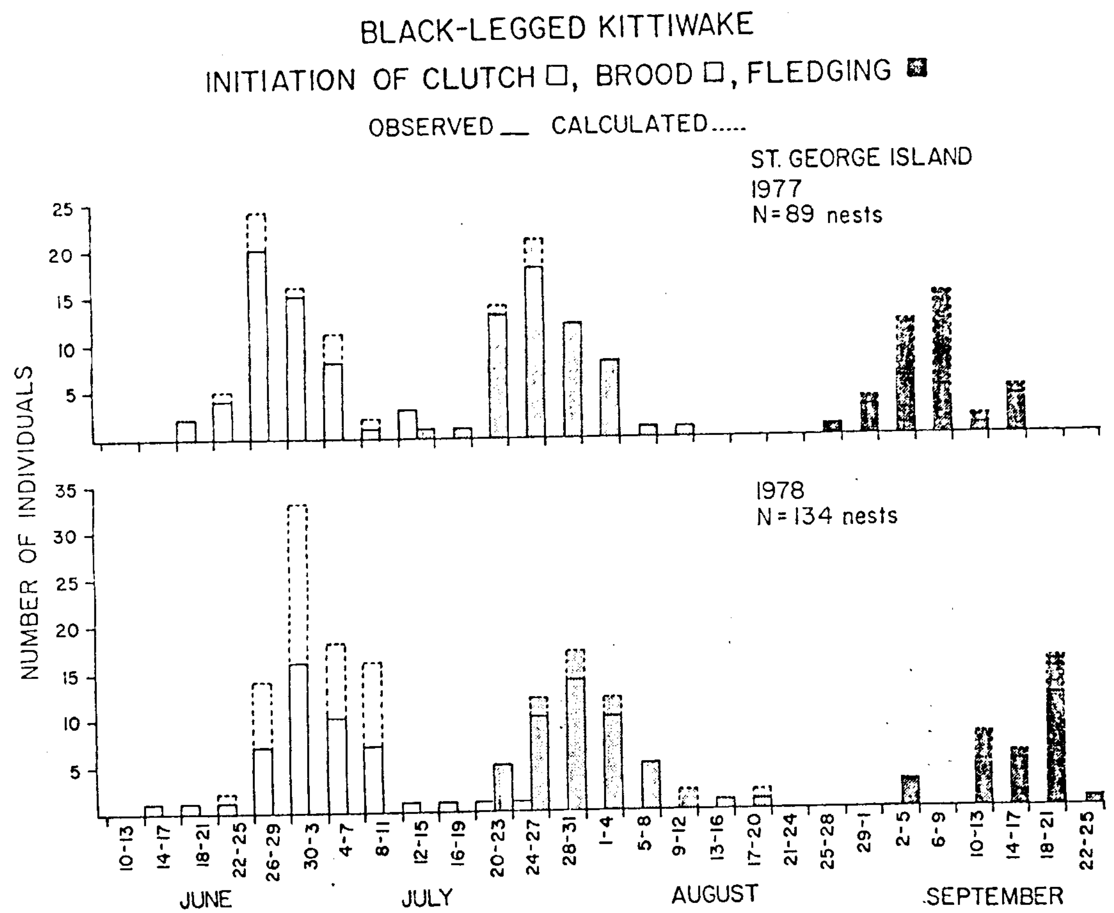

BLACK-LEGGED KITTIWAKE
INITIATION OF CLUTCH □, BROOD □, FLEDGING
OBSERVED __ CALCULATED.....
ST. GEORGE ISLAND
1977
N=89 nests
1978
N=134 nests
NUMBER OF INDIVIDUALS
10-13
14-17
18-21
22-25
26-29
30-3
4-7
8-11
12-15
16-19
20-23
24-27
28-31
1-4
5-8
9-12
13-16
17-20
21-24
25-28
29-1
2-5
6-9
10-13
14-17
18-21
22-25
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 40

and remain in the vicinity for about 10 days after they are capable of flight. Black-legged Kittiwakes are common on the Pribilofs until mid-October; they are occasionally sighted though the winter and early spring (Preble and McAtee 1923).

There are no apparent differences in the timing of breeding between Black-legged Kittiwake colonies on the two islands. Figures 41 and 42 summarize the breeding phenology of Black-legged Kittiwakes at the Pribilofs for 1975 through 1979. Phenology has been remarkably consistent throughout our study despite widely varying weather conditions and levels of reproductive success (Tables 6 and 7).

Daily Activity Patterns

The numbers of Black-legged Kittiwakes on the cliffs are fairly constant throughout the day (Hickey and Craighead 1977). Maximum numbers occur between 1100 and 1900 hours, with fewer birds staying on the cliffs overnight. Apparently, there is no movement of Black-legged Kittiwakes to or from the cliffs at night (Ron Squibb, pers. obs.).

The amount of time an adult attends the nest varies depending on the stage of the nesting cycle (Table 8). Adults continuously occupy their nests during incubation and when they have small chicks. During incubation and the small chick stage of nesting, adults trade-off attending the nest throughout the day, with peaks of trade-off activity occurring around 0700 and 1700 hours. Males and females share equally incubation and brooding activities. After chicks hatch, adults may make more frequent foraging trips (Table 8). When kittiwakes have large chicks, their visits become even shorter and the chicks may be left alone for long periods. In 1977, over half of the large chicks were unattended overnight.

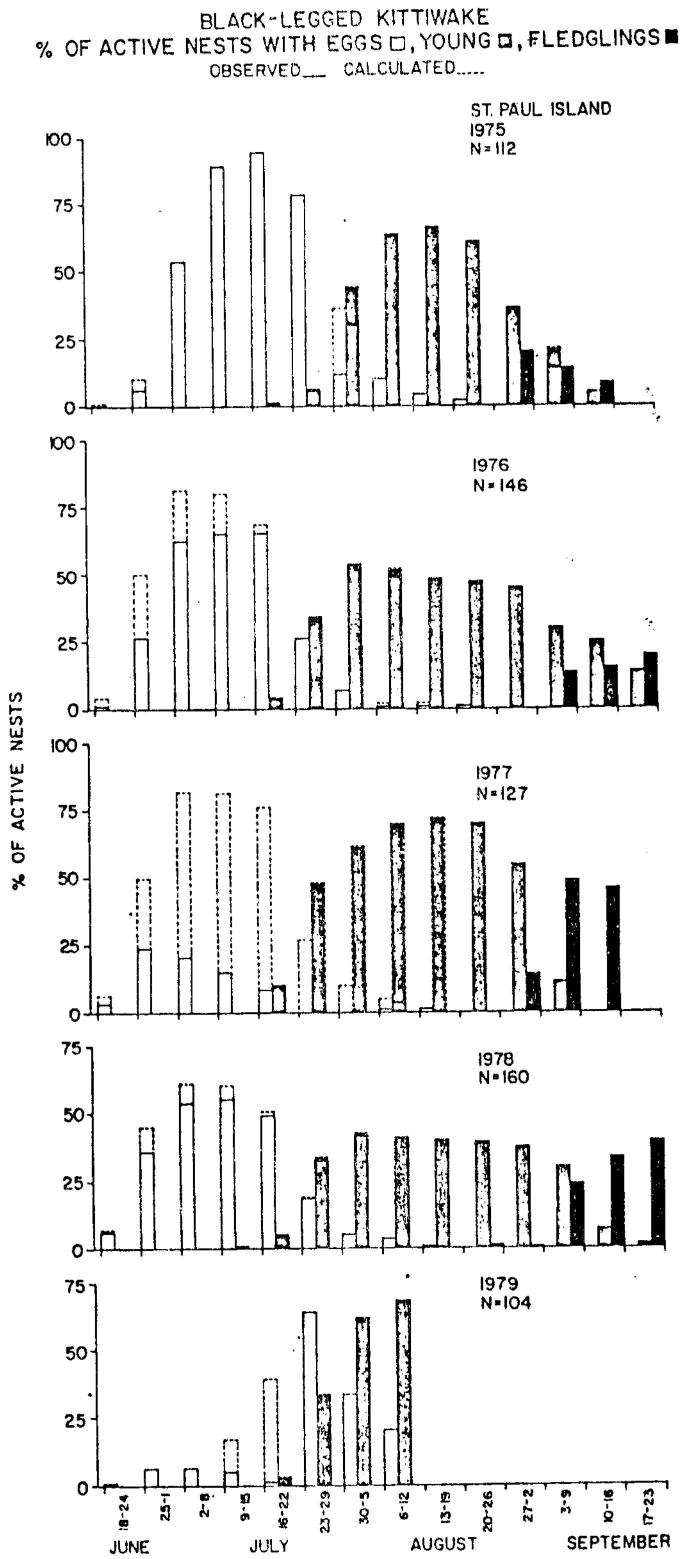
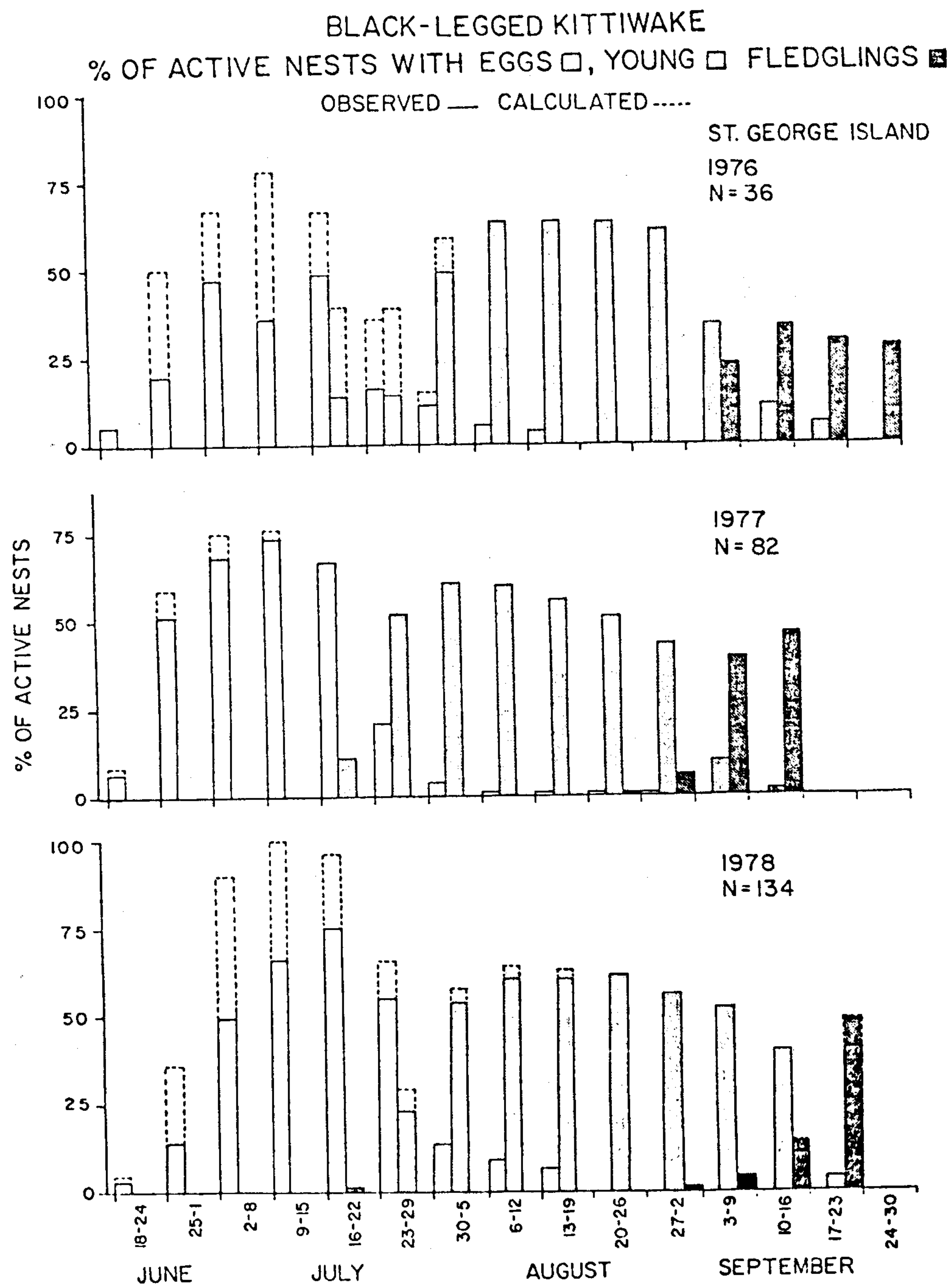

BLACK-LEGGED KITTIWAKE
% OF ACTIVE NESTS WITH EGGS □, YOUNG ▫, FLEDGLINGS ■
OBSERVED___ CALCULATED.....
ST. PAUL ISLAND
1975
N=112
1976
N=146
1977
N=127
1978
N=160
1979
N=104
% OF ACTIVE NESTS
18-24
25-1
2-8
9-15
16-22
23-29
30-5
6-12
13-19
20-26
27-2
3-9
10-16
17-23
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 41



BLACK-LEGGED KITTIWAKE
% OF ACTIVE NESTS WITH EGGS, YOUNG FLEDGLINGS
OBSERVED — CALCULATED -----
ST. GEORGE ISLAND
1976
N = 36
1977
N = 82
1978
N = 134
% OF ACTIVE NESTS
0
25
50
75
100
18-24
25-1
2-8
9-15
16-22
23-29
30-5
6-12
13-19
20-26
27-2
3-9
10-16
17-23
24-30
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 42

TABLE 8

Nest Attendance Patterns of Black-legged Kittiwakes at the Pribilof Islands, 1977-1979*

Stage	Period of Watch	No. nests	Duration of Adult Attendance (hrs) $\bar{x} \pm s$ (n)	Proportion of time nest is unoccupied	Feeding Rate $\bar{x}$	Trip time (hrs) $\bar{x} \pm s$ (n) (daylight)***
Incubation						
1977 STG	2030 1-0900 3 Jul	6	6.9 - 6.1 (32)	0	-	3.2 - 2.7 (13)
1977 STP	1730 14-1500 16 Jul	8	14.1 - 8.1 (23)	0	-	9.8 (2)
1979 STP	0700 9-2230 10 Aug	3	6.9 - 4.9 (8)**	0	-	3.5 - 3.1 (9)
Small Chick						
1977 STG	1600 28-1130 30 Jul	8	8.7 - 7.5 (43)	0	0.21	3.1 - 2.5 (14)
1977 STP	2000 1-1530 3 Aug	7	5.8 - 4.0 (5)	0.02	0.36	4.6 - 2.5 (21)
1978 STP	1700 26 Jul-2400 4 Aug	2	4.6 - 3.6 (18)	0	-	2.7 - 1.4 (14)
1979 STP	0600 4 Aug-1305 5 Aug	29	3.4 - 2.0 (91)*	0	-	3.4 - 2.0 (9)
Large Chick						
1977 STG	1600 18-1200 20 Aug	6	2.1 - 3.8 (69)	0.48	0.17	1.9 - 2.0 (32)
1977 STP	1300 20-2100 21 Aug	7	2.2 - 3.3 (37)	0.63	0.18	2.2 - 2.3 (22)
1979 STP	0612 20-1701 20 Aug	5	4.6 - 1.6 (8)*	-	-	4.6 - 1.6 (8)

* Data for Small Chick, STP, 1978, 1979 and Large Chick, STP, 1979 from Braun, in prep.
** not watched overnight
***excludes trips less than 15 minutes

The mean period of nest attendance during incubation actually may be longer than indicated in Table 8. Visits of over 20 hours were common and in one instance, we observed an adult incubating for over 41 hours. However, our observations only lasted 31 to 46 hours.

Productivity

The reproductive success of Bering Sea kittiwakes shows large yearly fluctuations, sensitive to variations in foraging ability as influenced by weather, competition and prey abundance (Hunt et al. 1980b). The Pribilof colonies, located near the productive waters of the shelf break have the most stable levels of Black-legged Kittiwake productivity found in the eastern Bering Sea (Hunt et al. 1980b). Other Bering Sea colonies show large variations in productivity from one year to the next.

During our study mean clutch size of Black-legged Kittiwakes was stable at about 1.4 eggs/nest (Table 9); in the early 1900's, there were reports of 3 egg clutches from the Pribilof Islands (Preble and McAtee 1923). Outside the Bering Sea, kittiwakes lay clutches of 1 to 4 eggs (Belopol'skii 1957, Coulson 1966). In recent years, Bering Sea kittiwakes have laid a maximum of 2 eggs/nest. In 1978, when fewer kittiwakes nested and productivity was depressed, clutch size was only slightly lower than normal, suggesting that when conditions are unfavorable, kittiwakes fail to lay eggs rather than reduce their clutch size. Ramsdell and Drury (1979) have also found that kittiwakes failed to lay when conditions were poor at Bluff colony in Norton Sound.

TABLE 9

Reproductive success of Black-legged Kittiwakes at the Pribilof Islands, 1975-1979

	ST. PAUL ISLAND					ST. GEORGE ISLAND			OVERALL
	1975	1976	1977	1978	1979	1976	1977	1978	(excluding 1979)
$\bar{X}$ CLUTCH	1.42	1.49	1.52	1.33	1.47	1.42	1.46	1.20	1.41
N=	85	70	102	110	87	19	78	68	
HATCHING SUCCESS (chicks hatched/ egg laid)	.60-.82	.72-.88	.59-.85	.74-.84	.73-.88	.70-.93	.73-.94	.57-.77	.66-.86
FLEDGING SUCCESS (chicks fledged/ chick hatched)	.47-.64	.57-.69	.52-.74	.58-.66	.50-*.60	.60-.79	.41-.53	.51-.72	.52-.68
REPRODUCTIVE SUCCESS (chicks fledged/ nest, known clutch)	.55	.74	.67	.65	.64*	.79	.56	.48	.63
PRODUCTIVITY (chicks fledged/ nest attempt)	.44	.52	.43	.36	.54*	.62	.45	.22	.43
N=	185	127	157	203	158**	34	110	229	

* number of chicks fledged in 1979 is projected from the number of chicks at last check (16 Aug), using 1975 to 1978 data to calculate mean survivorship of chicks by age.

**number of nest attempts estimated from the number of nests with known clutch using mean value of the ratio: number nests, known clutch/number nest attempts for 1975-1978.

The variability in Bering Sea kittiwake productivity arises from the number of young fledged rather than an adjustment of clutch size (Table 9). Siblicide is one mechanism that seabirds use to reduce their brood size (Nelson 1978). Siblicide has been documented in Bering Sea Black-legged Kittiwakes (Braun in prep., Ramsdell and Drury 1979) and appears to be triggered by hunger of the oldest nestling; it is sensitive to lowered food availability and interruptions in feeding due to storms (Braun in prep.). Siblicide occurs during a critical two week period immediately after hatching. The conditions which prevail during this period determine whether siblicide occurs and hence the level of productivity achieved. Siblicide commonly occurred during our study. We did not observe any kittiwake nest with two fledglings until 1978. On the whole, 1978 was a bad year for kittiwake productivity, although a few pairs did remarkably well. In 1979, approximately 10 per cent of the kittiwake nests in our study area fledged two young. The survival of 2 young in a nest implies that the food supply to the chicks was sufficient and without interruption.

Productivity of Black-legged Kittiwakes was tested for variation among years and between the two islands using a two-way ANOVA. The kittiwake colonies on the two islands did not differ significantly in their productivity (Island effect, $r^2 = 0.02$, $P = 0.148$). Major differences in Black-legged Kittiwake productivity occurred among years (Year effect, $r^2 = 0.32$, $P = 0.013$). Productivity was similar in 1976 and 1977 when it averaged 0.51 chicks fledged/nest attempt. Productivity was significantly depressed in 1978 when it averaged

0.29 chicks fledge/nest attempt (LSD, 1976 and 1977 combined versus 1978, P = 0.05). An obvious difference between 1978 and the previous years was the weather; 1978 was much windier and rainier. When compared to the thirty year average, rainfall in 1978 was normal, while average wind speed was much higher than normal.

We tested whether wind or rain had the greater effect on productivity by comparing the proportion of days with high winds or rain against a measure of productivity. For the hatching period we compared weather between 15 June and 15 July to hatching success (chicks hatched/egg laid), and for the chick phase we compared fledging success (chick fledged/chick hatched) to weather during the period 15 July to 15 August. Rain had little effect on either hatching or fledging success ($\chi^2_3 = 5.21$ $P > .10$). Hatching success was inversely related to the occurrence of high winds ($\chi^2_3 = 18.58$ $P < 0.001$), although winds had little effect on fledging success.

Black-legged Kittiwake chicks on St. Paul Island consistently showed higher growth rates than chicks on St. George Island (Table 10). Kittiwake chicks on St. Paul grew at a rate of 14.7 grams/day, while St. George chicks grew at a rate of 12.8 grams/day (Table 10). This difference may reflect the greater competition with murres and other kittiwakes on St. George Island. Belopol'skii (1957) stated that Black-legged Kittiwake productivity and growth rates were lower when kittiwakes had to compete for food with murres. He suggested that competition with murres forces kittiwakes to use more invertebrates, with lower nutritional value than fish, resulting in lower chick growth rates and productivity. The ratio

TABLE 10

Growth Rates and Fledging Weights of Black-legged Kittiwake Chicks at the Pribilof Islands, 1975 - 1979

	Growth Rate (day)	Fledging Weight
1975		
St. Paul	14.6 ± 2.3 (34)	
St. George		
1976		
St. Paul	12.8 ± 4.9 (33)	469.9 ± 52.4 (14)
St. George	11.5 ± 2.6 (24)	413.8 ± 46.4 (8)
1977		
St. Paul	14.5 ± 1.6 (22)	434.2 ± 25.2 (20)
St. George	13.8 ± 1.8 (21)	431.6 ± 41.8 (20)
1978		
St. Paul	15.1 ± 2.5 (16)	463.1 ± 30.9 (15)
St. George	13.0 ± 2.2 (16)	478.1 ± 49.6 (16)
1979		
St. Paul	16.6 ± 2.9 (14)*	--
Overall	14.0	448.5
St. Paul	14.7	455.7
St. George	12.8	441.2

* Rates appear to be higher than they actually are because they were taken over a shorter period than in previous years.

of murres to Black-legged Kittiwakes on St. George Island is 23.5 : 1, whereas on St. Paul Island, the ratio is only 4.8 : 1.

We infer that there is some competitive depression of growth rates on St. George Island, but the added stress is not great enough to depress productivity. Consistent with this hypothesis, we find no competition effect on fledging weight. Neither island differences nor year differences explained the variations observed in fledging weight (Two-way ANOVA, explained variation $r^2 = 0.05$, Island effect $P = 0.205$, Year effect $P = 0.276$). These results suggest that the effects of competition, or temporary food limitation on growth rates and fleding weight of kittiwake chicks at the Pribilofs are ameliorable.

There is a large amount of variation in growth rates that we are unable to explain by island and year (unexplained variation, $1 - r^2 = 82\%$). We did find significant differences in growth rates between islands, but not between years (Island effect $r^2 = 0.15$ $P < .0001$, year effect $r^2 = 0.01$ $P = 0.412$), just the opposite of our findings for productivity. The lack of difference in growth rates between years despite substantial differences in productivity suggests that Black-legged Kittiwakes adjust to a variable environment by changing the number of young they raise rather than by changing growth rates.

Red-legged Kittiwake (<u>Rissa brevirostris</u>)

<u>Numbers</u>

Red-legged Kittiwakes are endemic to the Bering Sea and even within this region, they have a limited range. This species nests only on the Pribilof Islands, Buldir and Bogoslof Islands in the Aleutian Chain and the Kommandorskie Islands (Sowls et al. 1978). The Pribilof Island support an estimated 222,200 Red-legged Kittiwakes, 220,000 of which nest on St. George Island (Hickey and Craighead 1977). The Pribilof Island population accounts for 89% of the Red-legged Kittiwakes in the eastern Bering Sea (Appendix 1). There are no current estimates of the population size for this species in the western Bering Sea and their nesting status there is presently unclear. The Pribilof Island population represents the major portion of the world population of Red-legged Kittiwakes.

Pelagic Distribution

The pelagic distribution of Red-legged Kittiwakes is given in Figures 43. Again, for this species both aerial and shipboard surveys were combined. Near the Pribilofs, most surveys were done by observers who were experienced with both kittiwake species. Although the two methods of censusing produced similar results, there is the possibility that Red-legged Kittiwakes were over-estimated in ship surveys since they are attracted to ships. Since most of the data comes from shipboard surveys, it is possible that our density estimates are slightly inflated.

On the basis of our data, we can say relatively little about the seasonal changes on the abundance or distribution of Red-legged Kittiwakes. According to Shuntov (1963), Red-legged Kittiwakes move out of the Bering Sea in winter. Although we encountered fewer areas of moderate density in spring and fall than in summer, this does not necessarily mean that they were moving out of the area. In addition, our sample sizes for spring and fall are sufficiently small to preclude meaningful comparisons.

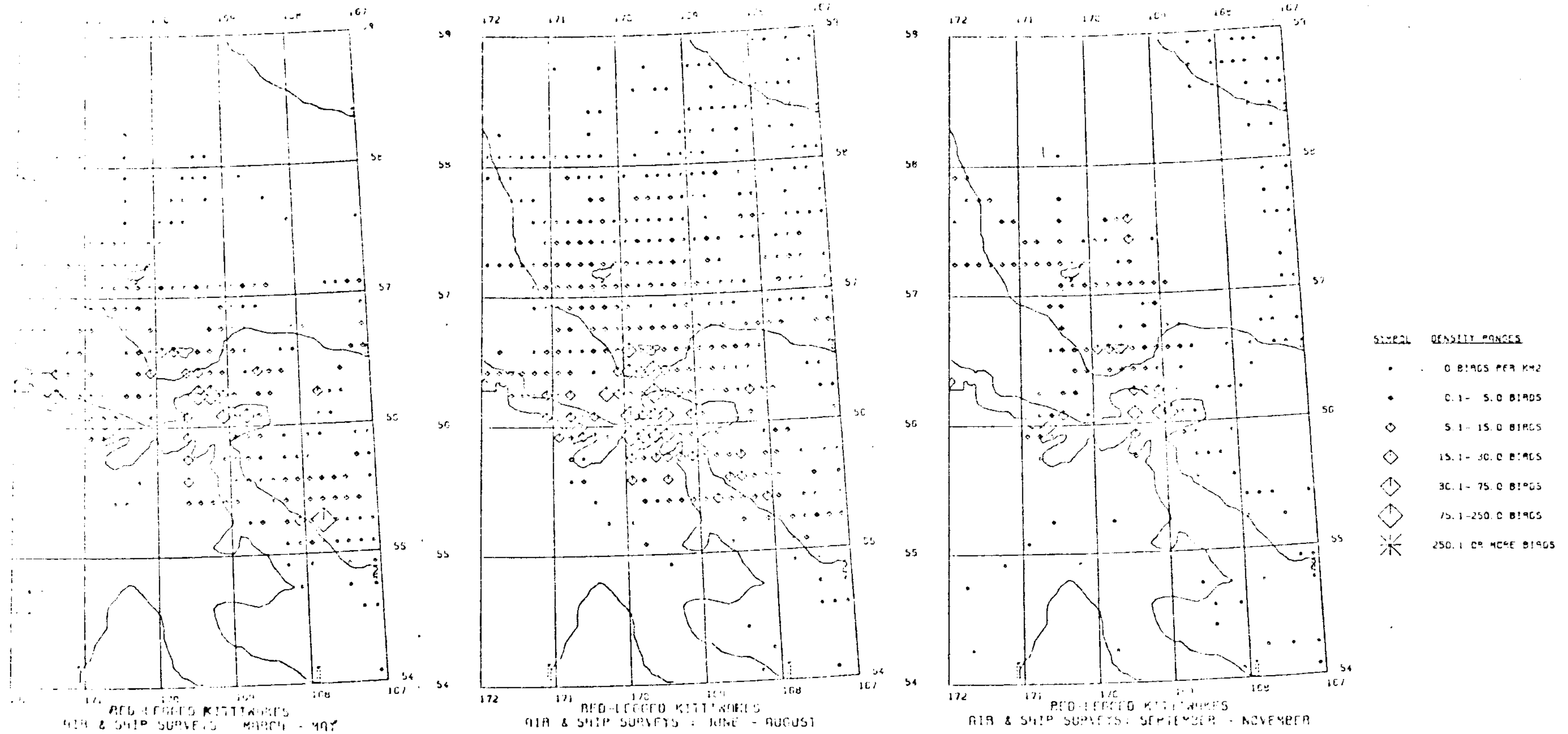
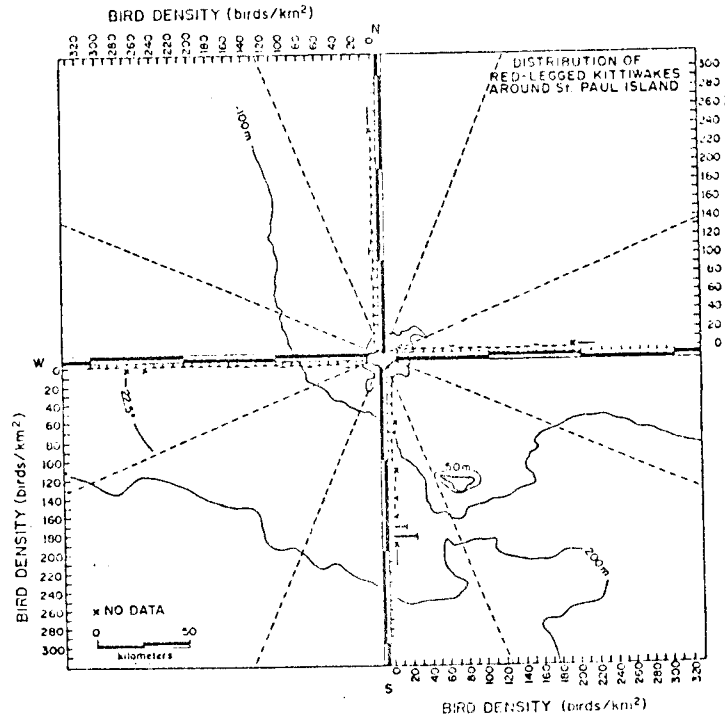

RED-LEGGED KITTIWAKES
AIR & SHIP SURVEYS : JUNE - AUGUST
AIR & SHIP SURVEYS: SEPTEMBER - NOVEMBER
SYMBOL DENSITY RANGES
0 BIRDS PER KM2
0.1- 5.0 BIRDS
5.1- 15.0 BIRDS
15.1- 30.0 BIRDS
30.1- 75.0 BIRDS
75.1-250.0 BIRDS
250.1 OR MORE BIRDS

FIGURE 43

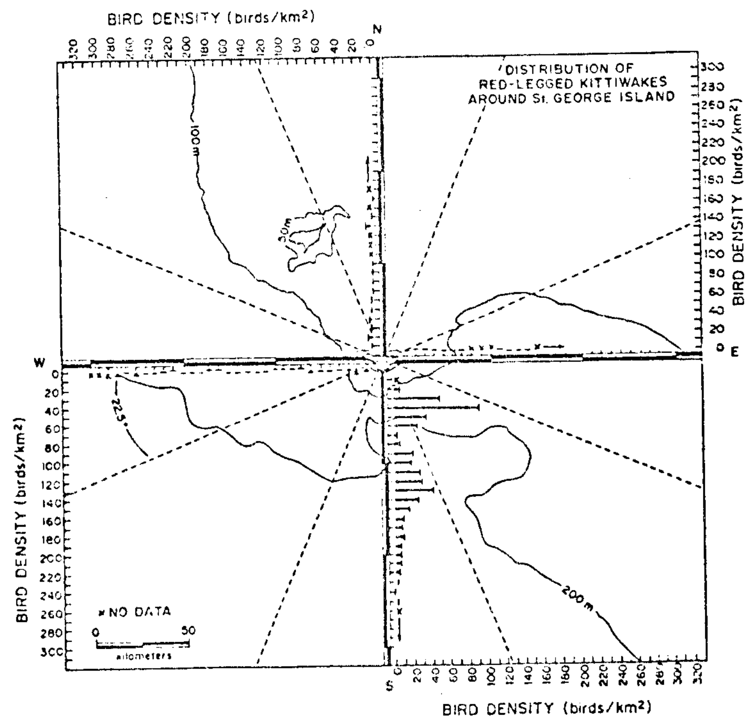
The overall pelagic distribution shows a marked concentration of Red-legged Kittiwakes in the general vicinity of the Pribilofs; few birds were sighted more than 120-150 km from these islands. Around the Pribilofs, there is a marked asymmetry in the distribution of this species. Densities are generally an order of magnitude higher south of St. George Island and along the edge of the continental slope, than they are north of the islands.

Examination of the histograms of density around the islands and the zonal analysis of pelagic distribution reinforce this interpretation (Figures 44 and 45). The density of Red-legged Kittiwakes in any direction is low except near the shelf break. Around St. George Island south to the shelf break and in waters up to 2000 m in depth, the densities of Red-legged Kittiwakes are significantly higher than in other zones (Modified LSD Procedure, $P < 0.05$). The higher density of this species over the shelf break relative to the shallower shelf waters undoubtably is a function of the food preferences of Red-legged Kittiwakes. Unlike the Black-legged Kittiwake, which feeds on a wide variety of prey frequently captured near their colonies, the Red-legged Kittiwake specializes on deep-water myctophid fishes, which are found at and beyond the shelf break.

Red-legged Kittiwake densities are low in the immediate vicinity of St. Paul Island while they are high near St. George Island, reflecting the relative sizes of the Red-legged Kittiwake colonies on the two islands. The colony on St. Paul is an order of magnitude smaller than the colony on St. George Island (2,200 versus 220,000) (Hickey and Craighead 1977).



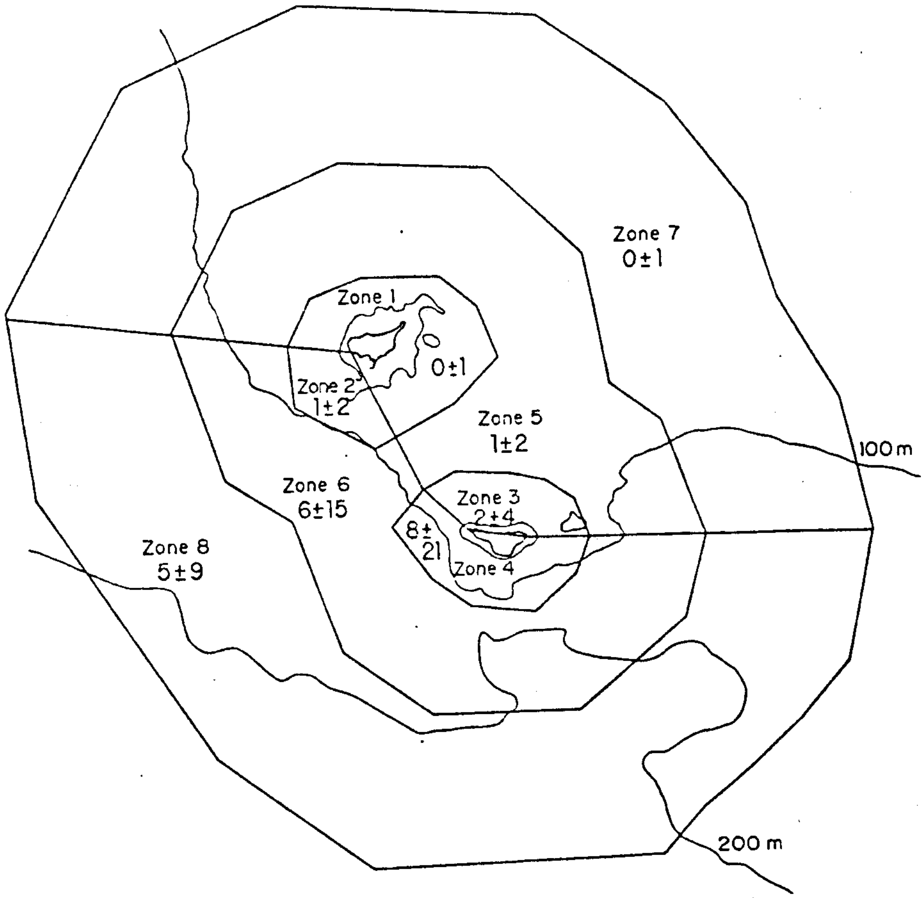
DISTRIBUTION OF RED-LEGGED KITTIWAKES AROUND St. PAUL ISLAND
BIRD DENSITY (birds/km²)
N
E
S
W
100m
50m
200m
22.5°
x NO DATA
0 50
kilometers



DISTRIBUTION OF RED-LEGGED KITTIWAKES AROUND St. GEORGE ISLAND
BIRD DENSITY (birds/km²)
N
E
S
W
100m
50m
200m
22.5°
x NO DATA
0 50
kilometers

FIGURE 44

Distribution of Red-legged Kittiwakes by zones near the Pribilof Islands 1975-1979 ($\bar{x} \pm s$)*



ANOVA across all zones, $F_{7,2154} = 24.479$, $P = 0.00001$

Homogeneous subsets by modified LSD Procedure, $\alpha = 0.05$

Subset 1 Zones 7,1,5,2,3
Subset 2 Zones 3,8
Subset 3 Zones 8,6
Subset 4 Zones 6,4

*rounded to whole numbers

FIGURE 45

Diet

Red-legged Kittiwakes forage in the top 0.5 m of the water column by dipping and shallow pursuit-plunging. At the Pribilofs, Red-legged Kittiwakes are usually found foraging near the shelf break and rarely join the large mixed species foraging flocks near the islands. There are indications that this species forages largely at night.

The types of foods used by Red-legged Kittiwakes (Figure 46) are generally similar to those used by Black-legged Kittiwakes at the Pribilofs. Fish is the principal food source for Red-legged Kittiwakes, and like Black-legged Kittiwakes, walleye pollock is used extensively. However, there are some striking differences in the particular food types used by the two kittiwakes. In particular, Red-legged Kittiwakes use myctophids extensively, which undoubtable accounts for their concentration along the shelf break.

Preble and McAtee (1923) examined 15 stomachs of Red-legged Kittiwakes taken form St. George Island. Seven of the stomachs contained only squid mandibles. In the eight stomachs containing measureable food volume, 25 per cent of the food was squid, 36.5 per cent crustacea and 37.5 per cent was fish. The crustacea were chiefly euphausiids from the genus *Thysanoessa*. These results differ from our own, but the differences may result from their small sample size, or may reflect seasonal differences in prey availability, since they did not specify the dates of collection.

MAJOR COMPONENTS OF THE DIET OF RED-LEGGED KITTIWAKES

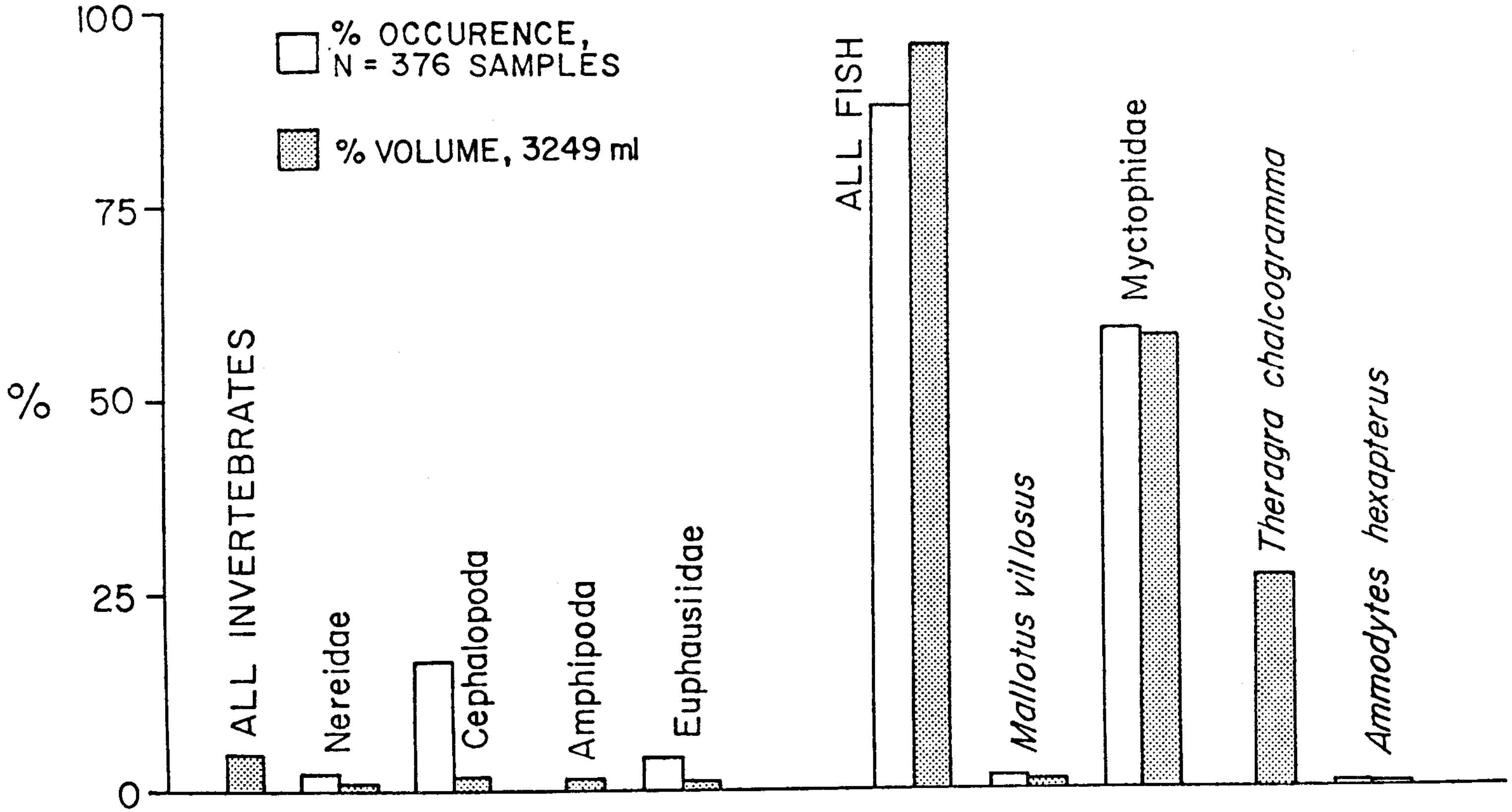
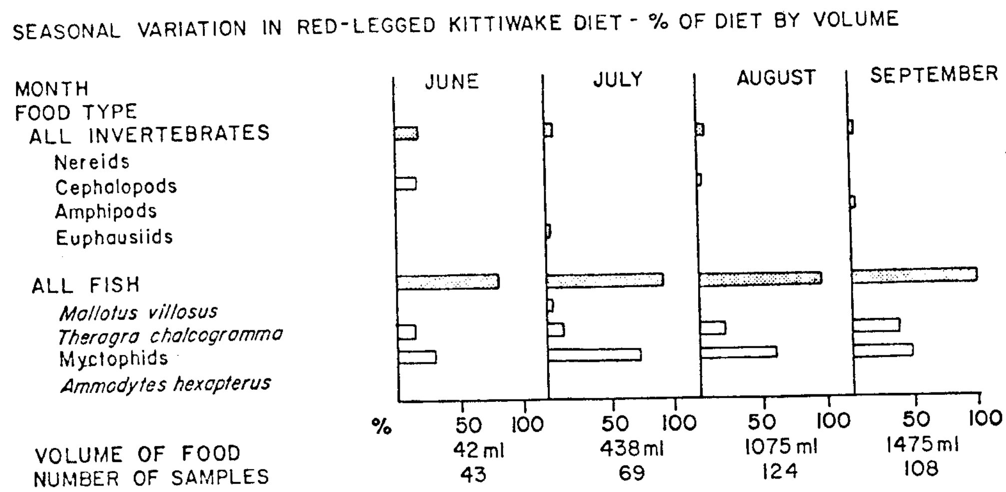


FIGURE 46

Data on seasonal changes in Red-legged Kittiwake diet during the period 1975 to 1978 show a drop in the use of cephalopods and an increase in the use of fish, particularly myctophids, as the season progressed (Figure 47a). This shift was not statistically significant using the median test; however, this test is comparatively insensitive. It is interesting that there is an apparent sharp drop in the use of pollock through the season, followed by a sharp increase in September. This pattern differs from that seen in Black-legged Kittiwakes. Pollock occurs in the diet of Red-legged Kittiwakes in June, but is conspicously absent from the diet of Black-legged Kittiwakes in that month. The early season use of pollock by Red-legged Kittiwakes may reflect their use of more oceanic foraging areas than Black-legged Kittiwakes, or differences in prey availability at the surface due to foraging at night. Red-legged Kittiwakes showed a much lower use of _P. libellula_, a shallow-water eastern shelf amphipod (Motoda and Minoda 1974), than Black-legged Kittiwakes, particularly early in the breeding season, again suggesting an oceanic foraging distribution.

Through the four years of our study, Red-legged Kittiwake diet has shown an increasing use of pollock (Figure 47b), probably reflecting the opportunistic use of pollock when unusually large year classes were available (Smith 1979). In 1977, there was an unusually high survival of pollock larvae (Cooney et al. 1978). Since kittiwakes take pollock up to 28 cm, presumably representing 2 year old fish (Smith 1979), the high survivorship of pollock in 1977 could account for a higher percentage of pollock in Red-legged


SEASONAL VARIATION IN RED-LEGGED KITTIWAKE DIET - % OF DIET BY VOLUME
MONTH
FOOD TYPE
ALL INVERTEBRATES
Nereids
Cephalopods
Amphipods
Euphausiids
ALL FISH
Mallotus villosus
Theragra chalcogramma
Myctophids
Ammodytes hexapterus
JUNE
JULY
AUGUST
SEPTEMBER
%
50 100
VOLUME OF FOOD
NUMBER OF SAMPLES
42 ml
43
438 ml
69
1075 ml
124
1475 ml
108

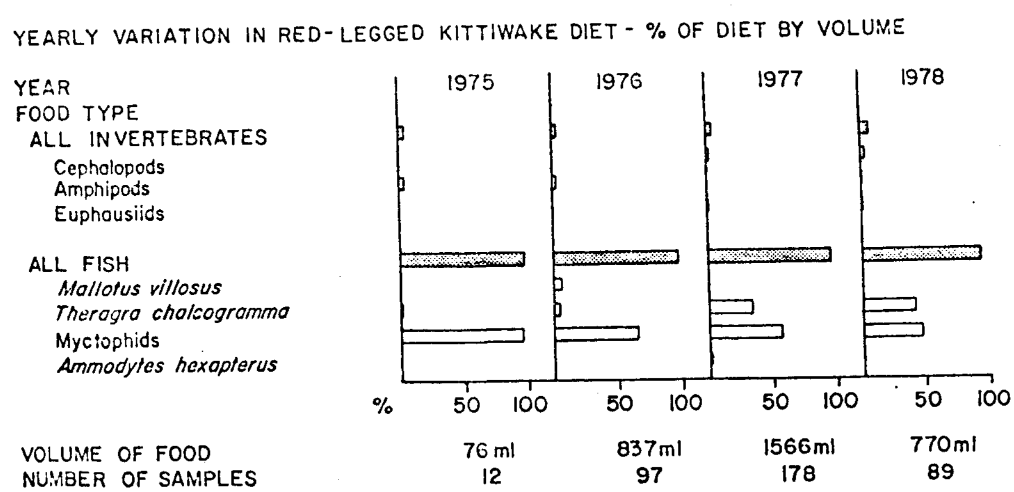

YEARLY VARIATION IN RED-LEGGED KITTIWAKE DIET - % OF DIET BY VOLUME
YEAR
FOOD TYPE
ALL INVERTEBRATES
Cephalopods
Amphipods
Euphausiids
ALL FISH
Mallotus villosus
Theragra chalcogramma
Myctophids
Ammodytes hexapterus
1975
1976
1977
1978
%
50 100
VOLUME OF FOOD
NUMBER OF SAMPLES
76 ml
12
837 ml
97
1566 ml
178
770 ml
89

FIGURE 47

Kittiwake diets in 1977 and 1978. Alternatively, this shift may also be due to a decrease in the availability of myctophids.

Nesting

Habitat

Red-legged Kittiwakes nest on vertical cliffs of islands near the continental slope (Hunt et al. 1980b). On the Pribilof Islands, Red-legged Kittiwakes nest on small, narrow ledges frequently sheltered by an overhang, either on low cliffs among numerous Black-legged Kittiwakes or on the highest cliffs in large, single-species aggregations.

Phenology

Preble and McAtee (1923) report that Red-legged Kittiwakes arrive at the Pribilofs as early as 8 April and as late as 22 April. In 1977, Red-legged Kittiwakes were in the vicinity of St. George Island by 1 April and were well established on the cliffs by the middle of the month. The first eggs are laid in mid-June, with the peak of laying occurring in the first week of July (Tables 11 and 12, Figures 48-50). Red-legged Kittiwake phenology is about a week behind that of Black-legged Kittiwakes at the Pribilofs (T Test, $P < 0.001$). Phenology differs between pure Red-legged Kittiwake nesting areas and those where they nest among Black-legged Kittiwakes. In pure colonies, mean egg-laying is earlier than in mixed colonies (T Test, $P < 0.001$), but egg-laying is less synchronous (F Test, $0.01 > P > 0.005$). Pure colonies have higher nesting densities than mixed colonies. Coulson and White (1960) have reported similar phenology differences between dense and less dense sections of Black-legged Kittiwake colonies. These

TABLE 11

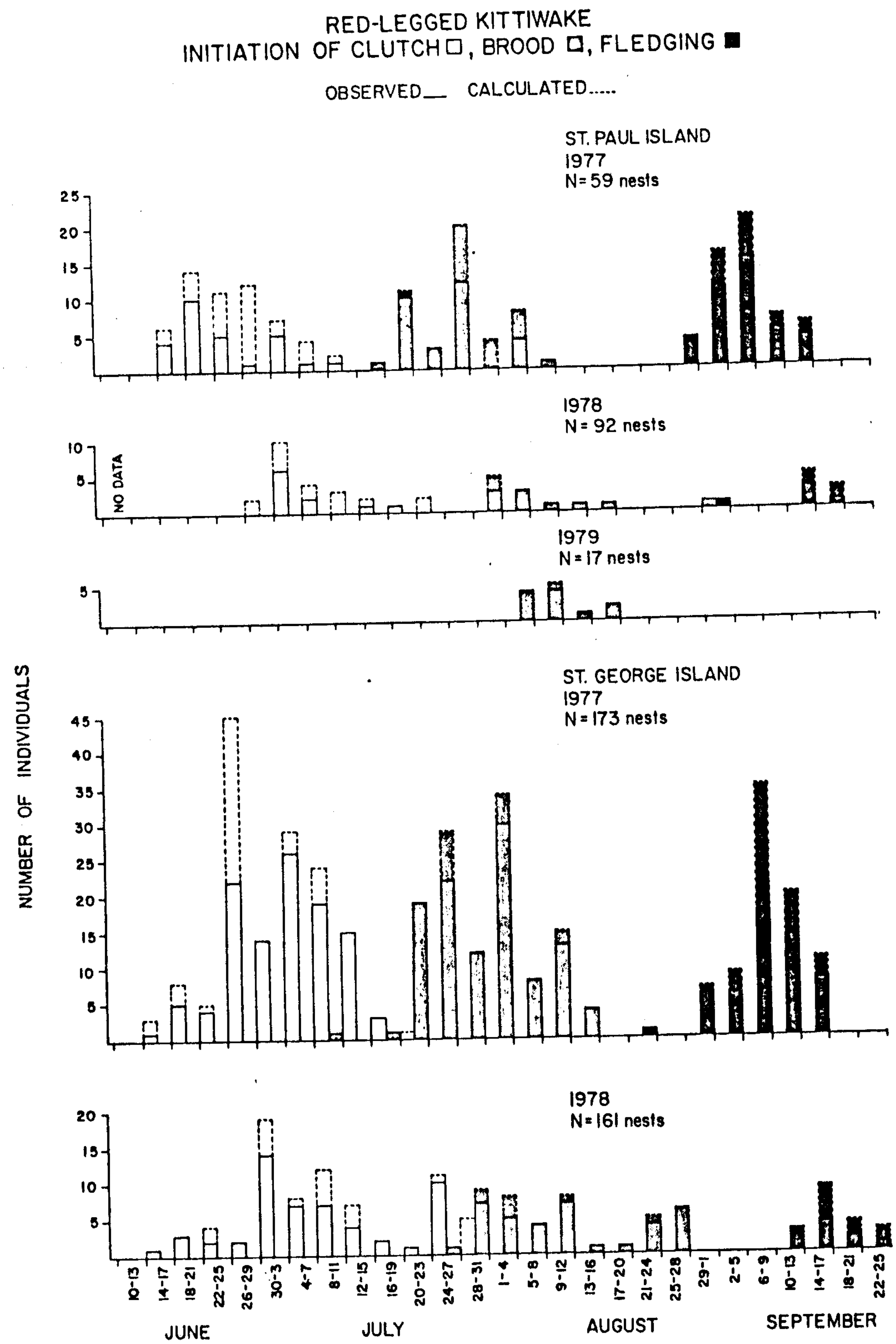
Phenology of Red-legged Kittiwakes on St. Paul Island, 1975-1979

	1975	1976	1977	1978	1979	OVERALL
FIRST EGG OBSERVED	25 June	29 June	21 June	1 July	-----	27 June
CLUTCH INITIATION $X \pm S$ (1st egg of clutch)	6 Jl $\pm$ 2.0	3 Jl $\pm$ 4.5	25 Jn $\pm$ 4.8	10 Jl $\pm$ 5.6	-----	3 July
N =	6	51	17	10		
FIRST CHICK OBSERVED	30 July	27 July	16 July	5 Aug	6 Aug	29 July
HATCHING $\overline{X} \pm S$ (1st chick of brood)	31 Jl $\pm$ 0.0	31 Jl $\pm$ 4.7	27 Jl $\pm$ 6.7	13 A $\pm$ 11.9	11 A $\pm$ 3.8	4 Aug
N =	3	41	10	7	12	
FIRST FLEDGING OBSERVED	10 Sept	10 Sept	29 Aug	2 Sept	-----	5 Sept
FLEDGING $\overline{X} \pm S$	-----	15 S $\pm$ 6.5	6 S $\pm$ 4.5	15 S $\pm$ 4.3	-----	13 Sept
N =		39	54	9		

TABLE 12

Phenology of Red-legged Kittiwakes on St. George Island, 1976-1978

	1975	1976	1977	1978	OVERALL
FIRST EGG OBSERVED	-----	27 June	15 June	15 June	19 June
CLUTCH INITIATION $\overline{X} \pm S$ (1st egg of clutch)	-----	7 Jl $\pm$ 6.0	4 Jl $\pm$ 7.2	7 Jl $\pm$ 11.1	6 July
N =		41	104	51	
FIRST CHICK OBSERVED	24 July	23 July	9 July	28 July	21 July
HATCHING $\overline{X} \pm S$ (1st chick of brood)	1 A $\pm$ 7.0	5 A $\pm$ 6.3	31 Jl $\pm$ 8.3	10 A $\pm$ 10.1	4 Aug
N =	19	35	93	25	
FIRST FLEDGING OBSERVED	3 Sept	10 Sept	21 Aug	10 Sept	4 Sept
FLEDGING $\overline{X} \pm S$	-----	18 S $\pm$ 6.6	10 S $\pm$ 4.6	16 S $\pm$ 3.7	15 Sept
N =		35	83	19	



RED-LEGGED KITTIWAKE
INITIATION OF CLUTCH, BROOD, FLEDGING
OBSERVED CALCULATED
ST. PAUL ISLAND
1977
N=59 nests
1978
N=92 nests
NO DATA
1979
N=17 nests
ST. GEORGE ISLAND
1977
N=173 nests
1978
N=161 nests
NUMBER OF INDIVIDUALS
10-13
14-17
18-21
22-25
26-29
30-3
4-7
8-11
12-15
16-19
20-23
24-27
28-31
1-4
5-8
9-12
13-16
17-20
21-24
25-28
29-1
2-5
6-9
10-13
14-17
18-21
22-25
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 48

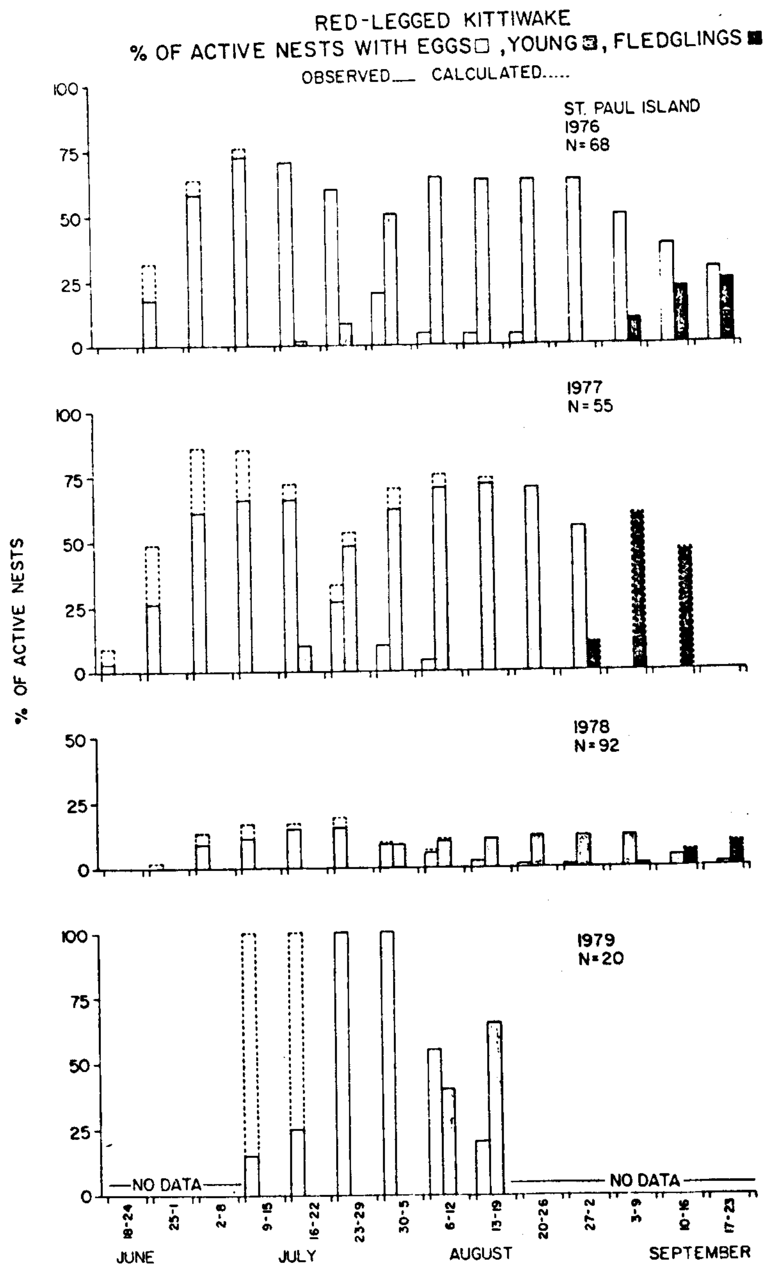

RED-LEGGED KITTIWAKE
% OF ACTIVE NESTS WITH EGGS, YOUNG, FLEDGLINGS
OBSERVED___ CALCULATED.....
ST. PAUL ISLAND
1976
N=68
1977
N=55
1978
N=92
1979
N=20
% OF ACTIVE NESTS
NO DATA
NO DATA
18-24
25-1
2-8
9-15
16-22
23-29
30-5
6-12
13-19
20-26
27-2
3-9
10-16
17-23
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 49

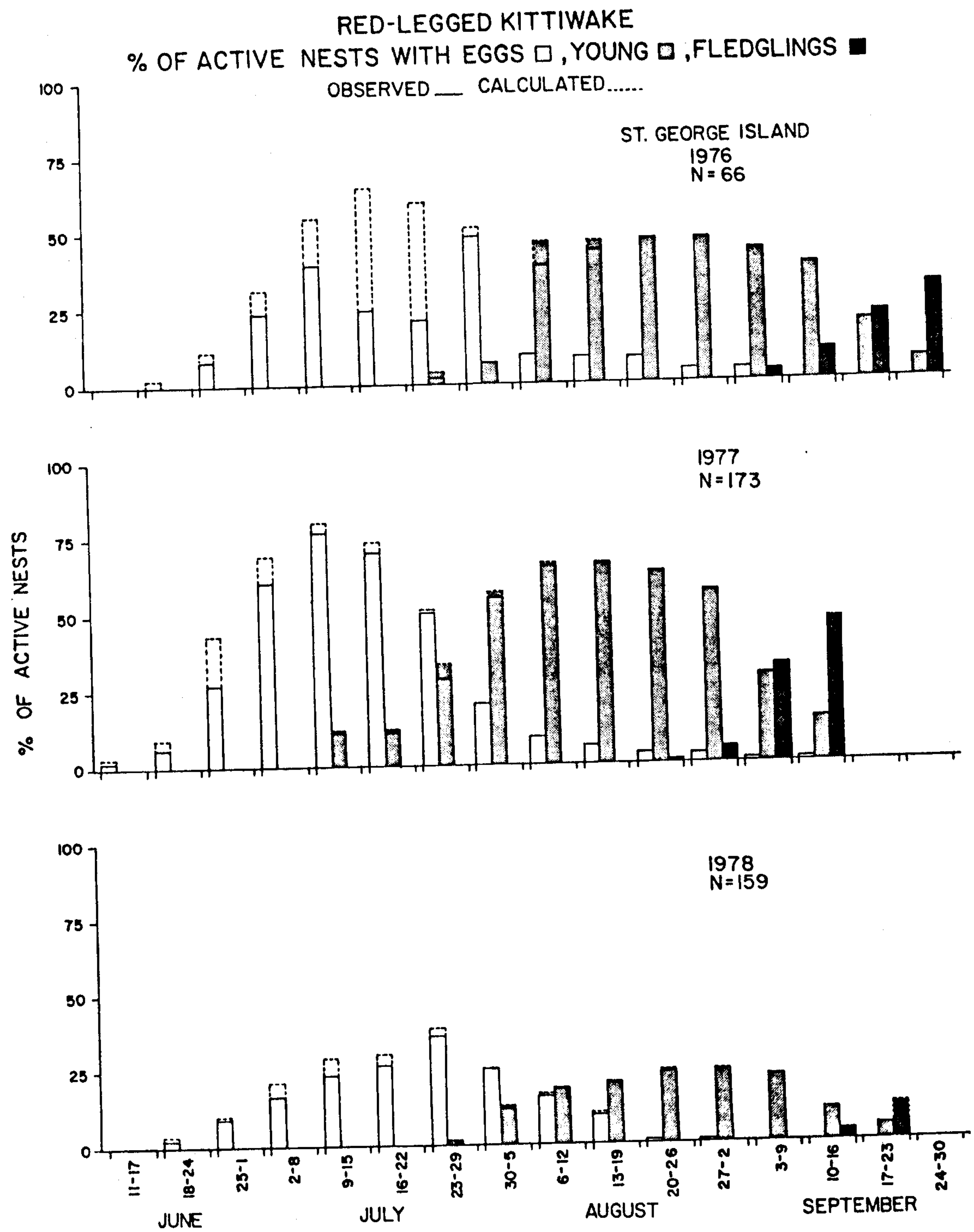

RED-LEGGED KITTIWAKE
% OF ACTIVE NESTS WITH EGGS □ ,YOUNG ▩ ,FLEDGLINGS ■
OBSERVED ___ CALCULATED......
ST. GEORGE ISLAND
1976
N=66
1977
N=173
1978
N=159
% OF ACTIVE NESTS
100
75
50
25
0
11-17
18-24
25-1
2-8
9-15
16-22
23-29
30-5
6-12
13-19
20-26
27-2
3-9
10-16
17-23
24-30
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 50

differences may also reflect microclimate differences, since pure colonies occur at high elevations while mixed colonies occur at low elevations, where snow is likely to persist.

At the Pribilofs, Red-legged Kittiwakes incubate their eggs for approximately 30 days. The peak of hatching occurs around 4 August (Tables 11 and 12). Chicks are capable of flight after 37 days in the nest but typically remain in the vicinity for a week to ten days during which time they are fed by the parents. Red-legged Kittiwakes leave the Pribilof Islands in September (Preble and McAtee 1923) although a few may remain during fall and winter.

Daily Activity Patterns

Numbers of Red-legged Kittiwakes on the cliffs varied throughout the day, with peak numbers occurring around 1500 h. Nesting kittiwakes continuously occupied their nests up to and sometimes after the young fledged. Adults trade-off attending the nest throughout the day, with a peak of trade-off activity occurring in the morning. Unlike the Black-legged Kittiwake, trade-offs do occur during darkness. The night trade-off probably relates to the Red-legged Kittiwake's use of myctophids in the diet. These fish come to the surface at night where they are available to foraging kittiwakes. Another indication that Red-legged Kittiwakes feed at night is that nesting adults rarely spent two consecutive nights on the nest, whereas it was a relatively common occurrence for Black-legged Kittiwakes.

Table 13 summarizes the attendance patterns observed during the different stages of the nesting cycle. Like the Black-legged

Kittiwake, attendance bouts became shorter as the season progressed. However, Red-legged Kittiwakes were much more attentive to their young. Black-legged Kittiwakes leave their large young alone in the nest 55 per cent of the time and start leaving them unattended at an earlier age than Red-legged Kittiwakes. Normally, Red-legged Kittiwake chicks were first observed alone in the nest at an average age of 41 days. However, in 1978, a poor reproductive year for Red-legged Kittiwakes, chicks were first observed alone at an average age of 25 days and in one instance a chick was left unattended at twelve days of age.

Productivity

Red-legged Kittiwakes are as productive as their congener, the Black-legged Kittiwake despite the fact that at present they lay a single egg at the Pribilofs versus the 2 eggs laid by Black-legged Kittiwakes (T Test, $P > 0.5$). (There is a report of 2 egg clutches in Red-legged Kittiwakes at the Pribilofs (Elliott 1875). In addition, Denby Lloyd (in litt.) reported a Red-legged Kittiwake nest containing 2 eggs on St. George Island in 1980). Patterns of reproductive success are similar for the two species, with both showing large yearly fluctuations (Table 14). We analyzed productivity for variations due to years and islands (Two-way ANOVA, explained variation $r^2 = 0.80$). We found no significant differences in productivity between St. Paul and St. George Islands (Island Effects $r^2 = 0.0$, $P = .965$). There were significant differences in productivity between years (Year effects, $r^2 = 0.73$, $P = .0001$). However, a significant interaction prevented further analysis. Both for Red-legged and Black-legged

TABLE 13

Nest Attendance Patterns of Red-legged Kittiwakes at the Pribilof Islands, 1977 - 1979.

	Period of Watch	No. nests	Duration of Adults Attendance (hrs) $\bar{x} \pm s$ (n)	Proportion of time nest is unoccupied	Feeding Rate $\bar{x}$
Incubation					
1977 STG	2030 1-0900 3 Jul	13	8.6 $\pm$ 8.3 (54)	0	-
1977 STP	1730 14-1500 16 Jul	9	17.2 $\pm$ 10.2 (24)	0	-
1979 STP	0600 4-1305 5 aug	5	2.8 $\pm$ 0.6 (2)	0	-
Small Chick					
1977 STG	1600 28-1130 30 Jul	7	10.9 $\pm$ 8.6 (29)	0	0.4
1977 STP	2000 1-1530 3 Aug	6	8.4 $\pm$ 5.0 (25)	0	0.2
Large Chick					
1977 STG	1600 18-1200 20 Aug	9	5.2 $\pm$ 6.0 (56)	0.3	0.2
1977 STP	1830 20-2100 21 Aug	6	3.1 $\pm$ 5.0 (38)	0.4	0.2

TABLE 14

Reproductive success of Red-legged Kittiwakes at the Pribilof Islands, 1975 - 1979

	ST. PAUL ISLAND					ST. GEORGE ISLAND			
	1975	1976	1977	1978	1979	1976	1977	1978	OVERALL
$\overline{X}$ CLUTCH	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N =	23	56	57	24	24	39	168	72	
HATCHING SUCCESS (chicks hatched/ egg laid)	.78-.91	.88-.93	.82-.91	.54-.71	.63-.71*	.79-.87	.78-.85	.57-.81	.7-.86
FLEDGING SUCCESS (chicks fledged/ chick hatched)	.81-.94	.92-.98	.81-.89	.65-.85	.76-.87*	.76-.84	.79-.86	.53-.76	.7-.87
REPRODUCTIVE SUCCESS (chicks fledged/ nest, known clutch)	.74	.86	.74	.46	.54*	.67	.68	.43	
PRODUCTIVITY (chicks fledged/ nest attempt)	.34	.63	.54	.10	.34*	.30-.45	.54	.13	
N =	50	76	78	112	56	88	240	235	

* number of chick fledged in 1979 estimated from number of eggs and chicks at last check compared to numbers on same date in previous years which fledged at end of season.

Kittiwakes, productivity was similar in 1976 and 1977 but was depressed in 1978. Yearly differences were more pronounced in Red-legged Kittiwakes. Between 1975 and 1977, productivity averaged 0.40 chicks fledged/nest attempt; in 1978 productivity averaged 0.12 chicks fledged/nest attempt, a 30 per cent reduction from previous levels (Table 14).

The fact that both kittiwake species were affected in 1978 makes prey scarcity an unlikely cause of lowered productivity, since the two species depend on different prey, and the major prey they shared in common, walleye pollock, was abundant in 1978 (Smith 1979). However, the kittiwakes are similiar in their flight capabilities and both appear to be inhibited in their foraging by high winds. Red-legged Kittiwakes were particularly strongly affected in 1978. One possible reason why Red-legged Kittiwakes were more severely affected than Black-legged Kittiwakes might be their longer foraging distances; these birds typically feed along the shelf break, a minimum distance of 30 km. Another reason might be that the 2 egg clutch of the Black-legged Kittiwake acts a buffer, the second egg being insurance against loss of the first. Red-legged Kittiwakes, with their single egg, lack such a buffer and can only replace lost eggs early in the breeding season. Any event causing egg loss or chick mortality would then be expected to affect Red-legged Kittiwake productivity more severely.

Growth rates of Red-legged Kittiwake chicks are given in Table 15. Red-legged Kittiwake chicks have typically grown at rate of about 13 grams per day, except in 1976 when growth

TABLE 15

Growth Rates and Fledging Weights of Red-legged Kittiwake Chicks at the Pribilof Islands, 1975 - 1979

	Growth Rate (g/day)	Fledging Weight (g)
1975		
St. Paul	no nests in reach	no nests in reach
St. George	13.2 ± 1.9 (16)	376.6 ± 33.9 (16)
1976		
St. Paul	11.7 ± 1.2 (4)	410.8 ± 37.9 (4)
St. George	10.5 ± 2.1 (12)	378.6 ± 47.4 (28)
1977		
St. Paul	13.6 ± 2.5 (3)	397.3 ± 14.1 (3)
St. George	13.1 ± 2.3 (42)	404.1 ± 47.4 (29)
1978		
St. Paul	no nests in reach	no nests in reach
St. George	13.1 ± 2.2 (13)	385.9 ± 35.1 (11)
1979		
St. Paul	12.3*	
Overall	12.53	392.2
St. Paul	12.65	404.1
St. George	12.48	386.3

* growth rate for one chick taken over short period (less than 1 week)

rates were lower (T test $P < 0.01$). Growth rates were similar on the two islands (T test $P > 0.5$). Although productivity suffered in 1978, growth rates were equal to 1975 and 1977 levels (T test $P > 0.5$). Red-legged Kittiwake chicks fledge at about 390 grams (Table 15).

Like Black-legged Kittiwakes, nesting Red-legged Kittiwakes have few predators on the Pribilof Islands. Mortality of eggs and chicks was about 20 percent for all nests, except in 1975 when it was about 40 per cent and 1978 when it was over 50 per cent. Most mortality occurs during the egg stage. Aleuts shoot flying young and adult Red-legged Kittiwakes for food. On St. Paul Island, Aleuts may shoot the equivalent of the entire Red-legged Kittiwake reproductive output for the year due to the small numbers nesting on the island and the accessibility of their nests. Most shooting occurs during the fall, rather than during the nesting season. Numbers of Red-legged Kittiwakes on St. Paul Island appear to have remained constant since at least the 1950's, so shooting has not caused the population to decline. On St. George Island, the large numbers of Red-legged Kittiwakes and their inaccessibility combine to make the effects of shooting negligible.

ALCIDAE

The North Pacific is the center of adaptive radiation for this family of diving seabirds (Bedard 1969c) that occupies the ecological foraging zone of the subsurface waters. The range of sizes and the variety of life history strategies among the species make this family of seabirds one of the most interesting. There is differentiation between the species in foraging areas; moreover, the distribution of alcid nesting colonies may reflect the availability of preferred foods, which in turn are restricted to particular water masses or ocean environments.

Common Murre (*Uria aalge*)

Numbers

The Common Murre is a widespread species, occurring throughout the northern oceans. The Pribilof Islands support an estimated 229,200 Common Murres, a small portion of the estimated 4.9 million in the eastern Bering Sea (Appendix 1).

As recently as 1949, Walrus Island in the Pribilof group supported one of the largest murre colonies in the world (Kenyon and Phillips 1965, Preble and McAtee 1923). Since that time, Steller's Sealions have displaced the murres on Walrus Island. The only remnant of this once immense colony is a group of about 200 murres who nest on a small offshore rock at the north end of the island.

Pelagic Distribution

The pelagic distribution of murres is given in Figures 51-53. Aerial and shipboard surveys are combined as both methods provide reasonably unbiased data on distribution and numbers. Data on

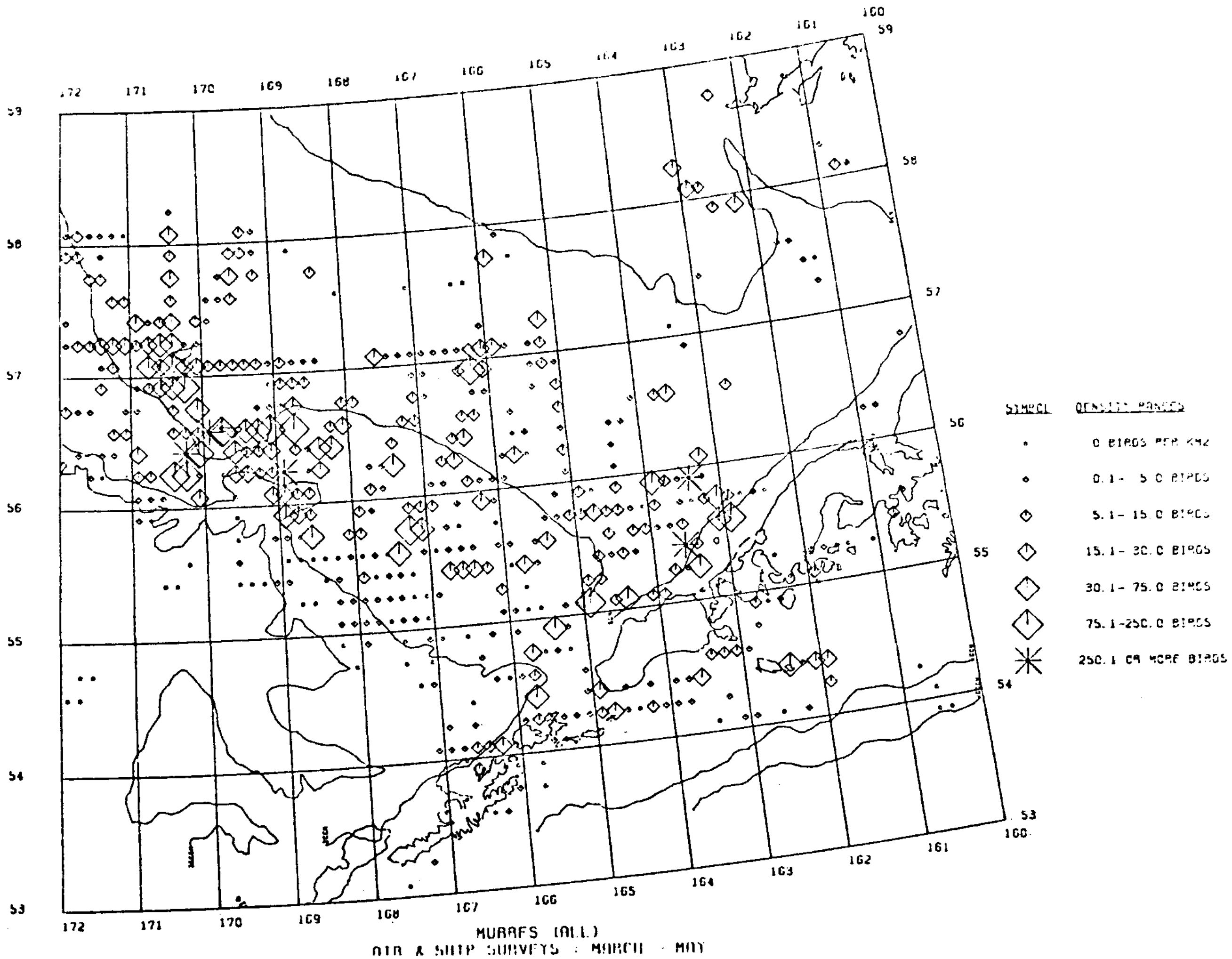
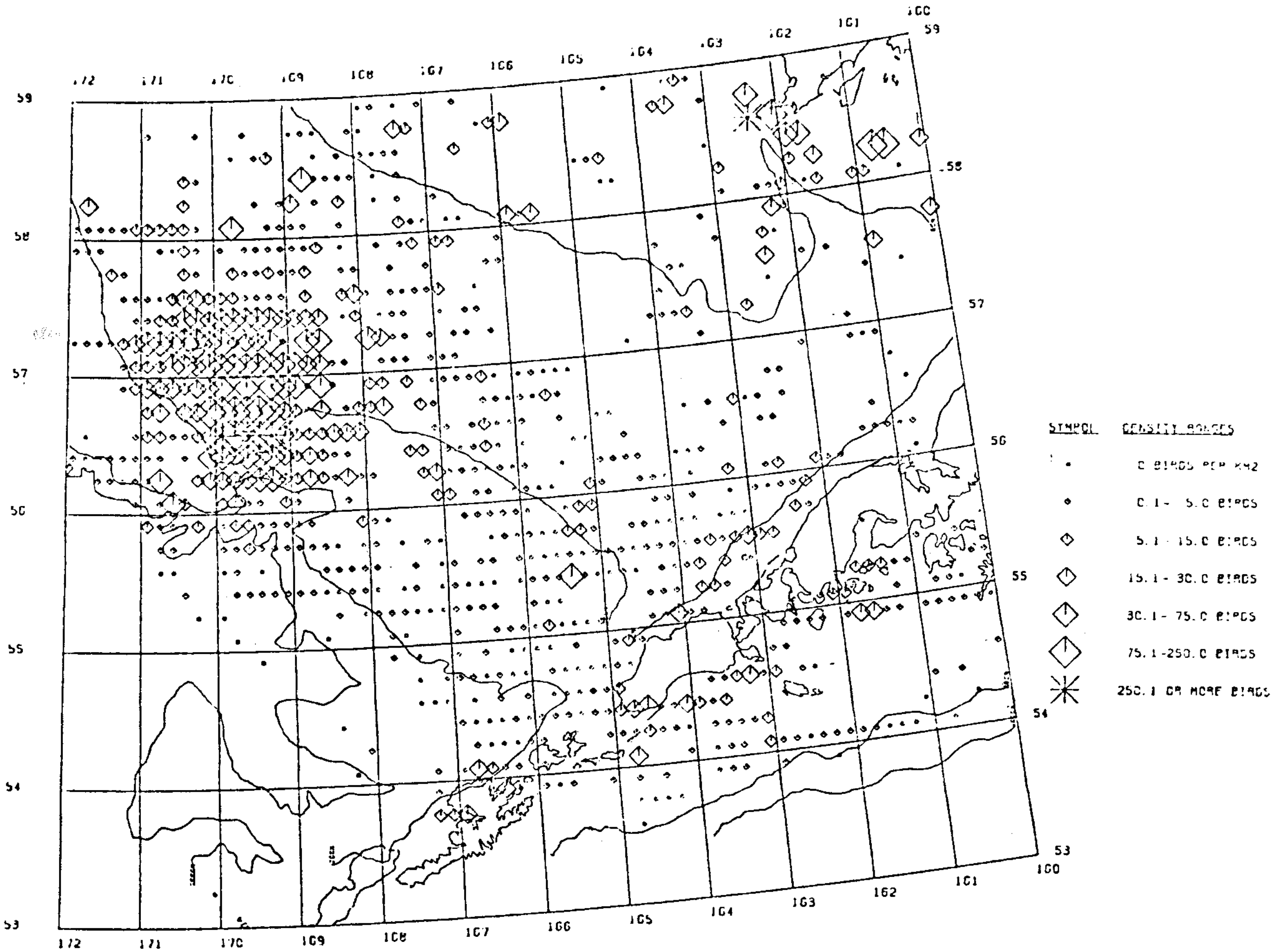
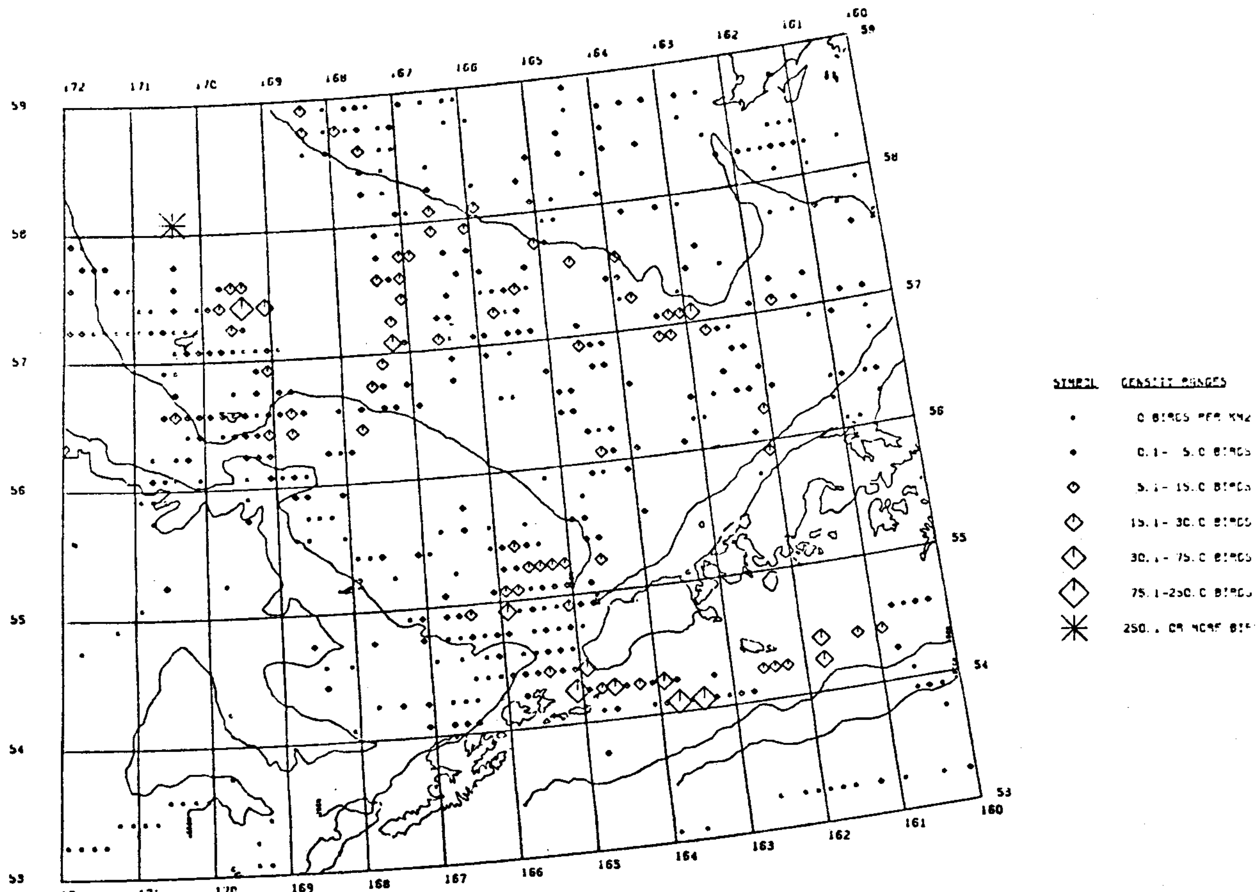

SYMBOL DENSITY RANGES
0 BIRDS PER KM2
0.1 - 5.0 BIRDS
5.1 - 15.0 BIRDS
15.1 - 30.0 BIRDS
30.1 - 75.0 BIRDS
75.1 - 250.0 BIRDS
250.1 OR MORE BIRDS
MURRES (ALL)
AIR & SHIP SURVEYS : MARCH - MAY

FIGURE 51



MURRES (ALL)
AIR & SHIP SURVEYS : JUNE - AUGUST

FIGURE 52



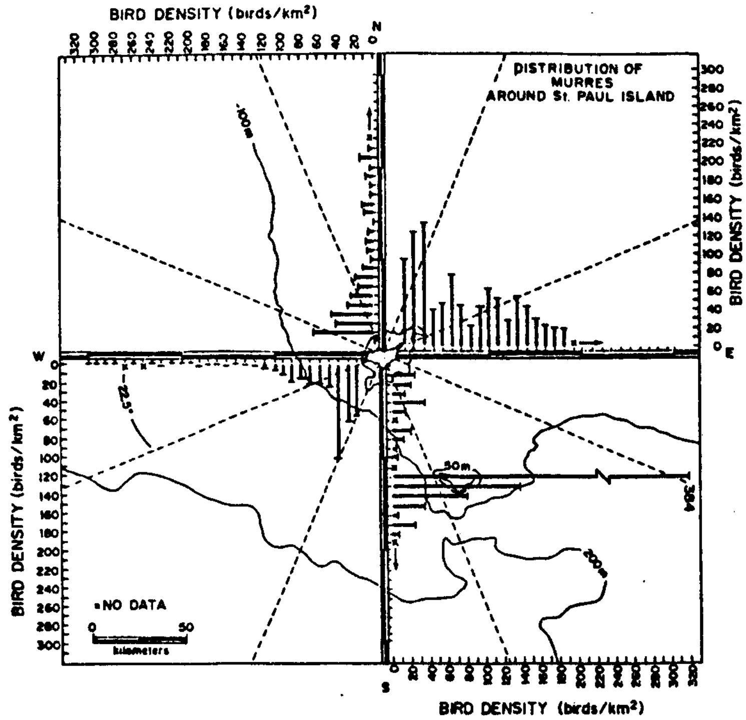
MURRES (ALL)
AIR & SHIP SURVEYS :SEPTEMBER - NOVEMBER

FIGURE 53

both Common and Thick-billed Murres are combined, as specific identification in the field, particularly in aerial surveys is often not possible. Near the Pribilofs, 80 percent of all murres are Thick-billed Murres; near the mainland coast, most murres are Common Murres.

According to Shuntov (1972), murres spend their winters on the open waters of the continental shelf. In late March and April, murres begin to concentrate around their colonies, but there are still large numbers over shelf water, particularly in the outer shelf domain (Appendix 2, Figure 1). By May, most murres are concentrated near the colonies and relatively few areas of high density are found more than 100 km from their colonies (Appendix 2 , Figure 2). This pattern persists through August. In late August and early September, when murres are finished nesting, they rapidly disperse (Appendix 2, Figures 3-6). Thus, there are very large and highly vulnerable concentrations of murres near their colonies in summer.

During the breeding season, the major concentrations of murres around the Pribilofs were found between 56° 10'N and 57° 30'N, 168° 30'W and 171° 10'W, an area within approximately 50 km of the islands (Figures 53 and 54). One exception to this pattern is the area east of St. Paul Island, where large numbers of murres were seen out to 100 km from the island (Figure 54). The distribution of murres on the water, which reveals the location of important foraging areas, reinforces the impression that the area northeast of St. George and east of St. Paul is a particularly critical foraging zone for murres during the breeding season (Figures 56


BIRD DENSITY (birds/km²)
DISTRIBUTION OF MURRES AROUND St. PAUL ISLAND
N
S
E
W
100 m
50 m
200 m
22.5°
384
NO DATA
kilometers

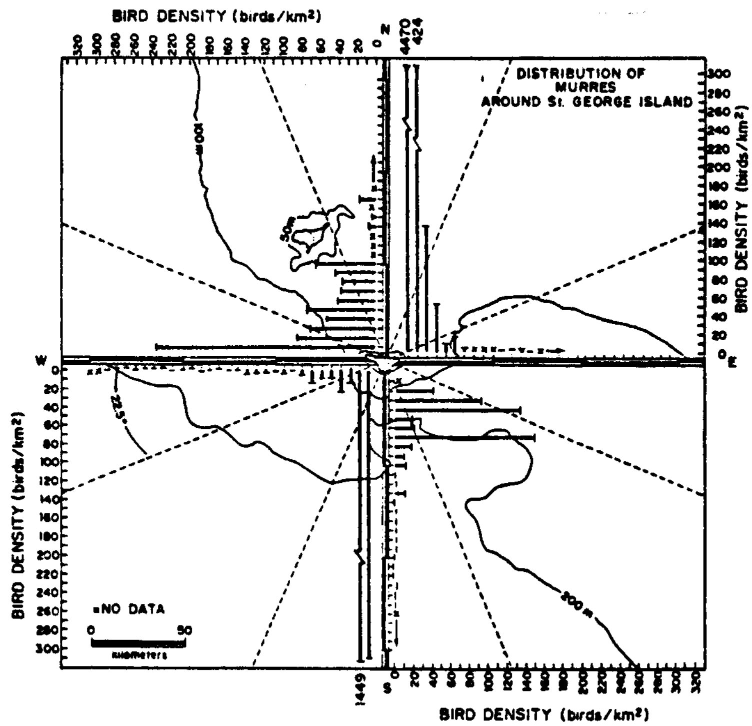
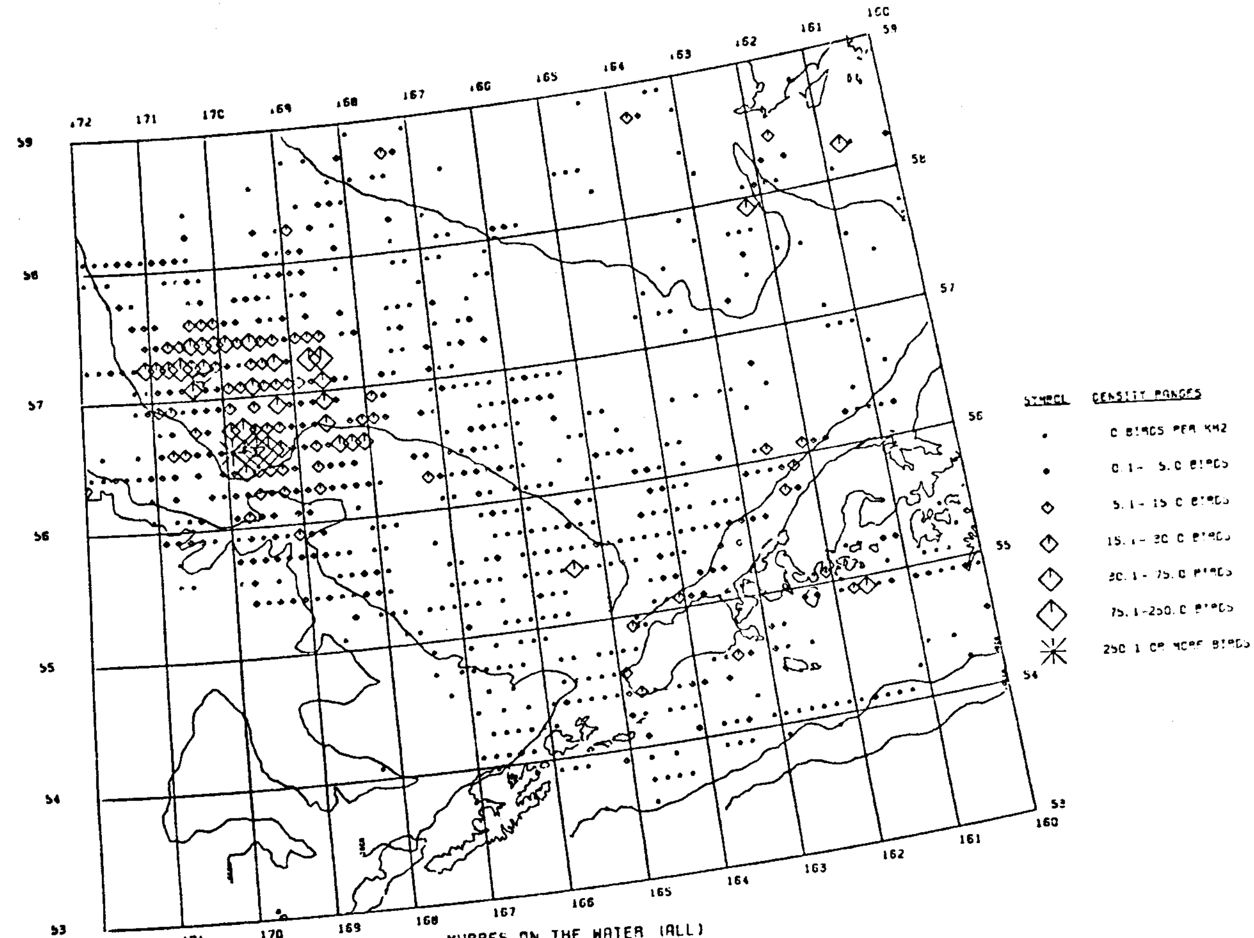
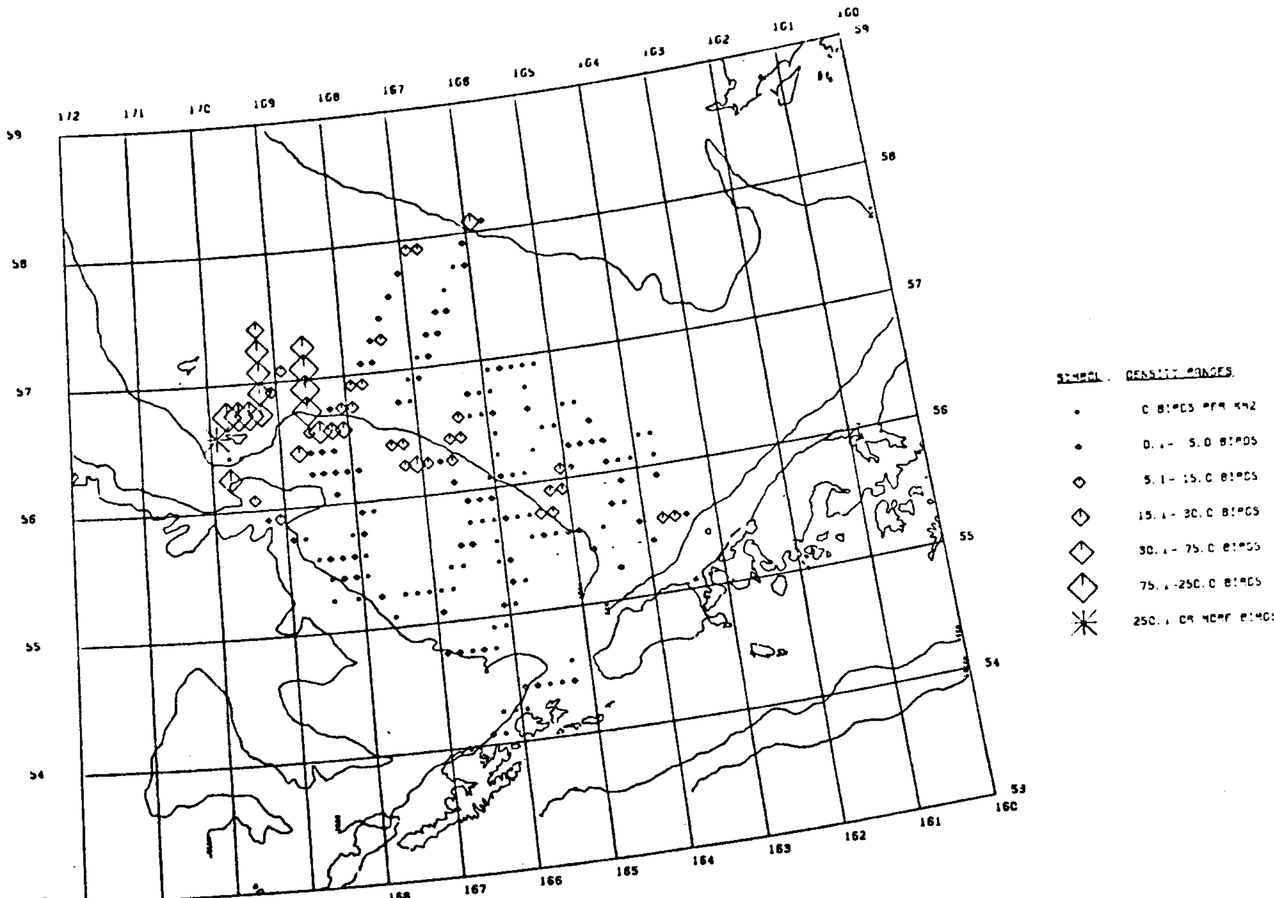

BIRD DENSITY (birds/km²)
DISTRIBUTION OF MURRES AROUND St. GEORGE ISLAND
N
S
E
W
4470
424
1449
100 m
50 m
200 m
22.5°
NO DATA
kilometers

FIGURE 54



MURRES ON THE WATER (ALL)
AIR & SHIP SURVEYS : JUNE - AUGUST

FIGURE 55



MURRES (ALL)
AIR & SHIP SURVEYS : JUNE 1978

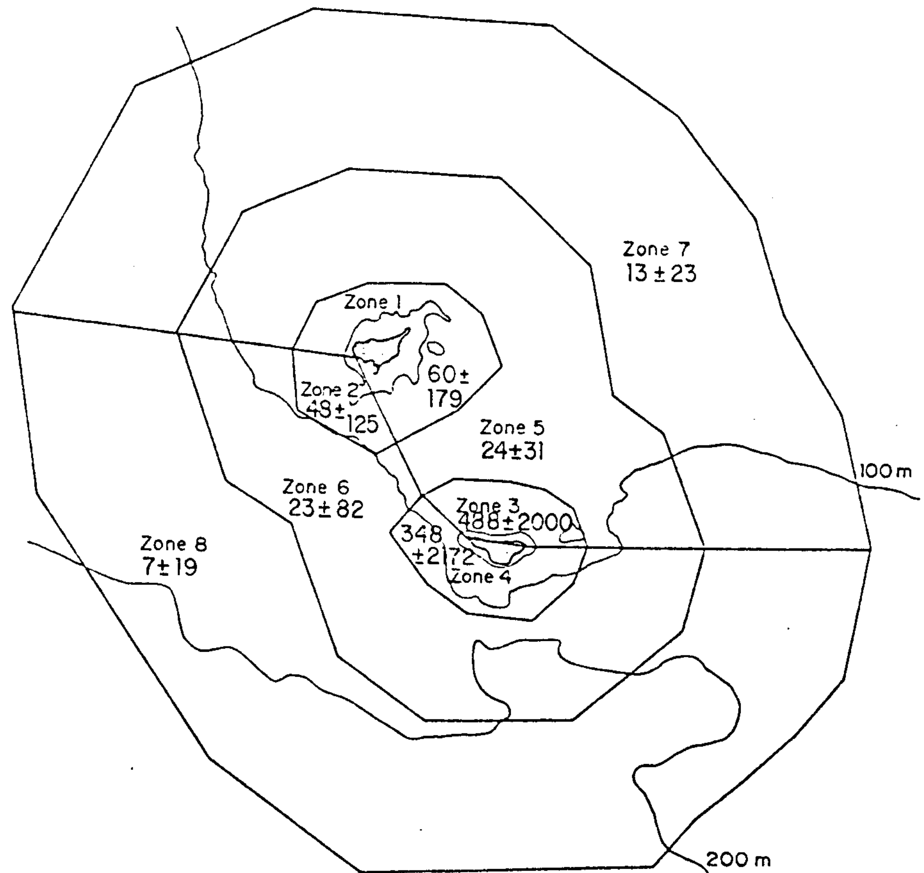
FIGURE 56

and 56). Southwest of the islands, densities are much lower and large numbers of murres on the water were rarely encountered more than 50 km from the colonies (Figure 54). We rarely encountered groups of adults and fledglings on the water and therefore we do not know if there are important "nursery" areas.

The zonal analysis of murre distribution around the Pribilofs shows large concentrations of murres near the islands which drop off rapidly with distance (Figure 57). In the most distant zones, murre densities were greater over the shallower waters to the north and lower over the deeper waters of the shelf break. These differences were statistically significant (T-Test, $T_{547.9} = 3.95$, $p < 0.0001$). Densities were greater around St. George Island than around St. Paul, reflecting the larger population of murres nesting on St. George Island (Modified LSD Procedure, $P < 0.05$).

The overall picture that emerges from this analysis is that foraging murres are highly concentrated close to their breeding colonies and that moderately high concentrations may be found out to 100 km or more. However, the distribution of murres around the island was not symmetrical. Rather, most birds were found to the north and east in waters less than 100 m deep. Murre densities dropped off rapidly to the south and west over deeper waters. Since some deep-water areas with low murre densities are closer to the colonies than some of the shallow-water areas with high murre density, it is reasonable to believe that murres are constrained from using these deep-water areas because foraging there is unproductive during the breeding season. However, at other seasons, murres are found foraging in moderate numbers over

Distribution of Murres by zones near the Pribilof Islands, 1975–1979 $(\bar{x} \pm s)$*



ANOVA across all zones, $F_{7,2128} = 9.084$, $P = 0.0001$

Homogeneous subsets by modified LSD Procedure, $\alpha = 0.05$

Subset 1 Zones 8,7,6,5,2,1
Subset 2 Zones 2,1,4
Subset 3 Zones 3,4

*rounded to whole numbers

FIGURE 57

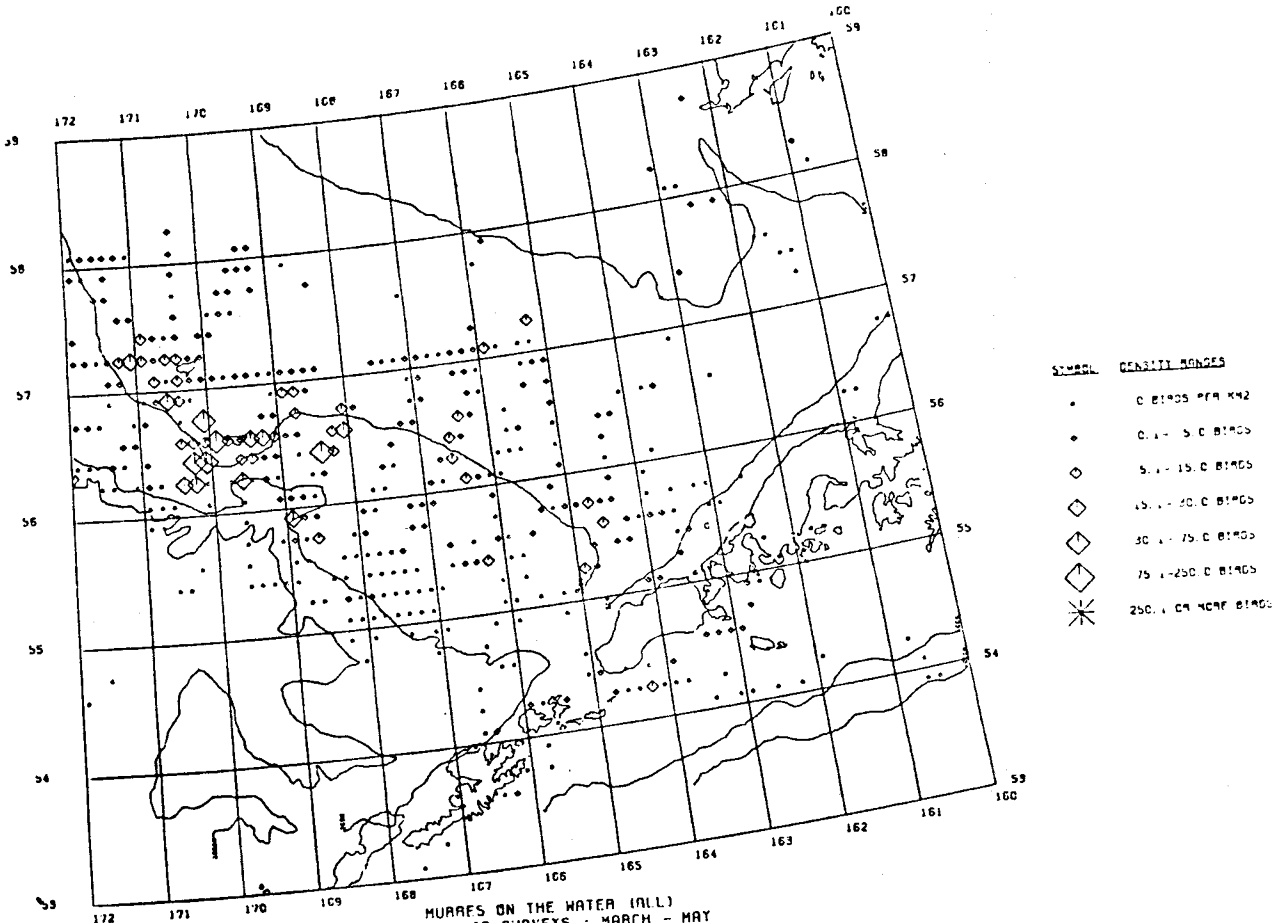


FIGURE 58

waters between 100 and 200 m deep (Figures 51, 53, 56, 58) suggesting that water depth is not the critical feature determining the asymmetrical distribution of murres around the Pribilof Islands in summer.

Diet

Common Murres dive to obtain their prey, often at considerable depths (60 m, Stettenheim 1959). They forage over the continental shelf, generally close to their colonies. At the Pribilofs, Common Murres are rarely encountered more than 100 km out from the islands.

Figure 59 summarizes the major foods used by Common Murres at the Pribilofs. Fish were the principal component of the diet and walleye pollock was the single most important species. Invertebrates comprised less than 5 per cent of the diet by volume (Figure 59). Invertebrates, particularly euphausiids, attained importance only in June (Figure 60). This trend of dependence on invertebrates early in the breeding season and dependence on fish later is similar to the pattern found in the diets of other Pribilof seabirds. Unfortunately, the small number of Common Murre food samples for June and September precludes the meaningful application of statistical analysis.

Preble and McAtee (1923) reported on the contents of 18 stomachs of this species taken from the Pribilof Islands, mostly in winter. In contrast to our results, the 12 stomachs with food contained almost exclusively amphipods, particularly *Pontogenia*. One stomach contained nereid worms. Only the nearly empty stomachs had traces of small sculpins (Cottidae). These data differ from

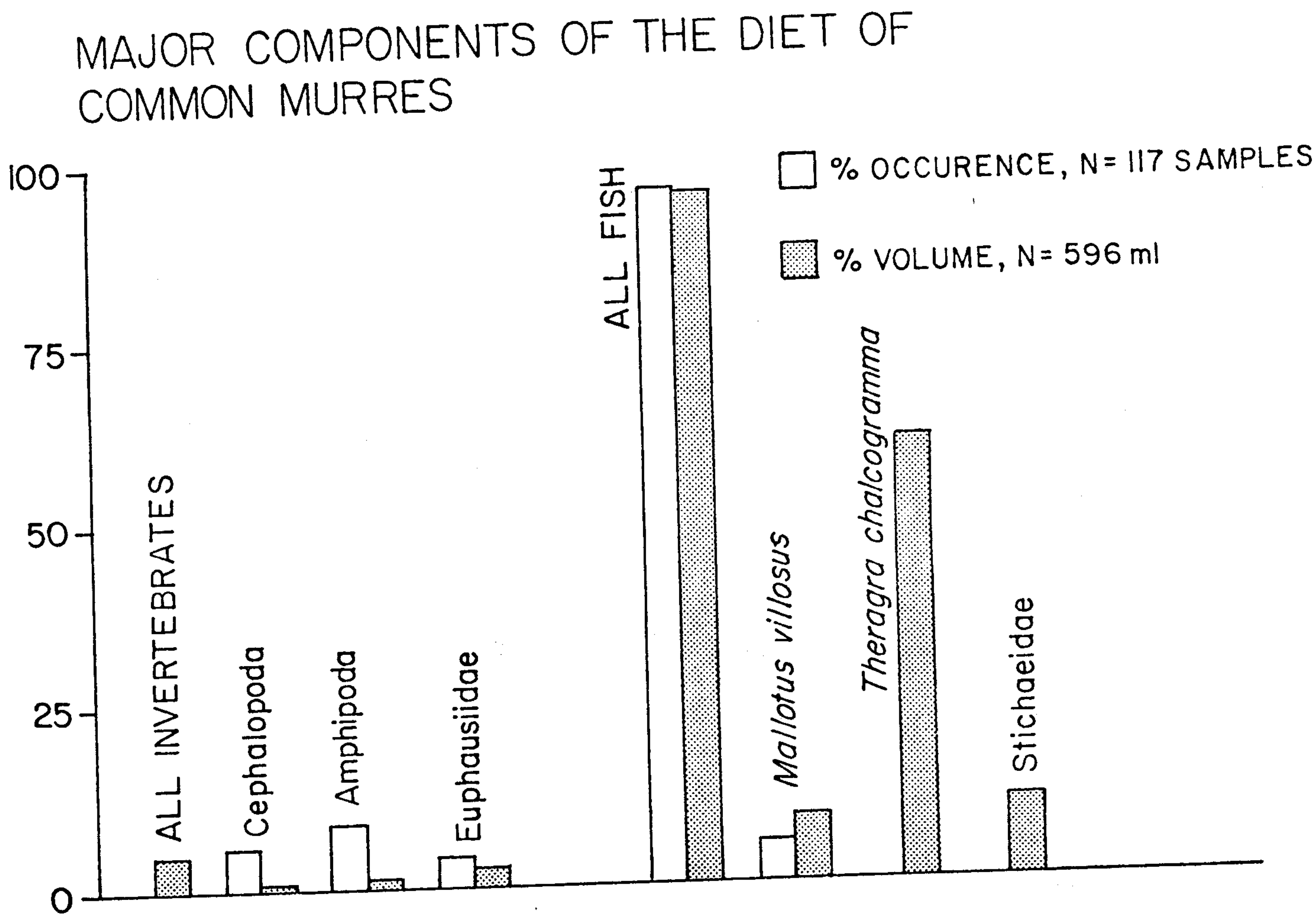
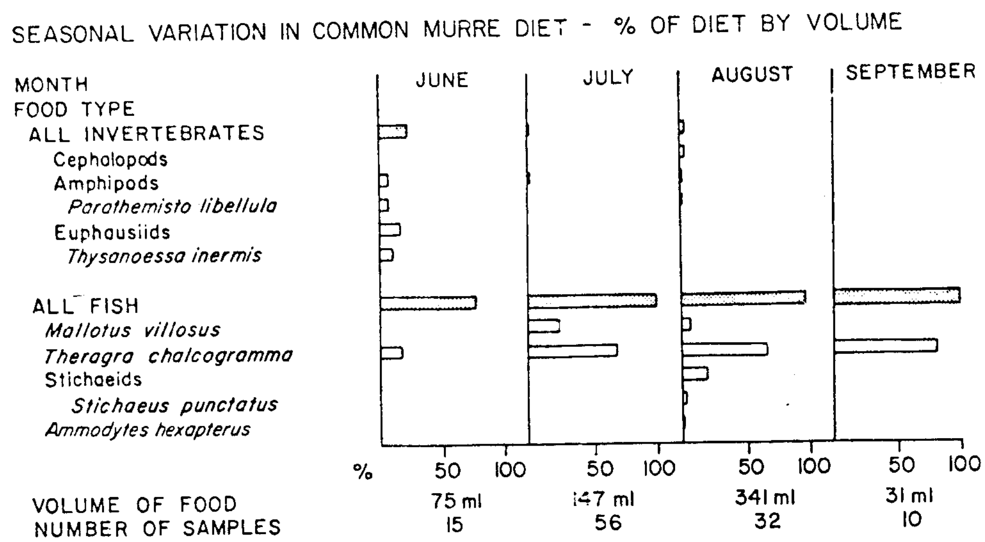

MAJOR COMPONENTS OF THE DIET OF COMMON MURRES
% OCCURENCE, N= 117 SAMPLES
% VOLUME, N= 596 ml
100
75
50
25
0
ALL INVERTEBRATES
Cephalopoda
Amphipoda
Euphausiidae
ALL FISH
Mallotus villosus
Theragra chalcogramma
Stichaeidae

FIGURE 59


SEASONAL VARIATION IN COMMON MURRE DIET - % OF DIET BY VOLUME
MONTH
FOOD TYPE
ALL INVERTEBRATES
Cephalopods
Amphipods
Parathemisto libellula
Euphausiids
Thysanoessa inermis
ALL FISH
Mallotus villosus
Theragra chalcogramma
Stichaeids
Stichaeus punctatus
Ammodytes hexapterus
JUNE
JULY
AUGUST
SEPTEMBER
%
50
100
VOLUME OF FOOD
NUMBER OF SAMPLES
75 ml
15
147 ml
56
341 ml
32
31 ml
10

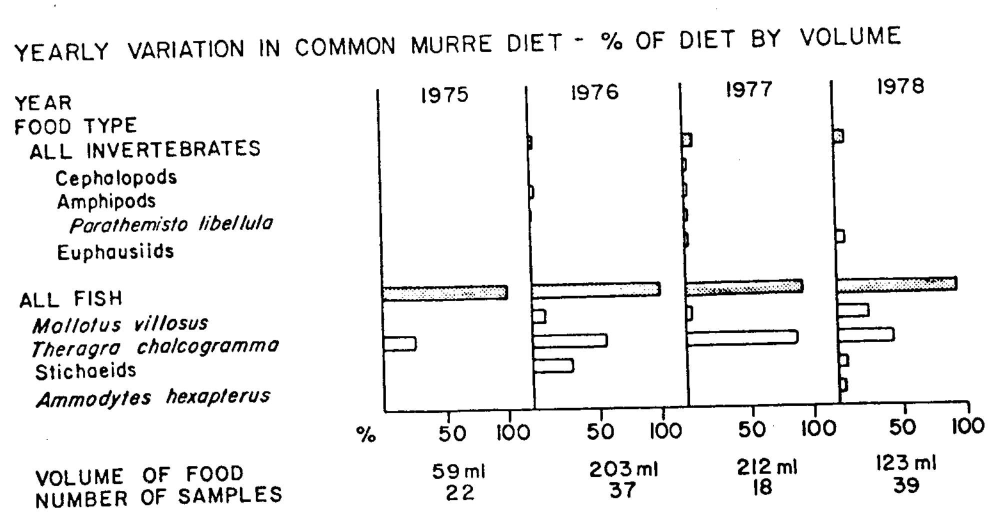

YEARLY VARIATION IN COMMON MURRE DIET - % OF DIET BY VOLUME
YEAR
FOOD TYPE
ALL INVERTEBRATES
Cephalopods
Amphipods
Parathemisto libellula
Euphausiids
ALL FISH
Mallotus villosus
Theragra chalcogramma
Stichaeids
Ammodytes hexapterus
1975
1976
1977
1978
%
50
100
VOLUME OF FOOD
NUMBER OF SAMPLES
59 ml
22
203 ml
37
212 ml
18
123 ml
39

FIGURE 60

ours, which were gathered mostly in summer. The question remains as to what these differences mean.

At St. Lawrence Island, Searing (1977) found Common Murres using both invertebrates and fish (N = 5). Ramsdell and Drury (1979), working at Bluff on the south coast of the Seward Peninsula, found adult Common Murres feeding on small sand lance (Ammodytes) 3 to 5 cm long. However, they brought pricklebacks (Lumpenus) to their chicks. Ramsdell and Drury made no mention of the use of invertebrates. Further north, at Cape Thompson in the Chukchi Sea, Swartz (1966) examined 86 Common Murre stomachs. The diet of Common Murres there, similar to the Pribilofs in summer, was almost exclusively fish, with Boreogadus saida replacing the related walleye pollock as the single most important food species. At Cape Thompson, the diets of adults also contained significant amounts of sand lance, which was not the case at the Pribilofs. Ammodytes was also used extensively by Black-legged Kittiwakes in the northern colonies. This use of Ammodytes in the northern colonies probably does not represent a north-south difference in the distribution of Ammodytes, but rather their greater abundance in the coastal versus pelagic habitat. The data on Black-legged Kittiwake food habits from the Bering and Chukchi Seas are similiar to those obtained by Belopol'skii (1957), working in the Barents Sea. He found that 95 per cent of the diet in Common Murres consisted of fish.

Nesting

Habitat

Common Murres nest on the tops of predator-free offshore rocks and islands or on wide ledges of sea cliffs. Their densely packed and typically remote and inaccessible nest sites made the Common Murre a difficult species to monitor on the Pribilofs. Their productivity is very sensitive to disturbance due to the crowded conditions on their nesting ledges. The sensitivity to perturbation and crowded nesting conditions combine to make phenology and productivity estimates crude, at best. A few Common Murres nest on narrow ledges among numerous Thick-billed Murres. For much of our study, we have used these atypical Common Murre sites because of the greater observational accuracy they afford. However, the productivity and phenology of Common Murres nesting in these atypical areas may not accurately reflect the biology of the larger population (Birkhead 1977).

Phenology

Common Murres were well established on their ledges when we arrived at the Pribilofs, as early as 3 May. Our least reliable estimates are for laying phenology. We think that the first eggs are laid in early June (Tables 16 and 17), with the peak of laying occurring in late June through early July (Figures 61-63). Murres incubate their eggs for an average of 31 days. The peak of hatching occurs around 5 August (Figure 63). Chicks remain on the nesting ledges for an average of 21 days, during which time they grow contour feathers. Chicks jump from the cliffs in late August (Tables 16 and 17) at one quarter of their adult weight. Once at sea, murre chicks continue to be fed by a parent until independent. Common Murres leave the Pribilof cliffs by 10 September, although they remain around the islands through fall and winter. During these seasons, they outnumber Thick-billed Murres.

TABLE 16

Phenology of Common Murres at St. Paul Island, 1975 - 1978

	1975	1976	1977	1978	
First egg observed	7 July	24 June	21 June	8 June	23 June
Clutch initiation $\bar{X} \pm S$	-----	8 Jl $\pm$ 8.1	14 Jl*	24 Jn $\pm$ 6.5	5 July
N =		61	14	58	
First chick observed	21 July	24 July	22 July	17 July**	21 July
Hatching $\bar{X} \pm S$	17 A $\pm$ 1.2	2 A $\pm$ 6.9	14 A $\pm$ 6.0	25 Jl $\pm$ 4.7	7 Aug
N =	3	3	14	7	
First fledging observed	-----	10 Aug	28 Aug	13 Aug	17 Aug
Fledging $\bar{X} \pm S$	-----	24 A $\pm$ 7.3	2 S $\pm$ 7.0	24 A $\pm$ 8.5	27 Aug
N =		15	17	11	

* calculated from known hatching dates

** first chick observed in 1979 was seen 27 July

TABLE 17

Phenology of Common Murres at St. George Island, 1976 - 1978

	1976	1977	1978	Overall
First egg observed	‡	26 June	18 June	22 June
Clutch initiation $\bar{X} \pm S$	‡	3 Jl ± 8.0	30 Jn ± 11.5	2 July
N =		14	15	
First chick observed	31 Jl	27 Jl	18 Jl	25 July
Hatching $\bar{X} \pm S$	3 A ± 3.7	4 A ± 7.0	2 A ± 9.9	3 Aug
N =	9	10	13	
First fledging observed	19 Aug	24 Aug	13 Aug	19 Aug
Fledging $\bar{X} \pm S$	23 A ± 3.4	3 S ± 7.8	25 A ± 6.7	27 Aug
N =	6	3	7	

‡ observations started after egg-laying

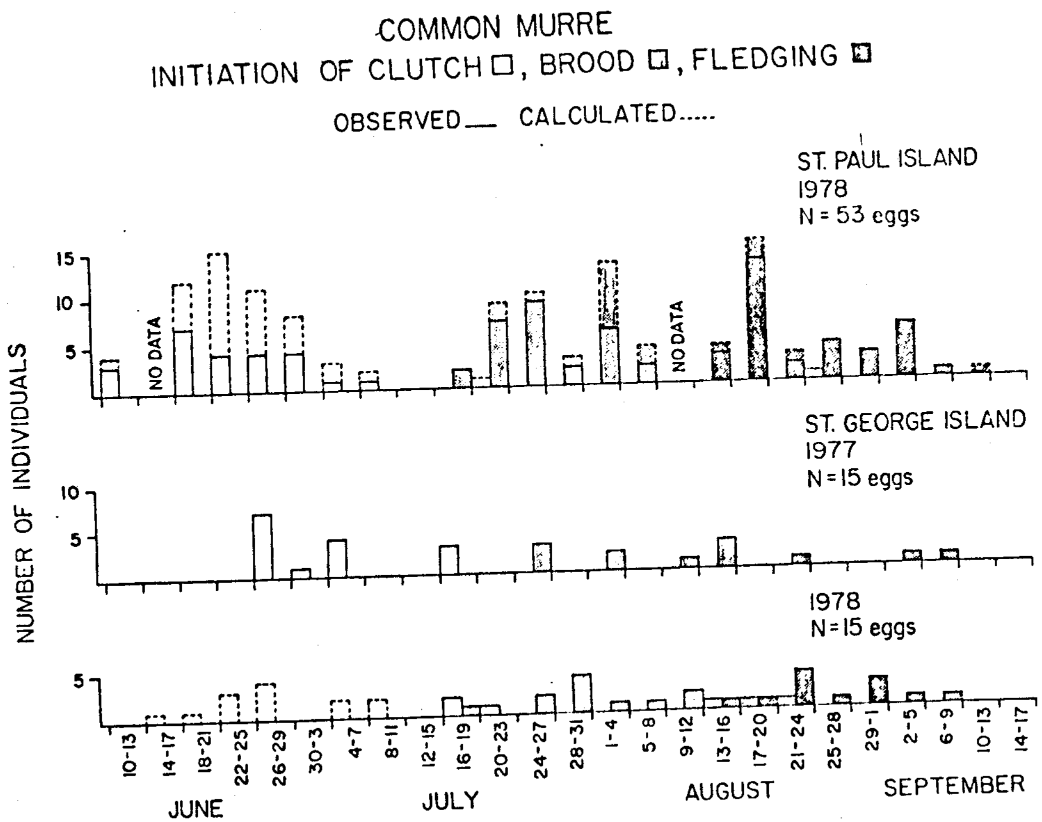

COMMON MURRE
INITIATION OF CLUTCH, BROOD, FLEDGING
OBSERVED — CALCULATED .....
ST. PAUL ISLAND
1978
N = 53 eggs
NO DATA
NO DATA
ST. GEORGE ISLAND
1977
N = 15 eggs
1978
N = 15 eggs
NUMBER OF INDIVIDUALS
15
10
5
10-13
14-17
18-21
22-25
26-29
30-3
4-7
8-11
12-15
16-19
20-23
24-27
28-31
1-4
5-8
9-12
13-16
17-20
21-24
25-28
29-1
2-5
6-9
10-13
14-17
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 61

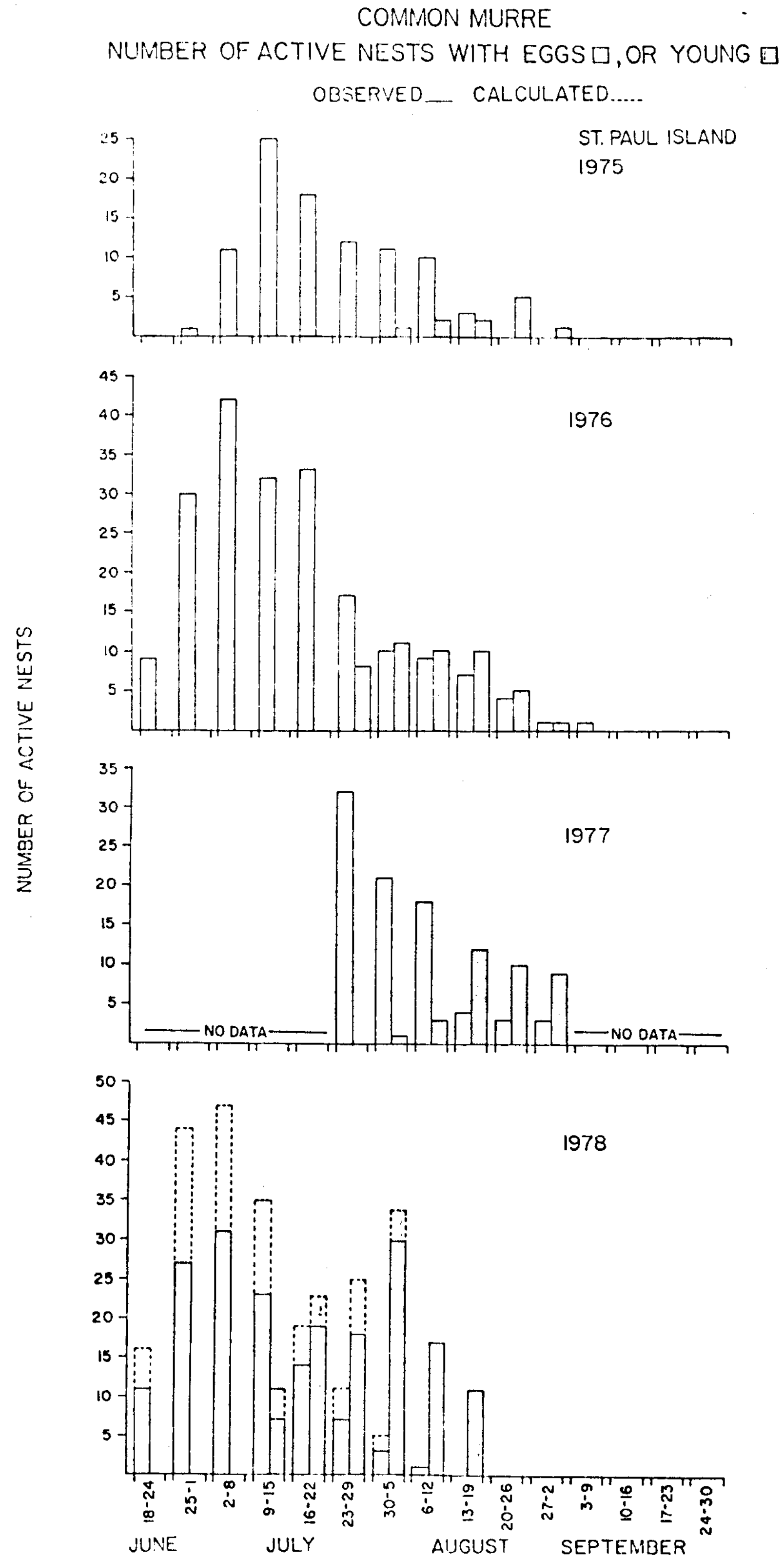

COMMON MURRE
NUMBER OF ACTIVE NESTS WITH EGGS □, OR YOUNG ⊡
OBSERVED___ CALCULATED.....
ST. PAUL ISLAND
1975
1976
1977
1978
NO DATA
NO DATA
NUMBER OF ACTIVE NESTS
18-24
25-1
2-8
9-15
16-22
23-29
30-5
6-12
13-19
20-26
27-2
3-9
10-16
17-23
24-30
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 62

COMMON MURRE
NUMBER OF ACTIVE NESTS WITH EGGS □, OR YOUNG □
OBSERVED ___ CALCULATED ......

ST. GEORGE ISLAND
1978

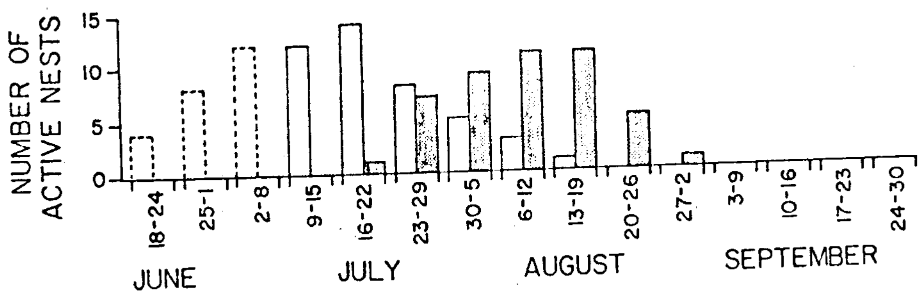


FIGURE 63

Due to the uncertainty in Common Murre data and our small sample size, we were not able to determine whether there are phenological differences between St. Paul and St. George Islands, or if phenology varies between years.

Daily Activity Patterns

We have limited data on the daily attendance patterns of Common Murres. However, their numbers appear to vary less during the day than do those of Thick-billed Murres (Hickey and Craighead 1977). We did not have access to a Common Murre nesting area where birds could be marked and nest attendance patterns could be investigated.

Productivity

Within our observational error, the productivity of Common Murres averaged 0.62 chicks fledged/egg laid at sites that were studied with a minimum amount of observer-initiated disturbance (Table 18). However, reproductive success varied from site to site depending on factors such as nesting ledge structure, numbers of murres and the degree to which an observer could conceal his presence. We suspect that productivity of the more typical sites which we did not study may have been substantially higher than our reported average due to the combined effects of low nesting densities (Birkhead 1977) and observer disturbance.

Given the observational error and the effects of disturbance on murre productivity, alternative measures of murre nesting success are the growth rate of chicks and chick jumping or departure weights (Table 19). We analyzed growth rates and jumping weight by year and by island using a two-way analysis of variance.

TABLE 18

Reproductive success of Common Murres at minimum-disturbance sites, Pribilof Islands, 1976 - 1978

	ST. PAUL IS.		ST. GEORGE IS.	OVERALL
	1976	1978	1978	
NUMBER OF EGGS	16	76	10	102
HATCHING SUCCESS (chicks hatched/ egg laid)	.75	.72	.80	.76
FLEDGING SUCCESS (chicks fledged/ chick hatched)	.75	.84	.87	.82
REPRODUCTIVE SUCCESS (chicks fledged/ egg laid)	.56	.61	.70	.62
PRODUCTIVITY (chicks fledged/ mean no. adults in the study area)	.16	.14	.26	.19

TABLE 19

Growth Rates and Fledging Weights of Common Murre Chicks at the Pribilof Islands, 1976 - 1978

	Growth Rate (g/day)	Fledging Weight (g)
1976		
St. Paul Is.	8.1 ± 3.5 (5)	207.8 ± 18.8 (5)
St. George Is.	7.0 ± 2.9 (4)	182.3 ± 13.1 (4)
1977		
St. Paul Is.	9.1 ± 1.3 (9)	192.4 ± 17.2 (11)
St. George Is.	6.9 ± 1.2 (3)	162.3 ± 21.7 (3)
1978		
St. Paul Is.	site abandoned due to early disturbance	
St. George Is.	7.1 ± 3.6 (12)	165.1 ± 21.1 (12)
OVERALL	7.8 ± 2.8 (33)	182.1 ± 24.2 (36)
St. Paul Is.	8.7 ± 2.2 (14)	197.6 ± 18.4 (17)
St. George Is.	7.0 ± 3.1 (19)	168.3 ± 20.2 (19)

The analysis of growth rates was not significant and explained only 12% of the observed variation, meaning that growth rates were fairly consistent from year to year and there was no discernable difference in growth rates of Common Murre chicks on the two islands. The analysis of jumping weight was significant, accounting for 46 per cent of the observed variation. Common Murre chicks on St. Paul Island had significantly higher jumping weights than did chicks on St. George Island (Island Effect, $r^2 = .29$, $P = 0.001$). We would expect growth rates and jumping weights to be higher on St. Paul than on St. George, due to the large number of murres on St. George Island, where we would expect, and did find, competitive depression of fledging weight. We do not know why growth rates were similar on the two islands, or how fledging weights could differ given that the chicks on the two islands left the cliffs at the same age.

As diving birds, murres have access to food throughout much of the water column. Under conditions of prey scarcity or unfavorable surface conditions, murres might be expected to have an advantage over surface-feeding seabirds. Murres are not immune to the effects of weather and prey scarcity (Birkhead 1976), but they should be less vulerable to fluctuations than the surface-feeding kittiwakes. Therefore, we would expect productivity or other measures of reproductive success in murres to be less variable on a year to year basis. At the Pribilofs, this appears to be the case, as both species of kittiwakes suffered a poor reproductive year in 1978, while murres were virtually unaffected by the unusually high winds that year.

Thick-billed Murre (*Uria lomvia*)

Numbers

Thick-billed Murres occur throughout the northern oceans (Tuck 1960), compared to the Common Murre, they have a more northerly distribution. The Bering Sea supports an estimated population of 4.9 million murres (Appendix 1). Over 1.6 million nest at the Pribilof Islands (Hickey and Craighead 1977). St. George Island harbors 1.5 million Thick-billed Murres and is the largest murre colony in the Bering Sea, if not the world. The Pribilof population of Thick-billed Murres accounts for 33 per cent of the estimated population in the eastern Bering Sea, and is probably also important in terms of the world population of this species.

Pelagic Distribution

The pelagic distribution of murres is discussed under Common Murres.

Diet

Thick-billed Murres obtain their food by diving, with dives recorded as deep as 73 m (Tuck and Squires 1955). Compared to the Common Murre, it has been suggested that Thick-billed Murres may forage at greater depths (Spring 1968) and at greater distances from their colonies (Spring 1968, Swartz 1966). At the Pribilofs, Thick-billed Murres are freqently found out to 105 km, foraging over both the shelf and the shelf break.

Figure 64 summarizes the major foods used by Thick-billed Murres on the Pribilof Islands. Although fish, particularly walleye pollock, were the principle component of the diet, invertebrates

MAJOR COMPONENTS OF THE DIET OF THICK-BILLED MURRES

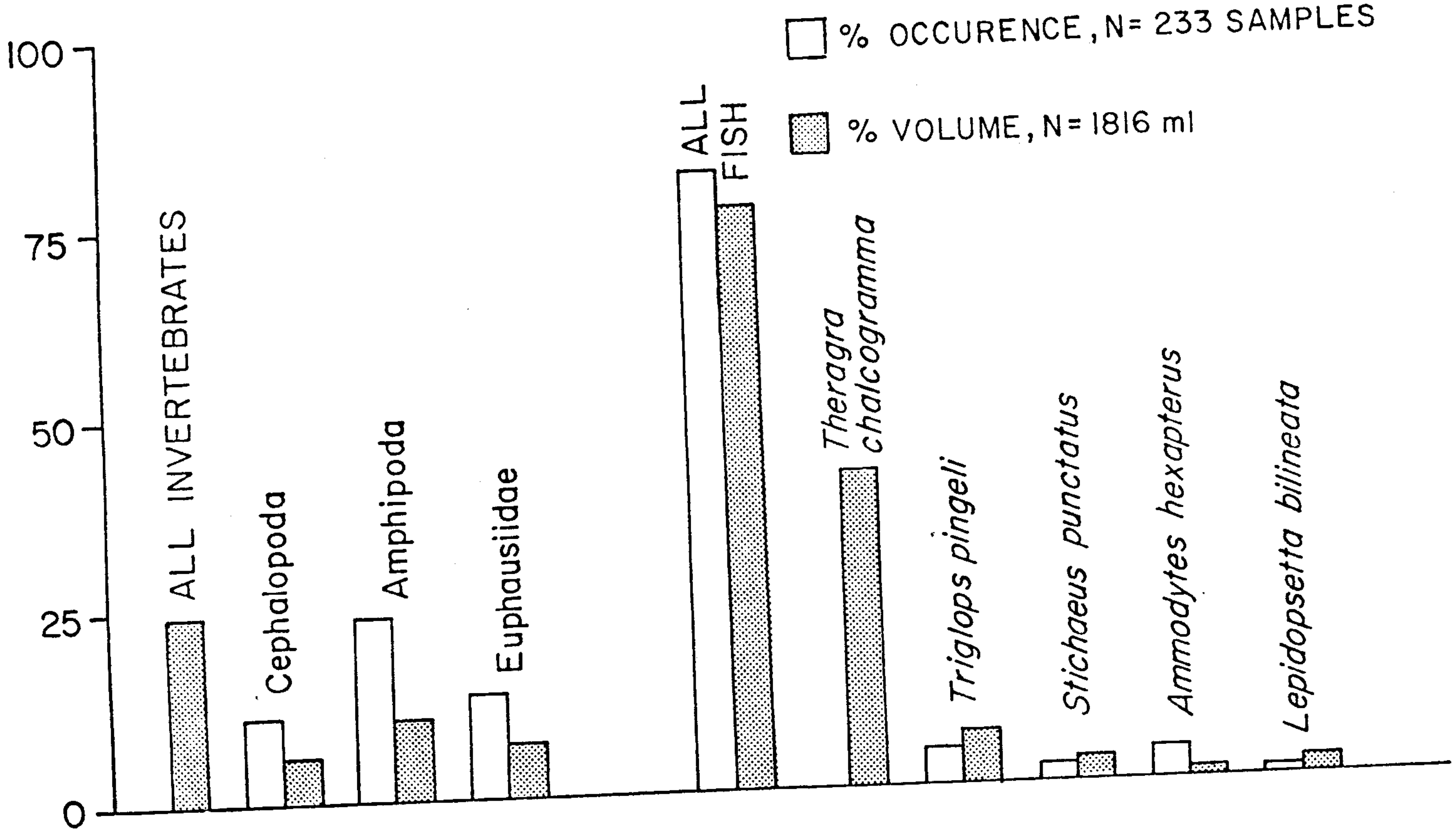


FIGURE 64

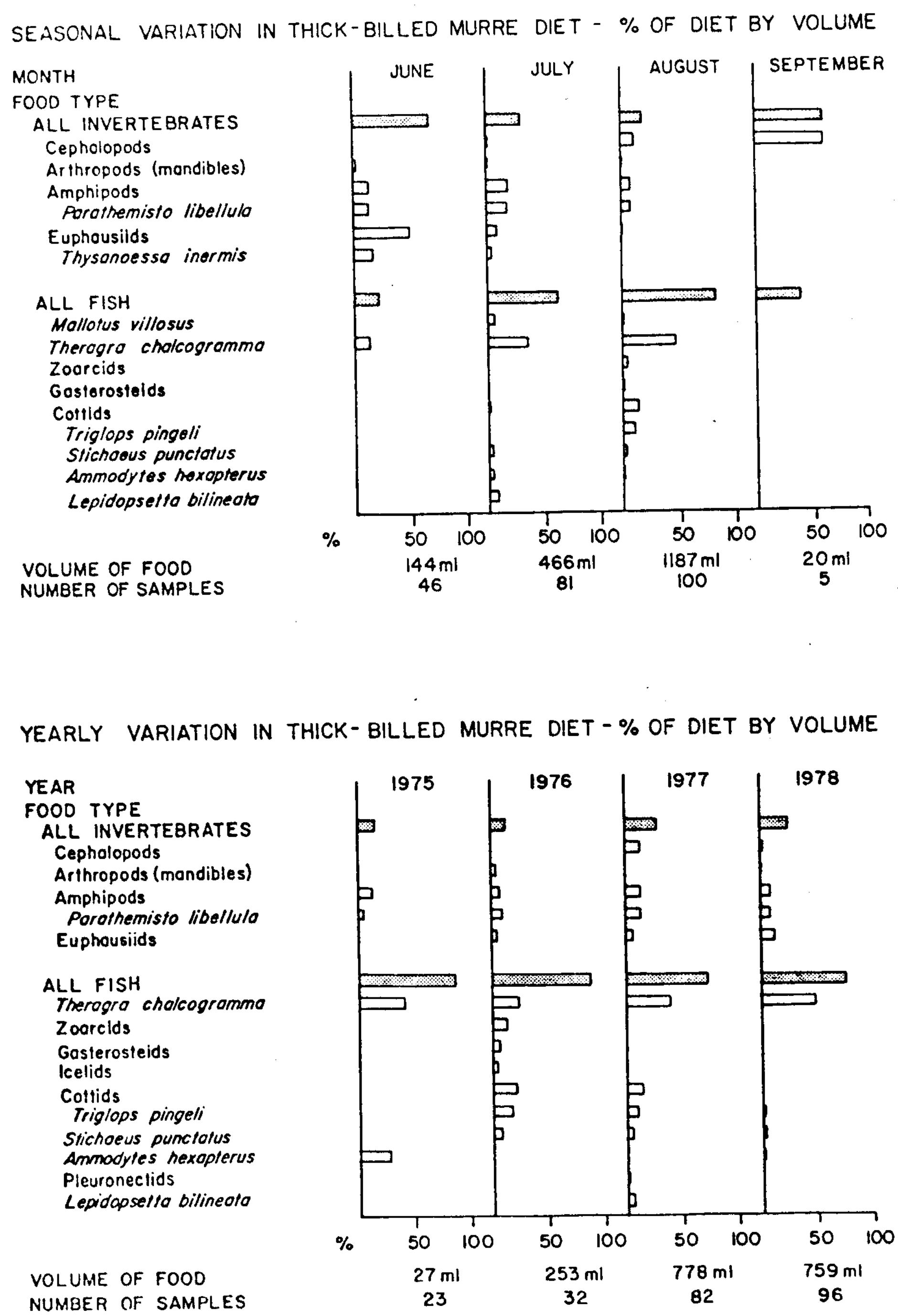

SEASONAL VARIATION IN THICK-BILLED MURRE DIET - % OF DIET BY VOLUME
MONTH
JUNE
JULY
AUGUST
SEPTEMBER
FOOD TYPE
ALL INVERTEBRATES
Cephalopods
Arthropods (mandibles)
Amphipods
Parathemisto libellula
Euphausiids
Thysanoessa inermis
ALL FISH
Mallotus villosus
Theragra chalcogramma
Zoarcids
Gasterosteids
Cottids
Triglops pingeli
Stichaeus punctatus
Ammodytes hexapterus
Lepidopsetta bilineata
%
50
100
VOLUME OF FOOD
NUMBER OF SAMPLES
144 ml
46
466 ml
81
1187 ml
100
20 ml
5
YEARLY VARIATION IN THICK-BILLED MURRE DIET - % OF DIET BY VOLUME
YEAR
1975
1976
1977
1978
FOOD TYPE
ALL INVERTEBRATES
Cephalopods
Arthropods (mandibles)
Amphipods
Parathemisto libellula
Euphausiids
ALL FISH
Theragra chalcogramma
Zoarcids
Gasterosteids
Icelids
Cottids
Triglops pingeli
Stichaeus punctatus
Ammodytes hexapterus
Pleuronectids
Lepidopsetta bilineata
%
50
100
VOLUME OF FOOD
NUMBER OF SAMPLES
27 ml
23
253 ml
32
778 ml
82
759 ml
96

FIGURE 65

also figured significantly. Invertebrates made up roughly one quarter of the diet by volume, with amphipods occurring most frequently (Figure 64). Parathemisto libellula, a shallow-water eastern shelf amphipod, was the predominant invertebrate.

Our data indicate that the diet of Thick-billed Murres may vary seasonally (Figure 65), although the trend was not statistically significant using the median test ($\chi^2 = 3.2$, $P > 0.1$). Early in the breeding season, before eggs are laid and late in the season after chicks had fledged, invertebrates assumed an important role in the diet and fish dropped from more than 70 per cent of the diet by volume to under 30 per cent. The heavy use of fish in late July and August probably represent preferential feeding of fish to murre chicks. Early in the breeding season, the most common invertebrates were euphausiids and amphipods, but cephalopods were the most common late in the season, if our scanty data from this period is representative.

Preble and McAtee (1923), working at the Pribilof Islands found Thick-billed Murre diet to be comprised of 49 per cent fish, 26 per cent squid and 25 per cent crustacea (N = 6). However, the dates of collection were not given, so we do not know whether the differences between our data and theirs represent seasonal differences, chance or a change in diet. Swartz (1966), working at Cape Thompson in the Chukchi Sea, found that Thick-billed murres depended on invertebrates in addition to fish as they did at the Pribilofs. Again the principle fish was a gadid, B. saida. Unlike Thick-billed Murre diet at the Pribilofs, the principle invertebrates used at Cape Thompson were polychaete worms. Searing

(1977) obtained 12 stomachs with food from Thick-billed Murres on St. Lawrence Island which were collected mostly in June. At this time, invertebrates were the primary food source, with the decapod Eualus fabricii and the amphipod Anonyx nugax occurring most frequently. Fish were present in only three of the birds. Apparently, fish is the principal food for Thick-billed Murres in the North Atlantic Ocean and in the Barents Sea. Tuck (1960) reports that invertebrates made up 6 per cent of the diet in the North Atlantic, while in the Barents Sea, invertebrates constituted between 5 and 15 per cent of the diet (Belopol'skii 1957). Ogi and Tsujita (1977), working in the Okshotsk Sea found geographical variation in the diet of Thick-billed Murres. Murres feeding over the continental shelf fed primarily on fish, those feeding in slope areas contained significant amounts of invertebrates in addition to fish, while those feeding over abyssal waters were taking primarily euphausiids.

A comparison of the diets of the two species of murres demonstrates clearly that Thick-billed Murres use more invertebrates than Common Murres. Swartz (1966), Tuck (1960) and Ogi and Tsujita (1977) as well as this study found similar patterns of greater reliance on invertebrates by Thick-billed Murres than by Common Murres. This conclusion agrees with that of Spring (1971) drawn on the basis of morphology. No difference was found by Belopol'skii (1957) in the percentage of invertebrates in the diets of the two murre species in the Barents Sea.

Ogi and Tsujita (1977) examined the stomachs of 163 murres caught in high seas gillnets in the eastern Bering Sea between

June and August in 1970 and 1971. Since these authors did not distinguish between the two murre species, their data is of limited value. However, they did show that of 131 stomachs containing food, 44 per cent contained fish, 26 per cent had euphausiids and 11 per cent had squid. On a per cent weight basis, fish were by far the most important prey taken. Species of fish taken included walleye pollock, sand lance and capelin. Two species of euphausiids were used, _T. raschii_ and _T. longpipes_; _T. inermis_, the important euphausiid at the Pribilofs, was not found.

Nesting

Habitat

Thick-billed Murres nest on narrow ledges on the face of sea cliffs. In the absence of predators, they will also nest on low, rocky islands.

Phenology

Thick-billed Murres were present on the cliffs in large numbers as early as 15 April (Preble and McAtee 1923). The first eggs were laid in mid-June (Tables 20 and 21, Figures 66 and 67); the peak of laying occurred around 27 June (Figures 68 and 69). Eggs were incubated for an average of 34 days. Chicks were first seen around 21 July with the peak of hatching occurring around 30 July. Chicks remained on the cliffs for about 22 days, during this time they grew contour feathers. Chicks jumped off the cliffs in the evening, beginning in mid-August, and were accompanied to sea by a male, presumably the father (Melody Roelke, pers. comm.). The peak of fledging occurred around 2 August (Tables 20 and 21). Females

TABLE 20

Phenology of Thick-billed Murres on St. Paul Island, 1975 - 1978

	1975	1976	1977	1978	OVERALL
FIRST EGG OBSERVED	2 July	17 June	14 June	11 June	20 June
CLUTCH INITIATION $\bar{X}$ - S	-----	30 Jn ± 7.8	24 Jn ± 4.7	25 Jn ± 7.3	26 June
N =		123	109	102	
FIRST CHICK OBSERVED	21 July	22 July	22 July	20 July	21 July
HATCHING $\bar{X}$ - S	29 Jl ± 6.6	31 Jl ± 6.4	30 Jl ± 5.7	26 Jl ± 4.8	29 July
N =	23	83	34	50	
FIRST FLEDGING OBSERVED	12 Aug	14 Aug	11 Aug	11 Aug	12 Aug
FLEDGING $\bar{X}$ - S	28 A ± 8.6	20 A ± 6.0	17 A ± 2.5	18 A ± 4.7	21 Aug
N =	21	55	48	97	

TABLE 21

Phenology of Thick-billed Murres on St. George Island, 1976 - 1978

	1976	1977	1978	OVERALL
FIRST EGG OBSERVED	19 June*	14 June	15 June	16 June
CLUTCH INITIATION $\bar{X} \pm S$	2 Jl $\pm$ 9.8	29 Jn $\pm$ 8.2	23 Jn $\pm$ 4.9	28 June
N =	40	53	50	
FIRST CHICK OBSERVED	23 July	20 July	20 July	21 July
HATCHING $\bar{X} \pm S$	3 A $\pm$ 9.1	5 A $\pm$ 8.3	29 Jl $\pm$ 5.0	2 Aug
N =	26	43	36	
FIRST FLEDGING OBSERVED	7 Aug	10 Aug	9 Aug	9 Aug
FLEDGING $\bar{X} \pm S$	27 A $\pm$ 8.3	25 A $\pm$ 7.5	19 A $\pm$ 7.2	24 Aug
N =	22	23	69	

* back calculated from laying date

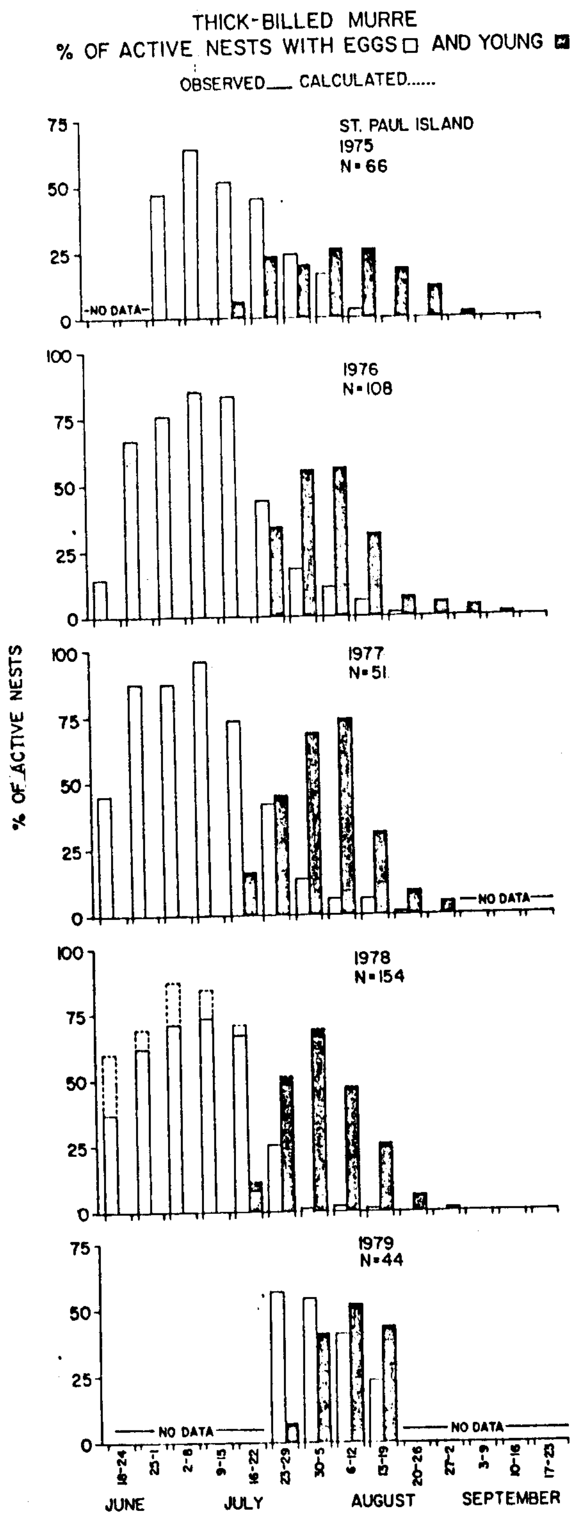
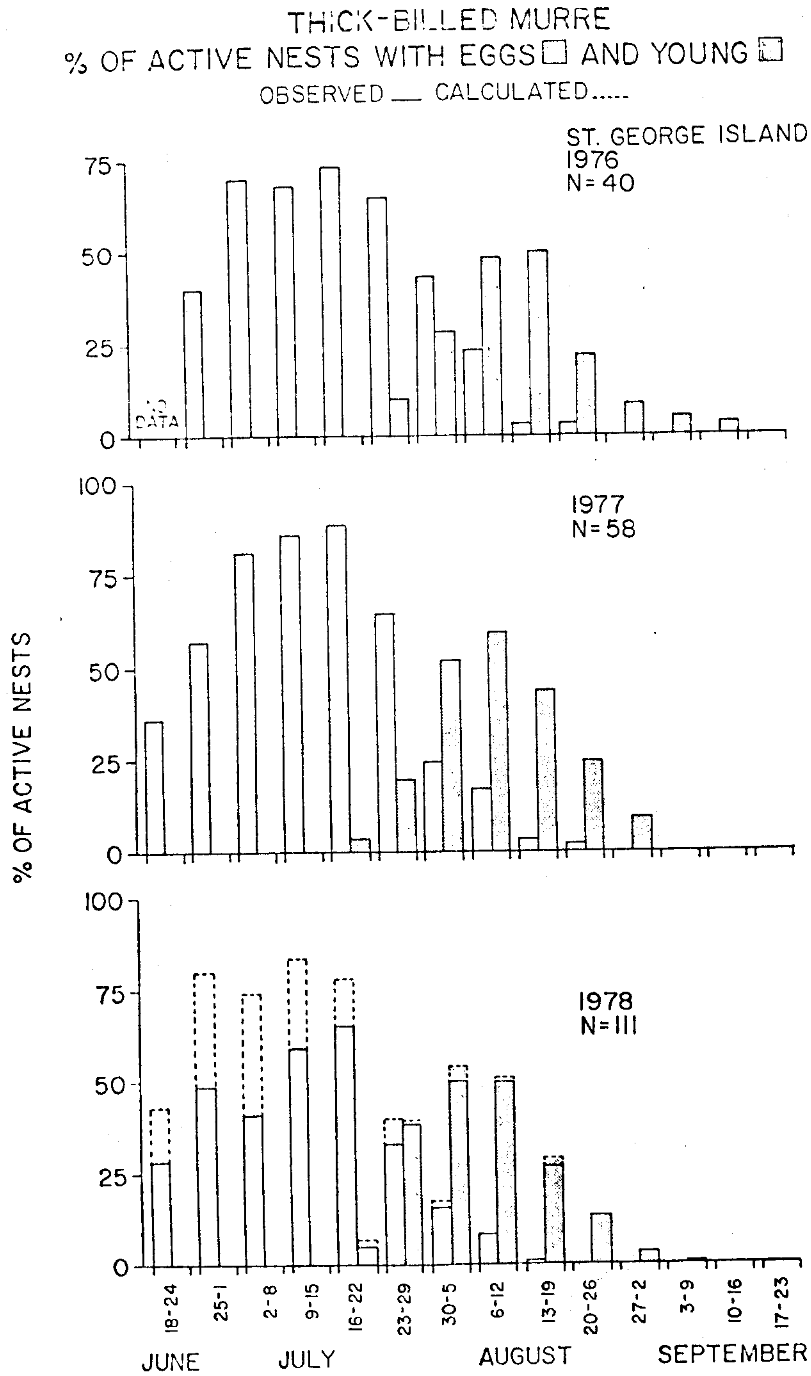

THICK-BILLED MURRE
% OF ACTIVE NESTS WITH EGGS AND YOUNG
OBSERVED___ CALCULATED......
ST. PAUL ISLAND
1975
N=66
NO DATA
1976
N=108
1977
N=51
NO DATA
1978
N=154
1979
N=44
NO DATA
NO DATA
% OF ACTIVE NESTS
0
25
50
75
100
18-24
25-1
2-8
9-15
16-22
23-29
30-5
6-12
13-19
20-26
27-2
3-9
10-16
17-23
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 66



THICK-BILLED MURRE
% OF ACTIVE NESTS WITH EGGS AND YOUNG
OBSERVED ___ CALCULATED.....
ST. GEORGE ISLAND
1976
N=40
NO DATA
1977
N=58
1978
N=111
% OF ACTIVE NESTS
0
25
50
75
100
18-24
25-1
2-8
9-15
16-22
23-29
30-5
6-12
13-19
20-26
27-2
3-9
10-16
17-23
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 67

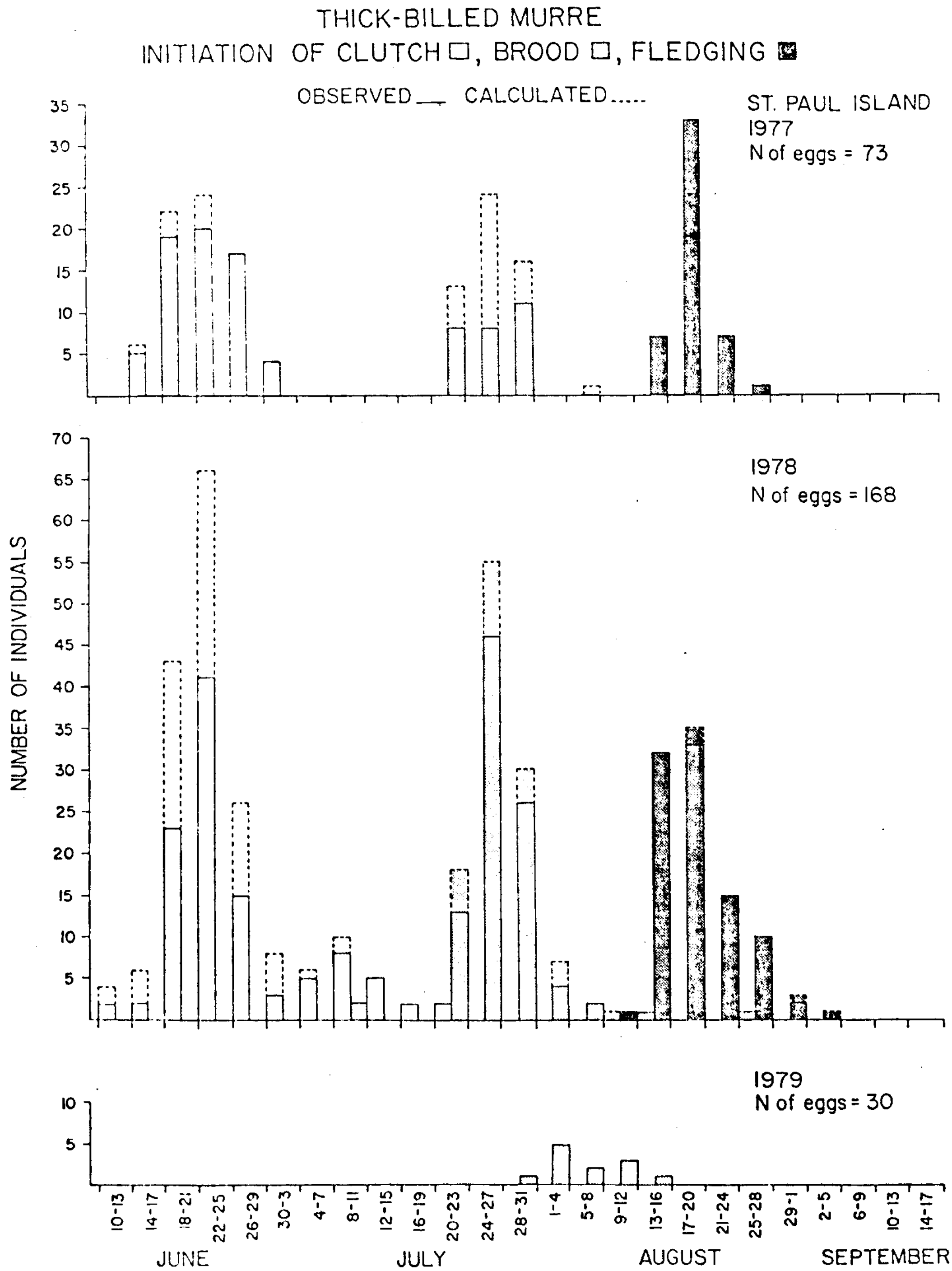

THICK-BILLED MURRE
INITIATION OF CLUTCH ☐, BROOD ☐, FLEDGING ▩
OBSERVED ___ CALCULATED .....
ST. PAUL ISLAND
1977
N of eggs = 73
1978
N of eggs = 168
1979
N of eggs = 30
NUMBER OF INDIVIDUALS
35
30
25
20
15
10
5
70
65
60
55
50
45
40
10-13
14-17
18-21
22-25
26-29
30-3
4-7
8-11
12-15
16-19
20-23
24-27
28-31
1-4
5-8
9-12
13-16
17-20
21-24
25-28
29-1
2-5
6-9
10-13
14-17
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 68

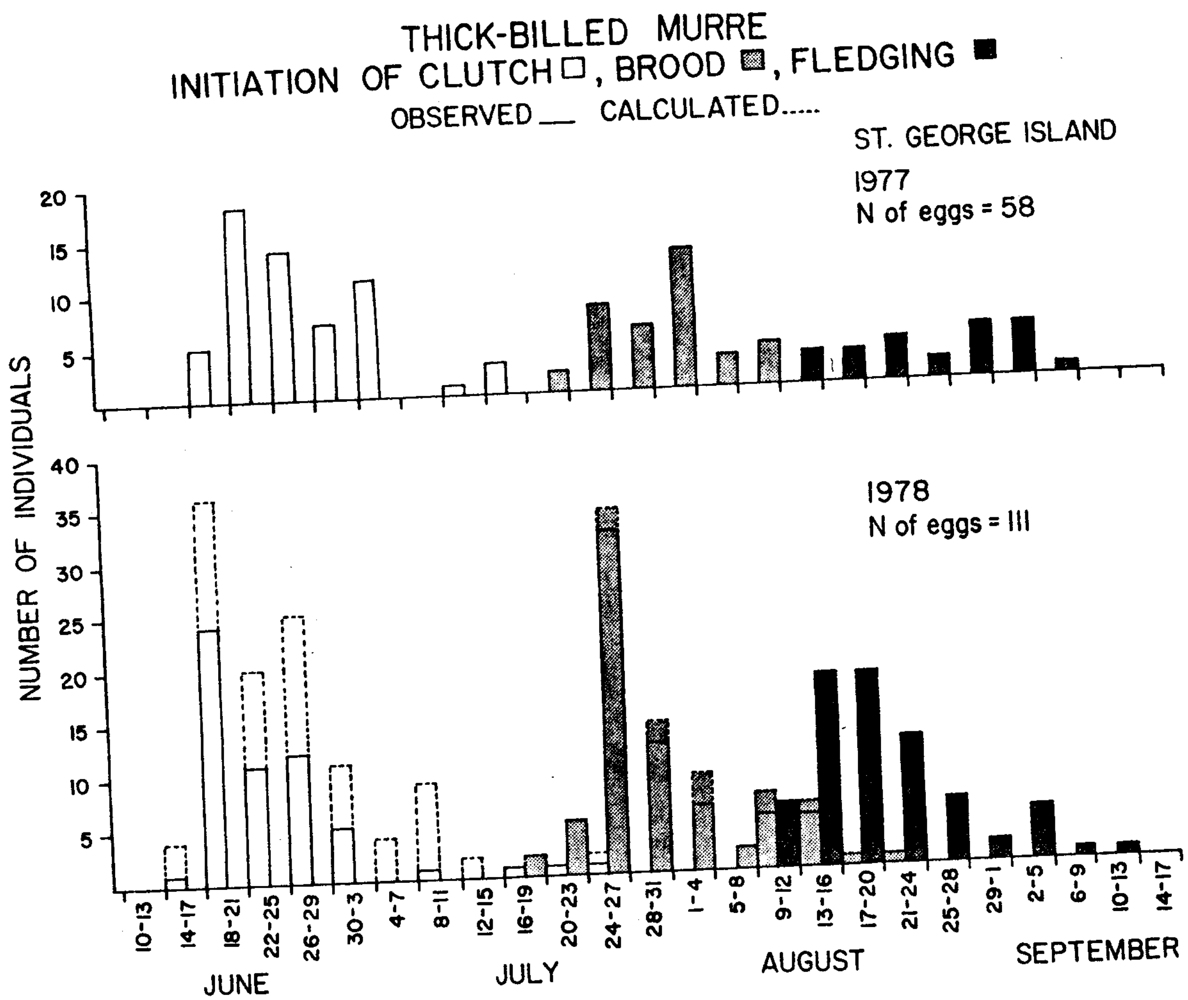

THICK-BILLED MURRE
INITIATION OF CLUTCH □, BROOD ▩, FLEDGING ■
OBSERVED __ CALCULATED.....
ST. GEORGE ISLAND
1977
N of eggs = 58
1978
N of eggs = 111
NUMBER OF INDIVIDUALS
20
15
10
5
40
35
30
25
20
15
10
5
10-13
14-17
18-21
22-25
26-29
30-3
4-7
8-11
12-15
16-19
20-23
24-27
28-31
1-4
5-8
9-12
13-16
17-20
21-24
25-28
29-1
2-5
6-9
10-13
14-17
JUNE
JULY
AUGUST
SEPTEMBER

FIGURE 69

remained on the cliffs until early September (Melody Roelke, pers. comm.) Thick-billed Murres have been found around the Pribilof Islands in small numbers throughout the fall and winter (Preble and McAtee 1923).

Daily Activity Patterns

There are marked daily and seasonal changes in the numbers of Thick-billed Murres present on the cliffs, with maximum numbers found during the egg-laying period (Hickey and Craighead 1977). During incubation, maximum numbers of birds were present on the cliffs around 1400 h (Hickey and Craighead 1977). Melody Roelke, working with known-sex birds on St. Paul Island, found that females were present on the cliffs in the morning during the chick phase; males arrived in mid-afternoon and remained on the cliffs with the young overnight (Figure 70, Roelke and Hunt 1978). Both sexes shared chick brooding and feeding. Table 22 gives trip times for known-sex birds in 1978 (Roelke, in litt.). In 1979, adults frequently returned with fish in less than 20 minutes, although sample sizes were small, trip times seemed to be generally shorter than in previous years (Figure 71), suggesting that food may have been more plentiful in 1979.

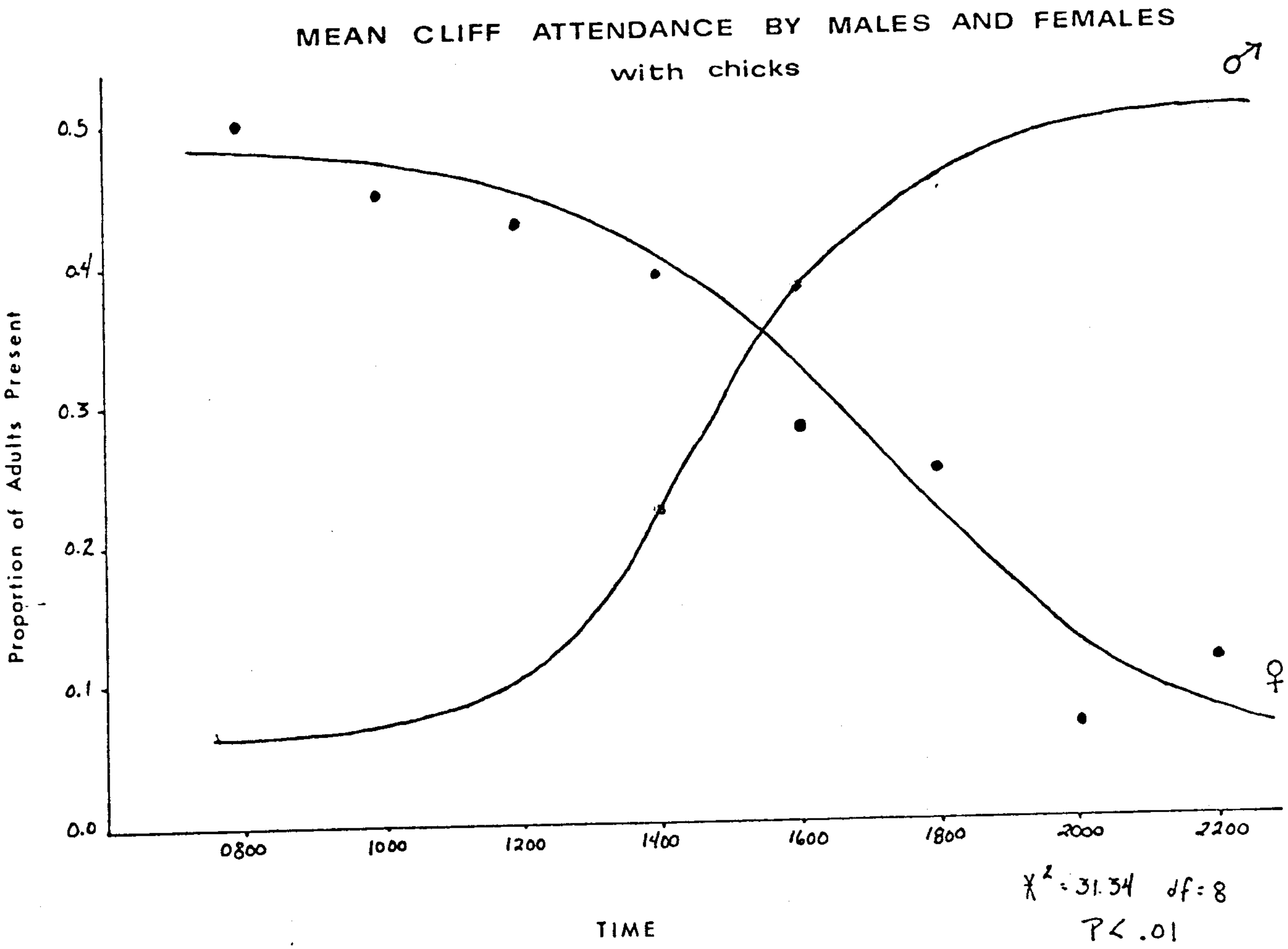

MEAN CLIFF ATTENDANCE BY MALES AND FEMALES
with chicks
♂
♀
Proportion of Adults Present
0.0
0.1
0.2
0.3
0.4
0.5
0800
1000
1200
1400
1600
1800
2000
2200
TIME
χ² = 31.34 df = 8
P < .01

FIGURE 70

THICK-BILLED MURRES - PRIBILOF ISLANDS
LENGTH OF TRIPS AWAY FROM CLIFF

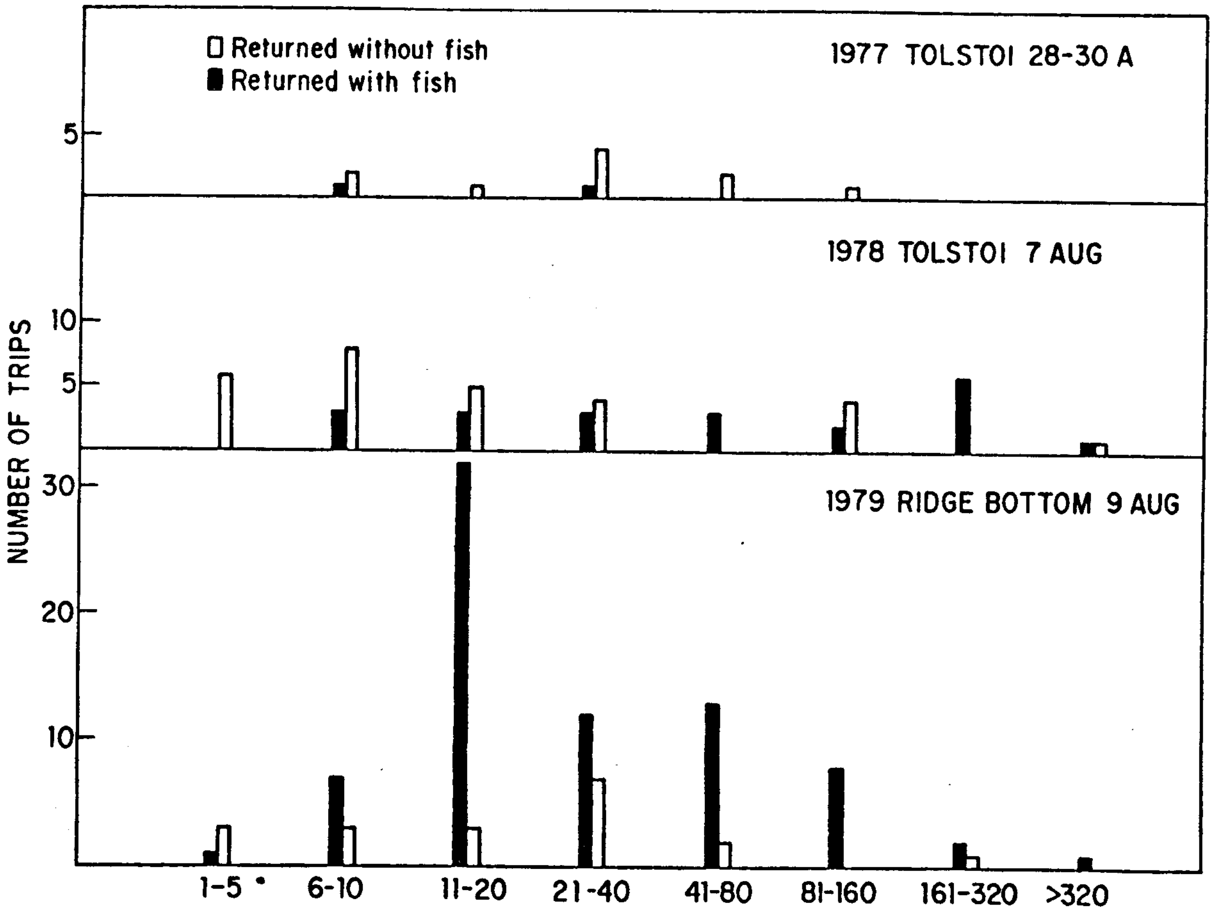


FIGURE 71

TABLE 22

Time spent away from the nest for known-sex Thick-billed Murres at St. Paul Island, 1978 (M. Roelke, 1978, in litt.).

	MALES	FEMALES
TRIP LENGTH (hrs)		
$\bar{X} \pm S$ (N)		
All Trips	3.1 ± 2.2 (16)	1.3 ± 1.5 (26)
Return with fish	2.3 ± 2.3 (12)	2.6 ± 2.1 (10)
Return without fish	none observed	0.4 ± 0.1 (5)

Productivity

We estimate overall productivity of Thick-billed Murres between 0.49 and 0.62 chicks fledged/egg laid for sites studied with a minimum of observer-initiated disturbance (Table 23). The ranges in this estimate reflect the potential for chicks to hatch and disappear from the nesting ledge without our knowing whether the chick successfully fledged. Hence, these ranges reflect minimum and maximum productivity. As with Common Murres, the productivity of sites not studied was probably higher than our estimate. Within our range of error, we are not able to detect any difference in productivity between St. Paul and St. George Islands, or between productivity in the different years studied.

As we found with Common Murres, growth rates and fledging weights may be sensitive indicators of the well-being of Thick-billed Murre colonies. In Thick-billed Murres, we find both yearly differences in growth rates and fledging weights as well as island

TABLE 23

Reproductive success of Thick-billed Murres at minimum-disturbance sites, Pribilof Islands, 1976 - 1978

	ST. PAUL ISLAND			ST. GEORGE ISLAND		OVERALL
	1976	1977	1978	1977	1978	
NUMBER OF EGGS	47	102	114	51	90	
HATCHING SUCCESS (chicks hatched/ egg laid)	.85	.66-.84	.74-.79	.59-.84	.61-.70	.69-.79
FLEDGING SUCCESS (chicks fledged/ chics hatched)	.85	.42-.84	.77-.91	.35-.97	.70-.86	.62-.89
REPRODUCTIVE SUCCESS (chicks fledged/ egg laid)	.72	.35-.62	.61-.68	.29-.57	.49-.52	.49-.62

TABLE 24

Growth Rates and Fledging Weights of Thick-billed Murre Chicks at the Pribilof Islands, 1975 - 1979

	Growth Rate (g/day)	Fledging Weight (g)
1975		
St. Paul Island	14.6 ± 3.3 (6)	215.0 ± 22.3 (6)
St. George Island		
1976		
St. Paul Island	11.7 ± 3.1 (16)	218.6 ± 28.8 (16)
St. George Island	6.0 ± 3.0 (23)	147.8 ± 26.0 (23)
1977		
St. Paul Island	12.2 ± 3.1 (17)	194.6 ± 19.5 (17)
St. George Island	7.9 ± 3.2 (34)	159.9 ± 23.9 (34)
1978		
St. Paul Island	14.8 ± 3.0 (16)	235.0 ± 25.6 (16)
St. George	9.3 ± 2.2 (25)	173.8 ± 21.4 (25)
1979		
St. Paul Island	8.25 ± 2.7 (15)*	

* taken over a shorter interval

differences (Table 24). Fledging weights and growth rates were both lower on St. George Island than St. Paul (Growth rates $r^2 = 0.48$, Island effects $r^2 = 0.38$, $p = 0.0001$, Fledging weight, $r^2 = 0.58$, Island effects $r^2 = 0.48$). Among years, 1976 and 1977 were similar, while 1978 growth rates were higher (growth rates, year effects $r^2 = 0.10$, fledging weights year effects $r^2 = 0.10$). As expected, we see a competitive depression of growth rates and fledging weights on St. George Island, even though chicks on the two islands fledge at the same age. It is interesting that Thick-billed Murres like Common Murres did better in 1978, which was a poor reproductive year for kittiwakes, suggesting, again that food resources were more available to murres in that year.

Parakeet Auklet (*Cyclorrhyncus psittacula*)

Numbers

The distribution of Parakeet Auklets is centered in the Bering Sea. Within this area, their colonies are ubiquitous but generally small, with an estimated population in the eastern Bering Sea of 530,000 (Appendix 1). The Pribilof Islands support 184,000 Parakeet Auklets, approximately 35 per cent of that population, which is probably an important part of the world numbers of this species.

Pelagic Distribution

The pelagic distribution of small auklets is given in Figure 72. Data for Parakeet, Crested and Least Auklets have been combined, as the distribution patterns of these three species are very similar around the Pribilof Islands. Parakeet and Crested Auklets are relatively scarce, when compared to Least Auklets. Data for aerial and shipboard surveys were combined for this analysis. Auklets

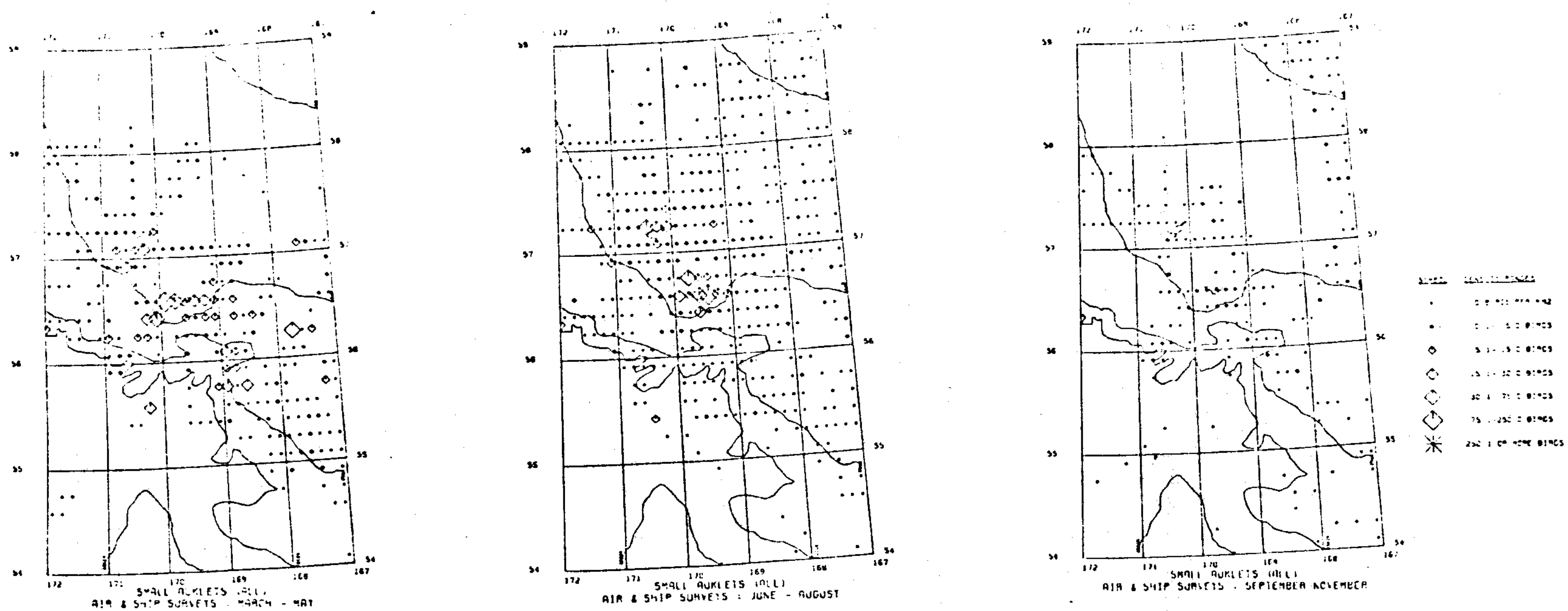
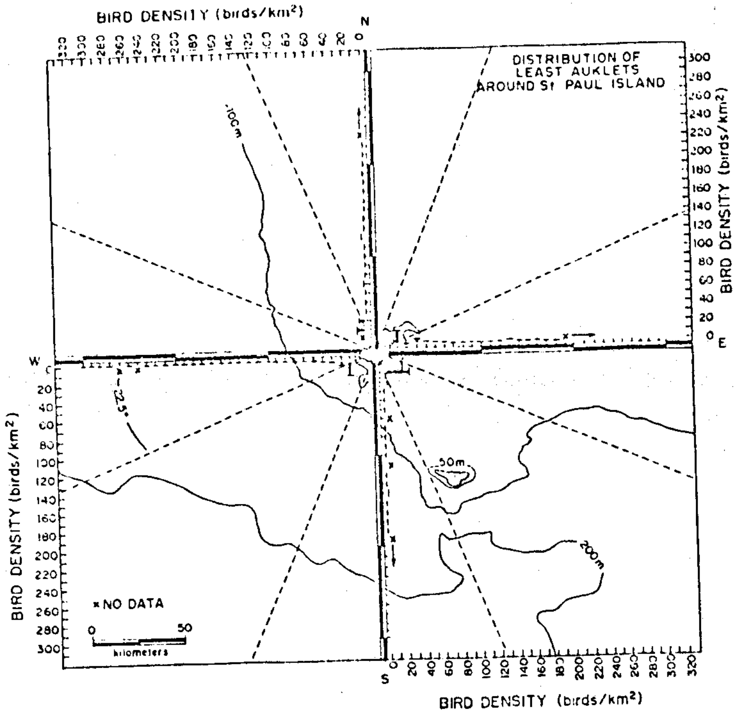

SMALL AUKLETS (ALL)
AIR & SHIP SURVEYS : MARCH - MAY
SMALL AUKLETS (ALL)
AIR & SHIP SURVEYS : JUNE - AUGUST
SMALL AUKLETS (ALL)
AIR & SHIP SURVEYS : SEPTEMBER NOVEMBER

FIGURE 72

were not attracted to ships, and both methods of survey probably underestimated true numbers of small auklets. These small birds are easily overlooked, especially when they are present in small numbers. Auklets were concentrated close to the islands, and since NOAA ships were unable to approach the islands closely, the density of these birds was probably underestimated not only because of their size, but also because of sample distribution.

In spring, small auklets, the majority of which were Least Auklets, were found concentrated in the vicinity of the islands and near the Pribilof Canyon and the shelf break. Small numbers of Parakeet Auklets were seen near the islands, while virtually no Crested Auklets were recorded. In summer, most records of auklets come from waters close to the islands. Only Least Auklets were reported in high concentrations, and again, they occurred in high numbers only close to the islands. Scattered records of all three species occurred away from the islands, but the concentrations of birds along the shelf break found in spring were absent. In fall, our much lighter survey coverage failed to reveal any areas of major concentration of auklets. Rather, scattered birds were seen over the shelf and along the shelf break.

Examination of the histograms of Least Auklet distribution around the islands reinforces the notion that auklets are concentrated near the islands, becoming scarce at even moderate distances from the islands during the breeding season (Figure 73). This conclusion is strongly supported by the zonal analysis (Figure 74), in which large numbers of small auklets were seen within the first zone around each island and very few beyond the 20 km


DISTRIBUTION OF LEAST AUKLETS AROUND St. PAUL ISLAND
BIRD DENSITY (birds/km²)
N
E
S
W
100m
50m
200m
22.5°
× NO DATA
kilometers

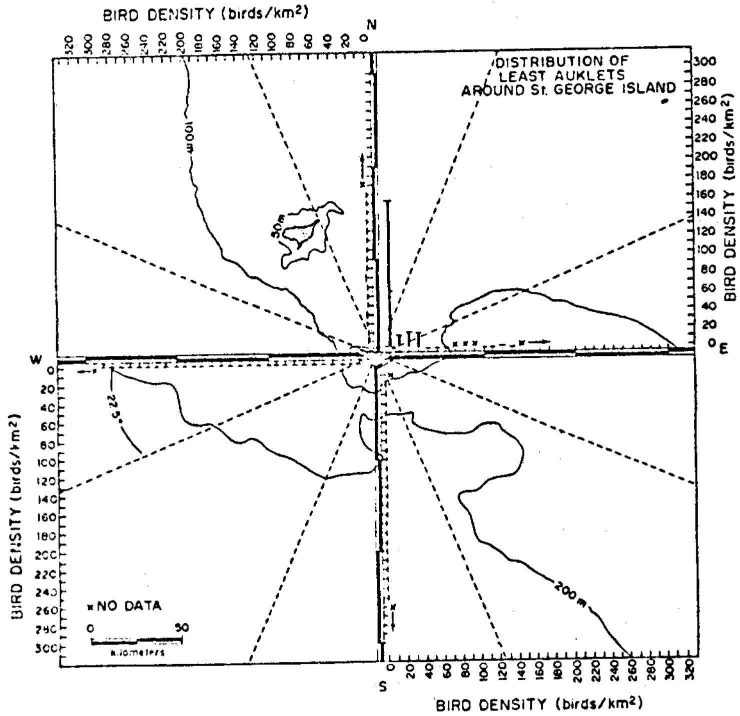
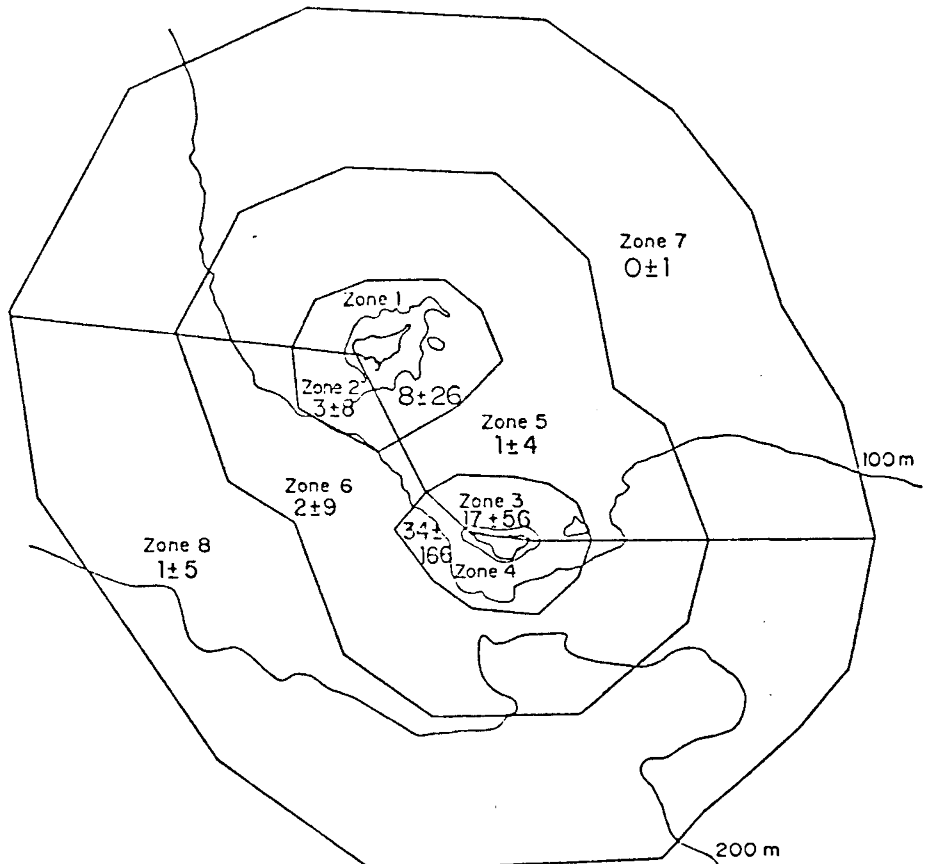

DISTRIBUTION OF LEAST AUKLETS AROUND St. GEORGE ISLAND
BIRD DENSITY (birds/km²)
N
E
S
W
100m
50m
200m
22.5°
× NO DATA
kilometers

FIGURE 73

Distribution of Small Auklets by zones
near the Pribilof Islands 1975-1979 ($\bar{x} \pm s$)*



ANOVA across all zones, $F_{7,2154} = 10.870$, $P = 0.00001$

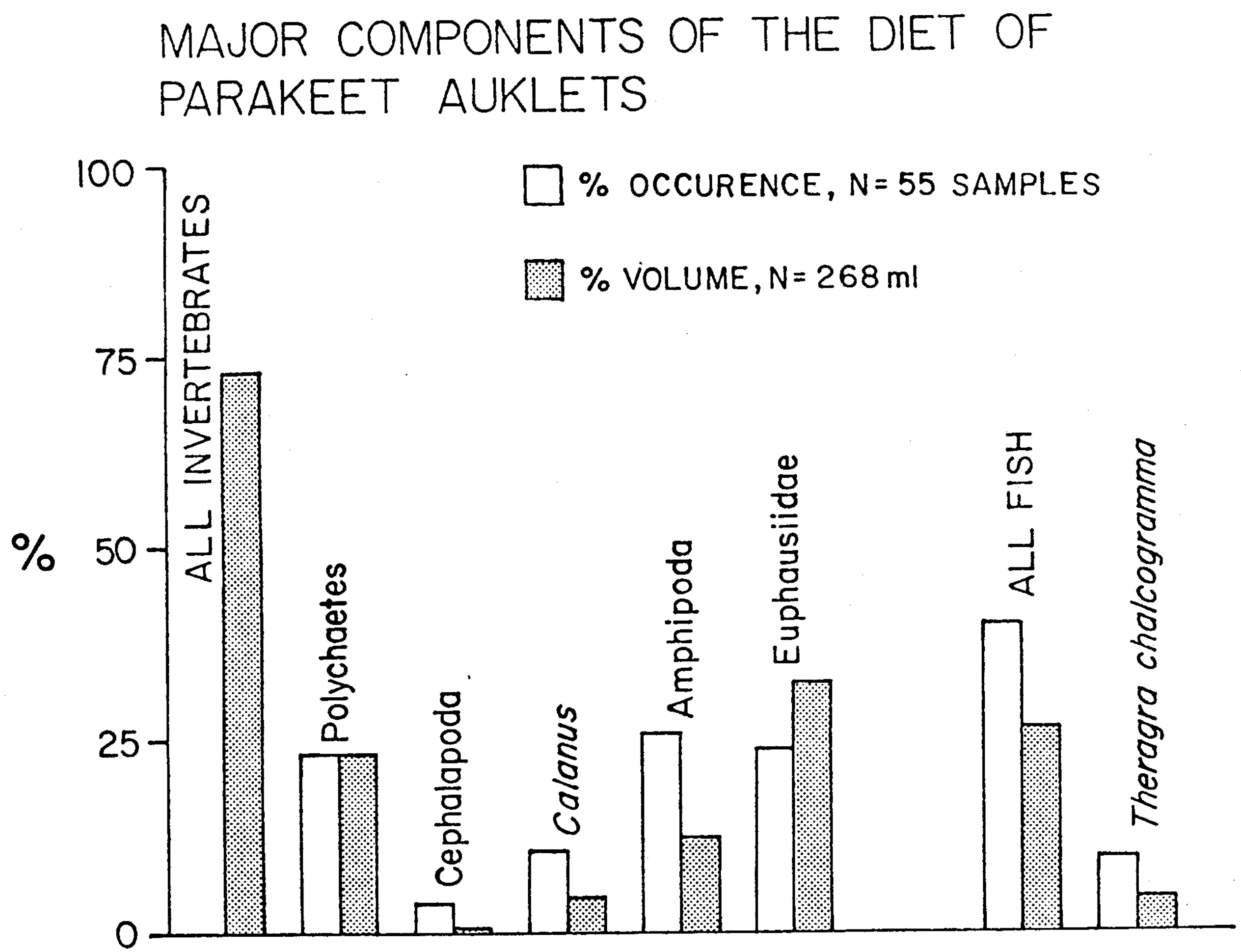
Homogeneous subsets by modified LSD Procedure, $\alpha = 0.05$

Subset 1 Zones 7,8,5,6,2,1,3

Subset 2 Zones 3,4

*rounded to whole numbers

FIGURE 74



MAJOR COMPONENTS OF THE DIET OF PARAKEET AUKLETS
% OCCURENCE, N=55 SAMPLES
% VOLUME, N=268 ml
100
75
50
25
0
%
ALL INVERTEBRATES
Polychaetes
Cephalapoda
Calanus
Amphipoda
Euphausiidae
ALL FISH
Theragra chalcogramma

FIGURE 75

ring. Concentrations, as expected, were much greater around St. George Island (Modified LSD Procedure, $P < 0.05$).

Diet

Figure 75 summarizes the most important foods used by Parakeet Auklets on the Pribilof Islands between 1975 and 1978. These results can be compared with those of Bédard (1969a) for St. Lawrence Island, the only other Bering Sea location for which extensive data exist on the food habits of these small auklets. Data from the Pribilof Islands were gathered primarily during the chick phase and represent gular pouch loads being brought to chicks.

At the Pribilof Islands, Parakeet Auklets used euphausiids and polychaetes extensively and made moderate use of fish larvae and amphipods. The euphausiids, T. inermis and T. raschii, were the primary prey species, while nereid worms (polychaetes) were of secondary importance (Figure 75). Pollock was the most important species of fish in the Parakeet Auklet diet. However, fish were less important than invertebrates, amounting to only 26 per cent of the diet by volume.

Bédard (1969a), at St. Lawrence Island found Parakeet Auklets to be feeding generalists, taking a wide variety of midwater and epibenthic prey, particularly calanoid copepods, euphausiids and amphipods. On St. Lawrence Island, fish were only a minor component of the diet, although Parakeet Auklets there consumed more fish than Least and Crested Auklets. Comparison of data from the Pribilof Islands and St. Lawrence Island show some important features of the food habits of Parakeet Auklets. At both sites, Parakeet Auklets take a wide variety of plankton, invertebrates and fish larvae, allowing them to exploit both neritic and oceanic water masses. This broad diet, undoubtably accounts for their very widespread distribution throughout the Bering Sea (Hunt et al. 1980b).

<u>Nesting</u>

Habitat

Parakeet Auklets nest in crevices and small caves in coastal cliffs or in crevices between boulders in talus slopes or boulder beaches. They nest in scattered pairs and are the least colonial of the Bering Sea auklets.

Phenology

Parakeet Auklets are present on the Pribilof Islands from April to the last week in August. Our phenology estimates suffer from a small sample size due to the limited number of accessible nests. The following information is based on 6 nests found in 1976. Hatching occurred in the last week of July and we extrapolated back from hatching dates to estimate that egg-laying probably occurred during the third week of June, based on an incubation period of 35 days (Sealy and Bédard 1973). Chicks fledged after about a month in the nest and apparently were independent after fledging.

Daily Activity Patterns

Colony attendance patterns are quite variable in this species. Hickey and Craighead (1977), working on St. George Island, found auklet numbers were low in the morning, with peak numbers occurring between 1500 and 2300 h, at least in August when the watches were conducted. On St. Paul Island, we found low numbers in the morning, with maximum numbers were found between 1100 and 1700 h during a watch on 19 July. On 26 July, peak numbers did not occur until 1500 h. Later in the season, on 13 August, maximum numbers of auklets on St. Paul were found at 2000 h.

Productivity

In the 6 nests studied in 1976, four chicks fledged. Given the inaccessibility of Parakeet Auklet nests to observers and to predators, we could expect productivity to be relatively high even though they lay a single egg. Two of the chicks in our sample were weighed and growth rates of 11.0 and 10.6 grams/day were obtained. Fledging weight for one chick was 295 grams.

Crested Auklet (Aethia cristatella)

Numbers

The breeding distribution of Crested Auklets is centered in the Aleutian Islands and Bering Sea. They nest on "oceanic" islands, typically in large colonies. An estimated 1.2 million Crested Auklets occur in the eastern Bering Sea (Appendix 1). The Pribilof Islands support a small colony of 34,000 Crested Auklets, which is an insignificant number when compared to the large colonies on St. Lawrence Island and the Diomedes.

Pelagic Distribution

The pelagic distribution of Crested Auklets is discussed along with that of the other species of auklets under the pelagic distribution of Parakeet Auklets.

Diet

Crested Auklets obtain their prey by diving, perhaps to 40 m (Bédard 1969a). At the Pribilofs, they are found foraging within a few kilometers of their colonies. Here, they specialize on euphausiids, which constitute over 68 per cent of the diet by volume (Figure 76). The most important species in the diet were the euphasiid T. inermis and the amphipod P. libellula. Our few samples (N = 20) were mostly taken while auklets had chicks and represent stomach and gular pouch samples.

Comparative data for this species are available from the studies of Bédard (1969a) and Searing (1977) on St. Lawrence Island. Bédard (1969a) found Crested Auklets specialized on Thysanoessa, as we found at the Pribilofs. In August, 1976, Searing (1977) collected a small number of Crested Auklets and found calanoid copepods predominating in the diet with little use of euphausiids. Although Bédard (1969a) found moderate use of calanoid copepods, they were conspicuously absent from the diet of Crested Auklets on the Pribilofs. On St. Lawrence Island, there appear to be substantial seasonal and yearly shifts in the species composition of the diet of Crested Auklets (Bédard 1969a, Searing 1977). The differences between our findings on the Pribilofs and data from St. Lawrence Island may reflect seasonal or yearly differences, or they may represent real regional variations in prey availability. More data are needed on the diet of Crested Auklets at the Pribilofs before conclusions can be drawn.

Nesting

Habitat

Crested Auklets nest in crevices and interstices between boulders in talus slopes and in boulder beaches and less frequently in crevices in coastal cliffs.

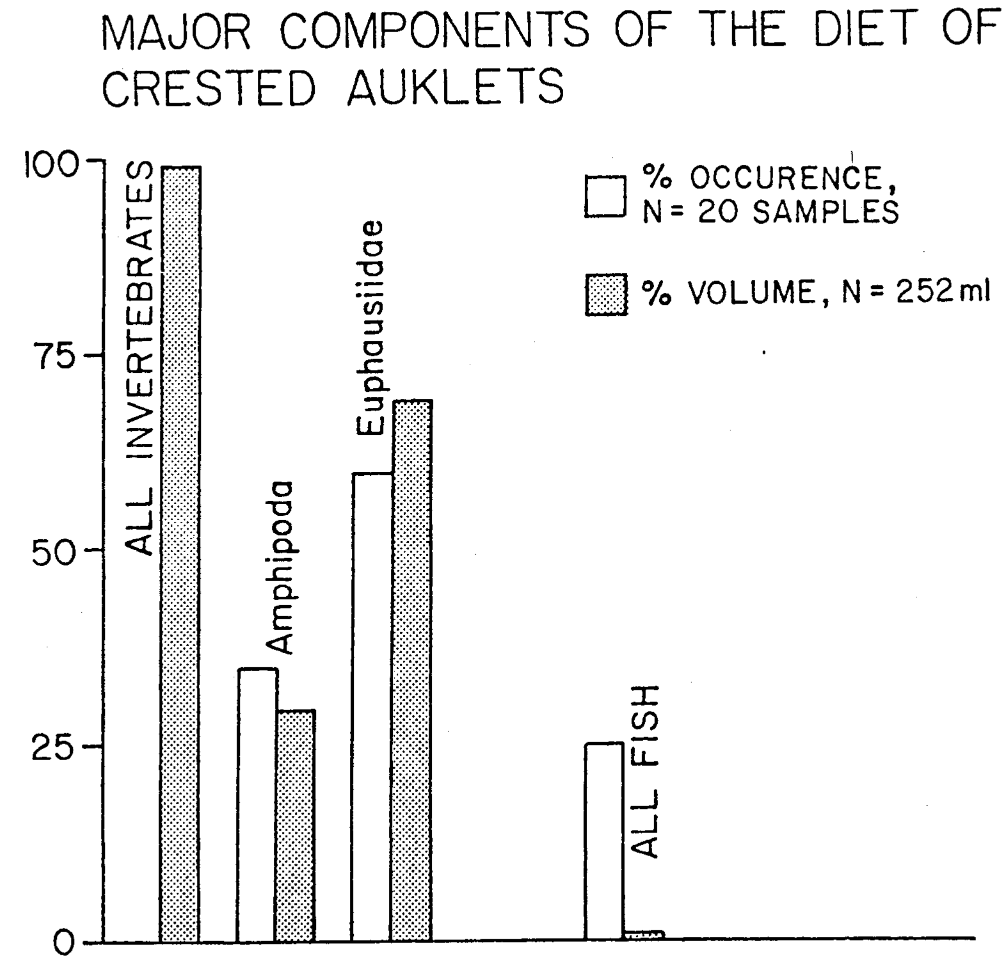

MAJOR COMPONENTS OF THE DIET OF CRESTED AUKLETS
100
75
50
25
0
ALL INVERTEBRATES
Amphipoda
Euphausiidae
ALL FISH
% OCCURENCE, N= 20 SAMPLES
% VOLUME, N = 252 ml

FIGURE 76

Phenology

Crested Auklets are present on the Pribilofs from April to the middle of August. We have no information on the phenology of this species because no nests were accessible. The behavior of this species prevented us from mist-netting large numbers and following phenology indirectly through changes in brood patches, etc.

Crested Auklets were present on the colony in large numbers at mid-day or late afternoon. The exact timing of peak numbers is variable; in four counts during July and August, maximum numbers were found as early as 1200 h and as late as 1900 h.

Productivity

The nests of Crested Auklets were equally inaccessible to predators as they were to us. Although Crested Auklets lay a single egg we expect that their productivity is relatively high because they are protected from predators and disturbance at the nest.

Least Auklet (Aethia pusilla)

Numbers

Least Auklets are endemic to the Bering Sea. They nest in the western Aleutian Islands as well as on the "oceanic" Bering Sea Islands. The population of Least Auklets in the eastern Bering Sea is estimated at 4.5 million (Appendix 1); this estimate does not include the vast numbers of Least Auklets that nest on Big Diomede Island, which lies in Russian waters. The Pribilof Islands support a population of 273,000 Least Auklets (Hickey and Craighead 1977) which accounts for only 6 per cent of the population in the eastern Bering Sea. The Least Auklet colonies on the Pribilofs, although large, are probably insignificant in terms of the Bering Sea and total numbers of this species.

Pelagic Distribution

The pelagic distribution of Least Auklets is discussed along with that of other auklets under the pelagic distribution of Parakeet Auklets.

Diet

At the Pribilof Islands, Least Auklets are generally found foraging within a few kilometers of the islands. They dive to obtain their prey which consists primarily of copepods and amphipods, at least when feeding chicks (Figure 77).

Comparative data for the diet of this species are available from St. Lawrence Island (Bédard 1969a, Searing 1977). Our data closely agree with those of Bédard (1969a) and Searing (1977) for the chick phase. At this stage in the reproductive cycle Least Auklets specialize on calanoid copepods. Apparently, the auklet colonies on the Pribilofs and St. Lawrence Islands depend on the same copepod, *Calanus marshallae* (Bédards's *C. finmarchicus*, Frost 1974). Our data suggest that adults may feed more on euphausiids for themselves, while preferentially feeding their young *Calanus*.

Bédard (1969a) found seasonal shifts in the prey taken by Least Auklets. Early in the breeding season, the auklets used a wide variety of invertebrates, but in July and August, when they had chicks, they switched to monophagy. Unfortunately, we do not have data on Least Auklet diets early in the season.

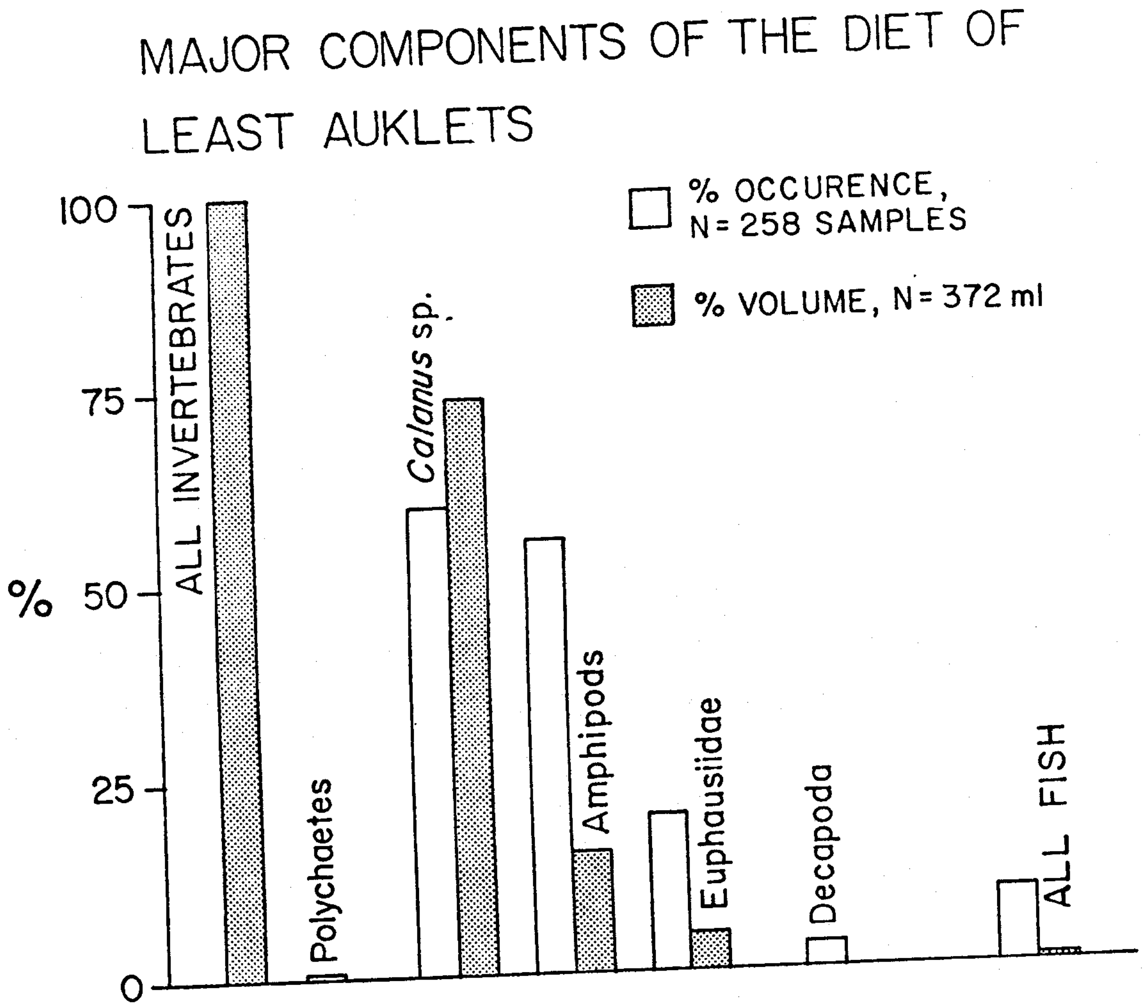

MAJOR COMPONENTS OF THE DIET OF LEAST AUKLETS
% OCCURENCE, N = 258 SAMPLES
% VOLUME, N = 372 ml
%
100
75
50
25
0
ALL INVERTEBRATES
Polychaetes
Calanus sp.
Amphipods
Euphausiidae
Decapoda
ALL FISH

FIGURE 77

This information would be interesting to have, since we have hypothesized (Hunt et al. 1980b) that the auklets on St. Lawrence Island depend on the arrival of Calanus carried on currents from the Bering Slope region. If this were the case, we would expect Pribilof Auklets to show heavy use of Calanus early in the breeding seasons since these colonies are very close to the supposed source of the Calanus.

Nesting

Habitat

Least Auklets nest in crevices in talus slopes and boulder beaches and in cliff faces. On St. Paul Island, they nest in dense colonies among the boulders below the surface of three rocky barrier beaches (East Landing, Antone Lake, Salt Lagoon); others nest in the rocky rubble at the base of cliffs or in small holes in the cliff face. On St. George Island, there are over a quarter of a million Least Auklets. Half of these nest in an inland talus slope.

Phenology

Least Auklets are present on the Pribilof Islands from mid-April until the last week in August. We infer from the presence of brood patches on birds collected in mist-nets, that the first eggs are laid in early June (Figure 78). Incubation in Least Auklets lasts approximately 31 days (Sealy 1968). During the second week of July, birds captured in mist-nets had full gular pouches, an indication that they were bringing food back for their chicks. Chicks fledge at about 30 days of age, and most chicks have fledged by the middle of August. After the last week of August, Least Auklets are uncommon on the

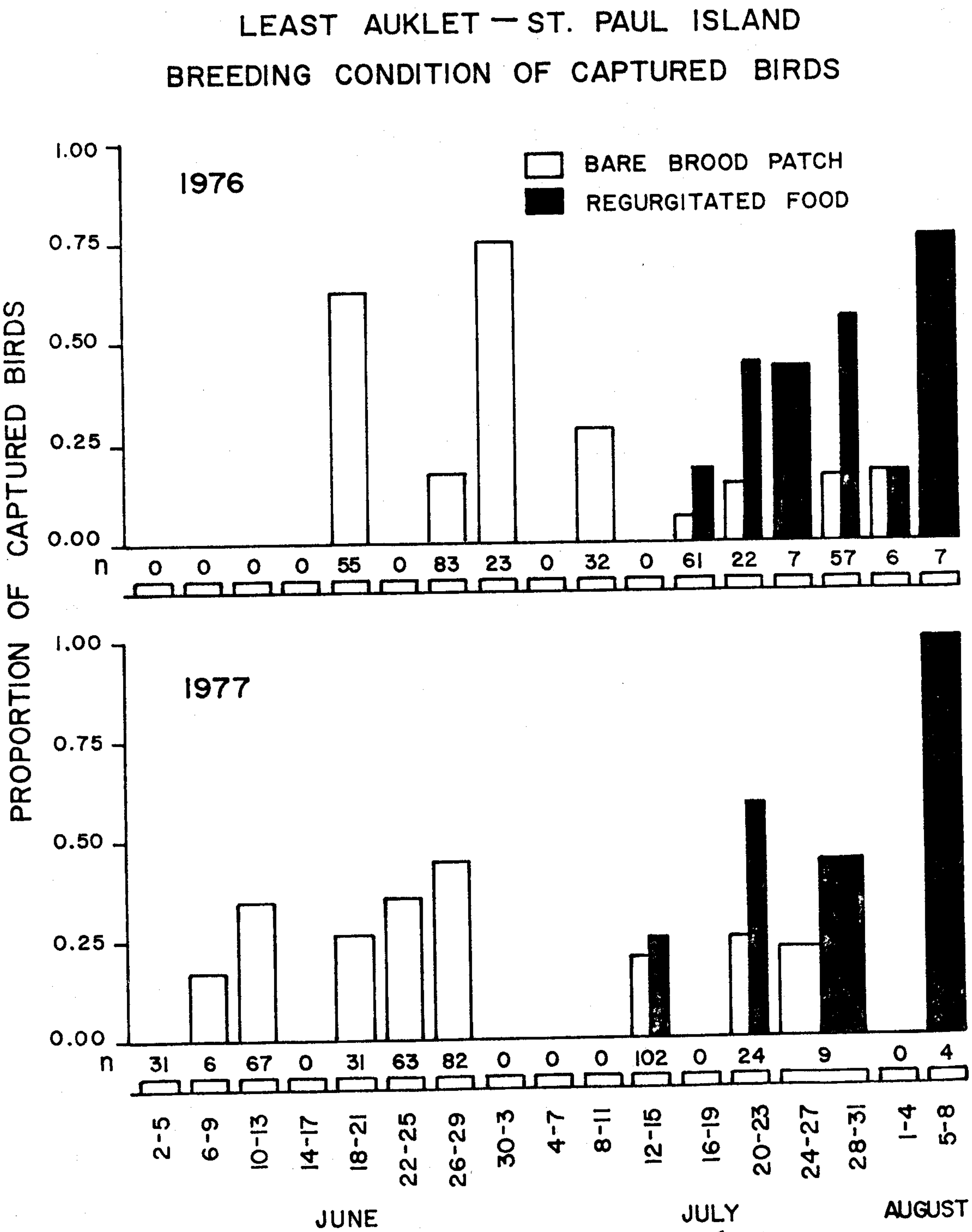

LEAST AUKLET — ST. PAUL ISLAND
BREEDING CONDITION OF CAPTURED BIRDS
PROPORTION OF CAPTURED BIRDS
1976
BARE BROOD PATCH
REGURGITATED FOOD
1.00
0.75
0.50
0.25
0.00
n
0 0 0 0 55 0 83 23 0 32 0 61 22 7 57 6 7
1977
31 6 67 0 31 63 82 0 0 0 102 0 24 9 0 4
2-5 6-9 10-13 14-17 18-21 22-25 26-29 30-3 4-7 8-11 12-15 16-19 20-23 24-27 28-31 1-4 5-8
JUNE
JULY
AUGUST

FIGURE 78

water close by the Pribilofs, although a few late breeders may remain into early September.

Daily Activity Patterns

In July, Least Auklets were present on the beaches in maximum numbers at 1300 and 2100 h. This bimodal pattern of attendance peaks was found consistently throughout July but broke down in August, at which time attendance patterns became quite variable. Because of the inaccessibility of nests we were not able to investigate nest attendance patterns.

Productivity

We were unable to obtain any information on productivity of Least Auklets due to the inaccessibility of their nests. Although they lay a single egg, we would expect Least Auklets to have fairly high productivity, because their nests are inaccessible to predators, with the exception of microtine rodents. Microtine rodents are a problem on St. Lawrence Island, and many Least Auklets chicks are lost to them (Sealy and Bédard 1973). On the Pribilofs, the only possible predators are the St. Paul Island shrew (*Sorex pribilofensis*) and the Black-footed Lemming at St. George Island (*Lemmus nigripes*). We have no data on the impact, if any, of these species on nesting auklets. As with productivity, the inaccessibility of nests precluded the gathering of data on chick growth.

Horned Puffin (*Fratercula corniculata*)

Numbers

Horned Puffins occur throughout the Bering Sea, southern Chukchi Sea and Gulf of Alaska. The eastern Bering Sea supports an estimated population of 200,000 (Appendix 1). The Pribilof Islands have a population of 32,400 Horned Puffins (Hickey and Craighead 1977), 28,000 of which nest on St. George Island. The Pribilof population of Horned Puffins accounts for approximately 16 per cent of the population on the eastern Bering Sea, but is probably insignificant in terms of world numbers.

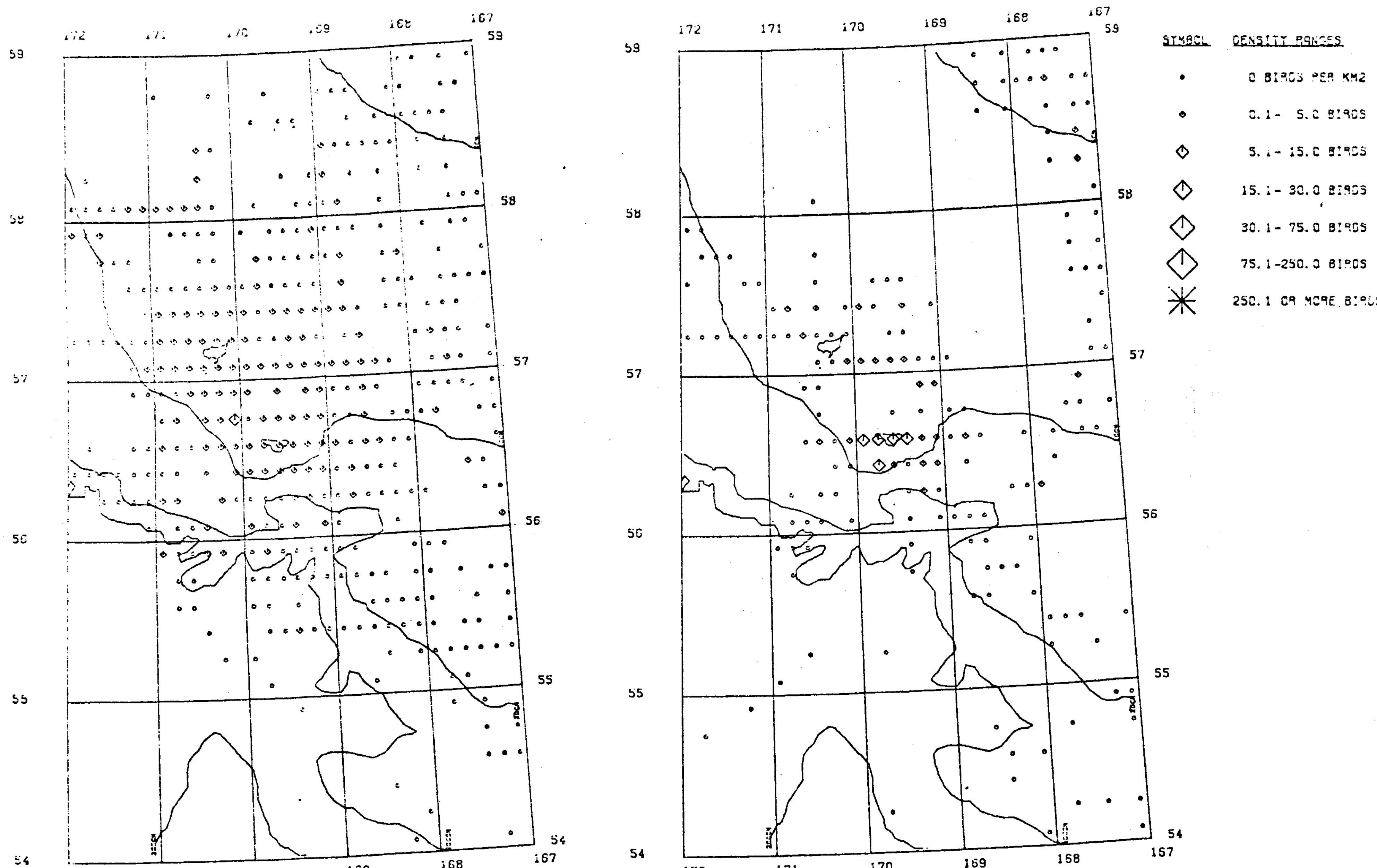
Pelagic Distribution

The pelagic distribution of Horned Puffins in the vicinity of the Pribilofs is given in Figure 79. Air and ship surveys are combined to give the best possible coverage of this relatively scarce species. No figure is presented for spring, as virtually no Horned Puffins were seen in the study area at this season.

In summer, Horned Puffins were spread fairly evenly over the water to a distance of 40 or more km from the islands. In the fall our surveys suggest that the birds are more concentrated near the islands than in summer. Examination of the histograms of distribution around the islands provided little information of value due to the uniform and extremely low densities of this species around the islands. Therefore, histograms for this species are not included. Zonal analysis of Horned Puffin distribution (Figure 80) show somewhat elevated densities near the breeding islands, and extremely low densities away from the islands (Modified LSD Procedure, $P < 0.05$). Horned Puffins appear to spend relatively more time near the islands than Tufted Puffins.

Diet

Horned Puffins obtain their prey by pursuit diving. During the breeding season, they forage near their colonies, often within 2 km of shore (Wehle, in prep.).

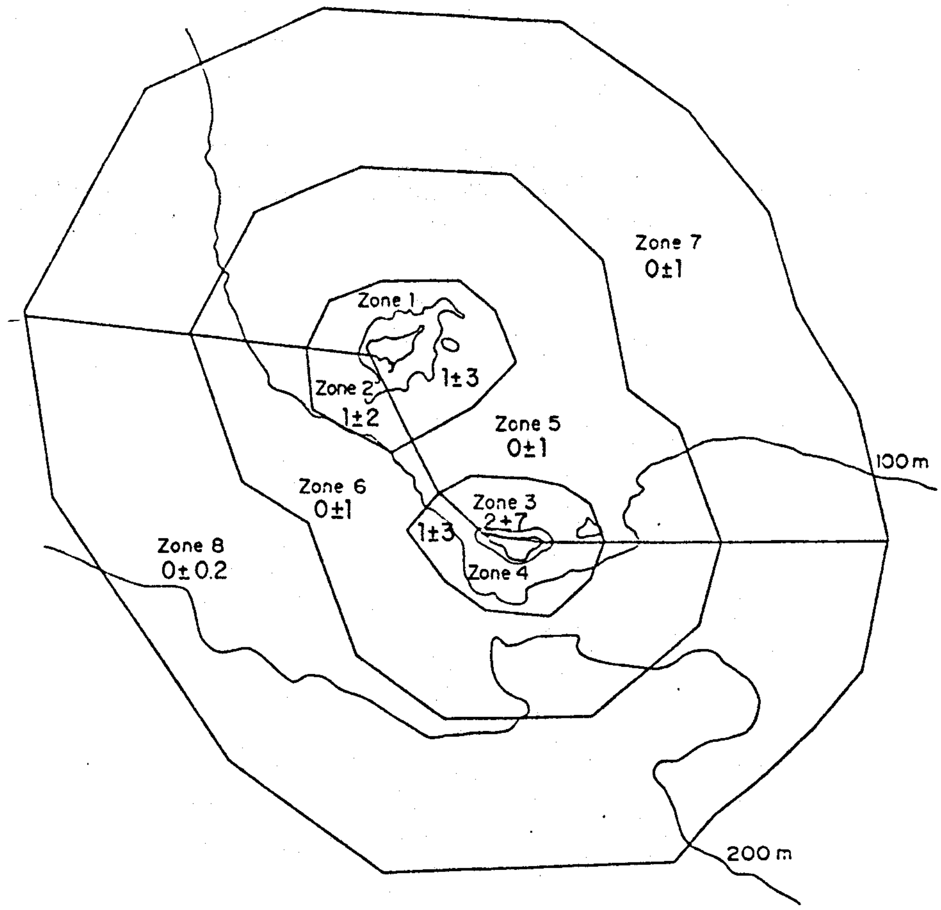


HORNED PUFFIN
AIR & SHIP SURVEYS : JUNE - AUGUST

HORNED PUFFIN
AIR & SHIP SURVEYS : SEPTEMBER-NOVEMBER

FIGURE 79

Distribution of Horned Puffins by zones
near the Pribilof Islands, 1975-1979 ($\bar{x} \pm s$)*



ANOVA across all zones, $F_{7,2152} = 24.861$, $P = 0.00001$

Homogeneous subsets by modified LSD Procedure, $\alpha = 0.05$

Subset 1 Zones 8,7,6,5,1,2
Subset 2 Zones 1,2,4
Subset 3 Zone 3

*rounded to whole numbers

FIGURE 80

Figure 81 summarizes the foods used by Horned Puffins at the Pribilof Islands between 1975 and 1978. Fish were the principal food source, with shallow-water, subtidal forms predominating. In addition, Horned Puffins made moderate use of a variety of invertebrates. Preble and McAtee (1923) reported the use of isopods at the Pribilofs in their sample of a single Horned Puffin. We found evidence that young are preferentially fed fish, particularly Hexagrammos and Ammodytes. We frequently observed Horned Puffins returning to their nests carrying squid, although squid did not occur in our recovered bill-loads.

Swartz (1966) provided data on eight full stomachs of Horned Puffins collected at Cape Thompson in the Chukchi Sea. Fish were found in six of the stomachs and invertebrates in five. Of the fish, gadids were most common, and polychaetes dominated the invertebrates. Given the small sample size, it is difficult to judge the significance of these data, but Horned Puffin diets at Cape Thompson appear less dominated by inshore, subtidal forms than Horned Puffins diet at the Pribilofs.

Nesting

Habitat

On the Pribilof Islands, Horned Puffins nest in natural rock crevices in cliff faces and secondarily in talus and boulder rubbles beneath cliffs. Horned Puffins nest in association with other cliff and crevice-nesting seabirds rather than in the large, single-species colonies typical of their congener, the Common Puffin.

Phenology

Horned Puffins were present on the Pribilof Islands from May to October. Egg-laying occurred between mid-June and mid-July.

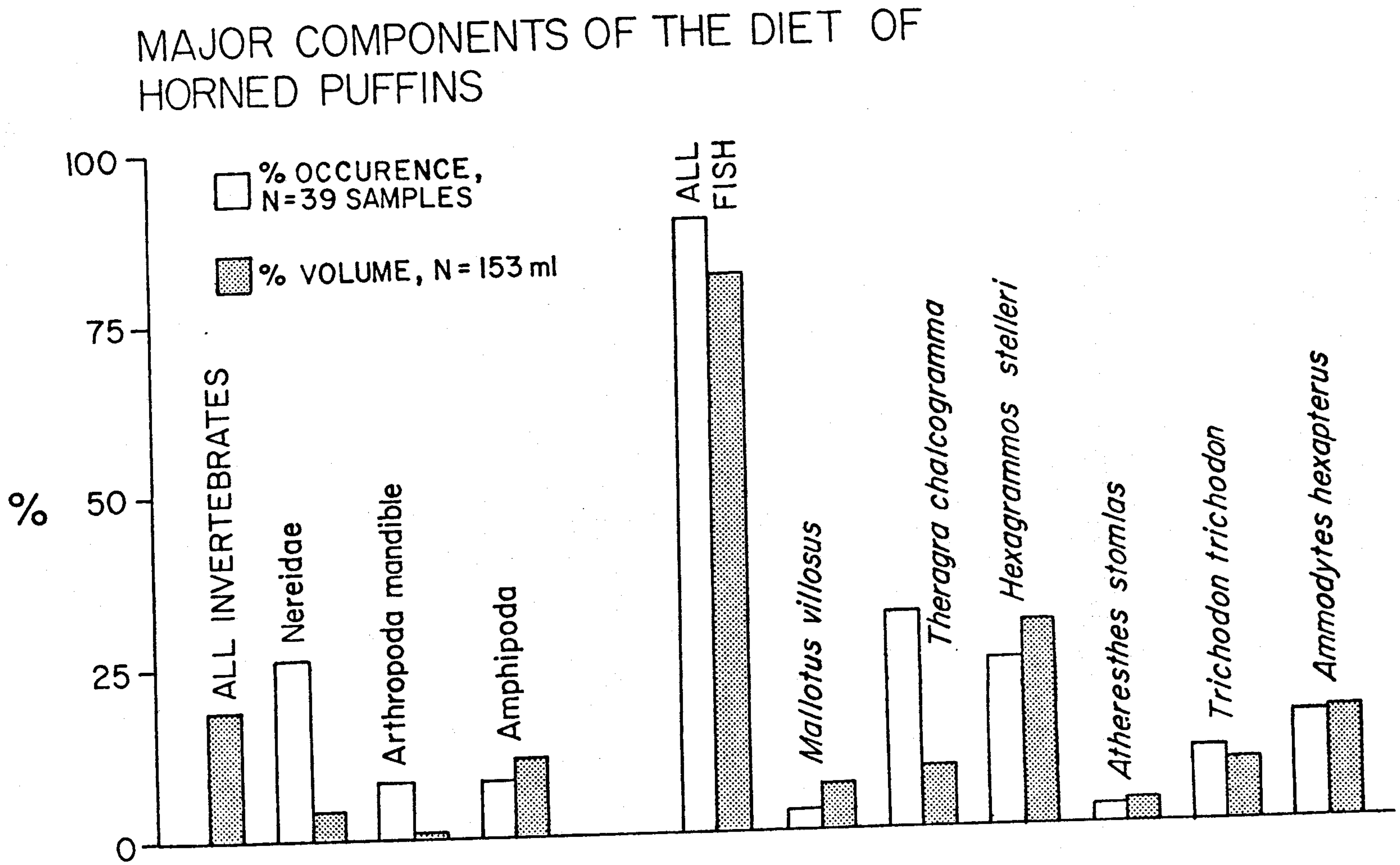

MAJOR COMPONENTS OF THE DIET OF HORNED PUFFINS
% OCCURENCE, N=39 SAMPLES
% VOLUME, N=153 ml
%
100
75
50
25
0
ALL INVERTEBRATES
Nereidae
Arthropoda mandible
Amphipoda
ALL FISH
Mallotus villosus
Theragra chalcogramma
Hexagrammos stelleri
Atheresthes stomlas
Trichodon trichodon
Ammodytes hexapterus

FIGURE 81

Eggs were incubated for approximately 42 days (Sealy 1973). Our laying dates were calculated from a known hatching date (Table 25). The first chicks were seen in late July (Table 25), and hatching continued into early September. Puffin chicks fledge at about 42 days of age (Sealy 1973). Using these data and projecting from known hatching dates, the last chicks in our study areas should then have fledged by mid-October. Horned Puffins nests were checked only once a week in 1975 and 1976, and less frequently in 1977. Any differences in phenology less than 10 days should be interpreted with caution.

Daily Activity Patterns

Hickey and Craighead (1977) found a bimodal pattern of colony attendance in this species on St. George Island, with maximum numbers occurring around 1200 and 1900 h. On St. Paul Island, however, we found a unimodal pattern of colony attendance, with a single peak in the afternoon occurring between 1500 and 1800 h. The exact shape and timing of this peak varied through the breeding season.

Incidental information on nest attendance was taken on one nest in August of 1979. Trips away from the nest averaged 1.6 $\pm$ 1.1 hours (n = 8 trips) and adults brought food back at a rate of 0.36 feedings/daylight hour.

Productivity

We estimate that Horned Puffins on the Pribilof Islands normally fledge 0.8 chicks/egg, as seen in 1977 (Table 26). The lower productivity seen in 1976 and 1975 probably reflects the higher degree of disturbance during the egg phase caused by

TABLE 25

Phenology of Horned Puffins on St. Paul Island, 1975 - 1977

	1975	1976	1977
FIRST EGG OBSERVED	25 June**	14 June**	15 June
CLUTCH INITIATION $\overline{X} \pm S$ (N)	8 Jl $\pm$ 8.5 (11)	28 Jn $\pm$ 13.9 (6)	29 Jn $\pm$ 7.9 (4)
FIRST CHICK OBSERVED	28 July	31 July	3 August
HATCHING $\overline{X} \pm S$ (N)	19 A $\pm$ 8.8 (11)	30 A $\pm$ 14.3 (6)	10 A $\pm$ 7.9 (4)
FIRST FLEDGING OBSERVED	9 Sept	none fledged by 16 Sept	3 Sept
FLEDGING $\overline{X} \pm S$ (N)	22 S $\pm$ 7.9 (5)	18 S $\pm$ 13.9+ (6)	9 S $\pm$ 6.5 (4)

* back calculated from hatching using a 42 day incubation period (Sealy 1973).

** observed on first nest check

\+ calculated from hatching using a 40 day nestling period

TABLE 26

Reproductive Success of Horned Puffins on St. Paul Island, 1975-1977

	1975	1976	1977
NUMBER OF NESTS WITH EGGS	11	25	10
HATCHING SUCCESS (chicks hatched/ egg laid)	1.00	0.56	0.90
FLEDGING SUCCESS (chicks fledged/ chick hatched)	0.45-1.00	0.79	0.78-0.89
PRODUCTIVITY (chicks fledged/ egg laid)	0.45-1.00	0.44	0.70-0.80

regular nest checks. Wehle (in prep.) states that Horned Puffins are very sensitive to disturbance at the nest during incubation, with disturbance often resulting in lowered productivity or desertion.

Growth rates allow a comparison of productivity between years without regard to disturbance. Puffin chicks grew at an average rate of 11.5 grams/day (Table 27). No significant differences were found in growth rates among years (T test, 1975/1976 T_{14} = 1.03 P = .3, 1976/1977, T_{12} = 0.42, P = .6, 1977/1978, T_6 = 0.46, P = .7).

TABLE 27

Growth Rates of Horned Puffin Chicks on St. Paul Island, 1975 - 1978

	(g/day)
1975	11.1 ± 1.3 (8)
1976	12.0 ± 2.1 (8)
1977	11.5 ± 2.3 (6)
1978	10.7 ± 0.6 (2)

Tufted Puffin (*Lunda cirrhata*)

Numbers

The distribution of Tufted Puffins is centered in the Aleutian Islands and northern Gulf of Alaska. An estimated 1.4 million Tufted Puffins occur in the eastern Bering Sea (Appendix 1). A population of 7,000 nests on the Pribilof Islands; this population is probably insignificant in terms of Bering Sea and world numbers.

Pelagic Distribution

The pelagic distribution of Tufted Puffins is given in Figure 82. Even though this species tends to approach and circle ships, data from shipboard and aerial surveys were combined to give the best indication of distributional patterns. However, because of the tendency to follow ships, the densities illustrated may be somewhat exaggerated.

In spring, relatively few Tufted Puffins were seen, and the largest concentrations were distant from the islands. In summer, low densities were seen both close to and far from the islands. Although the zonal analysis (Figure 83) shows a significant increase in density around the Pribilofs (Modified LSD Procedure, $P < 0.05$), neither the plot of density (Figure 82) or the histograms (not shown) show of an area of marked concentration around the islands. Rather, Tufted Puffins appear to have relatively uniform distribution from the Pribilof Islands out to at least 80 km. In fall, some indication of aggregations of higher density were found near the shelf break and in the outer shelf domain (Figure 82).

Diet

Tufted Puffins obtain their food by diving, and their pelagic distribution indicates that they are primarily offshore feeders at the Pribilofs. The diet of Tufted Puffins at the Pribilofs between 1975 and 1978 is summarized in Figure 84. Fish made up the major portion of the diet; walleye pollock represented close to one-half of the fish taken. Inshore, subtidal species, predominant in the diet of Horned Puffins, were absent from the diet. Nereid worms (Polychaeta) were the predominant invertebrate in Tufted Puffin diets at the Pribilofs.

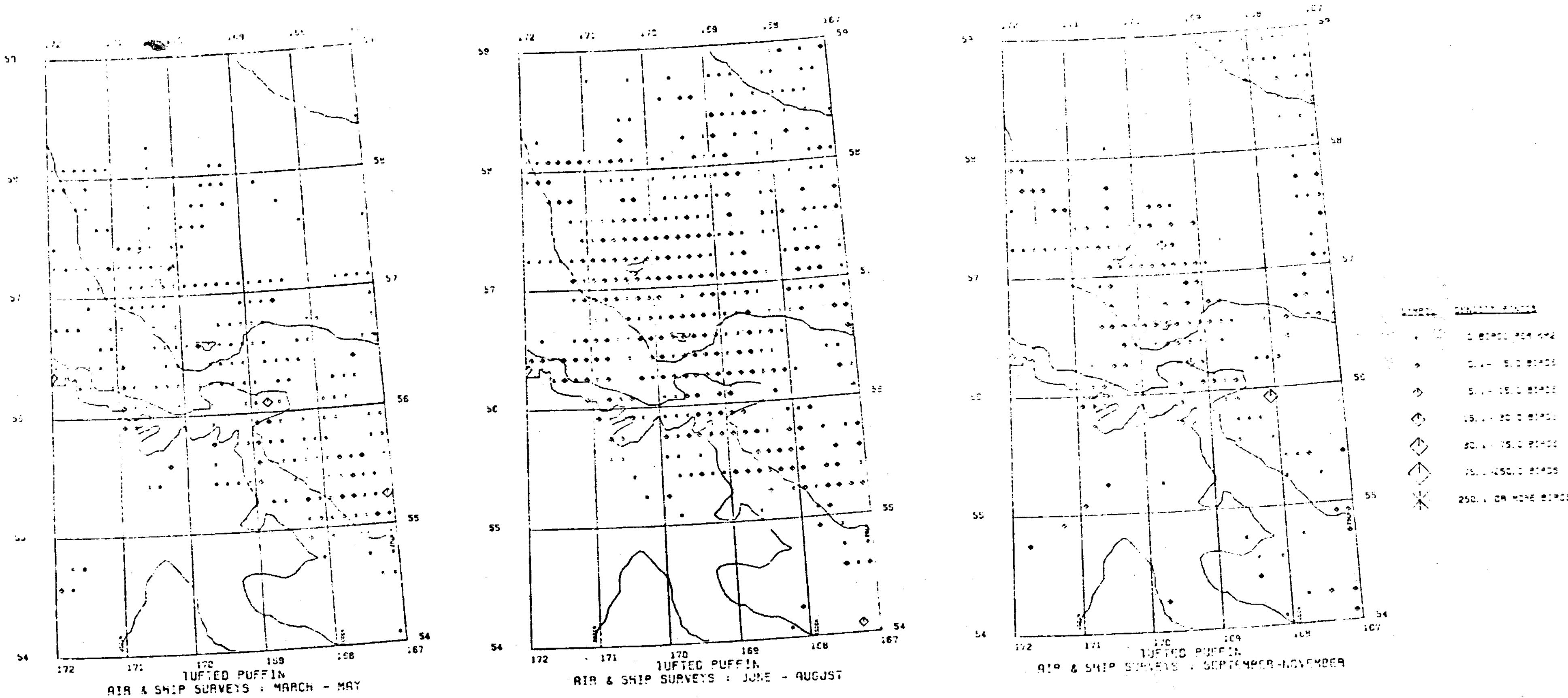
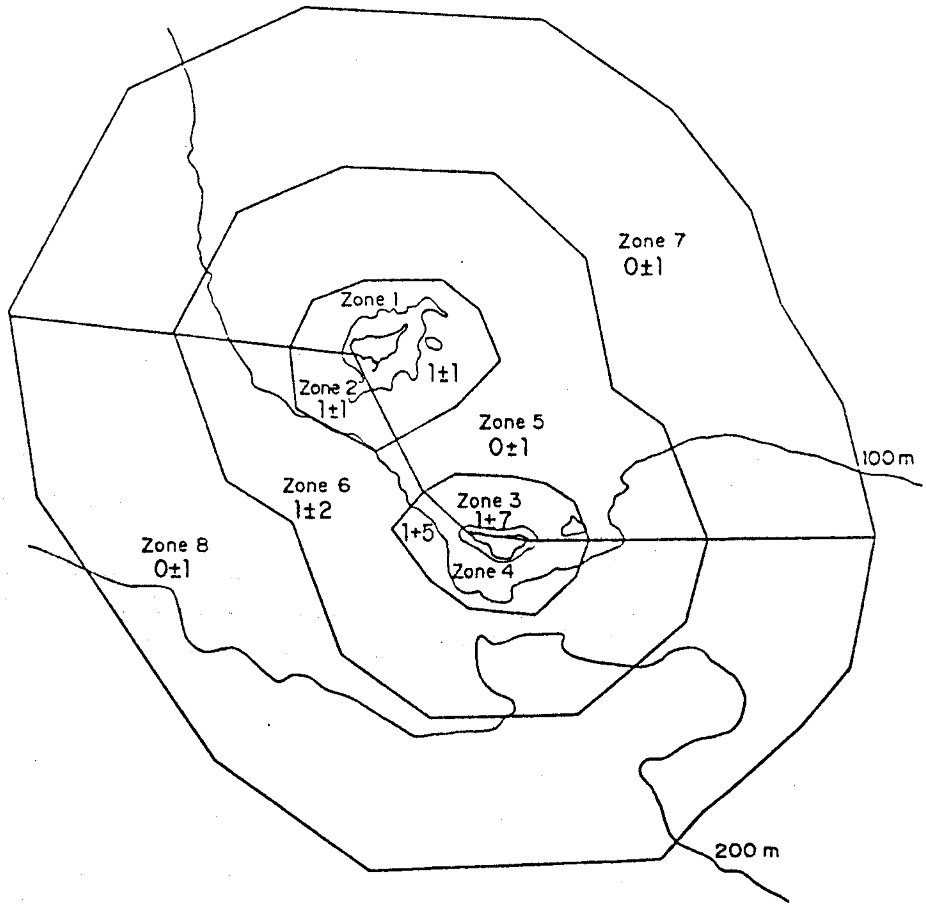

TUFTED PUFFIN
AIR & SHIP SURVEYS : MARCH - MAY
TUFTED PUFFIN
AIR & SHIP SURVEYS : JUNE - AUGUST
TUFTED PUFFIN
AIR & SHIP SURVEYS : SEPTEMBER-NOVEMBER

FIGURE 82

Distribution of Tufted Puffins by zones
near the Pribilof Islands, 1975-1979 ($\bar{x} \pm s$)*



ANOVA across all zones, $F_{7,2151} = 4.752$, $P = 0.00001$

Homogeneous subsets by modified LSD Procedure, $\alpha = 0.05$

Subset 1 Zones 7,8,5,1,6,2

Subset 2 Zones 1,6,2,4,3

*rounded to whole numbers

FIGURE 83

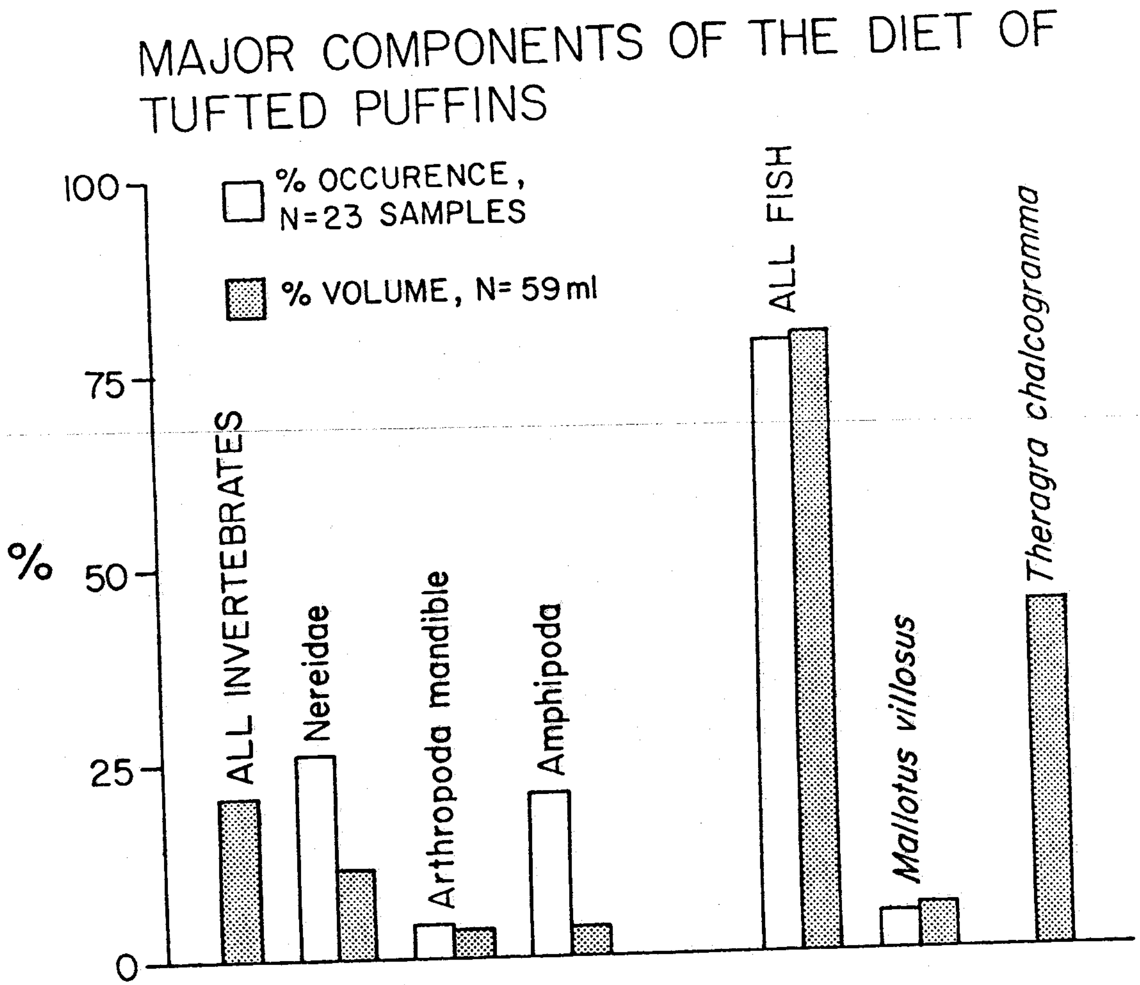

MAJOR COMPONENTS OF THE DIET OF TUFTED PUFFINS
% OCCURENCE, N=23 SAMPLES
% VOLUME, N= 59 ml
100
75
50
25
0
%
ALL INVERTEBRATES
Nereidae
Arthropoda mandible
Amphipoda
ALL FISH
Mallotus villosus
Theragra chalcogramma

FIGURE 84

Information on Tufted Puffin diets from elsewhere in the Bering Sea and North Pacific is summarized by Wehle (in prep.). Unpublished data from Sanger (U.S. Fish and Wildlife Service, Anchorage, Alaska) supports the contention that in the southwestern Bering Sea gadids, particularly walleye pollock, are important in Tufted Puffin diets, as are nereid worms and sand lance.

Nesting

Habitat

On the Pribilof Islands, Tufted Puffins nest in burrows which they excavate in grassy slopes, generally surrounded by steep sections of cliff. On fox-free islands, Tufted Puffins are not limited to cliffs, but will burrow in any grassy area.

Phenology

Tufted Puffins are present on the Pribilof Islands from May to October and possibly later. No nests were accessible to us and the behavior of these birds prevented their being mist-netted. Our information from collected birds and observations suggest that Tufted Puffins begin bringing fish back to the burrows near the end of August; the first observation was on 31 August. Tufted Puffins carrying fish became more common in early September. These observations suggest that Tufted Puffin chicks do not hatch until late August. If this is the case, then laying would occur in mid-July and chicks would not fledge until mid-October.

Daily Activity Patterns

Tufted Puffins showed a bimodal pattern of colony attendance in July, with a peak of attendance in the morning, around 0700, and a peak in the evening, between 1700 and 2000 hours (Hickey and Craighead 1977). Our watches in August found attendance was much more variable. Other investigators have found complex patterns of colony attendance in this species, with 3 to 4 day cycles of maximum numbers (Wehle 1978). Our study of attendance was not detailed enough to determine whether puffins on the Pribilofs also showed such intricate patterns.

Productivity

We have no data on the productivity of Tufted Puffins on Pribilof Islands, due to the inaccessibility of their nests. Tufted Puffins seem to be more vulnerable to fox predation than Horned Puffins. In surveying fox dens, Tufted Puffin carcasses were common, whereas only one Horned Puffin carcass, out of approximately 60 puffins carcasses, was found (Zoe Eppley, pers. obs.). We also frequently observed foxes traversing the gentler slopes in which Tufted Puffins nested. Under the circumstances, we would expect Tufted Puffins to have comparatively greater mortality of both adults and nestlings than Horned Puffins.

DISCUSSION

Reproductive ecology and variability

In comparing the productivity of the Pribilof colonies to other colonies in the Bering Sea, it is useful to put the productivity of Bering seabirds in a broader perspective. In particular, for some marine bird species with multiple egg clutches, populations in the North Pacific and North Atlantic have been found to have larger clutches, faster chick growth rates, and greater reproductive success than populations of the same species in the Bering Sea (Hunt et al. 1980b). Species for which this generalization appears to hold include Pelagic Cormorants, Glaucous-winged Gulls and Black-legged Kittiwakes.

Several factors may interact to cause depression of the productivity of marine birds in the Bering Sea. First, a number of the Bering Sea colonies are larger or denser than other northern hemisphere seabird colonies, and the potential for competitive depression of growth rates and productivity may be greater in large colonies. A second difference between the Bering Sea and the North Pacific and North Atlantic is sea temperature. The Bering Sea is much colder, and the energetic costs of survival are likely to be greater. Third, in the southeastern Bering Sea, frequent storms and bad weather may reduce the productivity of birds by interferring with their ability to obtain food. In contrast to the southeastern Bering Sea, in the northeastern Bering Sea, weather is generally good, but food resources appear to fluctuate greatly in abundance from year to year. Productivity in the northeastern colonies appears to depend on the migrations of fish schools into waters near the colonies. When food is available, productivity in these colonies is as high as in the colonies outside the Bering Sea. In other years, productivity is extremely low. Productivity of marine birds which lay a single egg, including the alcids and the Northern Fulmar, appears to be more consistent both within the Bering Sea and between the Bering and other regions than for species with multiple-egg clutches. However, we have much less information on the alcids and such conclusions may be premature.

Within the Bering Sea, our best comparative data are for Black-legged Kittiwakes. This species has been studied at the Pribilofs for five years, at Bluff in Norton Sound for 4 years and at Cape Peirce on the coast of Bristol Bay for 2 years. At Cape Peirce and Norton Sound, Black-legged Kittiwake productivity shows large fluctuations, ranging over as much as 3 orders of magnitude in 3 years. At the Pribilofs, kittiwake productivity is more stable. At Norton Sound, fluctuations in productivity appear to be caused by changing food supplies. These colonies depend on the migration of schools of sand lance (Ammodytes) into waters near the colonies. When large schools of fish are present, productivity is the highest seen in the Bering Sea (Hunt et al. 1980b). In years when the fish schools do not approach the colonies, productivity is abysmally low.

The interpretation of fluctuating kittiwake productivity at Cape Peirce is less certain, as there are no data on the foods used by Black-legged Kittiwakes at this colony. In addition, only 2 years of productivity data are available, so we do not know whether the low productivity seen in 1977 was a rare or frequent occurrence. However, an important Herring spawning and nursery area is located near Cape Peirce, and the location of spawning is affected by the southern limit of the ice-edge and sea temperature in the spawning season (F. Favorite, pers. com.). It is possible that the observed fluctuations in productivity of Black-legged Kittiwakes at Cape Peirce are also food related, and depend on the location of fish spawning areas and indirectly on weather.

At the Pribilofs, fluctuations in kittiwake productivity appear to be caused by weather. Specifically, productivity is depressed in years of unusually strong winds. During periods of high winds, food delivery to young may be reduced while energetic demands for survival are increased. In these periods, siblicide is increased (Braun, in prep).

There are at least two reasons why Pribilof Black-legged Kittiwakes show smaller fluctuations in productivity than kittiwakes elsewhere in the Bering Sea. First, the Pribilofs are located in one of the richest regions of the Bering Sea with large fish and zooplankton resources which, because of a multiplicity of year classes and apparently stable distribution patterns, provide consistent food resources. This abundance of food encourages high and stable productivity. Second, the consistently poor weather of the region interfers with the adults ability to deliver food to young at a rate sufficient to insure the survival of two young. The net result of these two opposing factors is a relatively stable but moderate level of productivity.

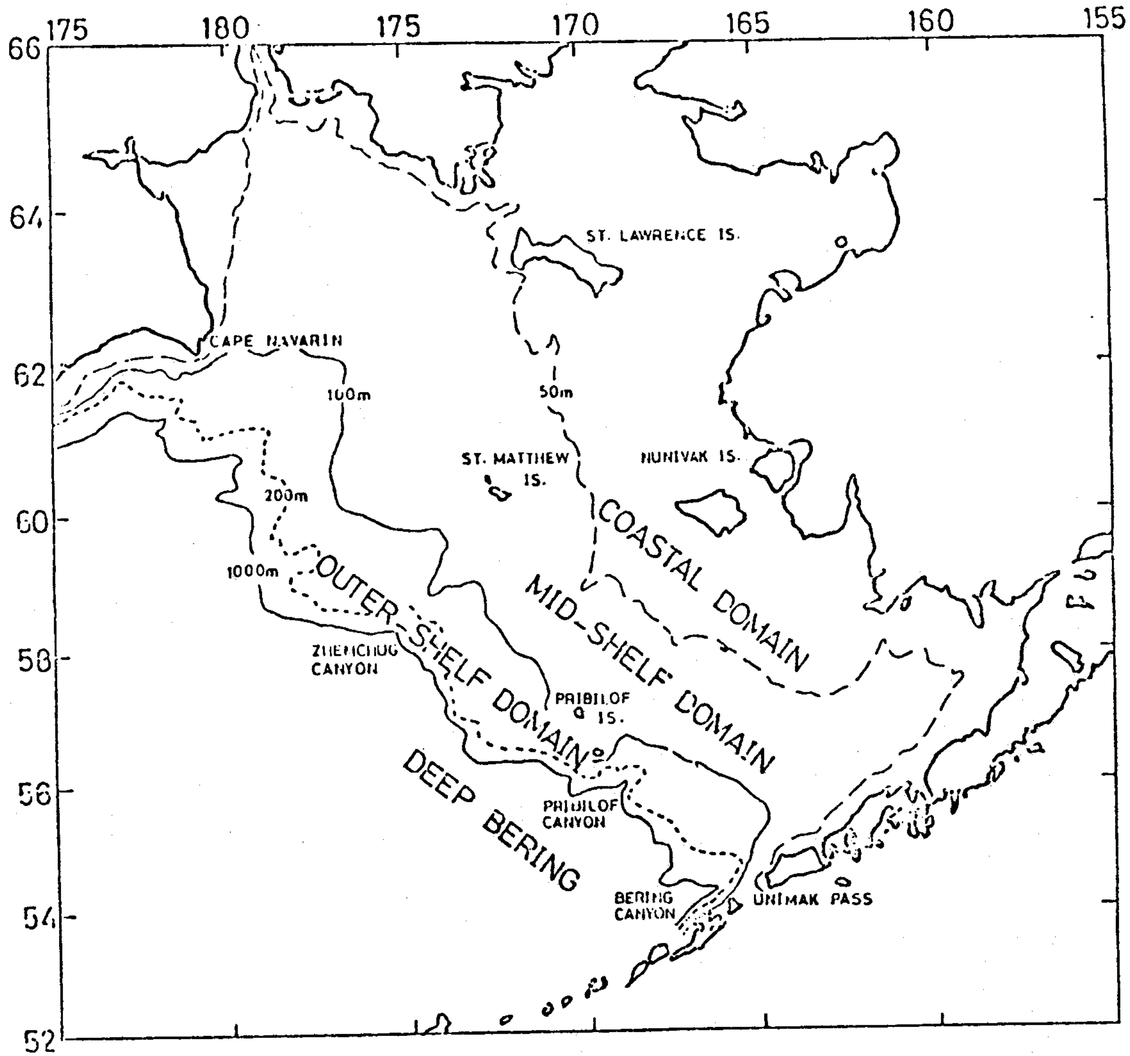
At present, the only other species for which sufficient data exists to allow a comparison of productivity within the Bering Sea are the two species of murres. Fluctuations in murre productivity were not as pronounced as in kittiwakes, partially because murres lay only a single egg and the potential for variation is less. In addition, the insensitivity of our measures of murre reproductive success preclude detection of small fluctuations in productivity. Because we did not find parallel fluctuations in kittiwake and murre productivity, and because we lack adequate data for other species, we are not confident about generalizing from kittiwake data to the reproductive status of other species of marine birds.

Having placed the Pribilofs within the broader perspective of northern hemisphere and Bering Sea colonies, we are now in a position to compare productivity on St. Paul and St. George Islands. When we look at various reproductive parameters such as clutch size, growth rates, and fledging weights, many species showed larger values for their population on St. Paul than for their population on St. George. Rarely, these differences were manifested in lower productivity for the population on St. George. These two islands are similar in weather and location, except St. George is closer to the rich foraging waters of the shelf break. Hence we might have expected birds to have done better there. One major difference between the two islands is the amount of cliff space; St. George Island has more space for cliff-nesting birds than St. Paul. The greater cliff area on St. George Island accounts for the seabird population being ten times larger there than on St. Paul Island. The larger numbers nesting on St. George Island increase the potential for competition in the waters near the island. We believe that clutch size, growth rates and fledging weights for some species are depressed on St. George Island relative to those on St. Paul Island due to competition among birds foraging near their colony. Although productivity is not depressed, lower fledging weights may reduce post-fledging survivorship (Lack 1966) and thus affect population dynamics.

Trophic Dynamics

Within the Bering Sea, there are few studies which combine seabird productivity studies with studies of food webs used by the birds. We have suggested how the size and location of prey populations may enhance or depress productivity in the colonies. Knowing the prey taken by seabird communities, and the stability of these prey resources is an integral part of understanding the natural fluctuations in seabird productivity and populations. Although our knowledge of the dynamics of the prey populations on which the Pribilof seabirds depend remains scanty, we do know something about the prey types taken and the flexibility of seabird diets.

As stated previously, the Pribilof Islands lie within a particularly rich region of the Bering Sea. The Outer Shelf Domain (Figure 85) is known for its large populations of fish and plankton, as well as for its high diversity of speices. Despite a wide variety of food resources, the Pribilof seabird colonies as a whole rely on comparatively few prey species (Figure 86).



Oceanic Domains of the eastern Bering Sea (from Hattori and Goering 1977)

FIGURE 85

SUMMARY OF SEABIRD DIETS AT THE PRIBILOF ISLANDS, 1975-1978

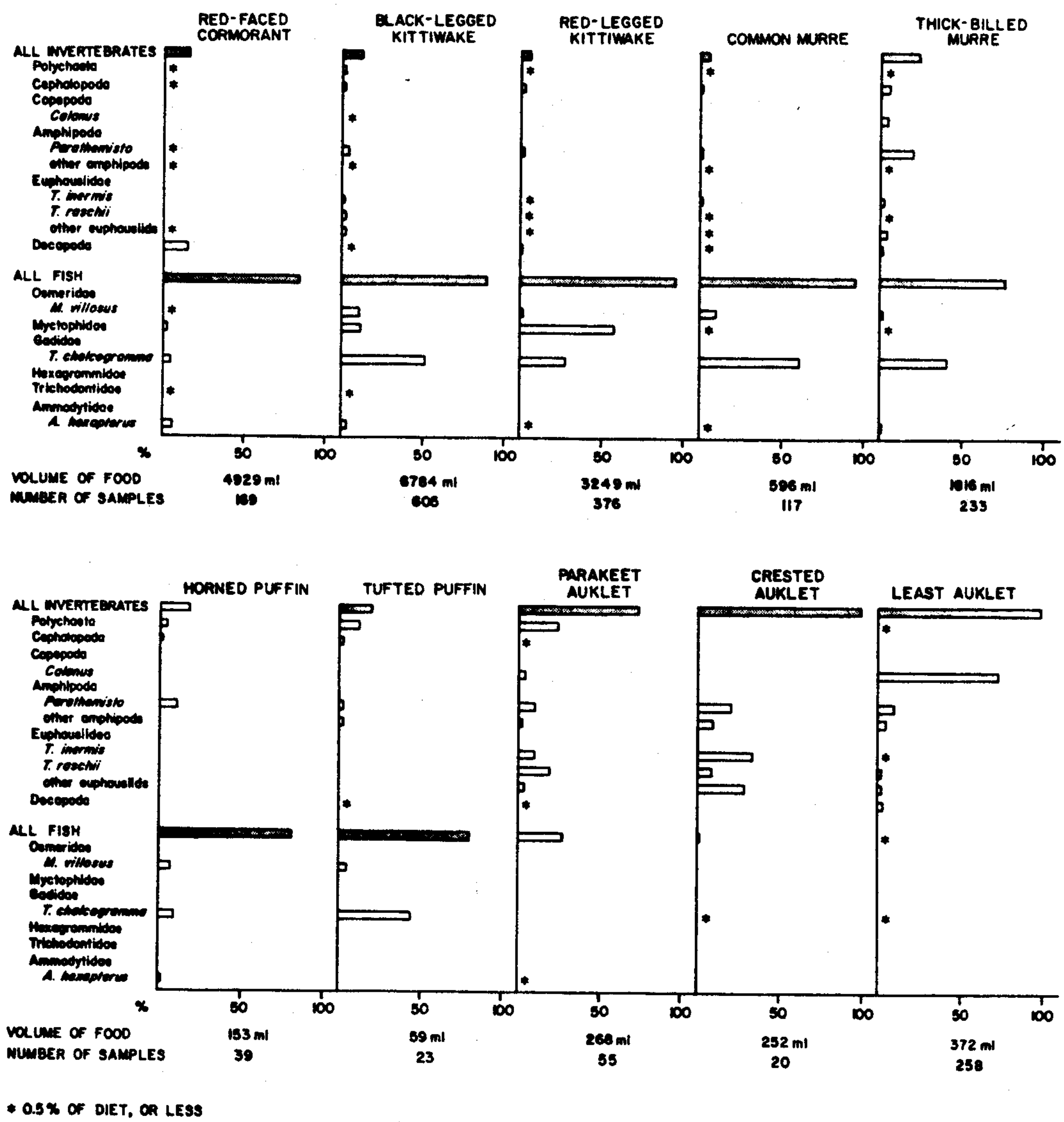


FIGURE 86

Considering the diet of the species, without compensation for bird biomass or residency time, we find that 84% of the seabird community diet is fish and 16% is invertebrates. The single most important prey species is walleye pollock, followed by *Thysanoessa*, *Parathemisto*, *Calanus* and myctophids. If we weigh the percentages of prey taken by the different seabirds by the biomass of the birds and the residency times of their populations at the Pribilofs, pollock makes up 41% of the food consumed, *P. libellula* makes up 8%, and euphausiids account for 6% (Table 28). Although myctophids, euphausiids and cephalopods together are only a small portion of the biomass consumed by Pribilof seabirds, they must be seen as critical foods because they are of major importance to one or more species.

The emphasis of the bird community as a whole on a single prey species, walleye pollock, would seem to make the community particularly vulnerable to prey shortages. We have looked at the year classes of pollock taken by Black-legged Kittiwakes at the Pribilofs. This species takes as many as 3 different year classes of pollock at the beginning of the nesting season, but as the season progresses and young-of-the-year pollock become available, kittiwakes increasingly select a single year class (Figure 38). Black-legged Kittiwakes may reduce their vulnerability to pollock shortages by spreading their consumption over three year classes. If pollock reproduction was poor one year, Black-legged Kittiwakes would be forced to take older and larger fish. Other seabirds which rely on pollock may also use this strategy. Murres and puffins carry bill loads of whole

Table 14. A comparison of bird nest densities on a mainland tundra plot and a barrier island tundra plot in the Simpson Lagoon-Jones Islands area of Alaska (1977-1978).

	Pingok Plot 2 (0.300 km^2)						Milne Pt. Plot (0.250 km^2)		
	1977			1978			1978		
Species	#Nests	Density*	Fate[§]	#Nests	Density	Fate[§]	#Nests	Density	Fate[§]
Pintail	-	-		-	-		1	4.00	+
King Eider	-	-		-	-		1	4.00	+
Spectacled Eider	-	-		-	-		1	4.00	+
Baird's Sandpiper	-	-		-	-		2	8.00	+
Dunlin	3	10.00	-	2	6.67	+	1	4.00	+
Semipalmated Sandpiper	-	-		2	6.67	+	1	4.00	+
Buff-breasted Sandpiper	-	-		-	-		1	4.00	+
Pectoral Sandpiper	-	-		-	-		1	4.00	+
American Golden Plover	-	-		-	-		1	4.00	+
Lapland Longspur	8	26.67	5+	2	6.67	+	5	20.00	+
TOTAL	11	36.67		6	20.01		15[†]	60.00	

*All densities are per km^2.

[†]Within a linear distance of approximately 2.50 km E and 0.25 km S, W and N of the Milne Pt. tundra plot, an additional 18 nests were recorded. These included nests of the arctic (1) and red-throated (1) loon, white-fronted goose (1), king eider (2), spectacled eider (2), dunlin (1), oldsquaw (2), Sabine's gull (4), arctic tern (3) and snow bunting (1). No additional nests were either observed or suspected in areas similarly adjacent to the comparable tundra plot on Pingok Island. All densities are per km^2.

[§]During 1978, no evidence was found of predation or desertion of nests on mainland or barrier island tundra plots; apparently all of these nests were successful. During 1977 all three dunlin nests were destroyed by predators and three of the eight longspur nests were destroyed by predators.

fish to their young and may be unable to utilize the larger pollock for feeding their young. However, adults may consume them on the feeding grounds. Thus, depsite heavy reliance on a single prey species, Pribilof seabirds are able to reduce the effects of ocsillations in prey availability by spreading their consumption over several year classes; this adaptation may, to a large degree, account for the stable productivity at the Pribilofs.

Although seabirds show a considerable amount of overlap in diet, this overlap does not preclude resource partitioning among the species. Figure 86 diagrams the diets of seabirds at the Pribilofs. Species with similar morphology and foraging methods might be expected to show the greatest similarities in diet. However, if we compare the diets of Black-legged and Red-legged Kittiwakes, we see that their major prey are different; Red-legged Kittiwakes depend on myctophids while Black-legged Kittiwakes depend on pollock. Common and Thick-billed Murres share pollock as their major prey species, but Thick-billed Murres are less dependent on fish than Common Murres, and Parathemisto is the second most important prey for Thick-billed Murres. Horned and Tufted Puffins also show major differences in diet; the primary prey of Horned Puffins are hexagrammids, while Tufted Puffins rely on pollock. Although Black-legged Kittiwakes, murres and Tufted Puffins all share pollock as their primary prey, these species forage at different times, locations and have access to different portion of the water column, thereby reducing competition.

The three species of auklets stand out among the Pribilof seabirds because pollock is not an important part of their diet. Bédard (1969a) has found major differences in the sizes of prey and taxa of prey taken by these three species at St. Lawrence Island. We found similar differences in the diets of the auklets. Fish are virtually absent from the diets of Least and Crested Auklets, while fish are a significant part of the diet of Parakeet Auklets. Crested Auklets depend on euphausiids as their primary prey but the major prey for Least Auklets are calanoid copepods. Where substantial overlap occurs in the diets of the auklets, they further partition resources by taking generally different sizes of prey. In general, Parakeet Auklets take the largest prey while Least and Crested Auklets take the smallest prey. For the prey taxa which both Least and Crested Auklets take in large numbers, Least Auklets tend to take smaller individuals than Crested Auklets.

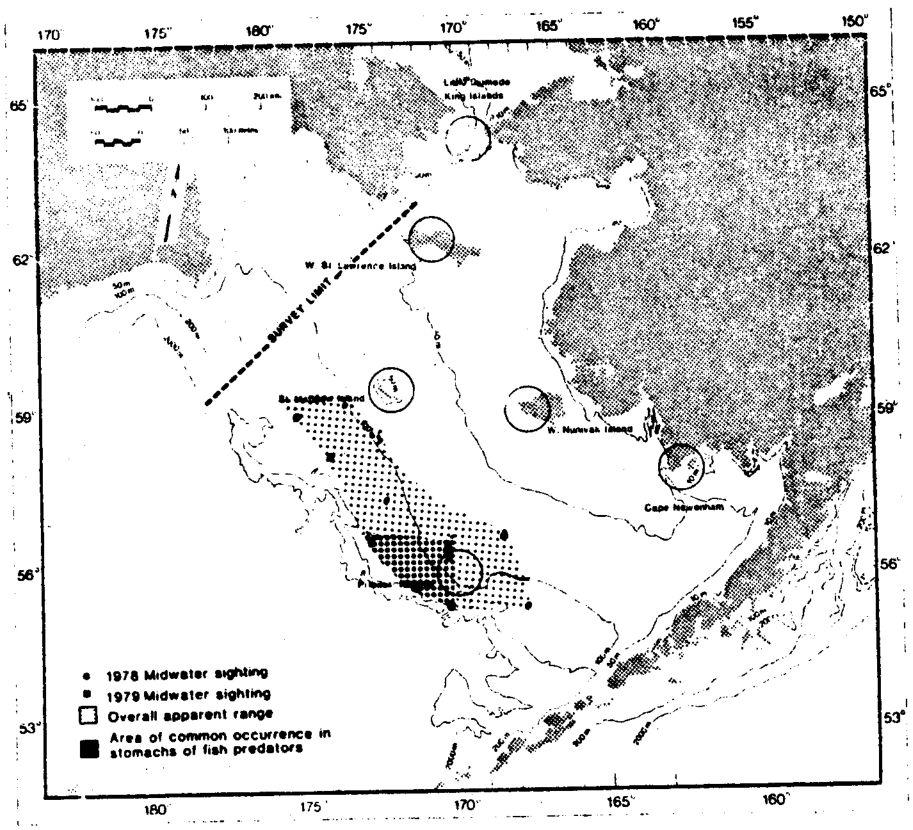
Although prey resource partitioning appears to predominate at the Pribilofs, multi-species foraging flocks are seen around the islands in summer. Local concentrations of prey at the surface are spotted by Black-legged Kittiwakes, and other species soon join the melee. We have seen multi-species foraging flocks composed of up to eight different species. These foraging flocks are only found within a few km of the islands, usually within sight of the colonies, and are conspicuously scarce away from the islands.

The previous discussion has portrayed seabird diets as fixed and immutable, when, in fact we find substantial evidence of opportunism among Pribilof seabirds. For Black-legged Kittiwakes, Red-legged Kittiwakes, Common and Thick-billed Murres, we have enough data on their diets to compare years. For all these species, we find an increased use of pollock in 1977 and 1978 compared to previous years. This increase of pollock in the diet accompanied an increase in the availability of pollock in 1977 and 1978 relative to 1975 and 1976 (Table 29, from Smith 1979). In both 1977 and 1978, due to the absence of storms during a critical hatching period for pollock, there were strong year-classes produced (Cooney et al. 1978). Figure 87 shows that the distribution on young pollock in the eastern Bering Sea is clustered around the Pribilofs (Smith 1979).

TABLE 29

Indices of relative abundance of Pollock age classes, measured by NMFS Crab-Groundfish research vessel surveys within a central area of the eastern Bering Sea during June to mid-August, 1975 - 1978 (10^6 individuals per 159,000 km^2) (from Smith 1979).

	Age Classes (yr)		
Year	1	2	3
1975	758	402	614
1976	729	500	480
1977	2242	630	146
1978	1171	400	806



Distribution of 2 to 4 month old pollock over the eastern Bering Sea shelf during June to mid-August (from Smith 1979).

FIGURE 87

Pelagic Distribution

The pelagic distribution of birds is influenced by many factors: the location of oceanic regimes and their associated food webs, the size of seabird populations and the magnitude of competition, the predictability and variety of resources and the energetic constraints of species which may limit their traveling distance from nesting sites. At the Pribilofs, most birds are found within 100 km of the islands (Figures 88-90). But within this region, there are distinct differences in the distributional patterns of species. Least, Crested and Parakeet Auklets are commonly found within 20 km of the islands, but are rare outside this zone. The radial distribution of murres is intermediate. Murres are concentrated within 50 km of the islands, except for east of St. Paul Island where high densities of murres are found out to 100 km. This area appears to be particularly important foraging area for a number of species.

Northern Fulmars, Red-legged Kittiwakes and Black-legged Kittiwakes forage at considerable distances from their colonies. Northern Fulmars and Red-legged Kittiwakes are generally concentrated near the shelf break, while Black-legged Kittiwakes are evenly distributed over the ocean within 150 km of the islands, except for their short-term participation in foraging flocks.

In summary, the critical foraging areas that support the Pribilof Island seabird colonies are the ocean areas within 50 km of the islands, the shelf break to the south and east of St. George, and east of St. Paul, where murres forage in large numbers. These areas and the food resources within them should receive protection.

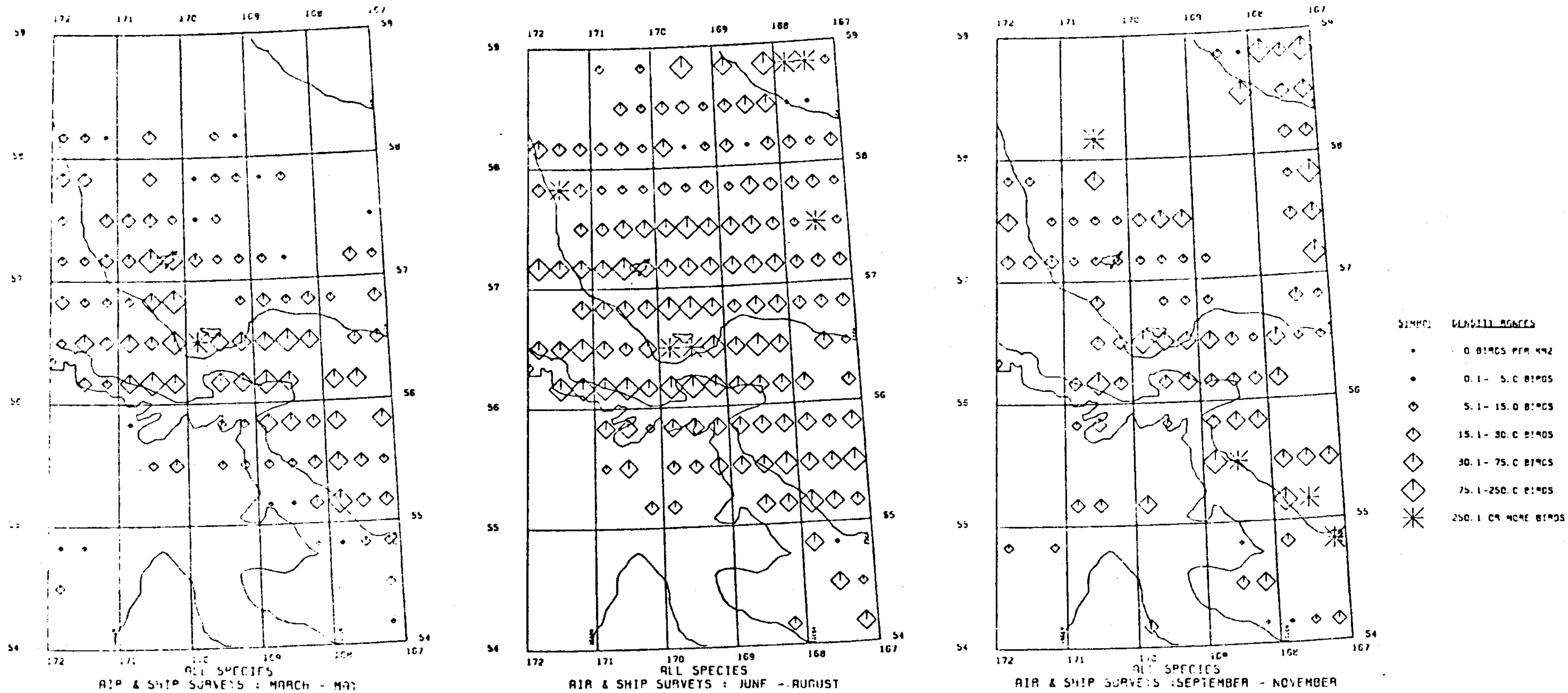
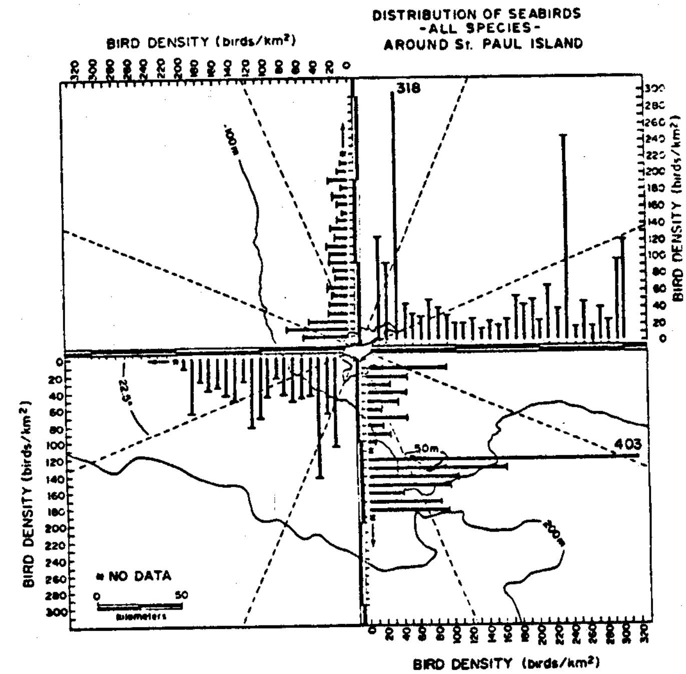

ALL SPECIES
AIR & SHIP SURVEYS : MARCH - MAY
ALL SPECIES
AIR & SHIP SURVEYS : JUNE - AUGUST
ALL SPECIES
AIR & SHIP SURVEYS : SEPTEMBER - NOVEMBER
0.1 - 5.0
5.1 - 15.0
15.1 - 30.0
30.1 - 75.0
75.1 - 250.0
250.1

FIGURE 90


DISTRIBUTION OF SEABIRDS
-ALL SPECIES-
AROUND St. PAUL ISLAND
BIRD DENSITY (birds/km²)
318
403
* NO DATA
kilometers
BIRD DENSITY (birds/km²)

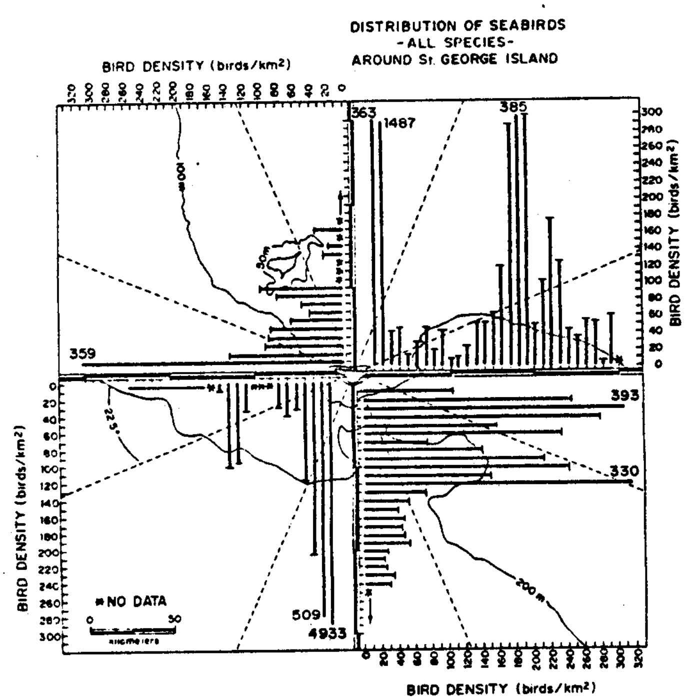
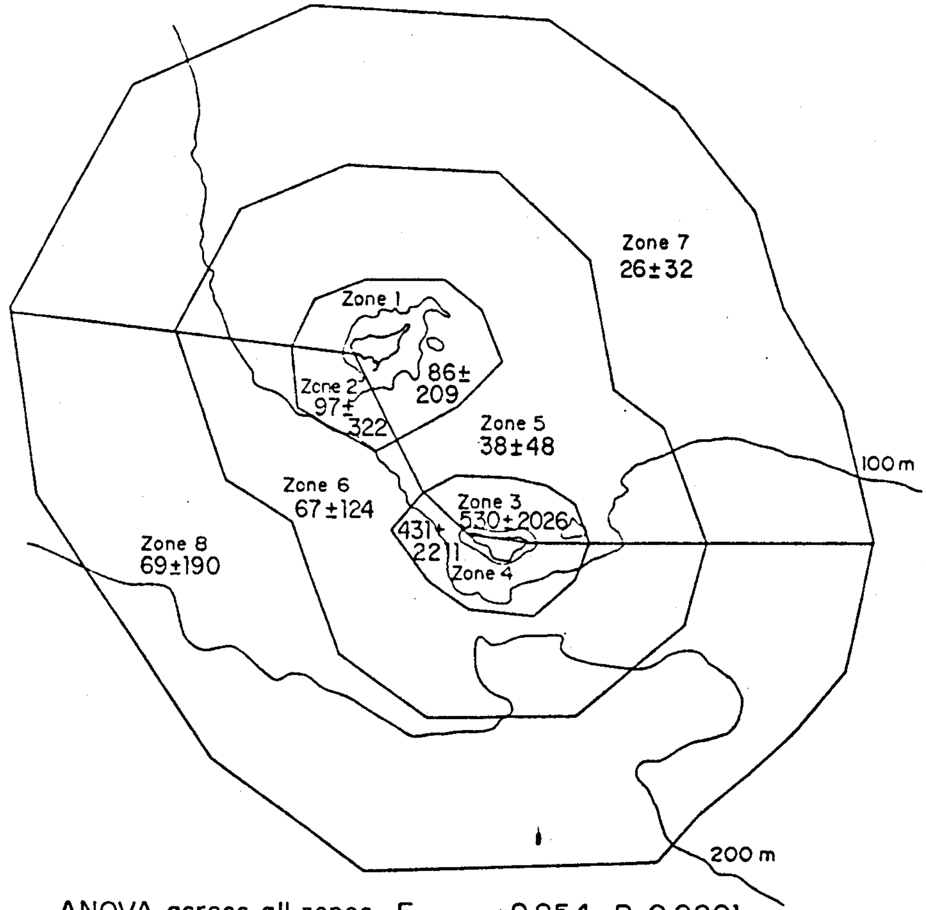

DISTRIBUTION OF SEABIRDS
-ALL SPECIES-
AROUND St. GEORGE ISLAND
BIRD DENSITY (birds/km²)
363
1487
385
359
393
330
509
4933
* NO DATA
kilometers
BIRD DENSITY (birds/km²)

FIGURE 89

Distribution of seabirds by zones
near the Pribilof Islands, 1975-1979 ($\bar{x} \pm s$)*



ANOVA across all zones, $F_{7,2125}=9.854$, $P=0.0001$

Homogeneous subsets by modified LSD Procedure, $\alpha=0.05$

Subset 1 Zones 7,5,6,8,1,2
Subset 2 Zones 2,4
Subset 3 Zones 4,3

*rounded to whole numbers

FIGURE 90

SUMMARY

OCSEAP studies have shown that the Pribilofs, particularly St. George Island, are among the largest and most diverse seabird colonies in the Bering Sea. Comparative data on the reproductive success of seabirds nesting in the Bering Sea exist for Common and Thick-billed Murres, Horned Puffins and Black-legged Kittiwakes. Productivity of the first three species at the Pribilofs is similar to that found in Norton Sound and at Cape Peirce, with relatively modest year to year variation. In contrast, productivity of Black-legged Kittiwakes nesting at Bluff in Norton Sound and at Cape Peirce is typified by boom and bust years, with reproductive success varying over orders of magnitude. Productivity of Pribilof kittiwakes differs from this pattern in that they have moderate and fairly stable success.

The location of the Pribilof Islands, close to the shelf break may be critical for support of not only the large populations of seabirds, but also their moderate and steady level of reproductive success. Between the shelf edge and the Pribilofs, shelf and oceanic faunas merge into a diverse and complex community (Motoda and Minoda 1974), combining the zooplankton resources of the shelf-edge with the vast fish populations of the shelf. The birds of the Pribilof Islands rely on the few dominant species of this unique food web. Walleye Pollock (<u>Theragra chalcogramma</u>), a gadid fish; <u>Thysanoessa raschii</u>, an oceanic euphausiid, and <u>Parathemisto libellula</u>, and amphipod inhabiting the shelf, account for 41, 6 and 8 percent, respectively of the prey taken by Pribilof seabirds. Most foraging by seabirds is concentrated within 100 km of the

islands, a reflection of the proximity of rich food resources. In many cases, immense flocks of seabirds are found on the water within a few kilometers of the islands.

Implications for Management

The size and diversity of the Pribilof seabird colonies, as well as their unique population of Red-legged Kittiwakes comples their protection. However, if protection is to be effective, three concerns must be addressed: 1) minimizing adult mortality away from the colony; 2) ensuring food resources remain adequate to sustain not only the adult population, but also reproductive efforts, and 3) minimizing disturbance of breeding birds at their colonies.

Almost certainly the greatest threat to the survival of the Pribilof seabird colonies is the possibility of increased mortality of adults at sea. Numerous studies have identified the vulnerability of seabirds to floating oil (Vermeer and Vermeer 1974) and King and Sanger (1979) have shown that certain groups of Alaskan seabirds, notably the alcids, are particularly vulnerable. Wiens et al. (1979) have shown that the recovery time of Pribilfof seabird populations, if reduced in numbers would be linked to reproductive rates, which are lowest in the alcids and the Red-legged Kittiwakes. While Wiens' group addressed questions related to major, catastrophic oil spills, evidence from England (Bourne 1968, Clark 1973, Wilson and Hunt 1975), Denmark (Joensen 1972), and South Africa (Westphal and Rowan 1970, Frost et al. 1976) shows that repeated small spills and chronic fouling have significant detrimental impacts on seabirds (see also Vermeer and

Vermeer 1975). Therefore, as oil extraction and related shipping traffic increase in the Bering Sea, it will be critical to guard against chronic low-level oil pollution as well as against major oil spills within 100 km of the islands, a region which our OCSEAP sponsored studies have shown is used extensively by seabirds.

The second concern is that there be adequate food supplies for Pribilof seabirds. During the non-breeding season, these birds have considerable latitude in choosing foraging areas. However, during the breeding season, they are tied to their nesting colonies, and most foraging is done within 20-50 km to 100 km of the islands, depending on the bird species involved. Our studies have shown that the Pribilof seabird colonies largely depend on a single prey, walleye pollock, which is also the mainstay of a large fishery effort. It is critical that fisheries management decisions take into account the needs of other segments of the ecosystem as well as the needs of man. The implementation of a maximum sustainable yield (MSY) fishery causes fish abundance to fall to half its pre-exploitation levels, substantially lowering food availability to seabirds. The collapse of some seabird populations is likely as fish abundance approaches or falls below MSY levels (MacCall 1979). This implies that fishery management decisions potentially may have as great an impact on Pribilof seabird populations as oil spills.

In South Africa (Crawford and Shelton 1978), Peru (Schaefer 1970), and southern California (Hunt and Butler 1980, D. Anderson, pers. comm.), we have found that seabird colony size and productivity is sensitive to food availability. In Norton Sound, the reproductive success of seabirds fluctuates greatly with the food supply, and in most years studied, productivity was probably not sufficient to sustain their populations. The reduction of the food supplies of the Pribilof seabirds would also undoubtably reduce productivity, and it is likely that these colonies would diminish in size if food availability were lowered on a long-term basis. Our OCSEAP studies of seabird productivity suggest that seabirds nesting on St. George Island are already showing evidence of food stress due to competition. While this concern applies more to fisheries management decisions than to oil development activities, secondary effects of oil pollution on food chains may impact Pribilof seabirds.

Finally, efforts should be made to minimize disturbance at the colonies, from human activities on or below the cliffs, aircraft and introduced predators. Chronic disturbance is likely to have long-term effects on productivity and possible deliterious and irreversible effects on the colonies themselves. According to our observations, aircraft flying over the colonies have an acute impact on productivity (Hunt et al. 1978). If nesting seabirds can habituate to chronic aircraft disturbance, then long-term effects may be neglible. However, reproductive failure over a period of years may cause seabirds to desert their colonies. Given the uncertainty of the long-term effects of disturbance, care should be made to reduce this potential impact.

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APPENDIX I

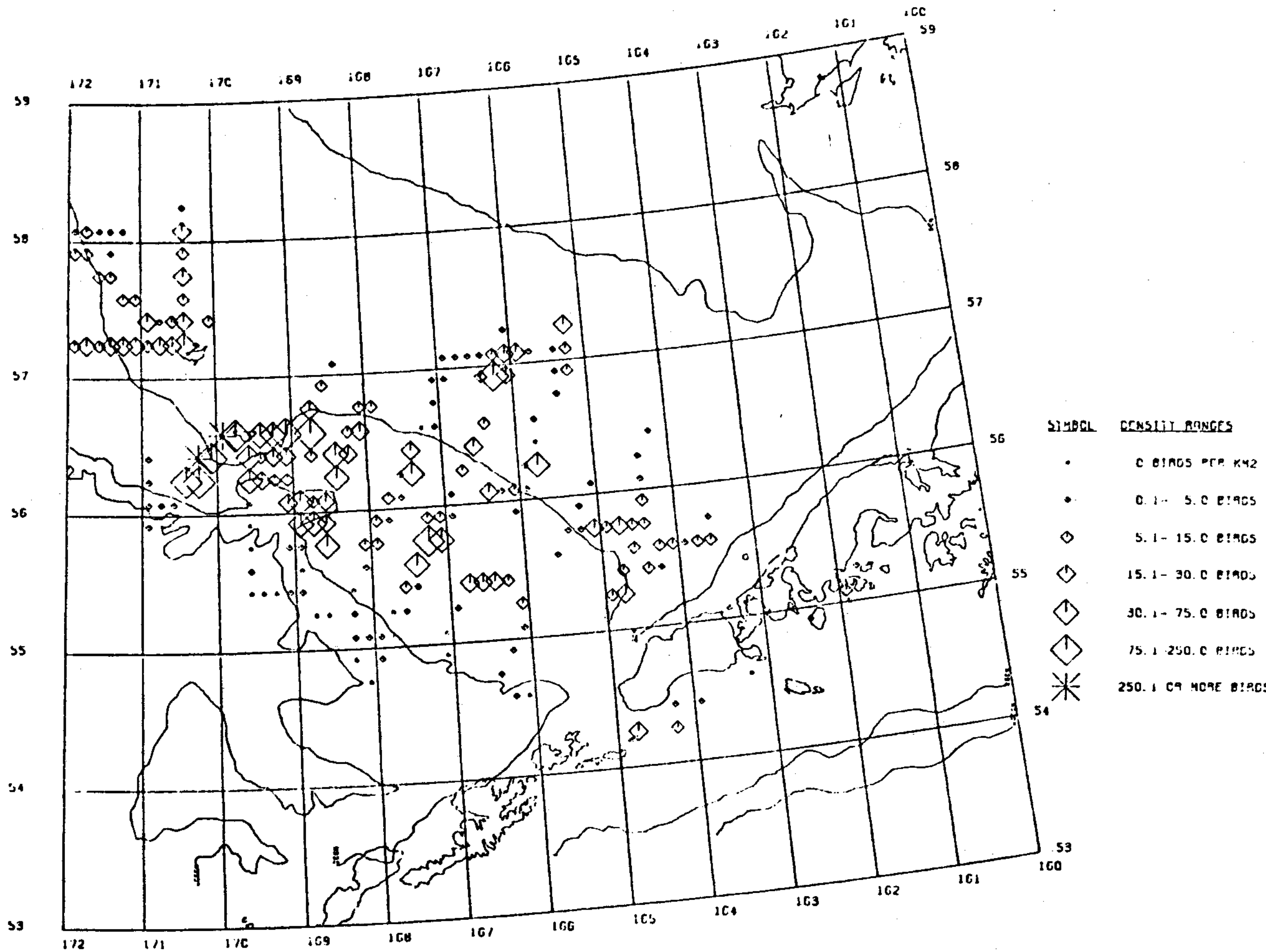
ESTIMATES OF MARINE BIRD POPULATIONS IN THE BERING SEA

Table 1-1. Estimates of marine bird populations in the Bering Sea. These counts were tabulated from the Catalog of Alaskan Seabird Colonies (Sowls et al. 1978), for the Bering Sea west to 174 W, excluding the Aleutian Islands and the south shore of the Alaska Peninsula. Estimates were obtained using the same ratios of estimated to censused numbers used by Sowls et al. (1978) for Alaska waters in general.

Species	Censused population	Estimated population
Northern Fulmars	970,700	1,300,000
Cormorants	41,284	97,000
Double-crested	1,758	2,600
Pelagic	21,656	47,600
Red-faced	16,394	41,300
Glaucous-winged Gull	38,575	84,000
Black-legged Kittiwake	661,239	940,000
Red-legged Kittiwake	226,802	250,000
Murres	5,199,081	9,800,000
Common		4,900,000
Thick-billed		4,900,000
Parakeet Auklet	285,140	530,000
Crested Auklet	833,000	1,200,000
Least Auklet	2,526,000	4,500,000
Horned Puffin	76,036	200,000
Tufted Puffin	751,539	1,400,000

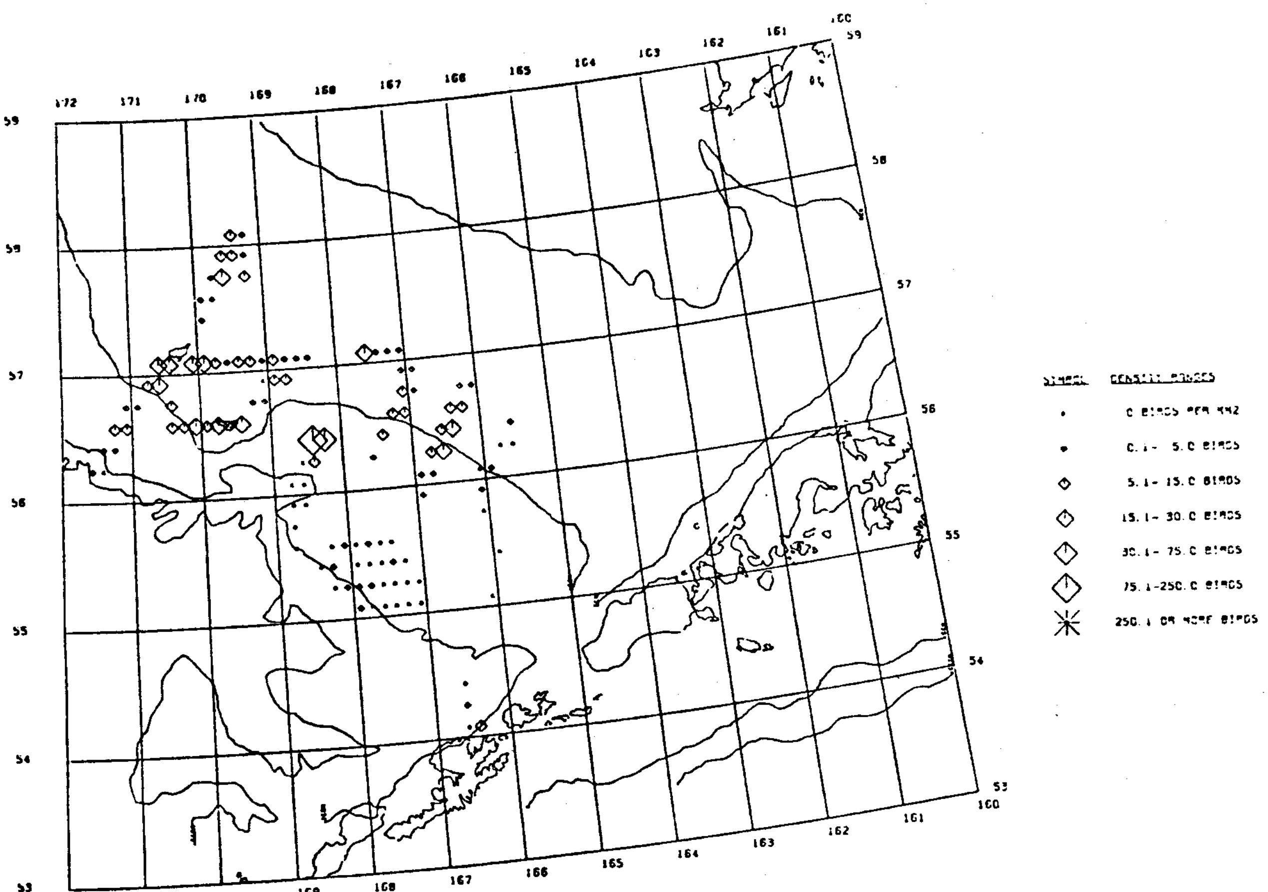
APPENDIX 2

MONTHLY CHANGES IN THE PELAGIC DISTRIBUTION OF MURRES IN 1978



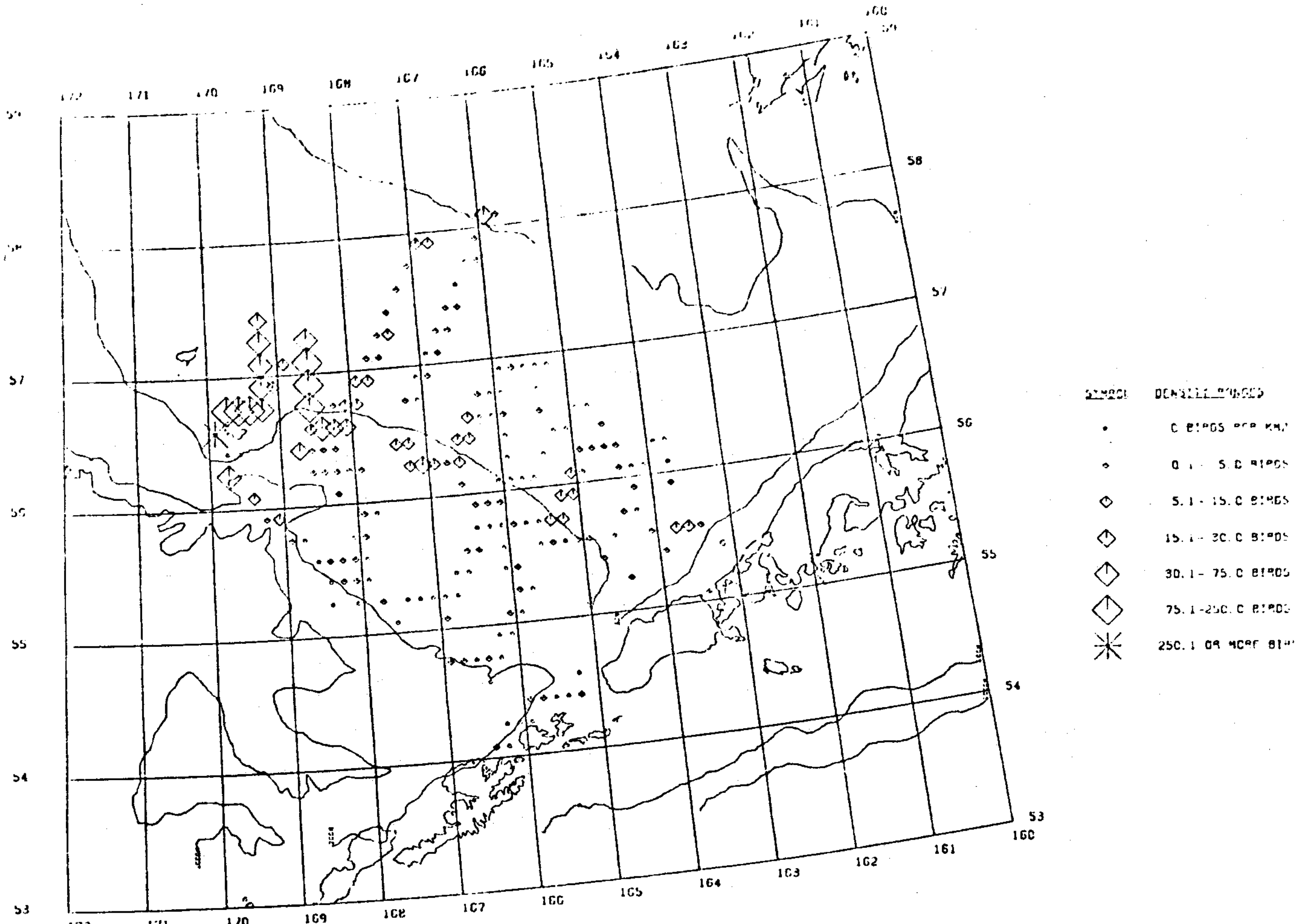
MURRES (ALL)
AIR & SHIP SURVEYS. MARCH - APRIL 1978

FIGURE 2-1



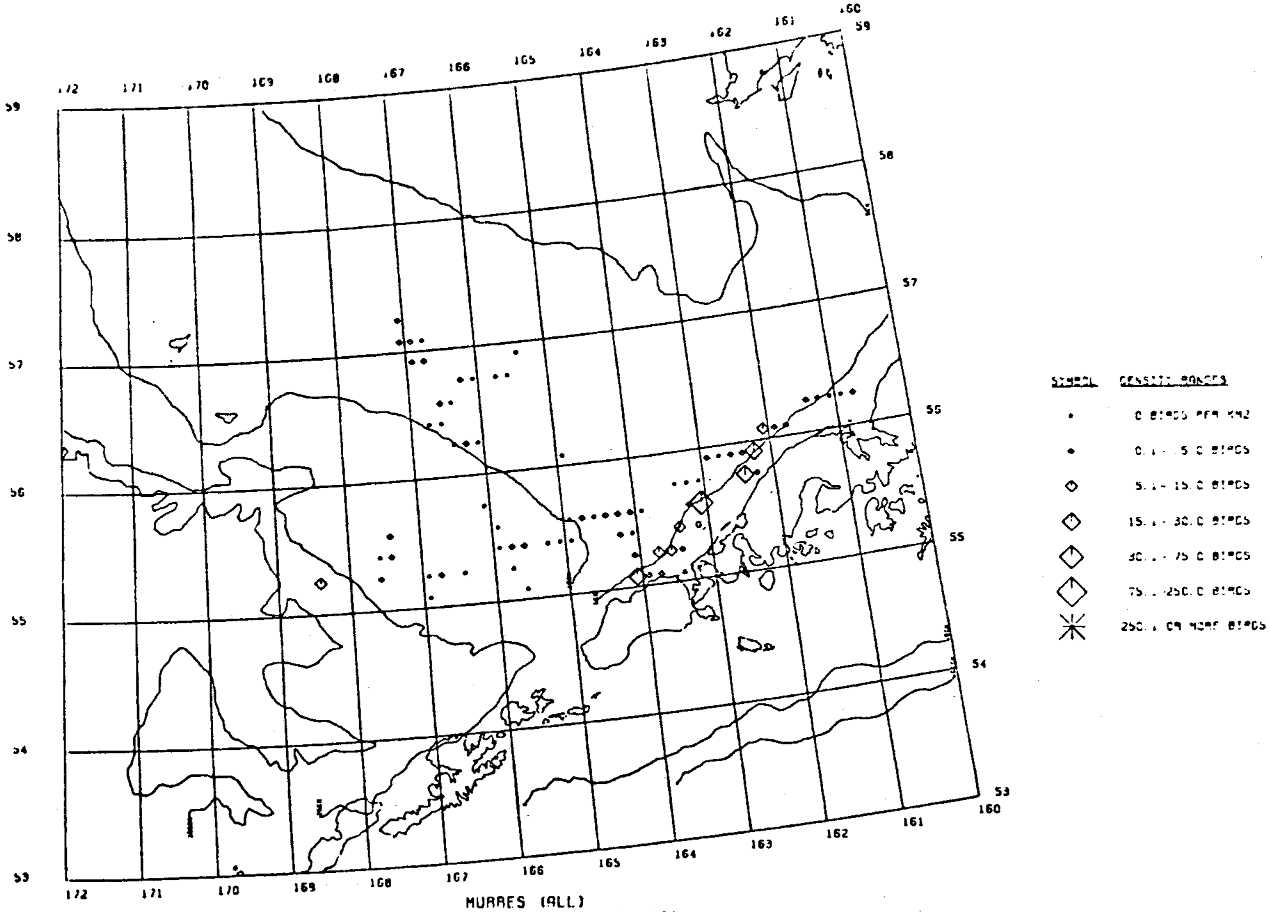
MURRES (ALL)
AIR & SHIP SURVEYS : MAY 1978

FIGURE 2-2



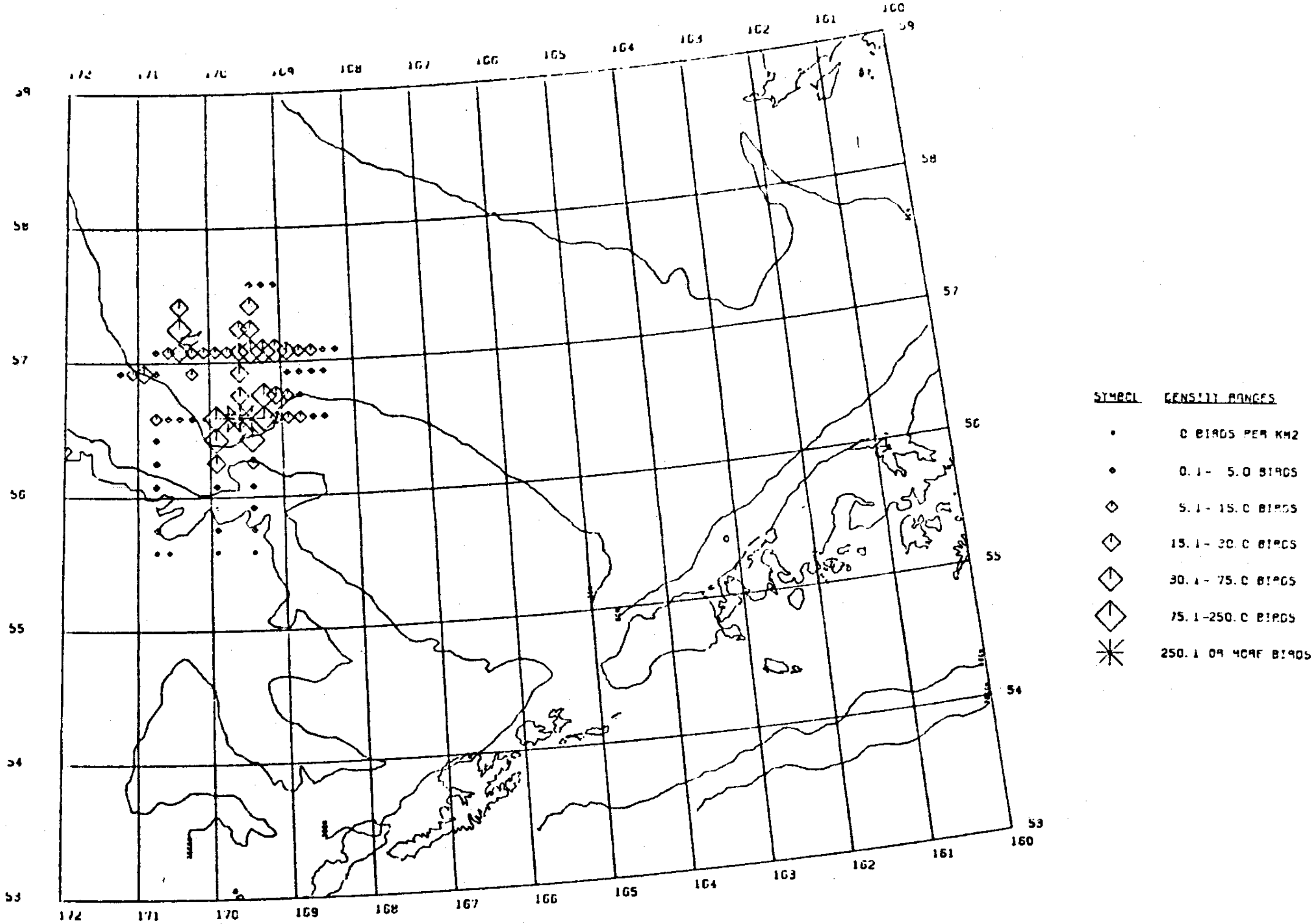
MURRES (ALL)
AIR & SHIP SURVEYS : JUNE 1978

FIGURE 2-3



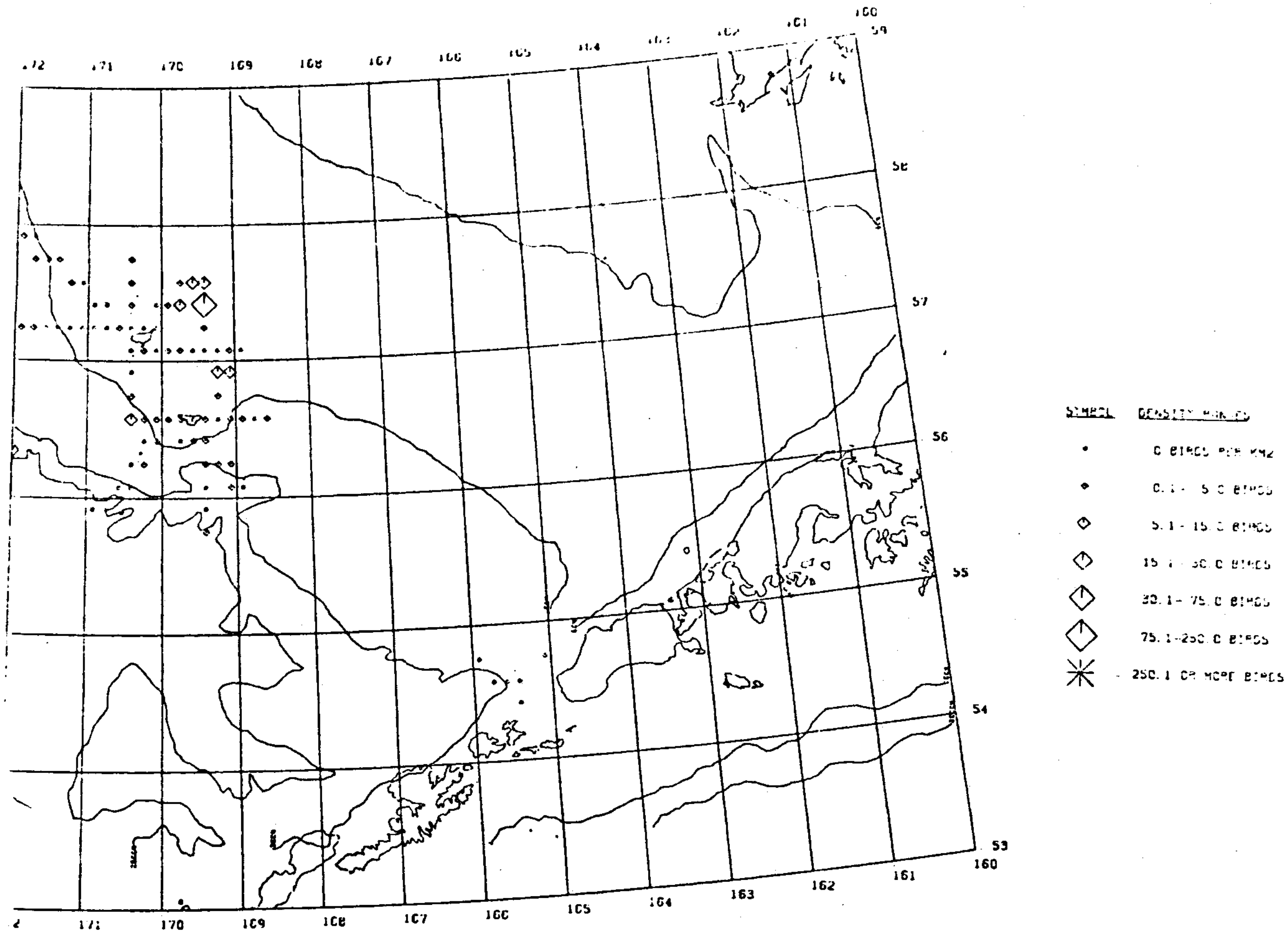
MURRES (ALL)
AIR & SHIP SURVEYS : JULY 1978

FIGURE 2-4



MURRES (ALL)
AIR & SHIP SURVEYS : AUGUST 1978

FIGURE 2-5



MURRES (ALL)
AIR & SHIP SURVEYS : SEPTEMBER 1978

FIGURE 2-6

Contract # 03-5-022-69
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FINAL REPORT

Pelagic and Demersal Fish Assessment in the Lower Cook Inlet Estuary System

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SUMMARY OF OBJECTIVES, AND RESULTS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

This was a multiple part study which included a survey of the nearshore community of fishes and commercial invertebrates in lower Cook Inlet to determine their distributions, relative abundance, seasonal movements and food habits; a review of available information on fisheries of Cook Inlet and Shelikof Strait; and a description of the potential for impact of oil related activities on marine resources of Cook Inlet and Shelikof Strait.

From the nearshore survey sampling, primarily in Kamishak Bay, the numerically predominant taxa in the beach seine catches were Pacific sand lance, juvenile chum salmon, Dolly Varden, juvenile pink salmon, Pacific herring, longfin smelt, whitespotted greenling, Pacific staghorn sculpin, *Myoxocephalus sp*., and starry flounder. The weight predominant taxa in the try net catches were yellowfin sole, Tanner crab, butter sole, flathead sole, Pacific halibut, rock sole, arrowtooth flounder, king crab, *Myoxocephalus sp*., and walleye pollock juveniles. The numerically predominant taxa in the tow net catches were Pacific sand lance, Pacific herring, whitespotted greenling, capelin, juvenile pink, sockeye, chum and chinook salmon. The numerically predominant species in the gill net catches were adult Pacific herring, chum salmon, Dolly Varden, and Bering cisco. The numerically predominant species in the trammel net were adult Pacific herring, whitespotted greenling, sturgeon poacher, yellowfin sole, masked greenling and Pacific staghorn sculpin. Features of distribution, seasonality and growth are presented.

A survey of nearshore fish while SCUBA diving at 3 to 23 m below the surface was conducted and is included as Appendix II. The composition of the ichthyofauna was different at each location. Non-schooling species predominated the nearshore fish fauna in all rocky locations. Sculpins, greenlings, ronquils and rockfishes were the major families in the rocky subtidal zone. However, only greenling were common on rock habitats in Kamishak Bay. Black rockfish and dusky rockfish were the most abundant schooling fish in the rocky subtidal zone in Kachemak Bay, while Alaskan ronquil and kelp greenling were the predominant demersal species. Whitespotted and masked greenling were the predominant demersal fishes on rock habitat in Kamishak Bay. Flatfish predominated the demersal fishes of soft substrates in both Kachemak and Kamishak bays. Important species on a sand beach in summer included Pacific sand lance, Pacific staghorn sculpin, English sole, rock sole, sturgeon poacher and Dolly Varden while only Pacific sand lance, Pacific staghorn sculpin and surf smelt were seen in winter.

Food habits were detetmined by stomach analysis for several species, including sand lance, herring, salmon, Dolly Varden, smelt, flounders and sculpins. Generally, each species had eaten a variety of prey, including copepods, decapod larvae, fish eggs and larvae, gammarid amphipods, clams, polychaetes, and insects. Food habits of other commercially important species, including crabs, shrimp, halibut and Pacific cod, were summarized from literature.

Important commercial fisheries in the Cook Inlet, Shelikof Strait area include five species of salmon, halibut, herring, king crab, Tanner crab, dungeness crab, shrimp, bottomfish and to a lesser extent, razor clams and scallops have been harvested. The fisheries history, size, distribution and seasonality are presented.

The residence time of oil spill contamination in lower Cook Inlet and Shelikof Strait depends upon the retention of oil in the water column, in coastal sediments, and along the shoreline. The various environmental conditions affecting the retention of oil in the marine environment inlcude circulation, tidal range, suspended sediments, bathymetry, bottom type, coastal morphology and winds. The physical processes and environmental conditions which will determine the residence time of oil or other contaminants in lower Cook Inlet as a whole as well as in each of the natural regions of lower Cook Inlet and Shelikof Strait are discussed. Drilling muds and cuttings, discharged during drilling of exploratory wells may result in adverse impacts to the marine environment such as toxicity to marine life, pollution of the substrate and smothering of benthic organisms. Relative sensitivities of pelagic and demersal species are given.

Polluted formation waters may affect both individual organisms and entire populations by causing short term (acute of lethal) biological effects such as death or long term (chronic or sublethal) effects including abandonment of a habitat and interference with the growth and reproduction.

Conflicts between drilling platforms and the commercial fishing industry may result in physical loss of fishing area, interference with fishing gear and vessels, direct effects of oil pollution on commercial species, and tainting of commercial species by oil pollution.

Impacts on the marine ecosystem by shore-based facilities arise from habitat destruction (site preparation or alteration), siltation of adjacent waters, the use of cooling waters, oil pollution, and interference with commercial fishing.

Dredging during pipeline laying affects fish resources in the coastal environment by 1) the physical destruction of benthic habitat, 2) altering water quality through the suspension of sediments which may contain toxic chemicals and have a high biological oxygen demand, 3) smothering benthic organisms when suspended silt and over burden are deposited on adjacent areas, 4) modifying water circulation patterns through the alteration of natural bottom contours and features, 5) modifying salinity concentrations in estuaries by changes and disruption of freshwater inflow, and 6) direct mortality when marine life is swept into dredging equipment. The effects of dredging may be short on long-term, depending upon the area dredged, the amount of material removed and the extent to which bottom contours and natural features are altered.

Long-term studies of several major oil spills indicate that oil have the following effects on marine life: 1) direct kill of organisms through coating and asphyxiation, 2) direct kill through contact poisoning, 3) direct kill through exposure to water soluble toxic components of oil at some distance in space and time from the spill, 4) destruction of the sensitive juvenile forms, 5) destruction of the food sources of higher organisms, 6) incorporation of sublethal amounts of oil and oil products into organisms, resulting in failure to reproduce, reduced resistance in infection, or physiological stress, 7) contraction of diseases due to exposure to carcinogenic components of oil, 8) chronic low level effects that may interrupt any of the numerous biochemical or behavioral events necessary for the feeding, migration, or spawning of many species of marine life and 9) changes in biological habitats. Oil polluted marine waters affect humans by reducing recreational opportunitites, tainting the flesh of commercial species of marine fish and crustaceans (e.g. halibut, clams, crabs, and salmon) and reducing commercial fisheries production. Potential conflicts between oil tankers and fishing activities include loss of fishing habitat from over crowding and increased navigational problems, interference with and destruction of gear, competition for space and services, and oil contamination and tainting from spills and ballast waste water disposal.

INTRODUCTION

General Nature and Scope of Study

This study is part of a survey of the nearshore finfish and commercial crab resources and food web relationships of lower Cook Inlet. Source material includes field collections and food habits analysis which constitute the bulk of the report. Field collections were made from April through October with collections in April and October made in Kachemak Bay and the remainder made in northern Kamishak Bay. This study is only one of a coordinated set of studies of several aspects of the Cook Inlet system which include bird, mammal, benthic invertebrates, plankton and several other studies by OCSEAP investigators.

Specific Objectives

1. Determine the feeding habits of principle life stages of dominant pelagic and demersal fish and provide an initial description of their role in the food web.

2. Describe the distribution and relative abundance of pelagic and demersal fish and their seasonal changes.

3. Identify areas of unusual abundance or of apparent importance to fish, especially commercially important species.

4. Review all past information on the fisheries in lower Cook Inlet including commercial and sports catch statistics in order to determine the past and future trends in the importance of these species and to define the geographical and seasonal locations of fishing areas.

5. Define the geographical locations and seasonal use of spawning areas to the highest resolution possible.

6. Identify the geographical and seasonal locations of important prey.

7. Describe and evaluate the potential for impact on commercial, potentially commercial, and sports fisheries by OCS oil and gas explorations, development, and production based on the findings of the above six objectives plus existing information on the sensitivity of various life stages of these species, and geographical areas of potential risk.

Relevance to Problems of Petroleum Development

Oil exploration in the Cook Inlet lease area constitutes a potential for environmental degradation and it is a legal requirement of the leasing agency, Bureau of Land Management (BLM), to consider this potential as a part of the cost of leasing. This study was funded by BLM as a part of the program to satisfy their requirements.

Study of the living marine resources of Cook Inlet is an especially pertinent portion of the pre-lease studies as the livelihood of the vast majority of the people of this area is based upon the harvest of renewable resources.

Acknowledgements

The personnel of the OCSEAP Juneau Project Office contributed considerably to the planning and execution of this study, especially George Lapiene and Paul Becker. All vessel support and field camp support was arranged by them.

The employees that conducted the sampling did a fine job and they were Jay Field, crew leader, Jim Sicina, Dan Locke, Robert Sanderlin, Harry Dodge and Tom Bledsoe. Karen Anderson conducted all the food habits analysis and Bill Johnson created the computer routines to analyze the data.

This study was supported by the Bureau of Land Management through interagency agreement with the National Oceanic and Atmospheric Administration, under which a multi-year program responding to needs of petroleum development of the Alaskan continental shelf is managed by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) Office.

CURRENT STATE OF KNOWLEDGE

In the Cook Inlet area previous survey type data on marine resources is largely lacking. The National Marine Fisheries Service (NMFS) conducted approximately 85 otter trawl hauls in Cook Inlet during 1958, 1961 and 1963 and these are summarized by Ronholt et al. (1978). The vessels were rigged for crab and operated between mid-July and late September.

A compilation of existing information on the Cook Inlet fisheries was prepared by the Alaska Department of Fish and Game under a program funded by the Federal Coastal Zone Management Program Development Funds (McLean et al., 1976). This work included a written narrative and a portfolio of mapped data. The narrative included characterizations of each fishery and the tabularizations of statistical data. Historical catch, effort, economic value, and escapement statistics were included. The map section included distribution mappings for all significant finfish and shellfish species, major fishing areas for all commercial species, critical salmon and shellfish spawning areas by species, where known, and shellfish rearing areas by species, where known.

A study of the effects of oil on biological resources was funded by the State of Alaska as a result of public concern over Alaska's 28th Oil and Gas Lease Sale of subtidal land in Kachemak Bay. These studies included the fishery resources, birds, coastal morphology, circulation and a synthesis of the impact of oil on the Kachemak Bay environment (Trasky et al., 1977).

The studies initiated in 1976 under the Outer Continental Shelf Environmental Assessment Program (OCSEAP) were hastily assembled and were faced with a paucity of data concerning what to expect. The scope was broad: as much of the inlet as could be physically covered efficiently. Sampling was conducted with beach seines and surface tow nets from the east Forelands to Port Graham on the east side of the inlet and from Amakdedori Beach to Chinitna Bay (with a few samples further north) on the west side of the inlet. Surveys were repeated monthly during June through September of 1976. An otter trawl was successfully used in the central portion of the inlet during June, July, August, September 1976 and March 1977. A power purse seine and gill nets were used to study pelagic fish during July, August and September 1976. A number of conclusions resulted from this study as did some questions (Blackburn, 1978).

In preparation for Cook Inlet Oil Lease Sale No. 60 a summary of available information on the Cook Inlet - Shelikof Strait area was prepared in October 1978 (Marine/Coastal Habitat Management, M.C.H.M., 1978). Much of the historical information reviewed in the current report was reviewed in that document, also. The M.C.H.M. document addressed fisheries resources, marine birds, marine mammals, circulation, and hazards and potential impacts.

The M.C.H.M. prepared a report with recommendations for minimizing the impacts of hydrocarbon development on living resources in Cook Inlet (Hamilton et al., 1979). This study was focused on impact potentials and their interaction with known resources. Materials from that report have been incorporated in this report.

Since this project was initiated the lease area has been expanded into Shelikof Strait. Information on resources in Shelikof Strait is quite limited. Ronholt et al. (1977) gathered together the results of all past NMFS trawl surveys in the north Pacific area, including those conducted in Shelikof Strait and lower Cook Inlet. From this report general species abundance can be obtained but distributional features within Shelikof are not clear.

Various fisheries have existed in the lease area for some time and information based on these fisheries and supporting management of these fisheries has been accumulating. A summary of pertinent information follows.

Salmon

All five species of Pacific salmon are harvested in the Cook Inlet - Shelikof Strait area. Pink salmon predominate in numbers of fish throughout the area with red salmon second in importance in Cook Inlet and third in the Kodiak area while chums are second in importance in Kodiak and third in Cook Inlet. Cohos rank fourth and kings fifth.

Pink salmon harvests are important throughout the area (Figures 1 and 2) with greatest catches generally north of Anchor Point, in Kachemak Bay, along Kodiak and Afognak islands and scattered along the shore of the Alaska Peninsula. Pinks spawn in virtually every stream with suitable spawning habitat throughout the area (Figures 3, 4 and 5). Pink salmon runs are not well known in the streams north of Anchor Point on both sides of Cook Inlet, due to silty water which makes counting from an airplane impossible, and emphasis has been placed on red salmon in this area. Over a million pink salmon have been estimated to return to the Susitna in one year (McLean et al., 1976). On the west side of Cook Inlet, from Bruin Bay to Cape Douglas there are eight rivers with runs of pink salmon estimated at about 10,000 or more. On the east side of Cook Inlet from Kachemak Bay south there are five rivers with runs of pink salmon estimated at 10,000 or more. On the Alaska Peninsula shore of Shelikof Strait there are seven streams in which average aerial counts exceed 10,000 pink salmon and on the Shelikof Strait side of the Kodiak Archipelago there are 14 streams in which average aerial counts exceed 10,000 pinks. Most notably the Karluk River and Red River on southwest Kodiak have averaged 380,000 and 320,000 pinks respectively (Figures 3, 4 and 5; App. Table 24). Both these rivers have much stronger runs on even years and each had more than a million fish in 1978.

Red salmon are harvested in nearly all areas of Cook Inlet - Shelikof Strait to some extent, but the greatest catches are in Cook Inlet north of Anchor Point, on the south side of Kachemak Bay, in the bays on the west side of the Kodiak Archipelago and in the Cape Igvak area of southwest Shelikof Strait where reds destined for Chignik are caught (Figures 6 and 7).

Since red salmon normally reside in a lake for one or two years before going to sea, there are fewer rivers that contain them and the few really large systems produce the bulk of them (Figures 3, 4, and 5; App. Table 24). In upper Cook Inlet, the primary rivers are the Kenai and Kasilof, while considerable runs have been counted in the Susitna River. There are a few other red salmon rivers in lower Cook Inlet, the largest are Crescent River, immediately north of Tuxedni Bay, English Bay River on the tip of the Kenai Peninsula and Mikfik Creek in southern Kamishak Bay. Kamishak Bay is unique in the number of small red salmon streams present. On the Alaska Peninsula side of Shelikof Strait there are runs of over 5,000 reds in two rivers. On the Shelikof Strait side of the Kodiak Archipelago there are 13 streams with red salmon runs, most notably the Karluk and Red rivers with average returns of 350,000 and 150,000 reds per year in the last ten years. In addition there are three rivers with more than 10,000 (two of which have been surveyed only in 1978).

Chum salmon are harvested throughout the lease area (Figures 8 and 9) with greatest catches between Anchor Point and the Forelands, in Chinitna Bay, Iliamna - Iniskin Bay in Kamishak, in the Port Chatham area on the tip of the Kenai Peninsula, in the Kukak Bay area and Wide Bay on the

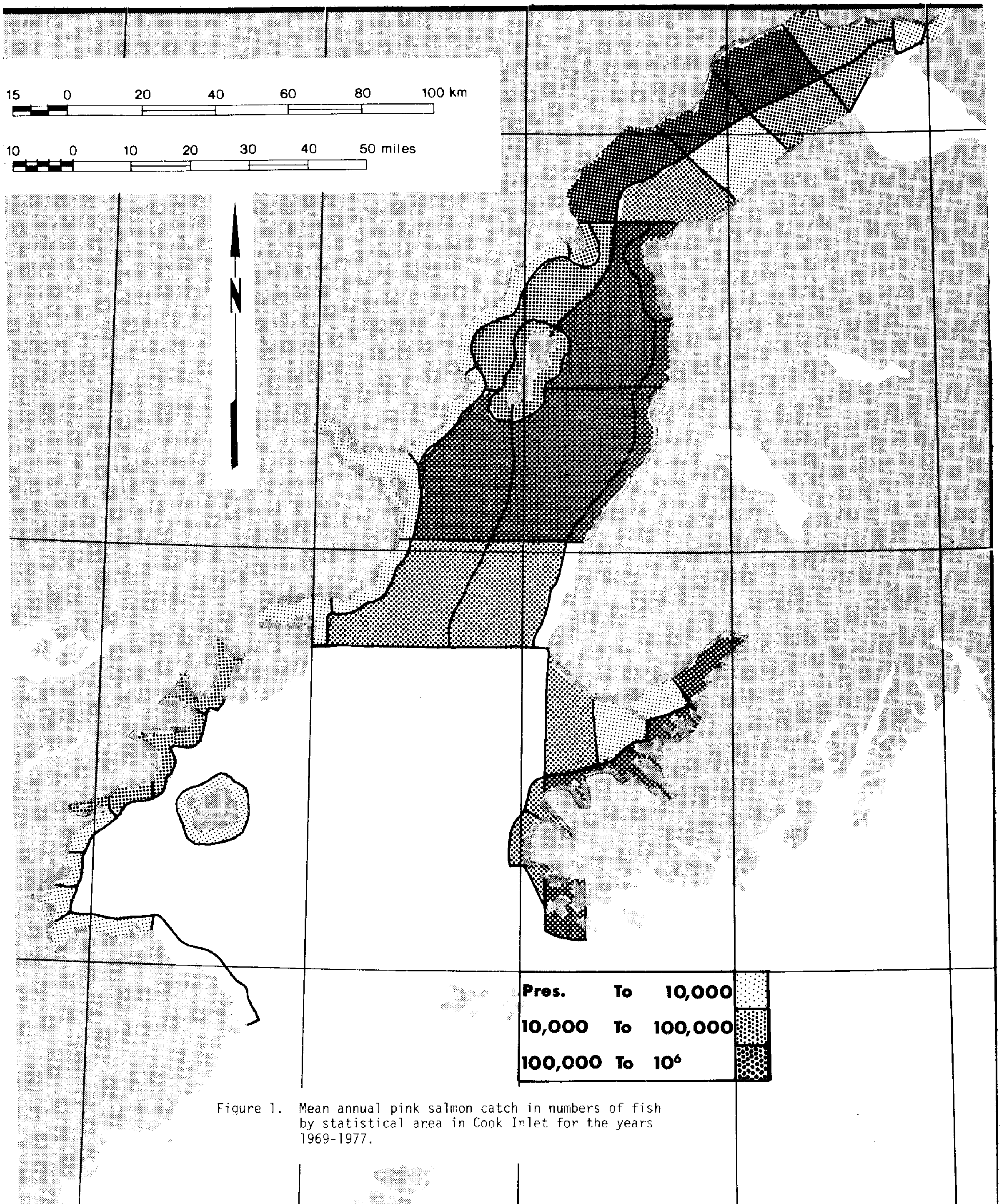


Figure 1. Mean annual pink salmon catch in numbers of fish by statistical area in Cook Inlet for the years 1969-1977.

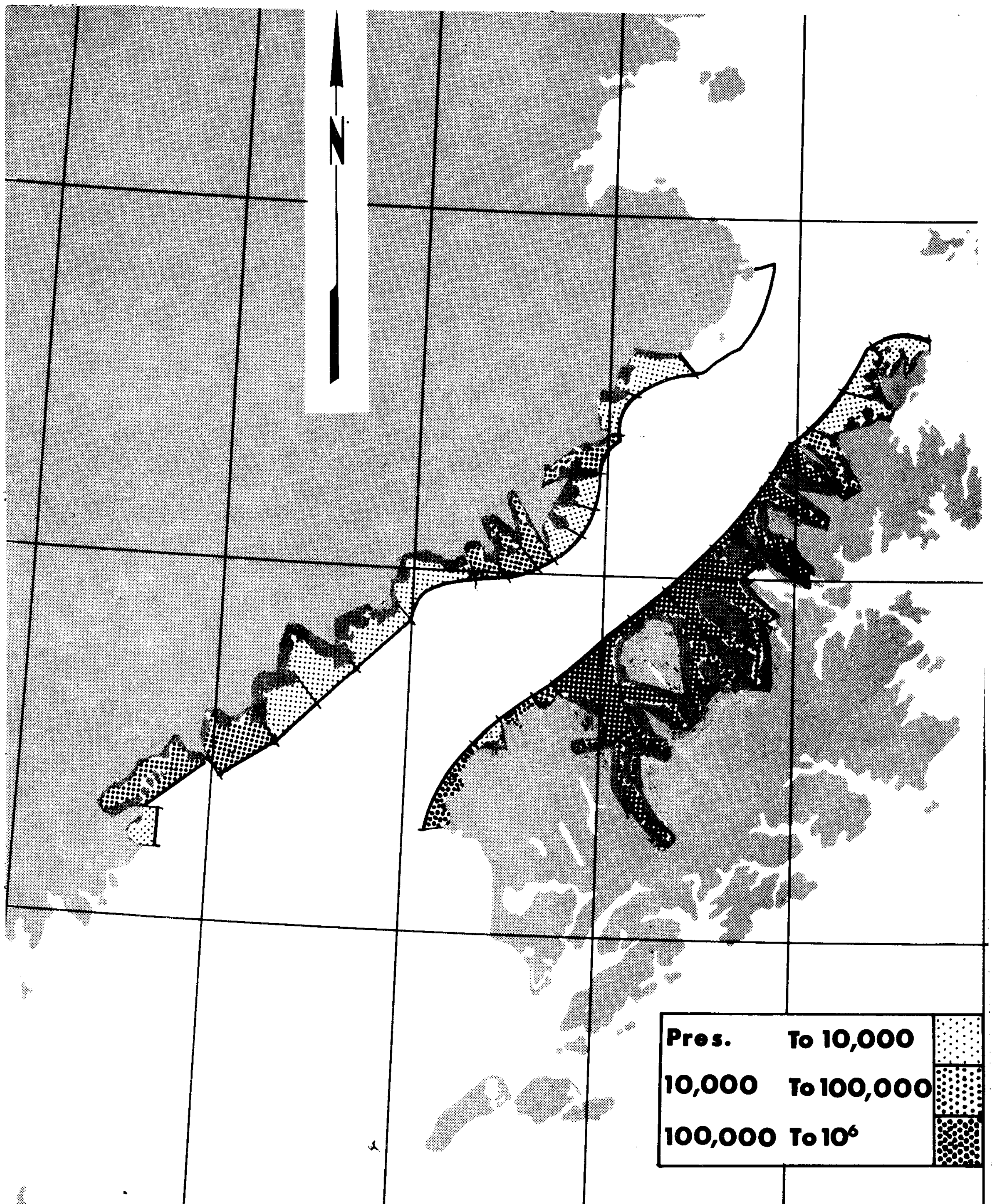


Figure 2. Mean annual pink salmon catch in number of fish by statistical area in Shelikof Strait for the years 1969-1977.

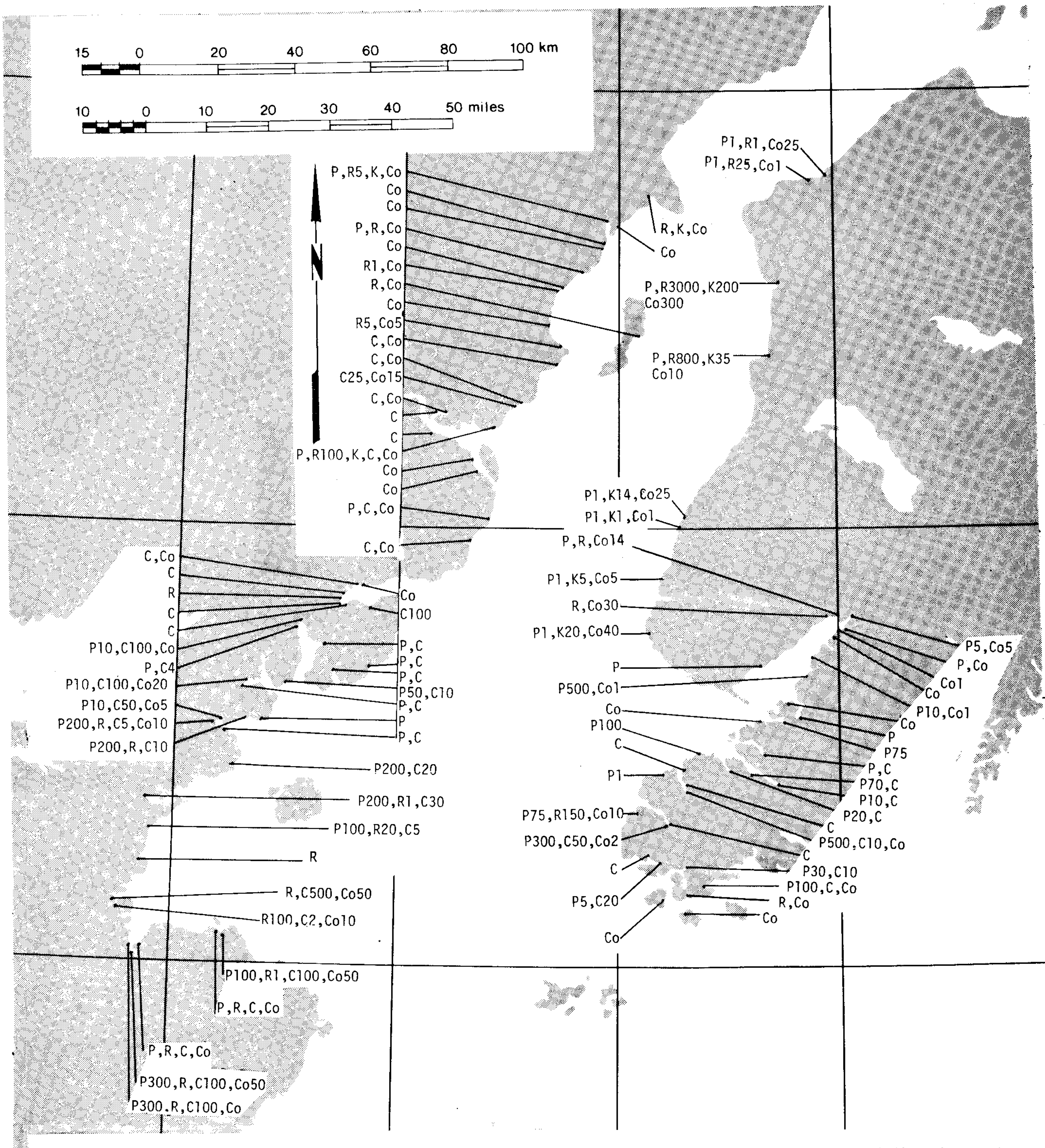


Figure 3. Salmon spawning streams in lower Cook Inlet. The species and run size, shown in hundreds of fish, is based on Hamilton et al. (1979). The symbols indicate: P - pink salmon, R - red salmon, Co - coho salmon, K - king salmon, C - chum salmon.

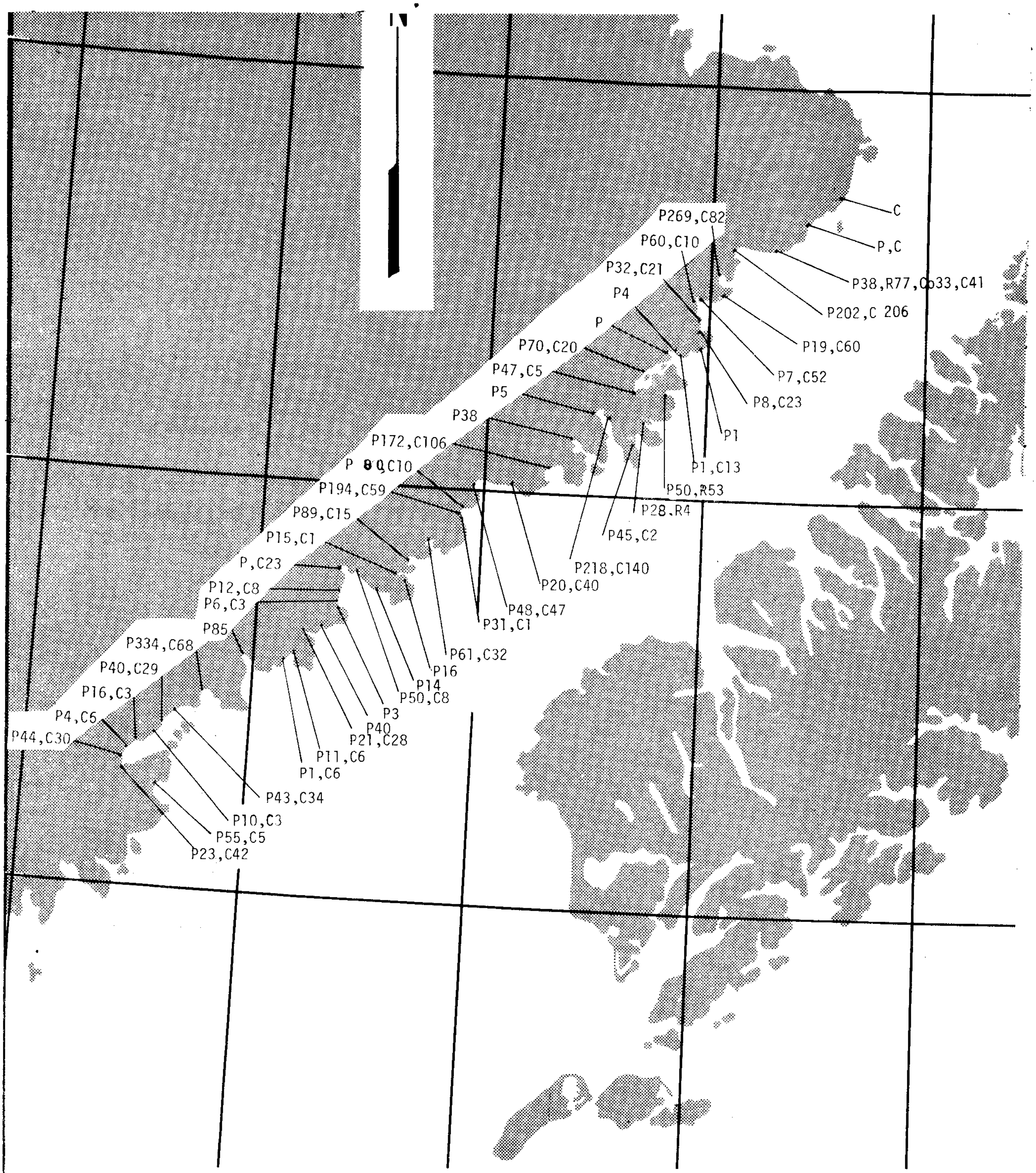


Figure 4. Salmon spawning streams on the Alaska Peninsula side of Shelikof Strait. The species and run size, shown in hundreds of fish, is based on aerial counts and weir counts from data files maintained by ADF&G as "Peak Counts" for the years 1969 through 1978. The symbols indicate: P - pink salmon, R - red salmon, Co - coho salmon, K - king salmon, C - chum salmon.

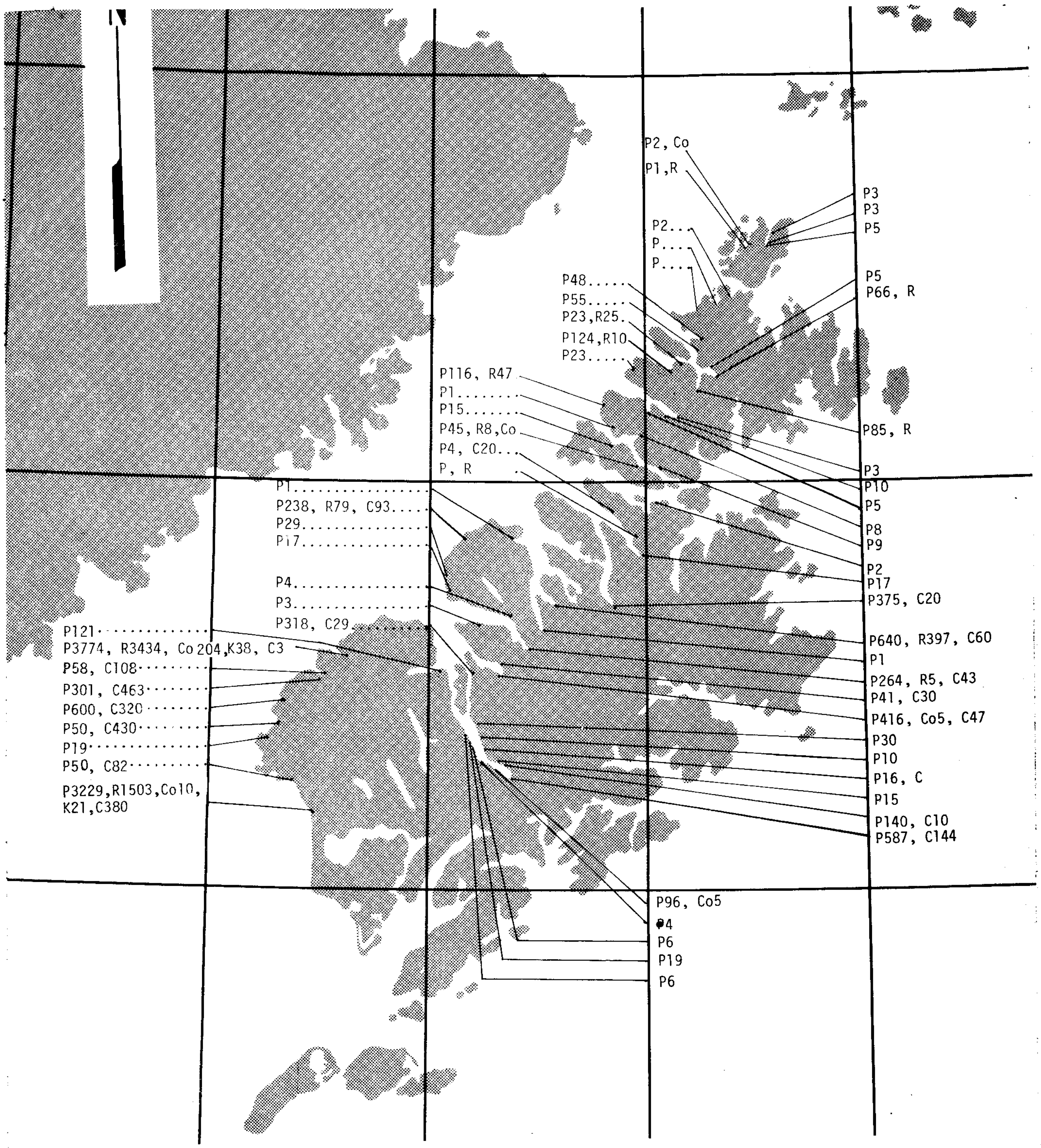


Figure 5. Salmon spawning streams on the west side of the Kodiak Archipelago. The species and run size. shown in hundreds of fish, is based on aerial counts and weir counts from data files maintained by ADF&G as "Peak Counts", for the years 1969 through 1978. The symbols indicate: P - pink salmon, R - red salmon, Co - coho salmon, K - king salmon, C - chum salmon.

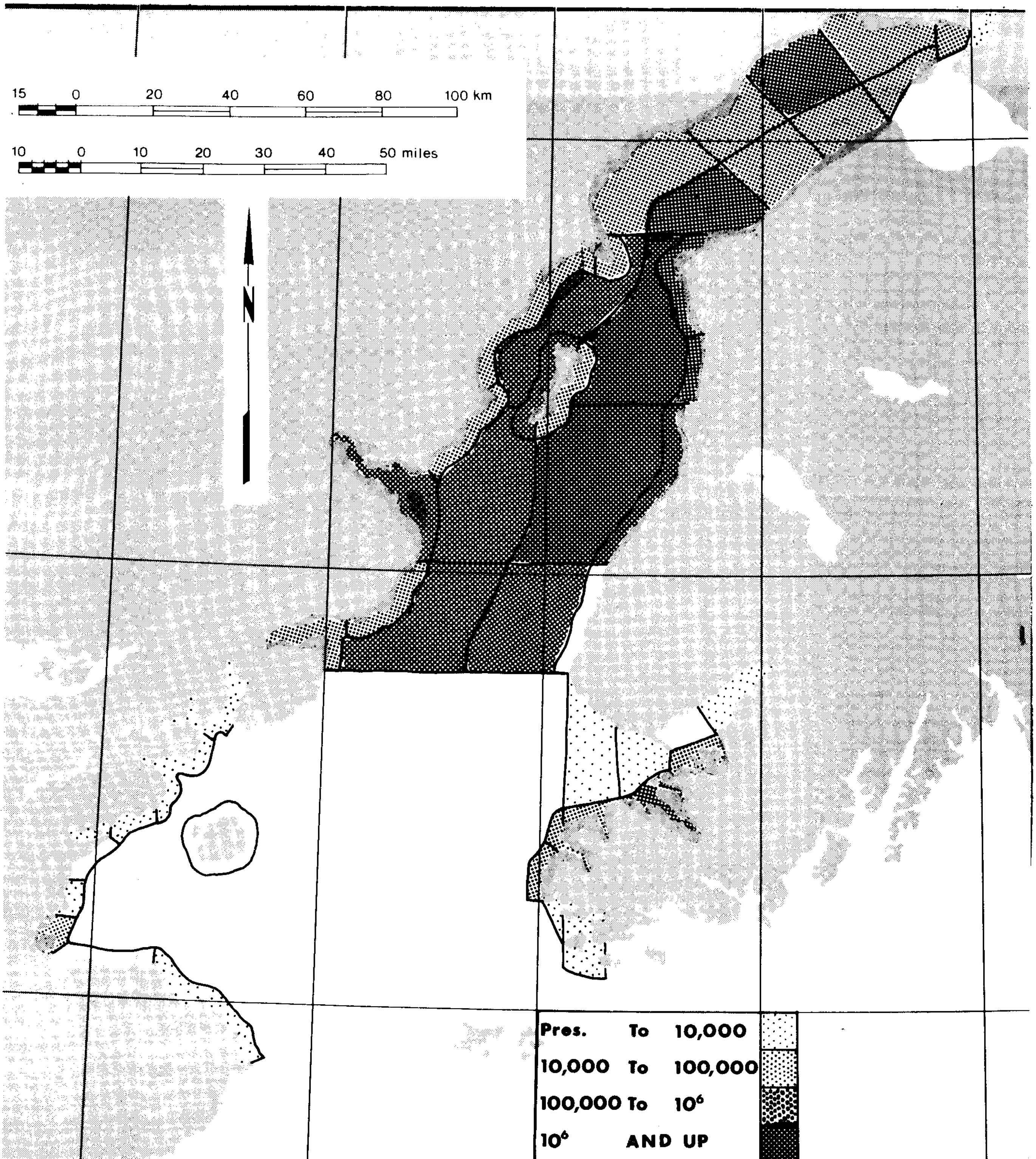


Figure 6. Mean annual red salmon catch in numbers of fish by statistical area in Cook Inlet for the years 1969-1977.

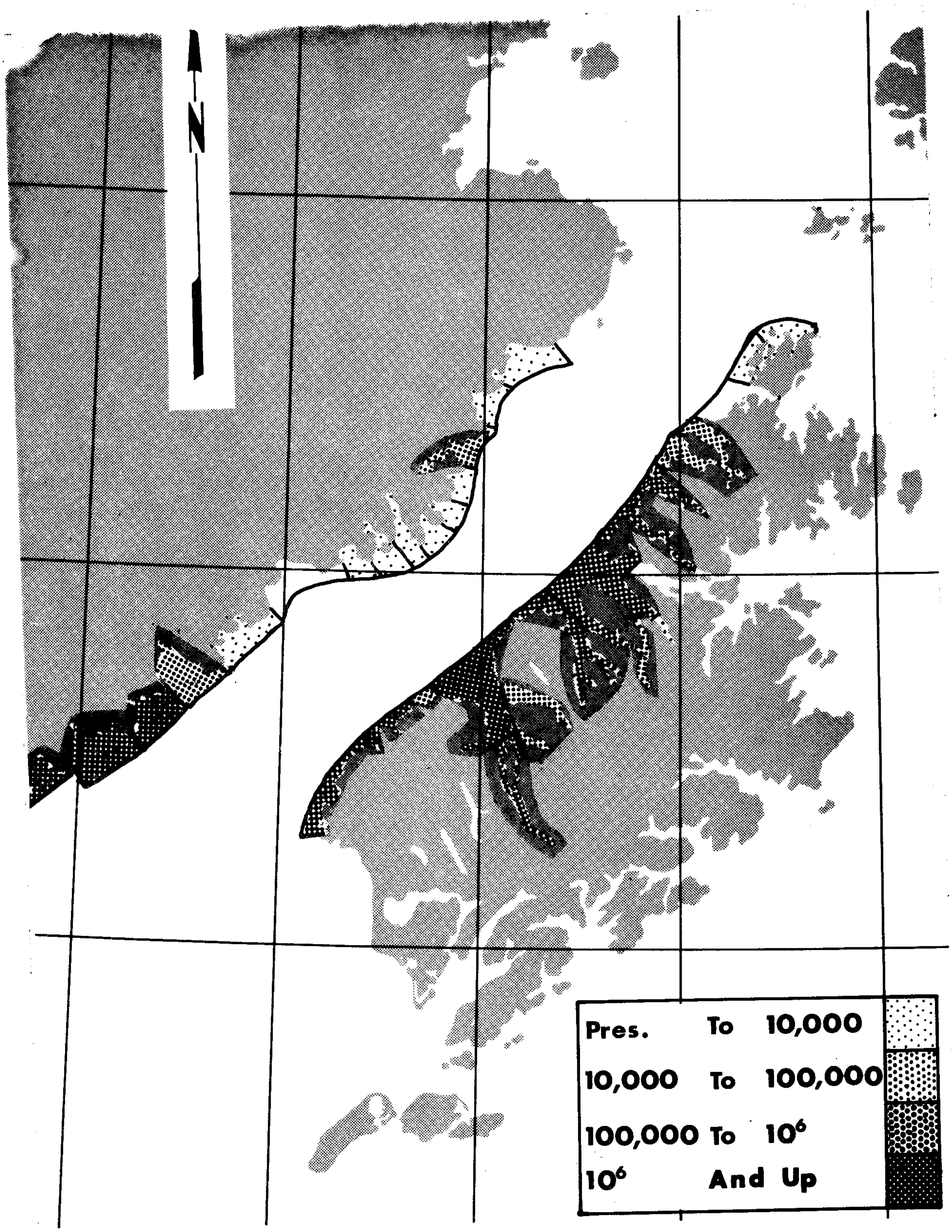


Figure 7. Mean annual red salmon catch in numbers of fish by statistical area in Shelikof Strait for the years 1969-1977.

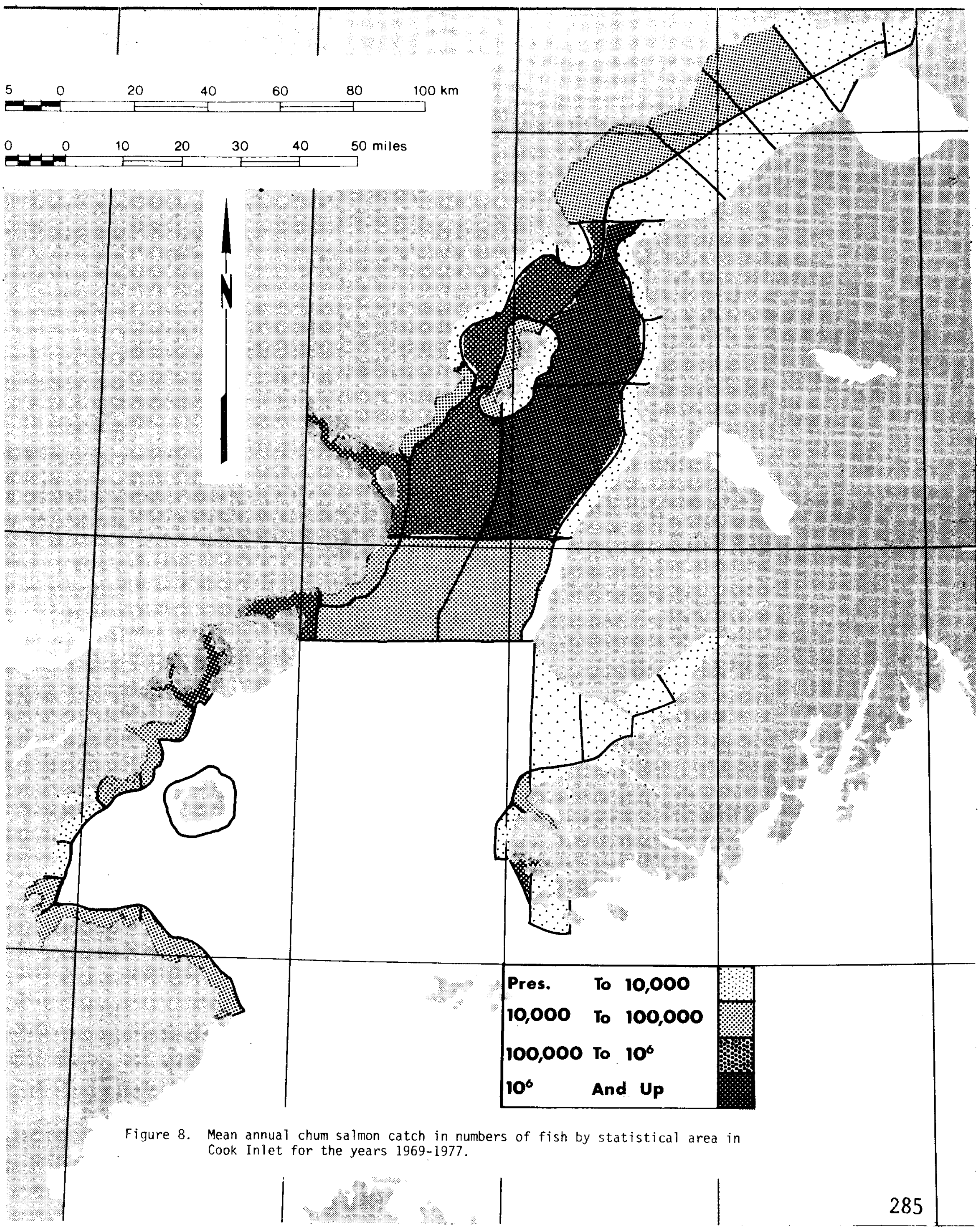


Figure 8. Mean annual chum salmon catch in numbers of fish by statistical area in Cook Inlet for the years 1969-1977.

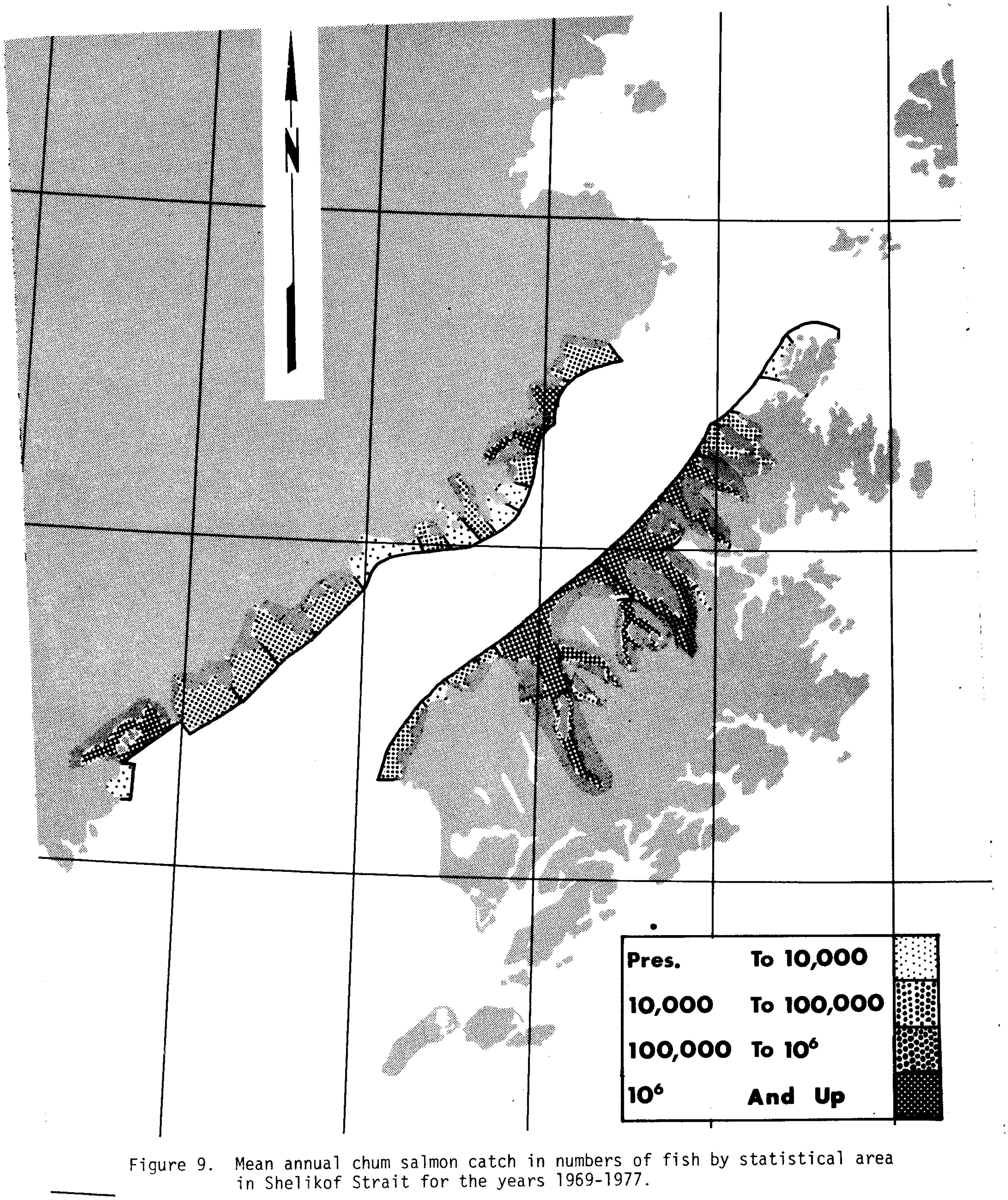


Figure 9. Mean annual chum salmon catch in numbers of fish by statistical area in Shelikof Strait for the years 1969-1977.

Table 34. Numbers of red and northern phalaropes observed on beach transects in the Simpson Lagoon-Jones Islands area during August, 1977 and 1978. Each of the 15 standardized transects was 1 km long; the extra single transect was 1.2 km long.

	August 1977											
	1	2	3	6	8	12	14	16	23	24	26	Total
Number of Red Phalaropes	150	4	77	193	525	69	16	3470	262	1340	24	6130
Number of Northern Phalaropes	0	0	53	60	51	23	0	1220	52	40	17	1516
Northern/Red Ratio	0/150	0/4	1/1.5	1/3.3	1/10.3	1/3	0/16	1/2.8	1/5	1/33.5	1/1.4	1/4.0
Number of Transects Surveyed	15	1	1	1	1	1	1	15	1	15	1	53

	August 1978															
	2	4	7	9	11	13	14	17	19	21	24	26	28	29	31	Total
Number of Red Phalaropes	0	37	0	23	22	4	277	4	242	0	104	7	0	232	97	1049
Number of Northern Phalaropes	0	6	0	2	0	0	0	0	103	0	10	1	0	112	27	261
Northern/Red Ratio	0/0	1/6.2	0/0	1/11.5	0/22	0/4	0/277	0/4	1/2.4	0/0	1/10.4	1/7	0/0	1/2.1	1/3.6	1/4.0
Number of Transects Surveyed	1	16	1	16	1	1	16	1	16	1	16	1	1	16	1	105

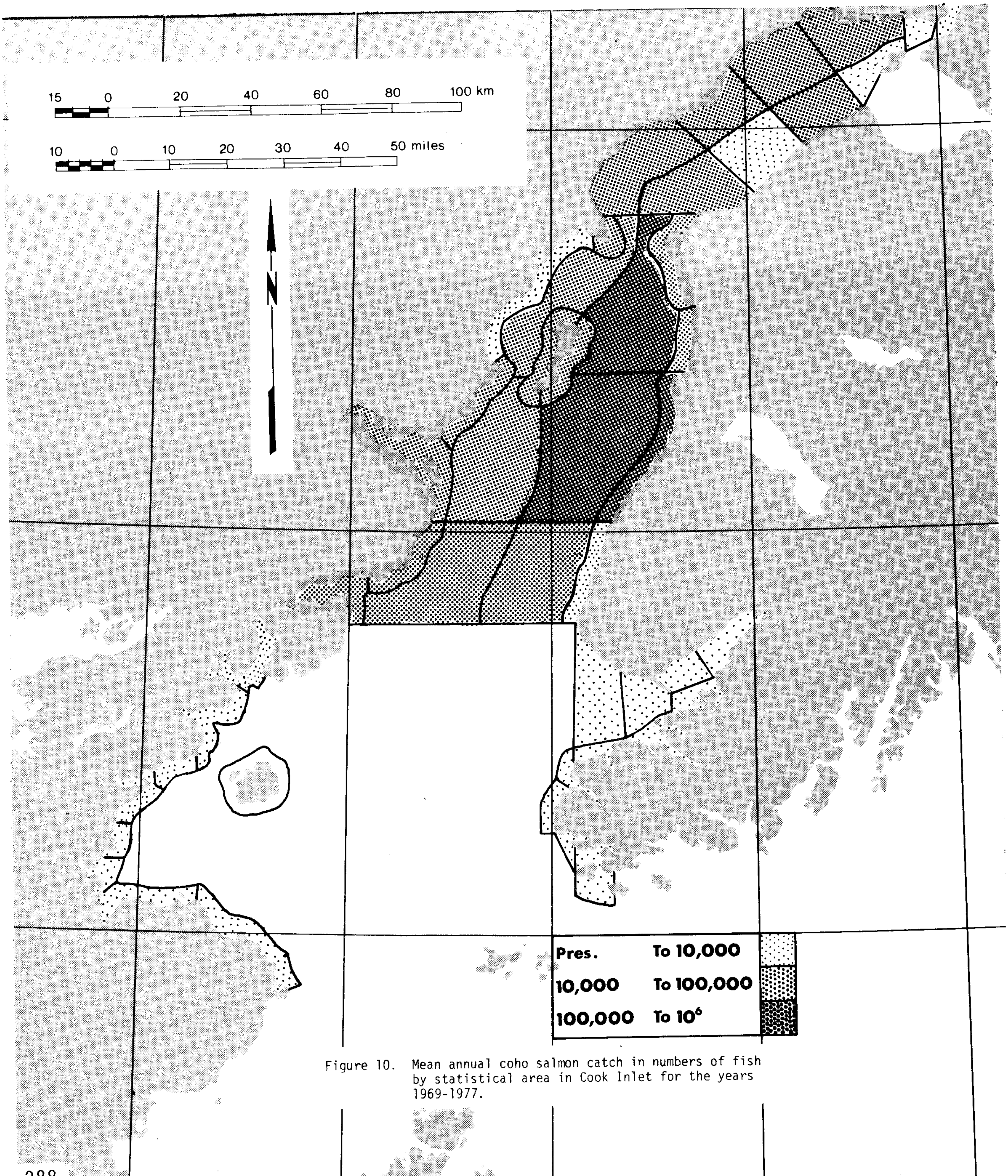


Figure 10. Mean annual coho salmon catch in numbers of fish by statistical area in Cook Inlet for the years 1969-1977.

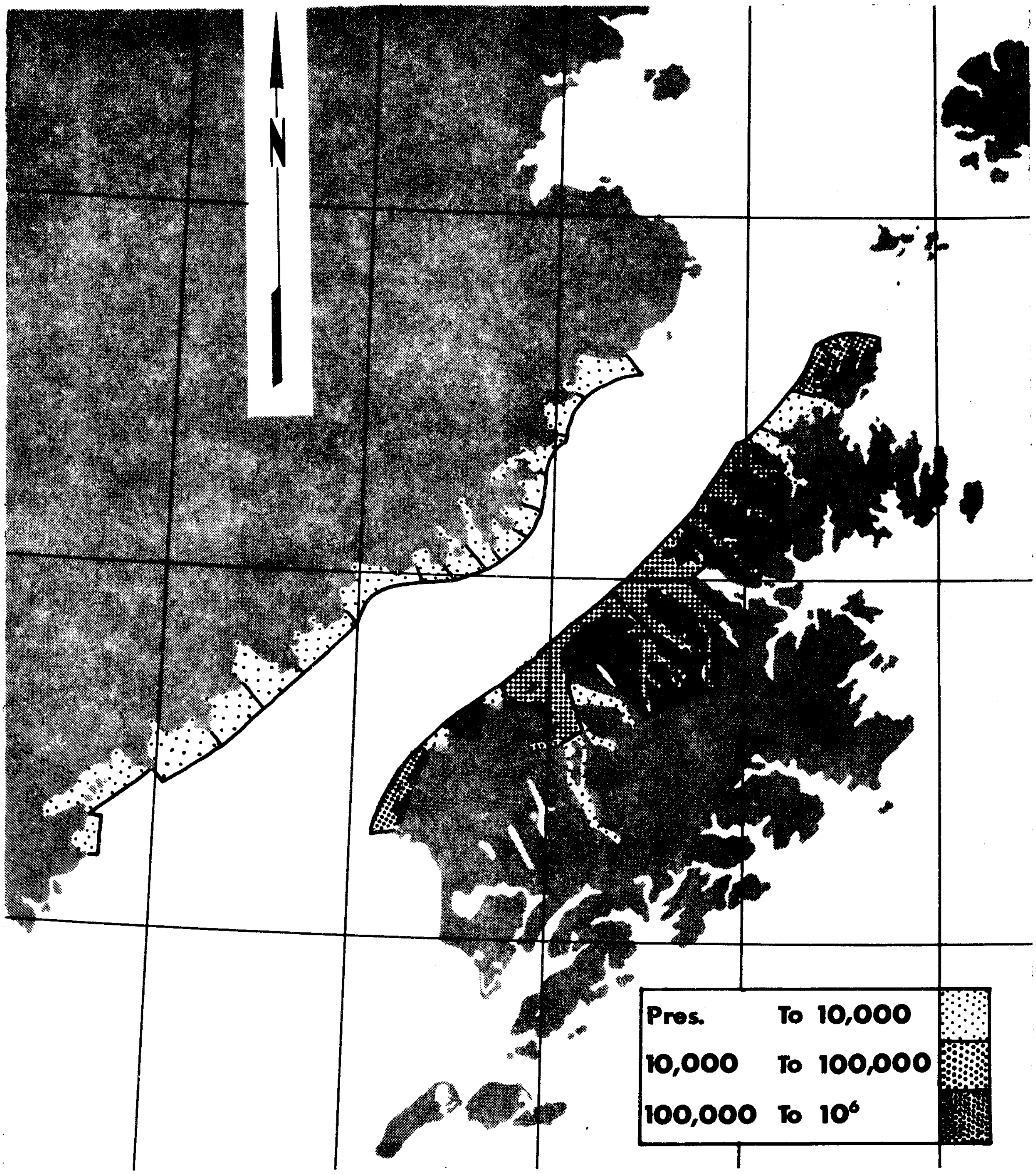


Figure 11. Mean annual coho salmon catch in numbers of fish by statistical area in Shelikof Strait for the years 1969-1977.

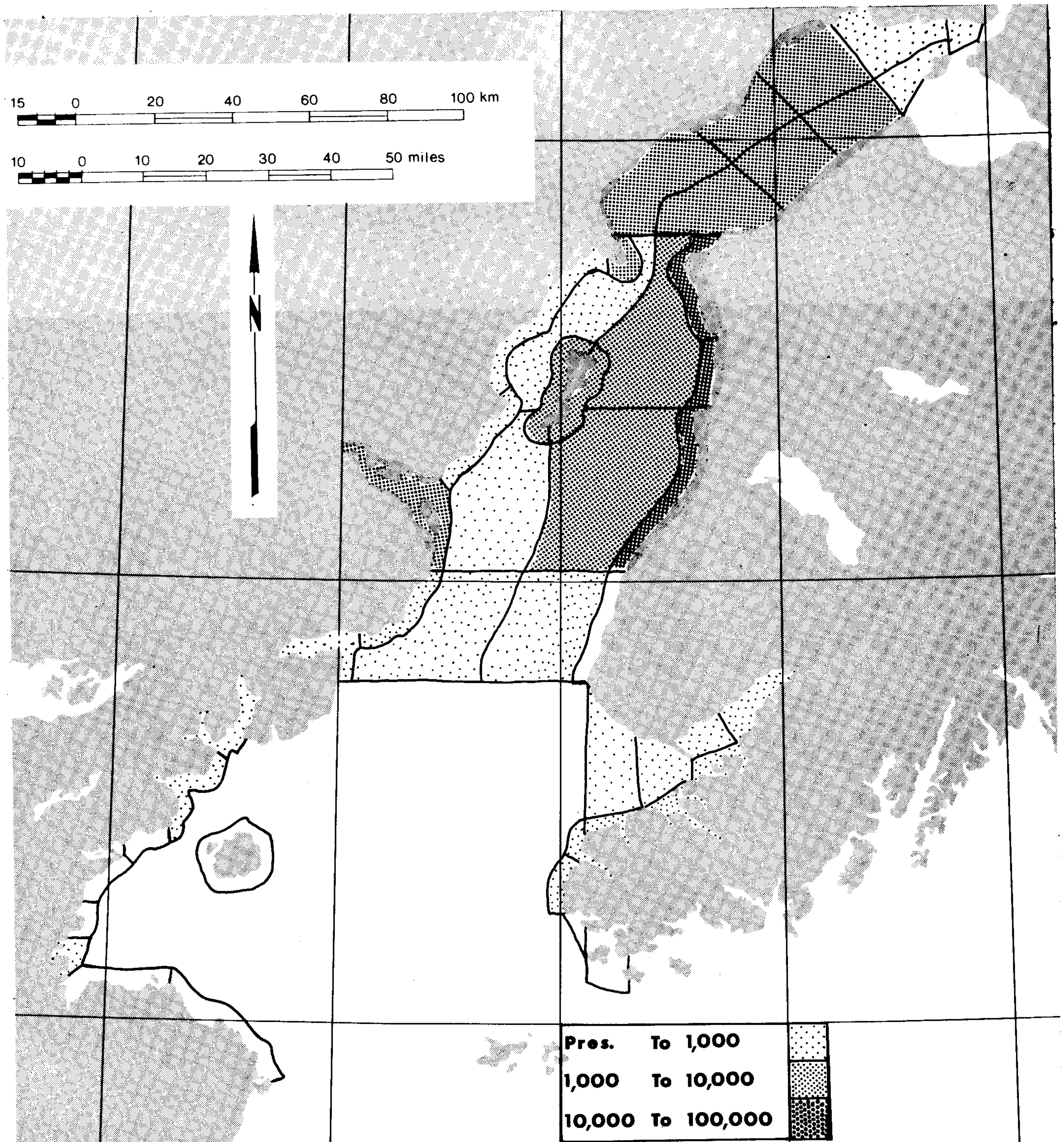


Figure 12. Mean annual chinook salmon catch in numbers of fish by statistical area in Cook Inlet for the years 1969-1977.

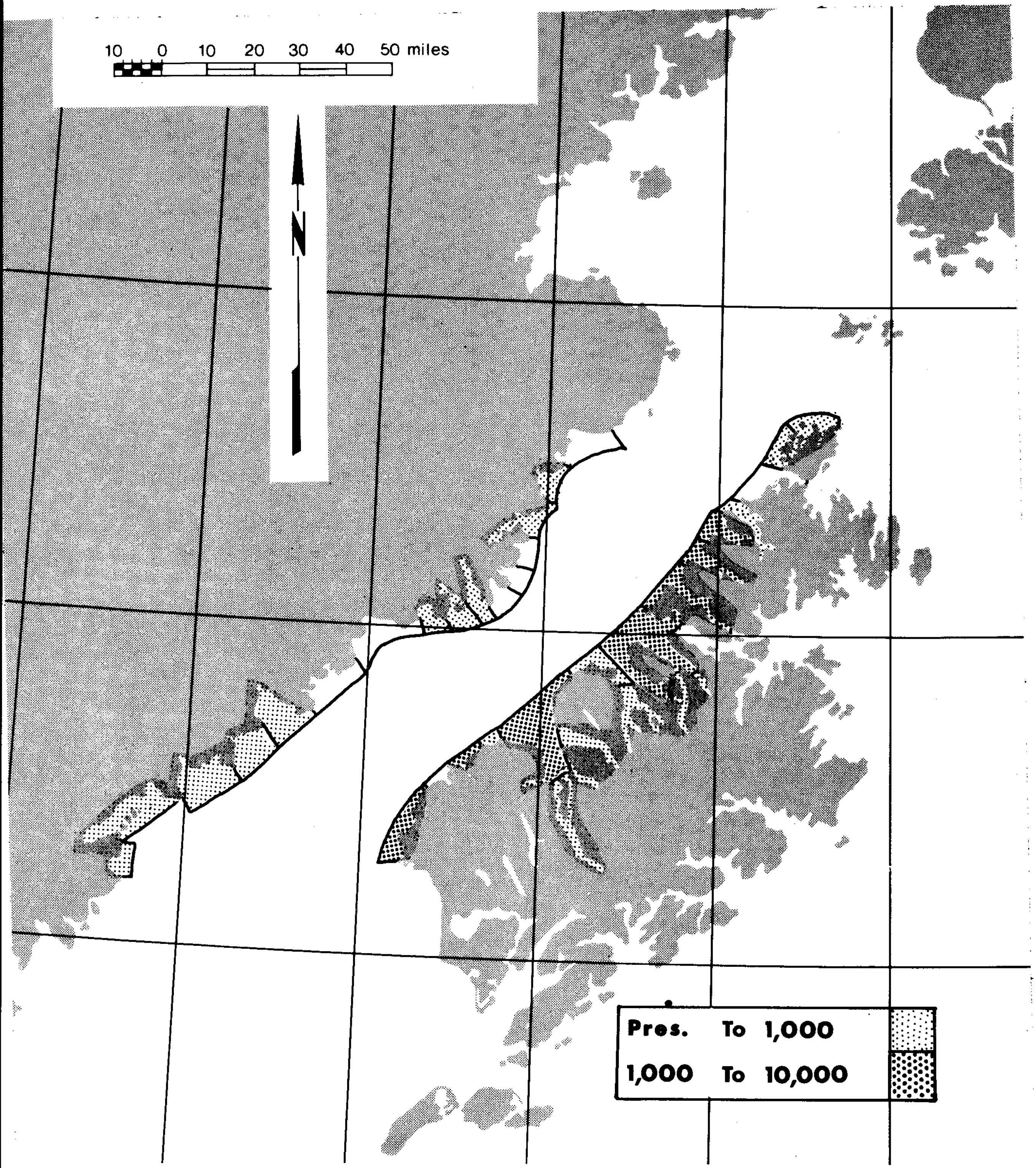


Figure 13. Mean annual chinook salmon catch in numbers of fish by statistical area in Shelikof Strait for the years 1969-1977.

King salmon, like cohos, spend a year or more in rivers before going to sea. Few rivers provide suitable habitat. King salmon are reported to use the Susitna River extensively. There are about nine streams in the upper inlet with kings and the total run to all of them is about 2,000 to 3,000. Rivers on the east side of Cook Inlet between Anchor Point and the Forelands contain more king salmon than any other portion of the lease area (Figures 3, 4 and 5; App. Table 24). The Kenai River supports a run of 20,000, the Kasilof River supports 3,500 and four other rivers on the east side of the inlet support between 100 and 2,000 kings each. On the west side of Cook Inlet there are three streams between Tuxedni Bay and the Forelands with unknown numbers of kings. There are no kings in rivers of Kamishak Bay or the Alaska Peninsula side of Shelikof Strait. On Kodiak there are only two rivers with kings, the Karluk and Red rivers with runs of about 4,000 and 2,000 respectively.

The salmon fishery is conducted during the months of May through September (Figure 14) with almost no catch in Kodiak in May (the figure is constructed from weekly catches and week ending dates, thus some June catch could be taken in the last days of May) and only a little catch in Cook Inlet in May. The red salmon fishery is the earliest in the Kodiak region while kings are the earliest in Cook Inlet. In both areas pinks peak in late July and early August. Reds peak in July in Cook Inlet and late June to early July in Kodiak. Chums peak in July and August in both areas and cohos peak in late July in Cook Inlet and in August in Kodiak. In the Kodiak area the coho run is sizeable in September and the species is considered to be underutilized. King salmon harvests are sizeable in June and July in both areas.

Although salmon are anadromous, pinks and chums often spawn in sections of streams that are within tidal influence. This practice is extensive through out the lease area south of the latitude of Anchor Point. Specific streams in which intertidal spawning is known have been identified in Kachemak and Kamishak bays (Figure 15). On the Alaska Peninsula and the Kodiak Archipelago virtually every stream is utilized in the intertidal portion. On Kodiak this spawning substrate is more important than in other areas as the rivers with the largest runs of pinks and chums are used the most in the intertidal portions.

The salmon fishery in both the Cook Inlet and Kodiak areas began in 1882 but catch data was first recorded in 1894. Initially the fishery was directed at sockeye salmon in both areas and other species were further exploited later. In the Kodiak area, sockeye catches peaked at over three million per year for the 1900-1909 period and have since declined (Table 1).

The Karluk River was very important in this early fishery and efforts are being expended to increase the productivity of the sockeye systems on Kodiak. The production of sockeye in Cook Inlet developed more slowly with peak production of more than 1.6 million in the 1930's and 1940's (Table 2). Catches of sockeye have declined since that time. Pink salmon catches expanded through the 1920's in Kodiak and through the 1930's in Cook Inlet. Chum salmon production has been relatively stable in the Kodiak area since

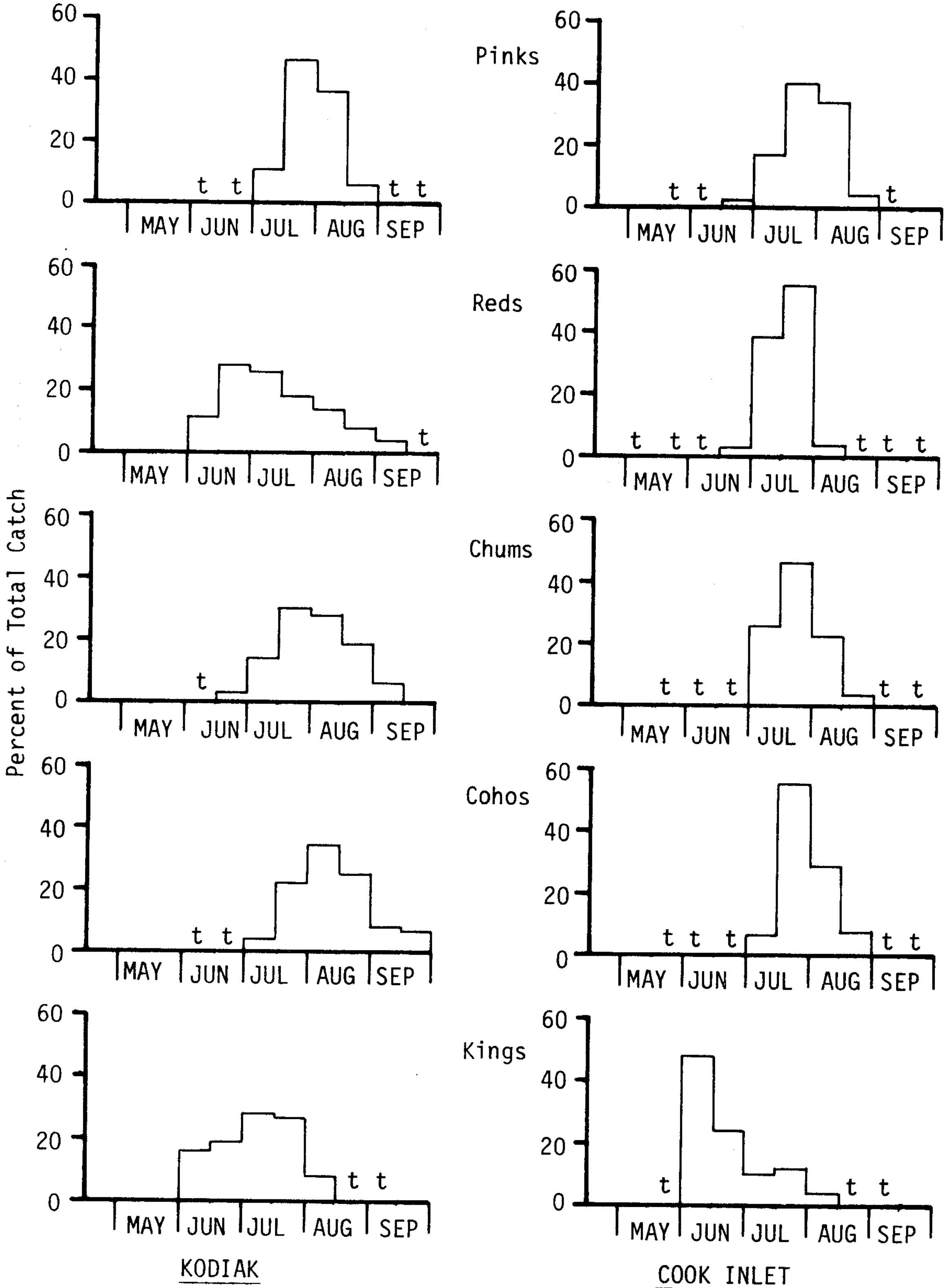


Figure 14. Commercial catch of salmon by species and time in the Kodiak and Cook Inlet management areas. Data taken from International North Pacific Fisheries Commission, Statistical Yearbooks for the years 1960-63 and 1970-73.

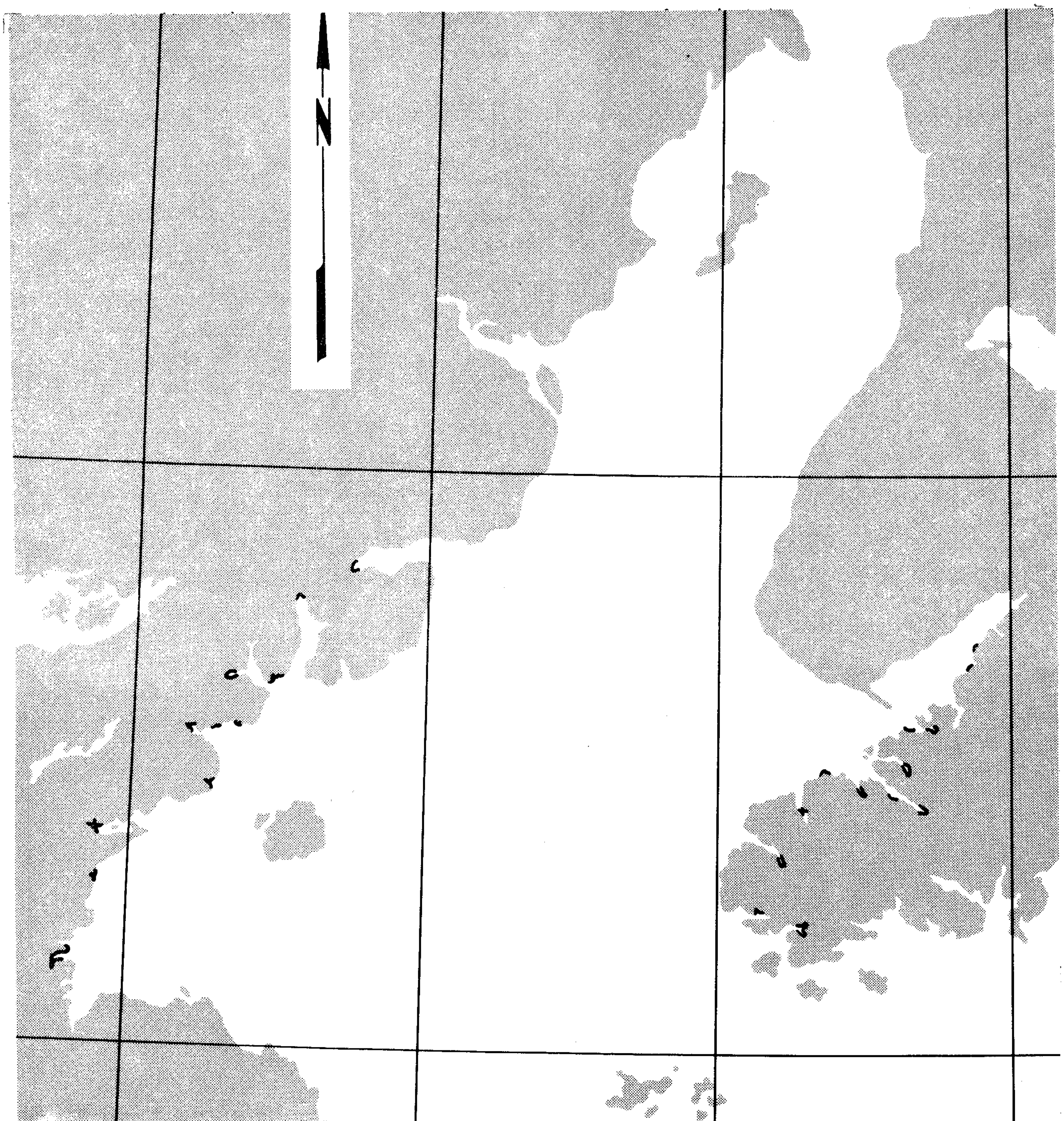


Figure 15. Intertidal spawning areas of pink and chum salmon in Cook Inlet. Spawning locations are within streams but in the lower portion within tidal influence. This habitat is especially productive since extremes of weather, which cause mortality, are amelioriated by the proximity of marine waters. A similar presentation is not made for Shelikof Strait streams since virtually all streams are used in the intertidal zone and there is little knowledge to justify exclusion of any stream. This figure based on Hamilton et al. (1979).

about the 1920's but has expanded slowly in Cook Inlet so that about 6-700,000 are taken each year in each area. Coho production in the Kodiak area peaked in the 1930's and 40's at about 130,000 annually and has since declined to about 40,000. Cohos are currently underutilized in the Kodiak area as a large share return after most of the other salmon fisheries are completed. Coho salmon harvests in Cook Inlet have remained fairly stable at 250,000 annually except for harvests of 400,000 in the 1940's. Chinook salmon harvests have never been very big in the Kodiak area but were greatest in the 1900-1909 time period. In Cook Inlet, Chinook harvests have been substantial, peaking in the 1940's and 1950's but declining considerably since then.

A substantial portion of all salmon production in the Kodiak area has come from Shelikof Strait. Virtually all the sockeye and chinook production has been in Shelikof as the Karluk River and Chignik River have been very important systems.

The Kodiak data discussed above includes the entire Kodiak area. Based on catches in the early 1970's the Shelikof Strait region accounts for about 38% of the annual pink salmon catch, 84% of the red salmon catch, 40% of the chum salmon catch, 55% of the coho catch and the bulk of the chinook catch in the Kodiak area.

The outlook for the salmon fishery in the lease area is optimistic. Improved management, habitat rehabilitation and enhancement of salmon runs will probably improve the returns in the future years. The early 1970's were relatively poor years due to several severe winters which greatly reduced freshwater survival and the later 70's were much better because of mild winters. In the future, weather will continue to be very important to the production of salmon.

Table 1. Mean annual salmon catch in thousands of fish in the Kodiak area by decade and species, 1893 through 1978.

Years	Species				
	Pink	Sockeye	Chum	Coho	Chinook
1893-99	-	2,772	-	15.4	1.1
1900-09	46	3,160	-	56.4	3.3
1910-19	972	2,200	25.5	45.8	1.3
1920-29	3,140	1,658	320.0	130.6	1.9
1930-39	8,078	1,587	437.6	138.5	2.0
1940-49	7,947	1,416	482.6	84.5	1.1
1950-59	5,043	392	827.0	40.7	1.8
1960-69	7,740	510	675.9	44.0	1.2
1970-78	6,346	518	764.5	27.4	1.1

Table 2. Mean annual salmon catch in thousands of fish in the Cook Inlet area by decade and species, 1893 through 1978.

Years	Species				
	Pink	Sockeye	Chum	Coho	Chinook
1893-99	38	382	-	41.2	19.5
1900-09	89	487	-	69.0	40.3
1910-19	574	1,396	57.2	132.5	53.5
1920-29	367	1,251	70.3	250.0	49.3
1930-39	592	1,609	137.4	273.2	67.9
1940-49	1,304	1,658	316.2	406.1	91.7
1950-59	1,297	1,353	592.1	230.4	79.0
1960-69	1,780	1,197	717.2	266.5	13.4
1970-78	1,139	1,215	756.6	183.4	11.9

Halibut

The halibut catch is widely distributed throughout the lease area (Figure 16). The catch is reported by much larger statistical areas than is the catch for other species. Log book data is collected from the commercial fishermen and examined for distribution of effort, among other things. There are a few areas where effort tends to be more concentrated than others and these areas, illustrated in Figure 16, are generally in the vicinity of Anchor Point, off the tip of the Kenai Peninsula south of Kachemak Bay, near the Barren Islands, along the south shore of the Kenai Peninsula, on the east side of Shelikof Strait and into the bays, along the south west tip of Kodiak Island and in the Wide Bay area on the west side of Shelikof Strait (International Pacific Halibut Commission 1978a; personal communication). There has also been a seasonal trend in the location of the fishing activity. As halibut migrate seasonally from deeper water in winter to shallow in summer the fishery follows. In the early season, about May, the fishery is most active in deeper areas and in mid-summer some of the activity is as shallow as 10 fathoms. Some of the fishermen have reported that halibut seem to follow the salmon into the bays and halibut have been found with salmon in their stomachs (R. Myhre, personal communication).

The catch of halibut by subarea for the last ten years is presented in Table 3. Statistical area 261, which represents Cook Inlet except Kamishak Bay has averaged 575,000 lbs. per year during this time and Kamishak, area 272, has averaged about 44,000 lbs. per year. Northern and southern Shelikof Strait, statistical areas 271 and 281 respectively, have averaged 263,000 lbs. and 491,000 lbs. per year.

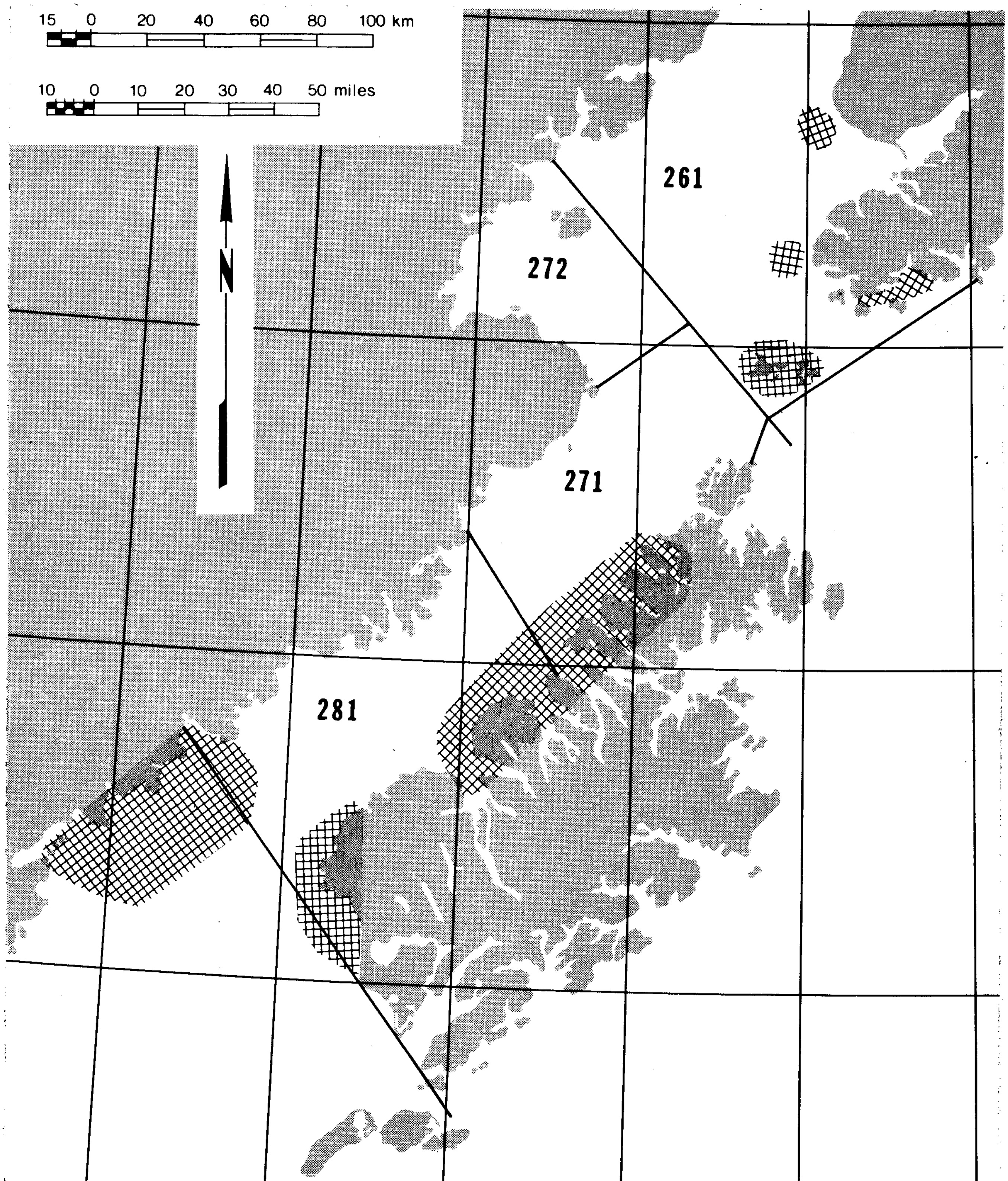


Figure 16. Halibut statistical areas and locations most actively fished in Cook Inlet and Shelikof Strait. Halibut fishing is conducted throughout the lease area and the hatched locations tend to be fished more heavily. Redrawn from Figure 2 I.P.H.C. (1978) with greater detail added by the author.

The halibut fishery has a long history of consistent production, until recent years (Figure 17). The total annual catch reached 69 million lbs. in 1915 and fell to 44 million lbs. in 1931. Thereafter, the annual catch generally increased and exceeded 70 million lbs. in 1962 but fell below 25 million pounds in 1974 (IPHC, 1978a). Incidental catch of juvenile halibut by foreign trawlers was indentified as the cause of the recent decline. The halibut commission has conducted surveys of the abundance of juvenile halibut in the Bering Sea and Gulf of Alaska. In the Bering Sea the abundance of juveniles declined from about 45 per hour of trawling in 1963 to less than 5 in 1972 and it has since increased to nearly 20 in 1977. In the Gulf of Alaska a similar catch rate in 1963 declined to about 20 per hour in 1975-76 and increased somewhat in 1977 (IPHC, 1978b). Since there is wide migration the abundance of juveniles in the Bering Sea directly affects abundance of adult halibut in the Cook Inlet and Shelikof Strait areas several years later. The outlook is, therefore, for increased catches in the 1980's but not as great as historic catches (IPHC, 1978b).

The commercial fishing season for halibut was closed in winter to protect fish on the spawning grounds by treaty with Canada in 1923. The active fishing season from 1960 through 1978 in area 3A, which includes lower Cook Inlet and Shelikof Strait is presented in Figure 18. During 1976 and earlier years there was a voluntary lay up program which was instituted by the fishermen to extend the duration of the fishery, thus avoiding long periods of dangerous overwork, overfishing of some portions of a stock to the exclusion of others and allowing a more orderly delivery of product. The system failed due to lack of support by the fishermen. Beginning in 1977, the International Pacific Halibut Commission instituted a split season consisting of four fishing periods of about 18 or 19 days duration with closed periods of 15 days between. As in the past the fishing season was closed when the catch limit was attained, regardless of the designated fishing periods.

Mature halibut concentrate on spawning grounds along the edge of the continental shelf at depths from 182 m to 455 m during November to March. Major spawning sites in the vicinity of lower Cook Inlet include Portlock Banks and Chirikof Island. In addition to these major spawning grounds, there is reason to believe that spawning is widespread and occurs in many areas, although not in concentrations as dense as those mentioned above. Evidence to support this conclusion is based on the widespread distribution of mature halibut during the winter months as indicated by research and commercial fishing (IPHC, 1978a).

Spawning of halibut on the Cape St. James spawning ground occurs from December through March with a peak in mid-January (Van Cleve and Seymour, 1953).

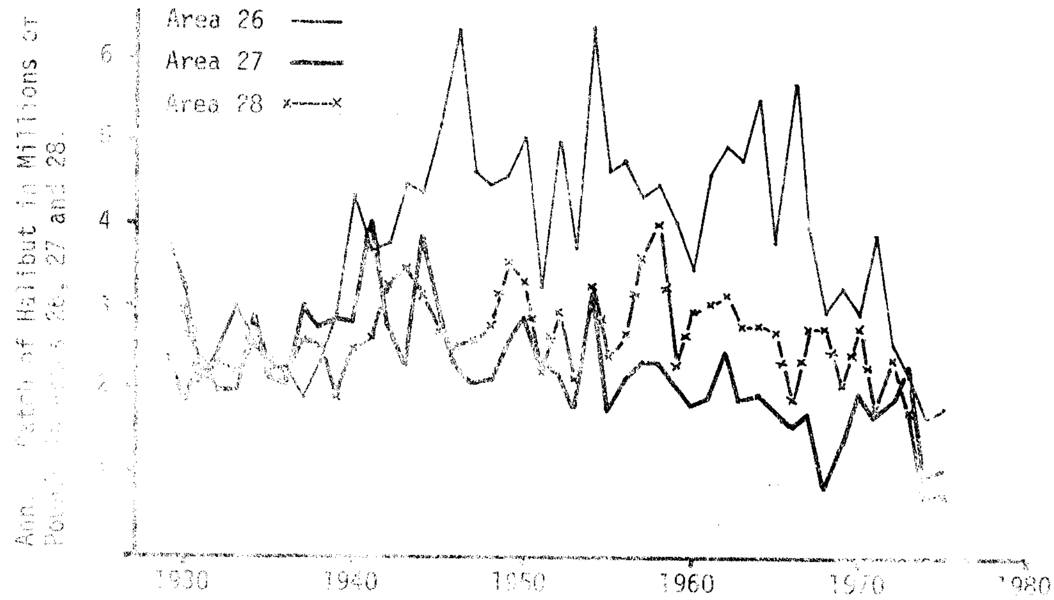


Figure 17. Annual catch of halibut in millions of pounds in statistical areas 26, 27 and 28 from 1930 through the present. Areas 26, 27 and 28 are 60 mile wide areas perpendicular to the coast. Area 26 includes Cook Inlet, area 27 includes the northern half of Kodiak and area 28 includes the southern half of Kodiak. Areas 261, 271, 272 and 281, shown in Figure 16, are subdivisions of 26, 27 and 28 with digits added.

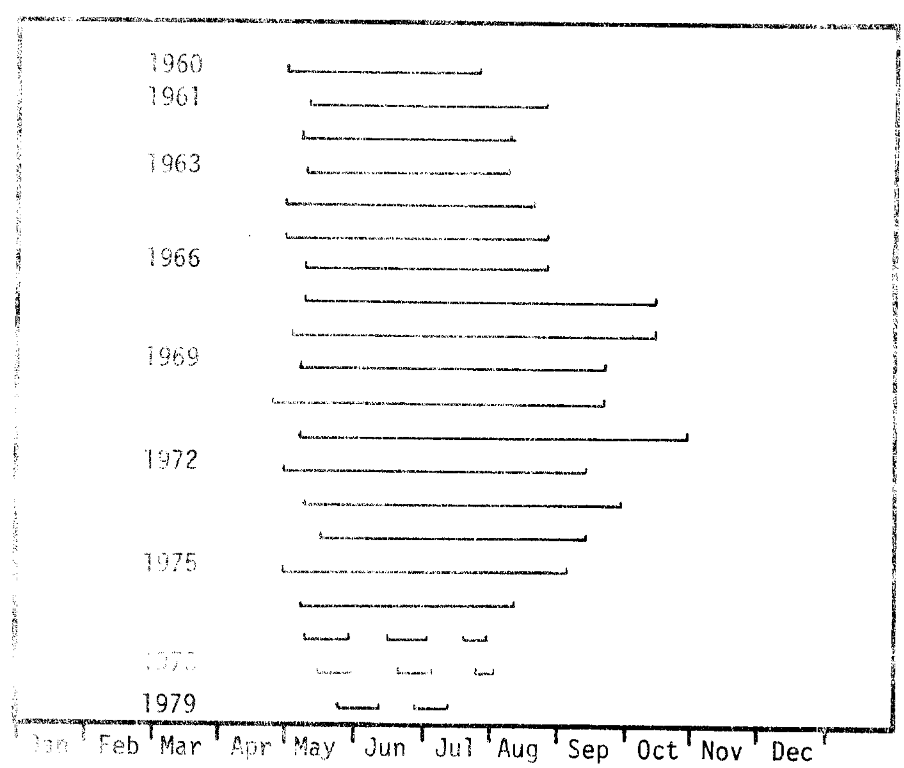


Figure 18. Commercial halibut fishing season openings, 1960 through 1979. Source, Int. Pac. Halibut Comm. annual reports.

Table 3. Catch of halibut in thousands of pounds dressed weight by statistical subarea in the Cook Inlet Shelikof Strait region for 1969-1978. Data courtesy of the International Pacific Halibut Commission. See Figure 16 for location of statistical area.

Year	Statistical Area 261	271	272	281
1969	515	62	11	500
1970	349	481	80	544
1971	541	73	43	473
1972	416	313	65	994
1973	665	533	34	759
1974	658	220	-	[illegible]
1975	547	390	13	[illegible]
1976	646	327	37	[illegible]
1977	726	163	57	380
1978	682	67	101	125

Bottomfish

The bottomfish fishery has been directed at walleye pollock and to a lesser extent, Pacific cod in central Shelikof Strait (Figure 19). The history of the bottomfish fishery in the lease area is short. The foreign fisheries were not active in Shelikof Strait between 1969 and 1974 (Ronholt et al., 1977). The domestic bottomfish fishery in the Kodiak area has just started to exploit the resource. In the Kodiak management area, the landings of bottomfish have been 14,000 lbs. in 1975, 520,000 lbs. in 1976, 638,000 lbs. in 1977, 2,311,000 lbs. in 1978 and 4,548,000 lbs. through July 1979. The bulk of these catches were in Shelikof Strait in each year.

During February through mid-April of 1979 catch rates averaging 4,000 lbs. per hour and ranging from 2,000 to over 6,000 lbs. per hour were documented in the domestic bottomfish fishery in Shelikof Strait by observers. The catches were 80 to 90% walleye pollock and about 10% Pacific cod. The extent of the area of abundance of these fish is not known. The fishery has not fully utilized the resource so the distribution of the catches does not reflect the distribution of the fish. There have been several research surveys that include this area and these have all been summarized by Ronholt et al. (1977). The surveys were in the summer, not during the February through mid-April period when pollock were abundant. Reliable distribution features (areas of greater or lesser catches) are not discernable from the data. A 1973 survey summarized in a different way by Hughes and Alton (1974) shows greatest pollock catches in the summer to be at less than 100 fathoms with catch rates of 1,100 lbs. per hour in northern Shelikof and 4,100 lbs. per hour in a small area in southern Shelikof. The deeper water in mid-Shelikof yielded smaller catch rates.

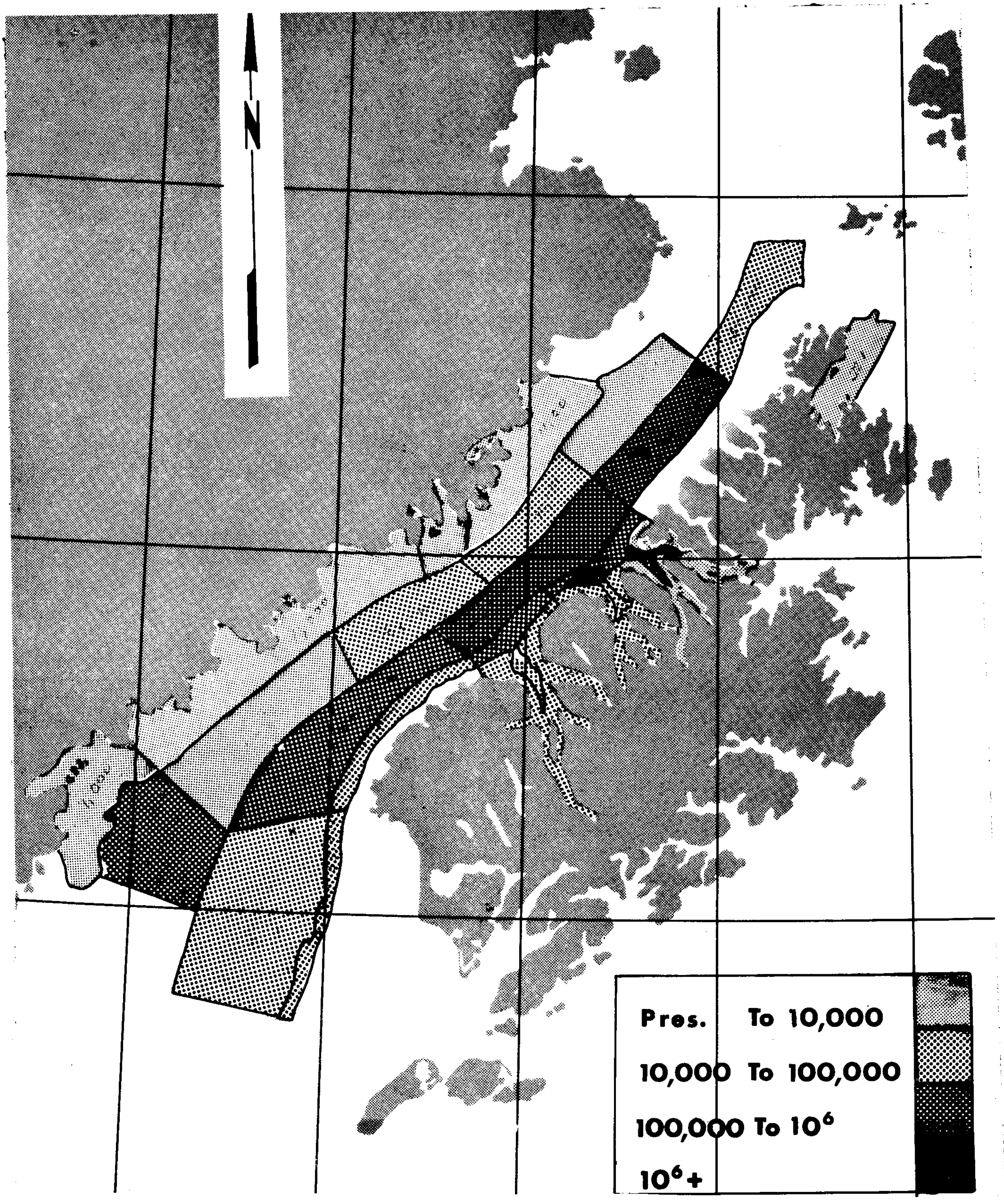


Figure 19. Total catch in thousands of pounds of walleye pollock and Pacific cod during January 1978 through May 1979 by statistical area in Shelikof Strait.

Population estimates have been calculated from the trawl surveys in Shelikof Strait. These surveys are known to be underestimates since pollock are not all on the bottom, many are in the water column and not available to the gear. In 1961 there were an estimated 3,000 mt (metric ton) in Shelikof Strait and in 1973-76 an estimated 14,000 mt. The outlook for bottomfish is continued expansion at a slow rate since it is a high volume, low profit product.

Other species caught in Shelikof in limited amounts have been sablefish and rockfish. Sablefish constitute about 3 to 5% of the catch of the March-April fishery and are all about 40 to 50 cm, and about age 2 (Low et al., 1976). Some rockfish have been caught but nothing is known of their distribution or abundance.

Flounders are collectively a relatively abundant group of fish in all areas. From a survey conducted between 1973 and 1976, flounders constituted 33% of the trawl caught biomass in the Gulf of Alaska and 29.5% of the biomass in Shelikof Strait (Ronholt et al., 1977). Some flounders have a limited commercial market. Yellowfin sole, flathead sole, butter sole and Alaska plaice have been utilized. The potential for a flounder fishery is quite limited, however, since most contain relatively little flesh and trawling for them is detrimental to the valuable halibut also caught.

Spawning areas for walleye pollock are not specifically delineated but the winter concentration in Shelikof is a spawning aggregation. The fish are adults full of ripe roe. During 1979, the fishery was very actively catching pollock and Pacific cod and during late April the catch rate dropped precipitously when the fish apparently spawned. There have been no plankton surveys in Shelikof Strait but in 1972 and again in 1978, National Marine Fisheries Service (NMFS) sampled plankton on the east side of Kodiak. These surveys extended to the south end of Kodiak Island and extremely high densities of pollock eggs were found in this area (Dunn et al., 1979; Dunn and Naplin, 1974). Since water flow in Shelikof is to the southwest (Science Applications Inc., 1979) eggs spawned in Shelikof would be transported to the southwest end of the island.

Herring

The fishery for herring in the lease area in recent years has been conducted in Kachemak Bay, on the west side of the inlet near the Forelands, throughout Kamishak Bay, in Kukak Bay, in all bays on the west side of Kodiak and Afognak islands, except Malina Bay and in southern Shelikof Strait between Uyak Bay and Cape Ikolik (Figures 20 and 21). According to Reid (1971) between 1936 and 1959 herring were taken in generally the same areas of Shelikof Strait but more were taken in central areas of Shelikof and herring were taken in Kinak and Portage bays on the south shore of the Alaska Peninsula.

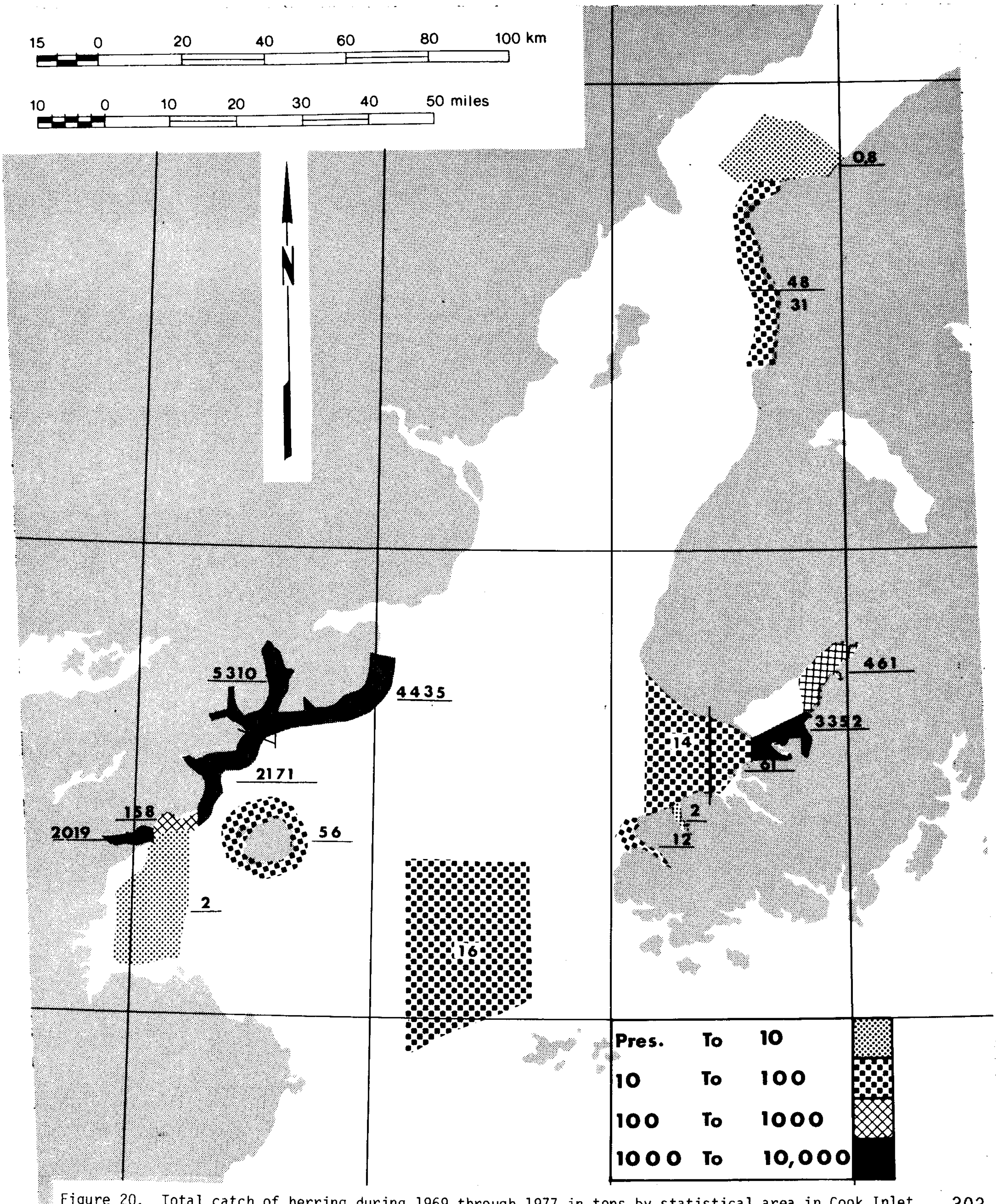


Figure 20. Total catch of herring during 1969 through 1977 in tons by statistical area in Cook Inlet.

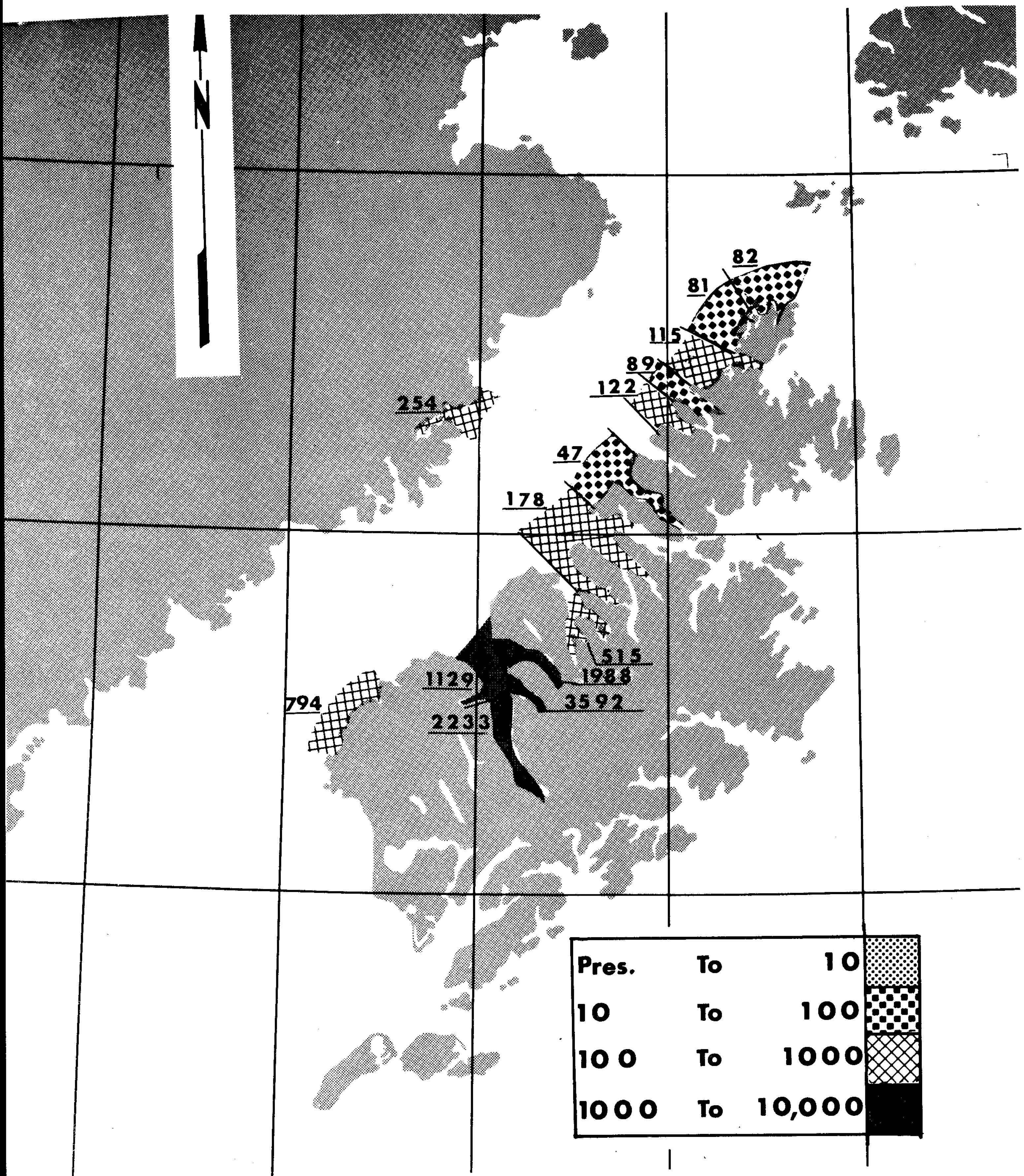


Figure 21. Total catch of herring in tons during 1969 through 1977 by statistical area in Shelikof Strait.

The herring fishery began in 1914 and during the period of 1914 to 1928 there was a substantial herring fishery in Kachemak Bay with annual catches over 1,000 tons per year in nine years and a maximum catch over 9,000 tons in 1925 (Table 4).

Table 4. Commercial catch of herring in Kachemak Bay during 1914 through 1928 (Rounsefell, 1929).

Year	Catch, tons	Year	Catch, tons	Year	Catch,tons
1914	155.7	1919	2,648.2	1924	7,040.0
1915	14.7	1920	959.2	1925	9,614.2
1916	69.2	1921	2,611.0	1926	7,136.2
1917	943.4	1922	503.8	1927	3,590.7
1918	1,985.0	1923	3,781.2	1928	2,152.1

The stocks were depleted, however, and the fishery ended. Between 1929 and 1968 there was little fishing, with herring taken only for bait, thus there are no catch records. From 1969 through the present there has been a substantial herring fishery in Cook Inlet, primarily during the spring as herring are taken for their roe. The harvest has been in Kachemak Bay but beginning in 1973, the Kamishak Bay area has been heavily fished and the area near the Kenai River and the east Forelands has been fished (Table 5).

Table 5. Commercial herring catch, Cook Inlet, by area, in tons of fish.[1]

	District		
Year	Central[2]	Southern[3]	Kamishak
1969		551.5	
1970		2,708.7	
1971		12.5	
1972		1.0	
1973	14.0	203.8	243.1
1974	36.6	110.2	2,108.8
1975	6.0	24.0	4,119.0
1976		Inlet Total	4,086.3
1977	17.1	291.0	2,917.5
1978	60.7	16.6	402.0
1979	17.1	13.1	417.6

[1]Source - McLean et al. 1976, and ADF&G catch statistics.
[2]The Central District is north of Anchor Point in Cook Inlet.
[3]The Southern District is Kachemak Bay for this data.

The first recorded herring harvest in the Kodiak area occurred in 1912 and a sustained fishery began in 1916. The herring fishery expanded to a large scale and continued through the 1930's, 1940's and through 1950. The area wide catches per year by decade were 121 tons in 1912-19, 2,613 tons in 1920-29, 27,095 tons in 1930-39, 31,753 tons in 1940-49, 9,143 tons in 1950-59, 879 tons in 1960-69 and 517 tons in 1970-74 (McLean et al., 1976). During 1934 over 120,000 tons were reported and from 1936 through 1950, the catch was 20,000 to 40,000 tons every year, except 1949 when there was no harvest.

The bays on the west side of the Kodiak Archipelago have contributed substantially to the herring harvest. Rounsefell (1920) reported total catches from 1917 to 1928 to be over 16,000 tons in the Shuyak Island area, 420 tons in Raspberry Strait, 15 tons in inner Kupreanof Strait, 122 tons in Uganik Bay and 22 tons in Uyak Bay. Reid (1971) showed the distribution of total catch by area from the 1936 to 1959 time period. Over 50,000 tons were taken immediately south of Cape Ikolik and also in Shelikof Strait between Uyak and Uganik bays. Between 10,000 and 50,000 tons were taken in three areas, in Shelikof Strait between Cape Ikolik and Karluk, in Uyak Bay, and in the area including Uganik and Viekoda bays, Kupreanof Strait, Raspberry Strait and Malina Bay. Smaller catches were reported from other areas.

In recent years the catches have been largest in Uyak Bay, in Kamishak Bay and Kachemak Bay but catches have been widely distributed throughout Shelikof Strait, Kachemak and Kamishak bays and near the Forelands (Figures 20 and 21).

At the present time the outlook is good for continued herring harvests. Prices have been increasing rapidly in the last few years and stocks do not appear to be depleted below the level of recent years.

The season that the herring fishery has been prosecuted has depended upon the product. Norwegian curing, the salting process first used in the fishery, used herring captured in the summer. Later, salted products used the fatter herring found in fall and winter. Much of the present fishery, however, is focused on the roe which is best just before spawning, thus the fishery is active on the spawning grounds from late April through early June. The bait fishery is generally active in the winter and spring. Table 6 illustrates that the bulk of the herring fishery occurs in May.

Table 6. Season of the herring fishery expressed as percent of total catch by month in each management area. The Cook Inlet data is based on a computer tabulation of the years 1969-1977 and the Kodiak data is based on Kodiak area management reports and summarizes the years 1968-1978, Shelikof Strait areas only.

Management Area	March	April	May	June	July	August	November
Cook Inlet		0.2	83	16	0.1		0.1
Kodiak	0.3	3	65	9	20	2	

Herring spawning has been documented or reported in nearly every bay on the west side of Kodiak Island (Figure 22). On the west side of Shelikof Strait herring spawning has been documented only in Kukak Bay. Herring spawning has been reported in virtually every cove and bay on the south side of Kachemak Bay and on the Homer Spit. Herring concentrations have been seen throughout Kamishak Bay in the spawning season and spawning has been specifically identified off the Douglas River, in Bruin Bay, Ursus Cove, Iniskin Bay, Oil Bay and Dry Bay (Figure 23). In the upper inlet the waters are too murky to confirm spawning of herring but an active gill net fishery yields mature adult herring in the vicinity of the Kenai River during spawning season and larval herring were found to be abundant in this area throughout the summer by this project in 1976.

The bulk of herring spawning occurs during May; however, they also have been reported to spawn in late April and in early June in lower Cook Inlet and as early as April 18 in Uyak Bay and as late as the first week of July in Red Fox Bay on Afognak Island (ADF&G staff).

Herring typically spawn in the intertidal zone, primarily upon vegetation. On the west side of Kodiak Island herring commonly spawn upon eel grass (*Zostera*), hair kelp (*Demarestia*) and rockweed (*Fucus*). Herring spawn in Kamishak Bay has been found on crab pots at considerable depth, but it is believed that most spawning occurs in the intertidal or immediate subtidal zone.

King Crab

King crab have been taken in virtually all of the lease area south of Anchor Point. Areas of greatest king crab catches are Kachemak Bay, a large area that encompasses Kamishak Bay, the central inlet toward the Barren Islands and north central Shelikof Strait; a small area in Viekoda Bay and Kupreanof Strait where approximately 4 million lbs. have been landed in the nine years summarized and the southern end of the lease area encounters the fringe of the highly productive area at the south west end of Kodiak Island (Figure 24).

King crab was first harvested in the Kodiak and Cook Inlet management areas in 1951. Since that time the catches increased to their historically highest values in 1965, when approximately 95 million lbs. were taken in Kodiak, and have since declined (Table 7). The fishery now depends primarily upon recruit crab and thus the catch in any season depends heavily upon the reproductive success of a single year class. Catches were very low in 1972, 1977 and 1978, but a very large group of recruits will enter the fishery in 1979 and 1980. The king crab catch in the Kodiak management area is greatest on the south end of the island, with Shelikof Strait providing a relatively small portion of the catch.

The king crab fishery operated during every month of the year through the 1960's. Now it opens September 1 in the Kodiak management area and August 1 in the Cook Inlet management area and remains open until November 30 in the Kodiak area and until March 15 in the Cook Inlet area,

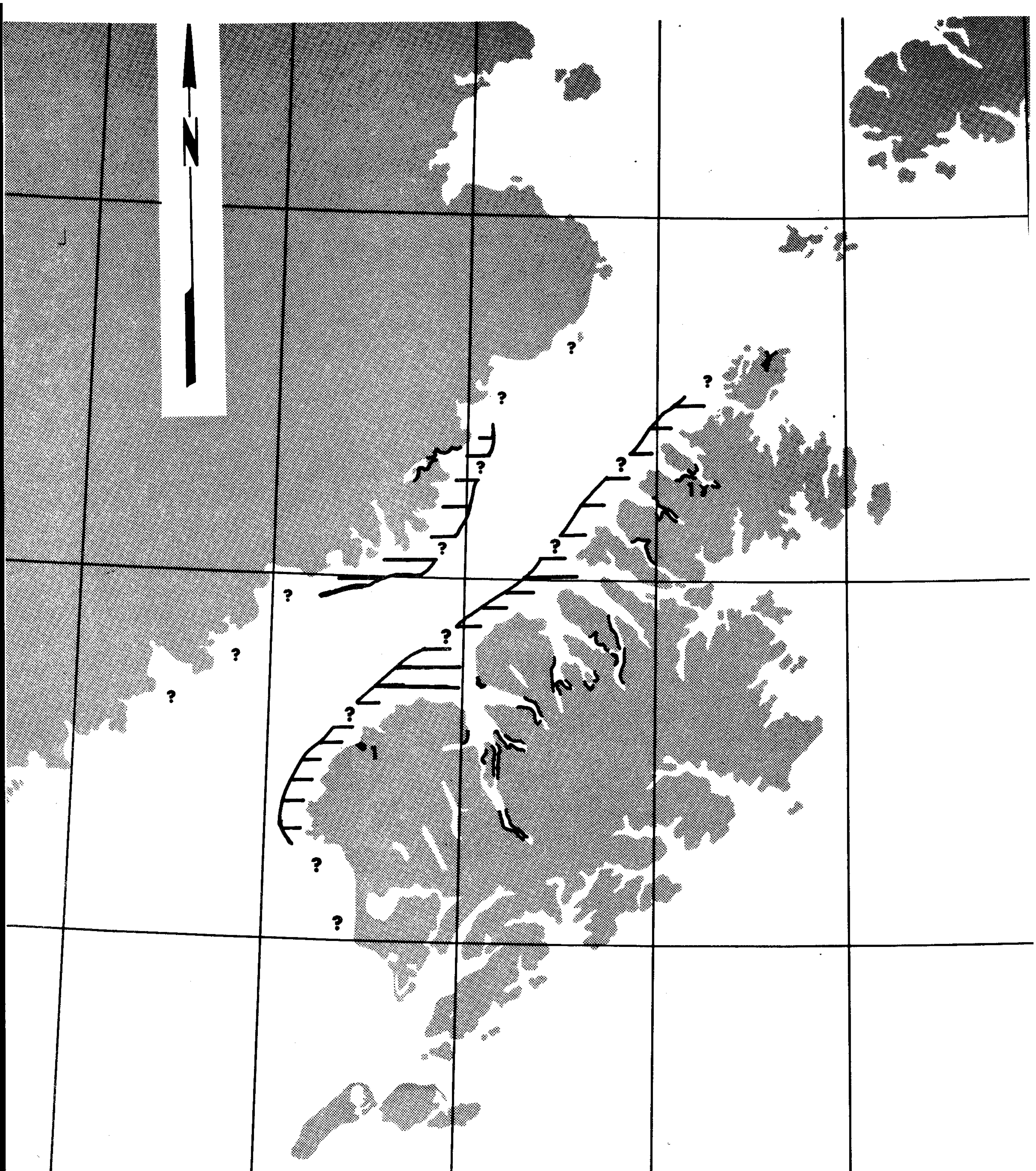


Figure 22. Herring spawning areas and feeding areas in waters of Shelikof Strait. The spawning areas are marked along the shoreline and the feeding areas are most likely all areas within the hatched area. There is very little information available on feeding areas. The two areas marked 1 are reported but unsubstantiated spawning locations. Data from Rounsefell (1929) and ADF&G biologists.

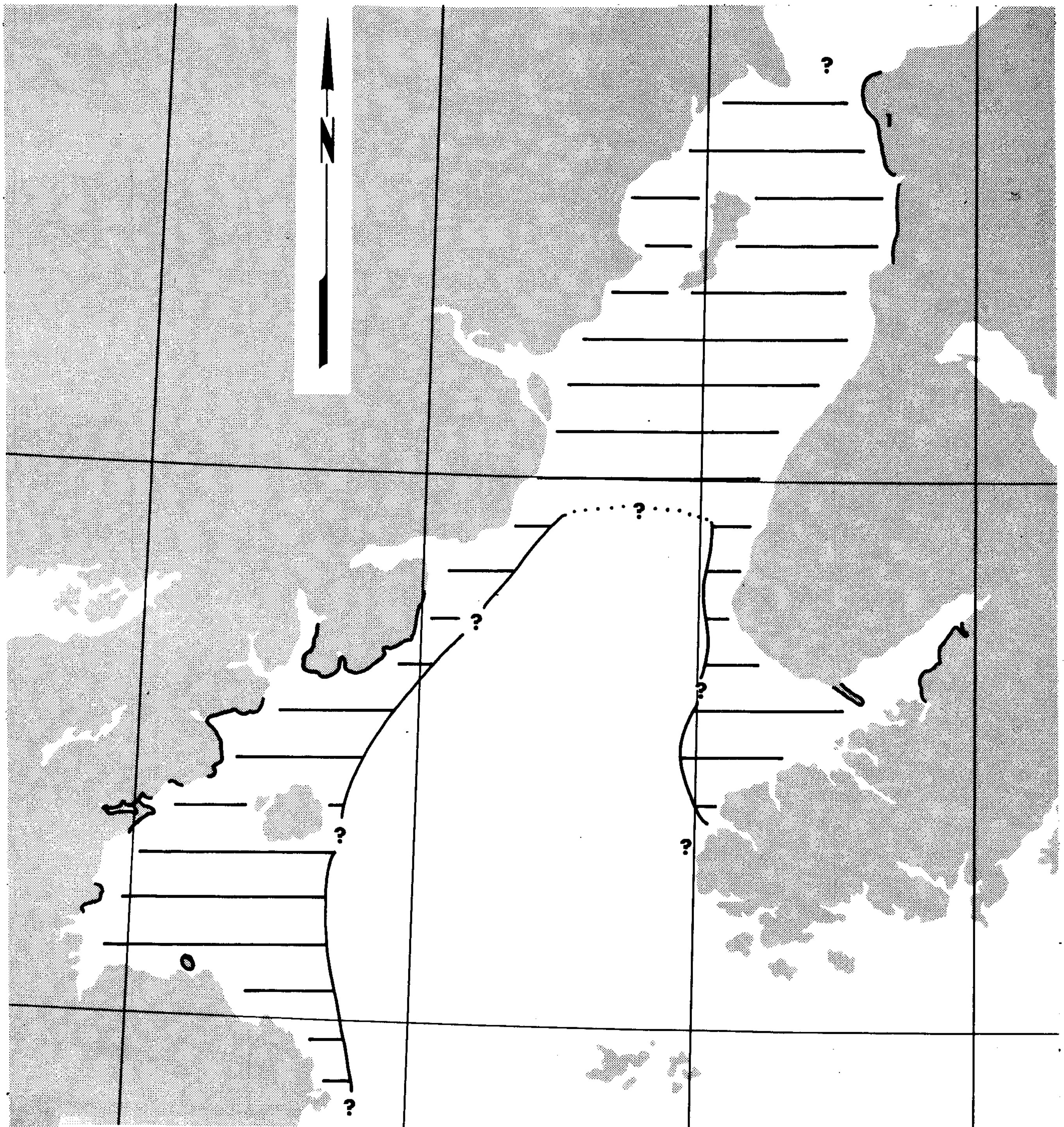


Figure 23. Herring spawning areas and feeding areas in waters of Cook Inlet. The spawning areas are marked along the shoreline and the feeding areas are most likely all areas within the hatched area. There is very little information available on feeding areas but the central area between Kachemak Bay and Augustine Island appears to have less herring in surface waters than along both shores, although herring consistently occurred in small numbers in otter trawls in this area. The spawning location marked 1 is based on the presence of mature fish in the fishery and the presence of larvae in summer, and its actual location and extent is not known.

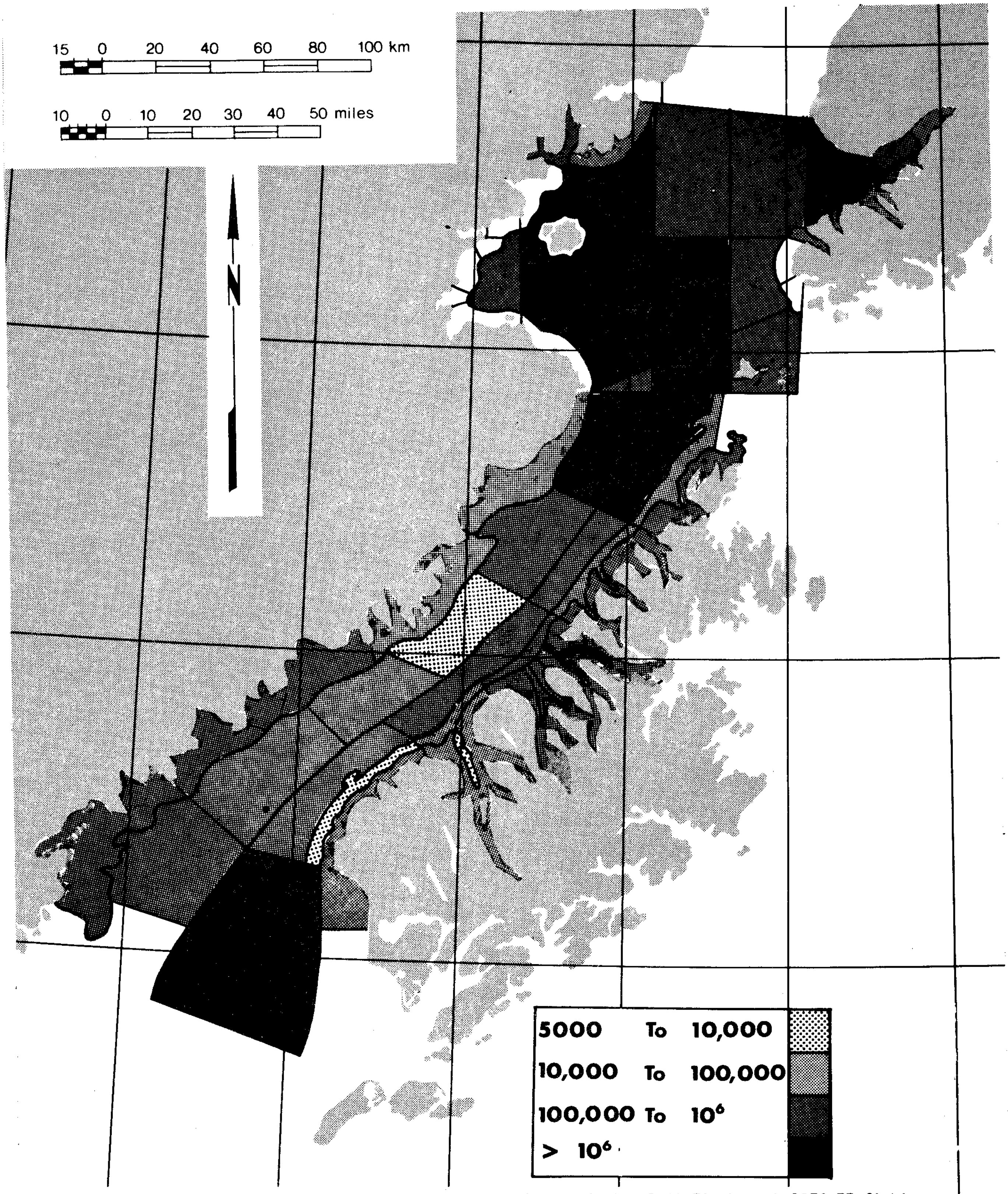


Figure 24. Total catch of king crab in thousands of lbs. during 1969-70 through 1976-77 fishing season by statistical area in Cook Inlet and Shelikof Strait. The total catch in outer Kachemak Bay exceeded 10 million pounds.

or until the guideline harvest is taken. On December 1 the fishery re-opens for eight inch crab in the Kodiak area and remains open through January 15. In the Cook Inlet area the eight inch season is opened and closed by emergency order but is restricted to the August 1 through March 15 season.

King crab move into relatively shallow water in winter where their eggs hatch during the February through April time period. This is followed by moulting and mating so that the female carries eggs for about 11 months of the year. During this time the adults are quite concentrated.

King crab are known to concentrate in Kachemak Bay for spawning. Much less is known about the Shelikof Strait and Kamishak Bay stocks. Nearly all of the bays on Kodiak are known or suspected to harbor spawning concentrations and virtually all shallow water is used by crab during spawning. Greatest concentrations are undoubtedly in the Uganik Bay, Viekoda Bay and Kupreanof Strait areas. The spawning location used by Kamishak Bay king crab is not known. They clearly move into shallower water in winter, into Kamishak Bay, but areas of concentration are not known nor is the extent of inshore movement.

Table 7. King crab catch in thousands of pounds by area and fishing season, 1960-61 season to present.

Fishing Season	Cook Inlet District: Southern[2]	Cook Inlet District: Kamishak Barren Is.	Kodiak by Stock[1]: 5	Kodiak by Stock[1]: 6
60-61	3,338	772	1,885	383
61-62	1,999	3,138	3,197	1,293
62-63	2,304	4,884	2,805	344
63-64	1,790	4,684	3,041	48
64-65	2,192	3,299	2,578	109
65-66	1,852	1,637	1,181	110
66-67	1,412	1,168	1,312	103
67-68	1,123	2,327	1,520	1,027
68-69	751	1,711	1,476	676
69-70	1,465	1,689	1,748	789
70-71	1,540	2,116	880	1,438
71-72	1,998	2,868	236	258
72-73	1,391	2,756	206	529
73-74	1,962	2,236	360	386
74-75	1,811	2,965	1,045	156
75-76	1,667	1,833	1,161	304
76-77	978	3,130	722	314
77-78			244	142
78-79	666	2,713	349	116

[1]Stock 5 is central Shelikof Strait and catch is primarily in Viekoda Bay and Kupreanof Strait. Stock 6 is northern Shelikof Strait in the vicinity of Cape Douglas.

[2]Southern District of Cook Inlet is essentially Kachemak Bay.

Tanner Crab

Tanner crab have been taken in virtually all the lease area south of Anchor Point. Areas of greatest Tanner crab catches are Kachemak Bay, the entire area on the western half of the lower inlet, including the northern half of Shelikof Strait and a strip down the eastern side of the southern half of Shelikof Strait; Uyak Bay and Viekoda Bay-Kupreanof Strait (Figure 25).

The Tanner crab fishery has been in existence since 1967. The catches increased in the first few years of the fishery and by the 1971-72 fishing season, harvest was less than 10 million lbs. in the Kodiak management area. As king crab abundance declined in the late 1960's and early 70's, markets opened up, prices increased and more vessels participated in the fishery. By the completion of the 1972-73 season, Tanner crab had become the predominant winter and spring shellfishery with 30.5 million lbs. harvested in the Kodiak area. Since that time the annual landings in Kodiak have varied between about 13.6 and 33.3 million lbs., largely due to disputes over price and competition with other fisheries.

Within the lease area, catches reached 2 million lbs. in northern Shelikof Strait and 1.4 million lbs. in Kachemak Bay in 1969. Since that time catches in Kachemak have fluctuated between about 1 to 2.8 million lbs. per year. The fishery in Kamishak and northern Shelikof Strait expanded a little more slowly at first. About 2 million lbs. were landed from Shelikof and virtually nothing from Kamishak in 1969 but by the 1973-74 fishing season about 4.7 million lbs. were taken in the Kamishak area of lower Cook Inlet and an additional 9 million lbs. were taken in Shelikof Strait. Since that time the Kamishak area has yielded about 2 to 3 million lbs. per year and Shelikof has yielded about 4 to 10 million lbs. per year.

The outlook for the Tanner crab fishery is essentially unchanged. There are no indications at this time that future catches will differ from the historical performance.

The Tanner crab fishing season has included landings in every month of the year, however, there were problems with crab dying in the tanks before delivery, termed deadloss, during summer. Apparently Tanner crab could not survive summer surfacewater temperatures. The fishery has been restricted to the winter-spring time period. In Kachemak Bay the season extends from December 1 through April 30; in other areas of Cook Inlet it is December 1 through May 31 and in the Kodiak management area the season is from January 5 through April 30. All these areas are closed earlier when the catch reaches the guideline harvest level and seasons may be changed by the Alaska Board of Fisheries.

Spawning areas of Tanner crab are not known. Very little information exists on the life history of Tanner crab. Juvenile Tanner crab have been found to be abundant in a few specific locations. Howard Feder (personal

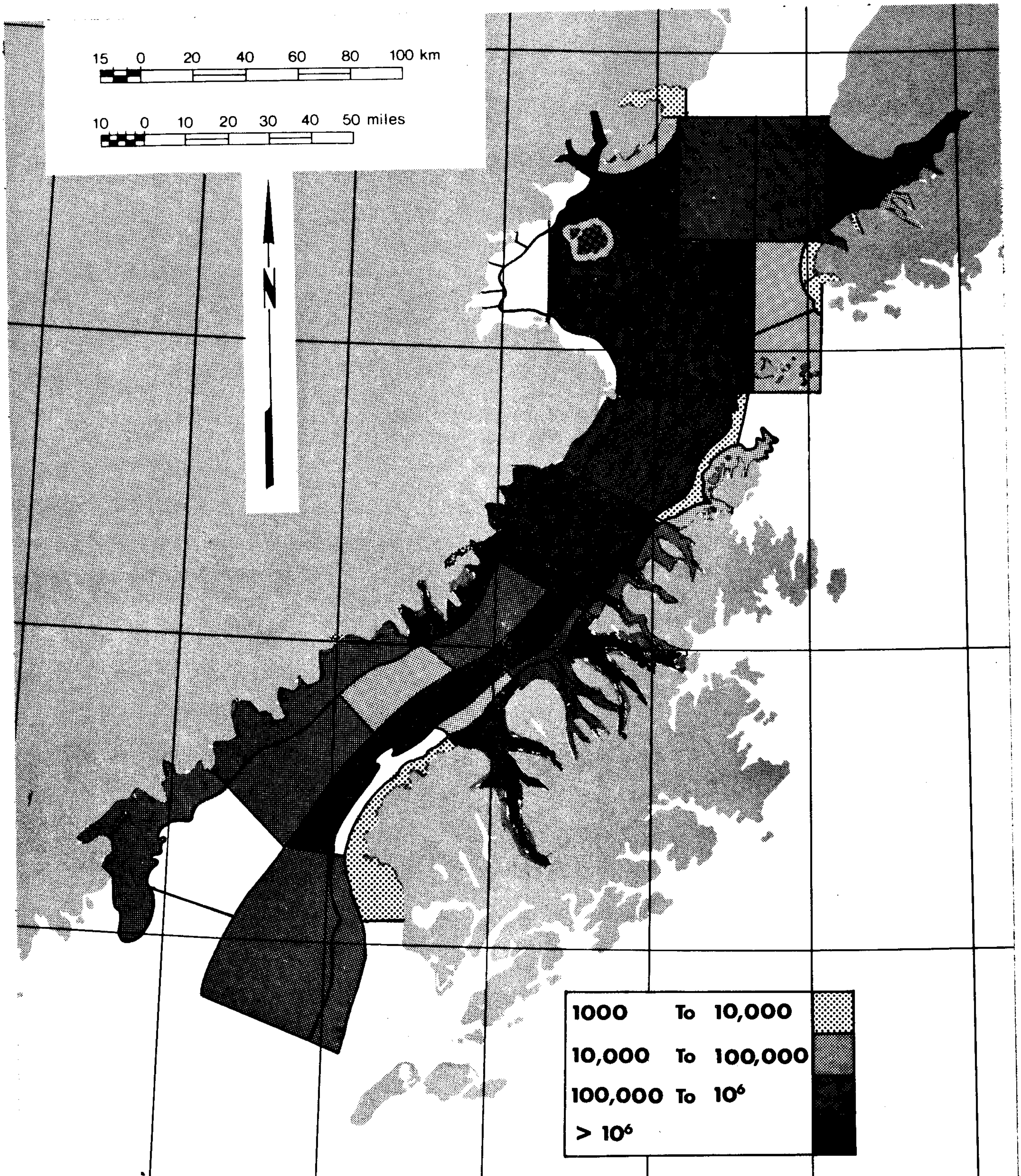


Figure 25. Total catch of tanner crab in thousands of lbs. during 1969-70 through 1977-78 fishing season by statistical area in Cook Inlet and Shelikof Strait. The total catch exceeded 10 million lbs. in two areas, outer Kachemak Bay and the central Shelikof Strait area adjacent to Cape Douglas.

communication) in OCSEAP research found them in the vicinity of Cape Douglas, as did this research project in 1976-77. Dennis Lees (personal communication) found concentrations of juvenile Tanner crab in the area of Iniskin Bay.

As Figure 25, depicting the distribution of the Tanner crab fishery, indicates, this species is more widely distributed than king crab. This generalization also applies to available trawl data. Studies conducted in Kachemak Bay and lower Cook Inlet (Trasky et al, 1977) found king crab spawning and settling areas but did not document a Tanner crab spawning area in Kachemak Bay. The available information suggests that Tanner crab spawning is widely distributed and areas of high concentration of juveniles are known.

The areas utilized by Tanner crab for spawning should be researched.

Dungeness Crab

Catches of dungeness crab have been widespread throughout the lease area south of Anchor Point but greatest catches have occurred in outer Kachemak Bay, in the lower central inlet and along both shorelines of Shelikof Strait, except on Afognak Island (Figure 26).

The dungeness crab fishery began in the Cook Inlet management area with a 190,000 lbs. harvest in 1961 and a 1.9 million lbs. harvest in the Kodiak area in 1962. As a result of favorable market conditions and large virgin stocks in the Kodiak area, commercial harvest increased and peaked in the four year period from 1967-1970 with an average annual harvest of 6.3 million lbs. During the early 1970's the fishery in the Kodiak area declined due to biological and environmental factors accompanied, sometimes, by adverse marketing conditions. In the mid 1970's low prices and other more lucrative fisheries have kept the dungeness production at a low level. In the Cook Inlet area the greatest catch, 1.7 million lbs. occurred in 1963, since then the catches have fluctuated widely from about 7,000 to 750,000 pounds.

The Shelikof Strait area has yielded over 2 million lbs. in one year and yields averaged 1.27 million lbs. between 1962 and 1969. Statistics since that time are not clearly accurate but catches have apparently averaged about 470,000 lbs. in Shelikof Strait between 1969 and 1977. Catches have fluctuated widely with the 1977 catch less than 10,000 lbs. and the 1978 catch 455,000 lbs.

The outlook for the dungeness crab fishery is no different from its history. The stocks are in satisfactory abundance but market conditions will probably continue to fluctuate from year to year.

The bulk of the dungeness catch is taken during July through October in both the Cook Inlet and Kodiak management areas. The Cook Inlet area is open year round except for two areas in Kachemak Bay; inner Kachemak is

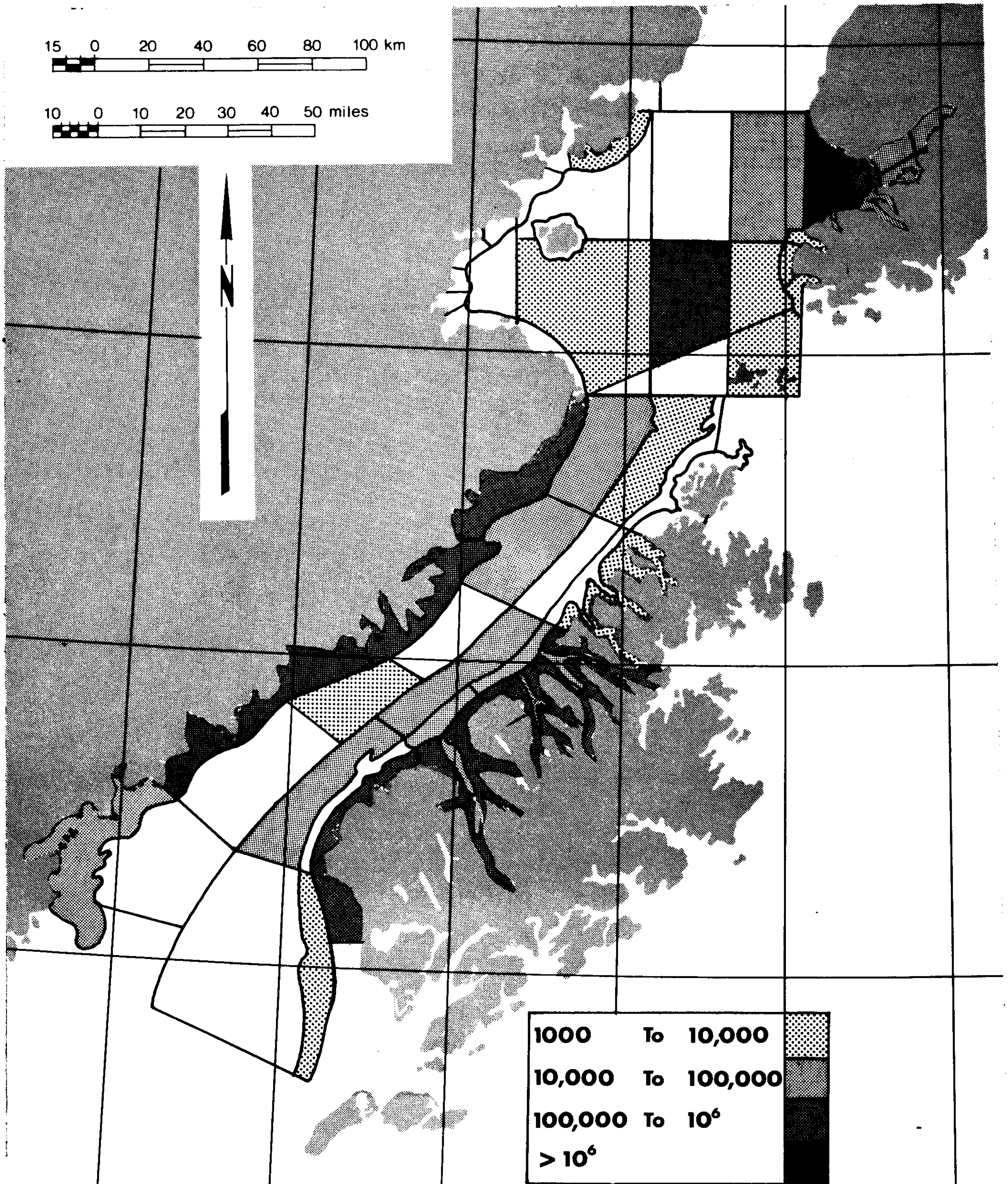


Figure 26. Total catch of Dungeness crab in thousands of lbs. during 1969-70 fishing season through 1976-77 fishing season by statistical area in Cook Inlet and Shelikof Strait.

open September 1 through April 30 and the northern portion of the outer bay is open May 1 through December 31. In the Kodiak management area, that is Shelikof Strait, dungeness crab may be taken May 1 through December 31 except south of Cape Ikolik where the season does not open until June 15.

Dungeness crab spawning areas are not identified anywhere in the lease area. In Kachemak Bay only a couple of egg bearing females have been seen, and these in March or April (this is a lack of knowledge, not a lack of spawning). Movements of dungeness crab are poorly known. In Kachemak Bay they have been shown by tagging data to move to deeper water in the fall, about October through November. At about this time the catch rate decreases markedly. In the early summer, about June, the catch rate rises, as the crab apparently move to shallower water. Dungeness are believed to carry their eggs through the winter as they do in areas further south (Al Davis, personal communication; McLean et al., 1976).

Shrimp

The shrimp fishery in the lease area is conducted in Kachemak Bay, in Kukak Bay on the Alaska Peninsula, and in virtually all of the bays on the west side of the Kodiak Archipelago (Figure 27) including the north end of Afognak Island.

The pink shrimp (*Pandalus borealis*) is the primary species harvested, but the humpback shrimp (*P. goniuris*), coonstripe shrimp (*P. hypsinotus*) spot shrimp or prawn (*P. platyceros*) and sidestripe shrimp (*Pandalopsis dispar*) are also utilized. A small fishery specifically targeted at the large spot shrimp for local markets exists in Kachemak Bay; prawn pots or traps are used to harvest the shrimp which occur primarily in rocky areas. However, the majority of the shrimp harvest is trawl caught from vessels ranging in length from 40 to 90 feet. As the shrimp fisheries in Kachemak Bay and Shelikof Strait are widely seperated, differ in nature, and are in different fishery management units, they are discussed separately.

The Kodiak shrimp fishery began in 1958 with a harvest of 2.9 million pounds. Since 1960, the shrimp fishery has steadily developed and the greatest annual catch in the Kodiak area, 82 million lbs., occurred in 1971. In 1972, quotas were established limiting the total yearly harvest and in 1973 a complete closure during the period of egg hatch was established, creating a fishing season of May 1 through February 28. Since 1971, the catch declined to 20.5 million lbs. during the 1978-79 fishing season.

Shelikof Strait south of the latitude of Cape Douglas is part of the Kodiak management area and has been the site of a shrimp fishery since the early 1960's. Although catches from this area have been a relatively minor portion of total Kodiak area catches, the most consistently productive sections, Uyak, Uganik, West Afognak, Northern and Kukak, have yielded total annual catches of 4.0 to 7.8 million lbs., with a mean of 5.2 million lbs. during the six fishing seasons 1973-74 through 1978-79. In the 1978-79 season, Wide Bay and Puale Bay, on the Alaska Peninsula,

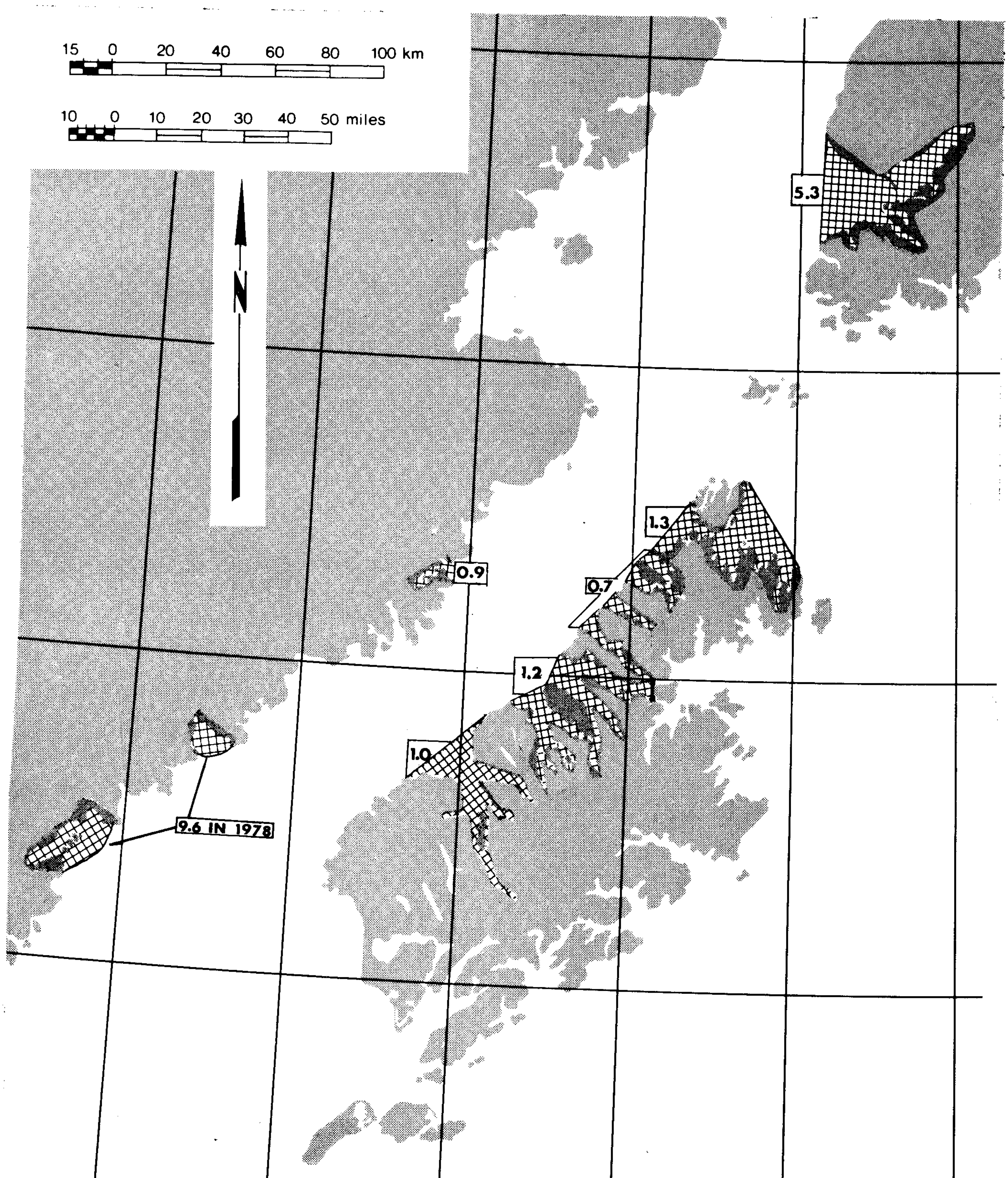


Figure 27. Shrimp catch areas and mean annual catch in millions of pounds in Cook Inlet and Shelikof Strait. Mean annual catch is based on 1973-74 through 1978-79 fishing seasons.

produced 9.6 million pounds. This catch occurred when severe catch declines in known shrimp grounds of the Kodiak and Alaska Peninsula area forced fishermen to explore unfished areas. The Uyak and Uganik sections on Kodiak Island have consistently produced the highest annual catches since 1973-74, with the Kukak Bay and West Afognak sections ranking as the third and fourth consistently large producers, repspectively. Annual fluctuations do not necessarily represent changes in abundance, but rather fluctuations in fleet effort in response to discovery and development of more productive fishing grounds elsewhere.

The outlook for the shrimp fishery in the bays of Shelikof Strait is not substantially changed from its history. In Wide and Puale bays adult shrimp seem to be absent in 1979. Population trends have not been detected in other areas.

The shrimp fishery in Kachemak Bay yielded catches fluctuating between 25,000 lbs. per year and 1.9 million lbs. per year during the 1960's. In 1970, 5.8 million lbs. were harvested and the catch has remained stable since that time, with total annual catches ranging from 4.4 to 7.2 million lbs. through 1978. Indications are that shrimp catches will continue at about the same level.

Prior to 1971 there were no closed seasons and the fishery was pursued throughout the year. In 1971 some areas were closed during March and April, the period of shrimp egg hatching. Beginning in 1973 the months of March and April have been closed throughout the Kodiak management area while in Kachemak Bay the months of April and May have been closed. With the increased fishery in recent years there have also been closures for management purposes.

Shrimp life history involves a period during which the female carries developing eggs. In pink shrimp this is about six months. Shortly before the eggs hatch, the ovigerous females tend to congregate in deep holes near the mouths of bays where they remain for egg hatching. Studies were conducted in Kachemak Bay that followed the larvae through their pelagic phase until settling so that the outer portion of Kachemak Bay is a known shrimp spawning area.

No other areas are known to be shrimp spawning areas with the same level of established knowledge, but it goes without saying that every population reproduces. The fished populations have been observed through the fishery to congregate in the outer portion of a bay, in a deep hole, where egg hatching occurs. Thus shrimp spawning areas are probably located in Kukak Bay, Wide Bay, Puale Bay, Uyak Bay, Uganik Bay, Viekoda Bay, Malina Bay, Perenosa Bay and probably a few other bays.

Razor Clams

Commercial digging of razor clams (*Siliqua patula*) has been conducted on Swikshak Beach which is just south of Cape Douglas and on Polly Creek Beach, which is just north of Tuxedni Bay. Extensive recreational and subsistence digging is widespread in the lease area. Razor clams are also dug for use as bait for dungeness crab from whichever beach is handy for the fisherman.

Razor clams occur throughout the lease area wherever there are sandy beaches. Known razor clam beds are identified in Figures 28 and 29.

In the Kodiak area, virtually all the digging has been conducted on Swikshak Beach. Since 1960 there have been four distinct periods with different catch levels. From 1960 through 1963 there were 297,000 to 421,000 lbs. dug each year, from 1964 through 1969 annual harvest ranged from zero to 20,000 lbs., from 1970 through 1974 annual harvest ranged from 132,000 to 198,000 lbs. and since 1975 there have been only a few thousand pounds harvested.

The causes of the fluctuations in catch are not related to the population of clams but to regulations, market conditions and logistics of harvesting in a remote area on a National Monument. The future of the razor clam fishery is difficult to predict. There exists a potential to harvest perhaps as much as a million pounds of clams per year in the Kodiak area. If mechanical digging is developed, this potential may be realized.

This fishery is conducted entirely during the summer months.

Weathervane Scallop

The fishery for weathervane scallops (*Patinopectin caurinus*) has been conducted primarily on the east side of Kodiak with about 24,000 lbs. per year or 3.5% of the total catch coming from Shelikof Strait during 1970 through 1976 (Table 8). The catch has been primarily on the eastern and western shores in the southern half of Shelikof Strait (Figure 30).

Table 8. Historic commercial catch of weathervane scallops in the Kodiak area and the Shelikof portion of the Kodiak area.

Year	Kodiak Area Total	Shelikof Strait[1]
1967	7,788	
1968	872,803	
1969	1,012,860	
1970	1,417,612	3,000
1971	841,211	15,306
1972	1,038,793	74,140
1973	935,705	19,812
1974	147,945	6,895
1975	294,142	43,801
1976	75,245	0

[1] Data for Shelikof Strait is not readily available for 1967,68, and 69.

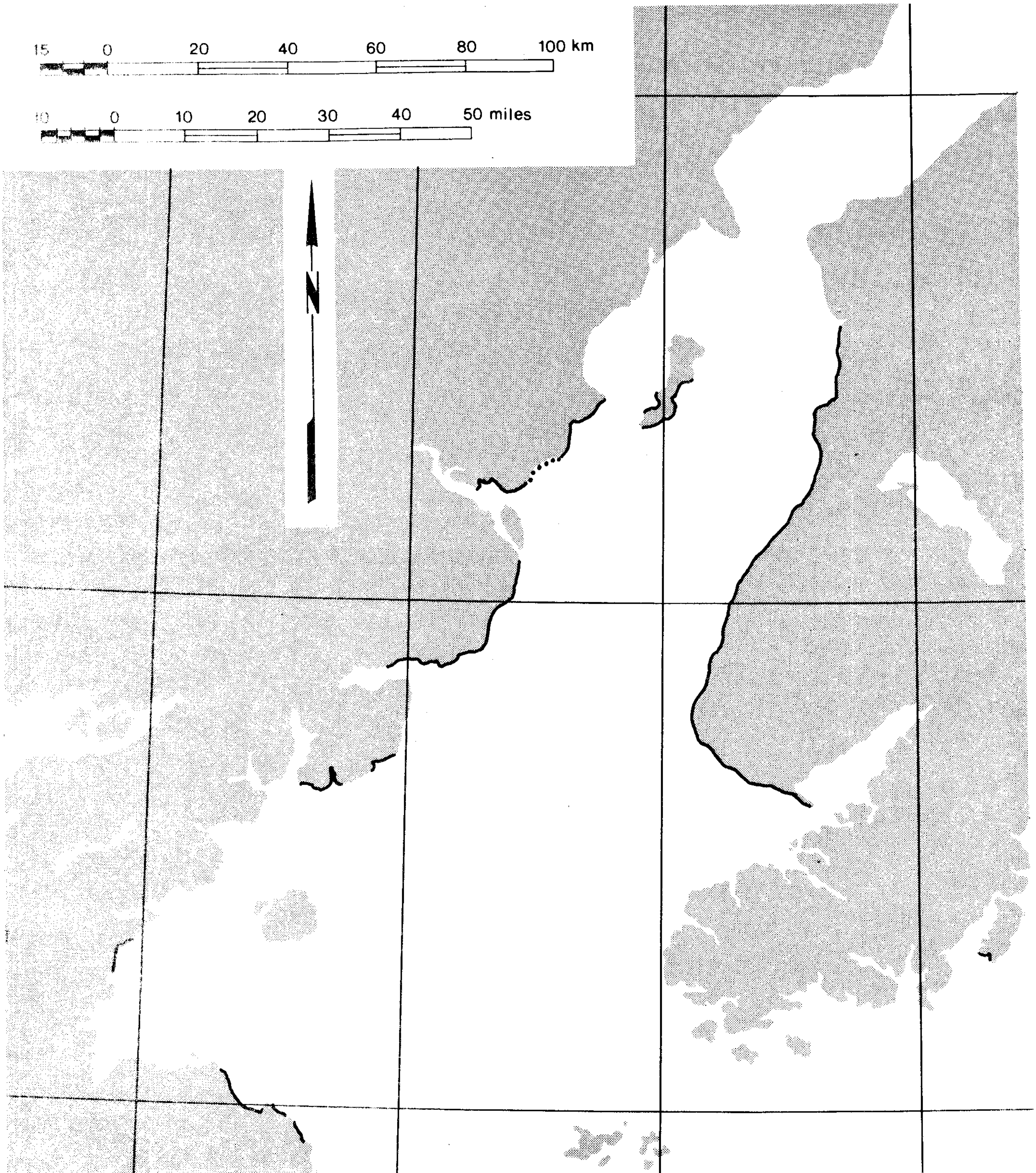
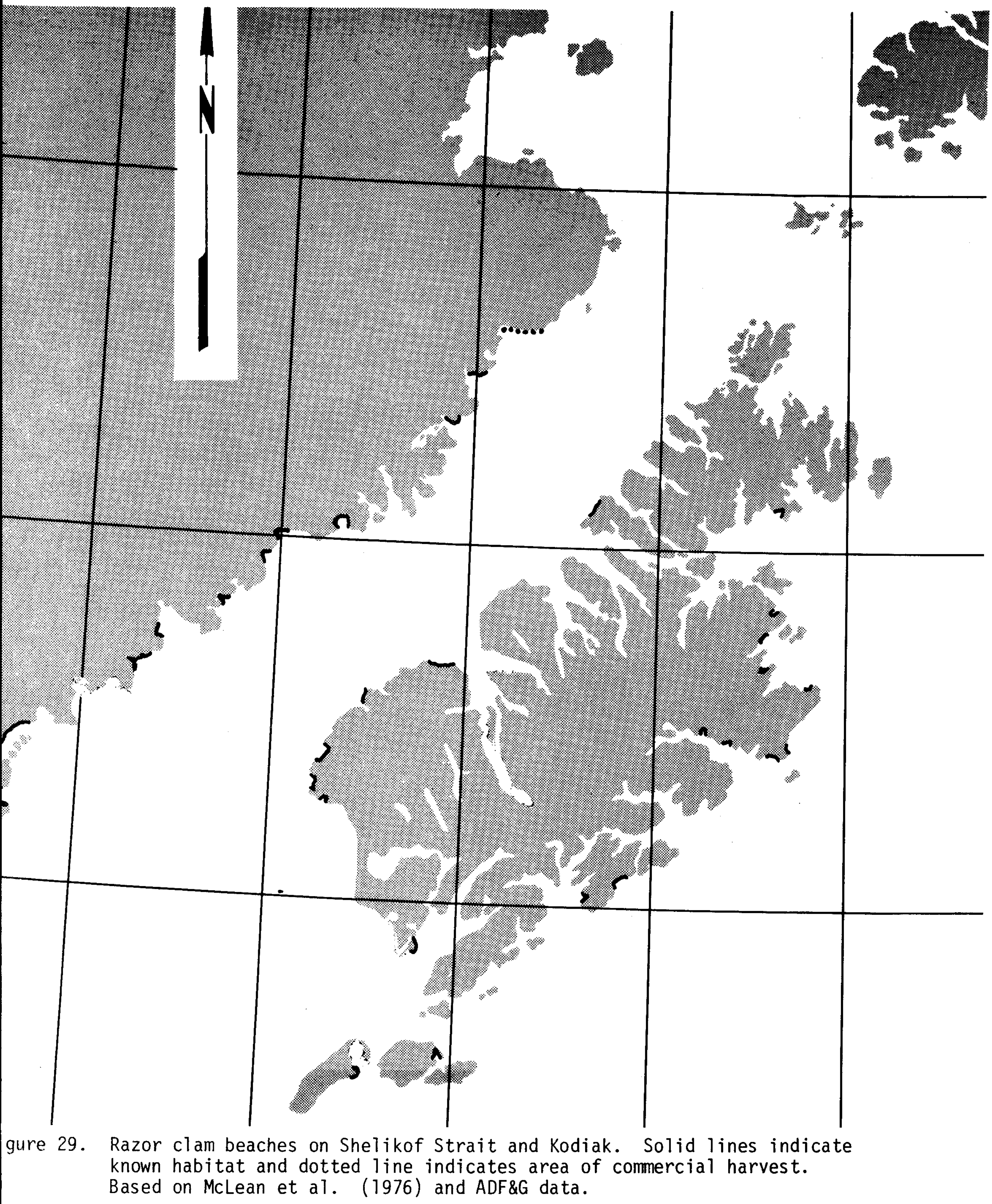


Figure 28. Razor clam beaches in lower Cook Inlet. Solid lines indicate known habitat and dotted line indicates area of commercial harvest. Based on McLean et al. (1976).



gure 29. Razor clam beaches on Shelikof Strait and Kodiak. Solid lines indicate known habitat and dotted line indicates area of commercial harvest. Based on McLean et al. (1976) and ADF&G data.

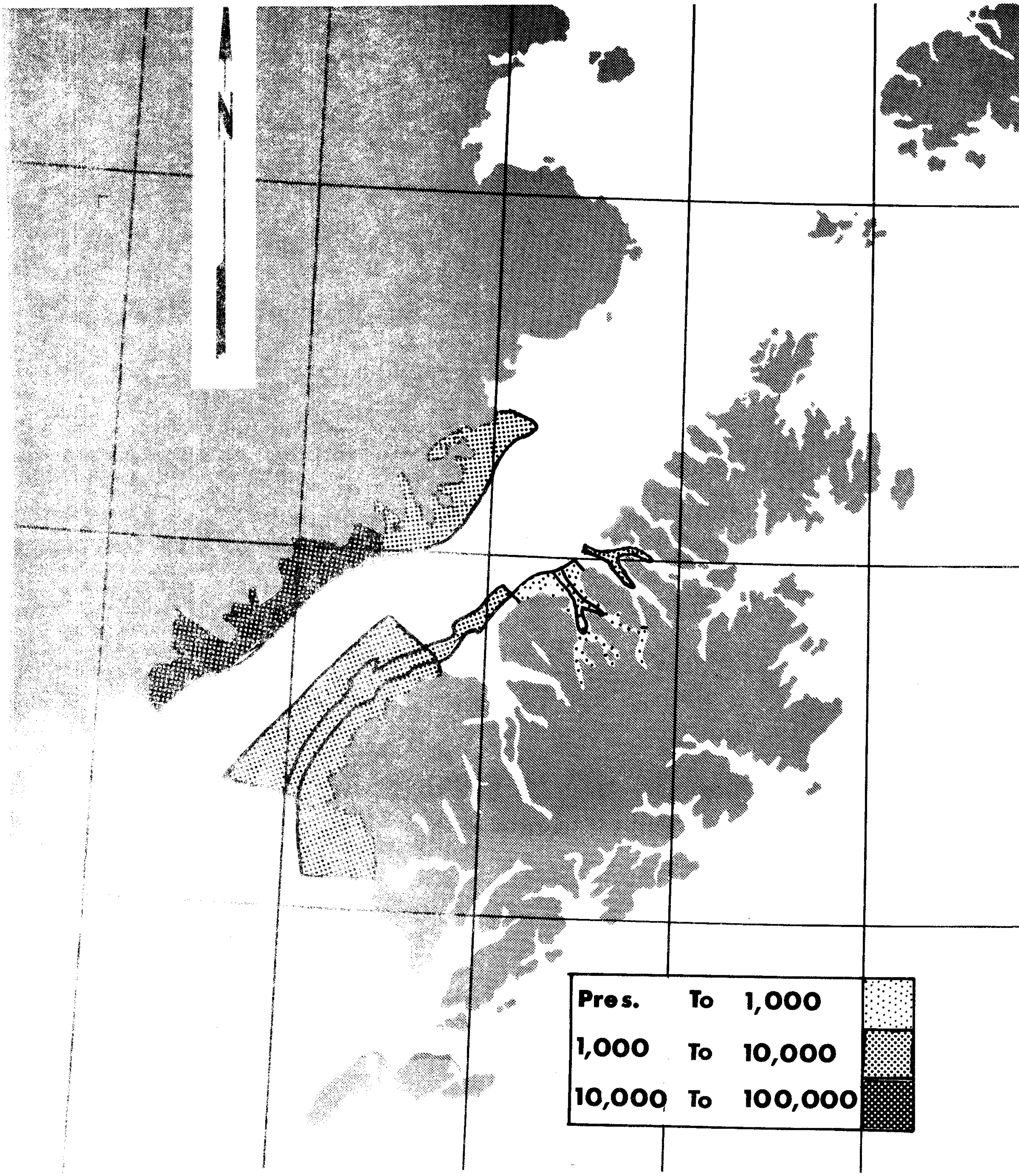


Figure 30 Total catch of weathervane scallops in lbs. during 1970 through 1976 by statistical area in Cook Inlet and Shelikof Strait. The total catch during this time was 167,000 lbs. and no catch was landed in 1976.

The scallop fishery began in 1967 and expanded in the Kodiak area to 1.4 million lbs. in 1970 and decreased thereafter, with the last landings made in 1976. A considerable amount of exploration was conducted by the fishermen and it is considered likely that all productive areas have been identified.

The future of the scallop fishery will depend upon a number of unpredictable factors. For example, at this writing there are rumors that the east coast scallop fishery has declined and the vessels are considering travelling to Alaska to fish for scallops. If this occurs, there will probably be another period of scallop production.

STUDY AREA

The study area for this project includes lower Cook Inlet from the Forelands south, including Kachemak and Kamishak bays, Kennedy Entrance and all of Shelikof Strait.

Cook Inlet receives the waters of several substantial rivers including the Susitna, Matanuska, Knik, 20 Mile, Kenai and Kasilof. These and others are glacier fed and contribute sufficient suspended material to the inlet that the entire upper inlet and a substantial portion of lower Cook Inlet contains intensely silty waters. The shoreline around Anchorage and into lower Cook Inlet consist of vast deposits of silt. Apparently, considerable areas of the bottom of lower Cook Inlet are covered by sand, which may be of overriding importance in the ecology of considerable portions of the inlet. Water flow in lower Cook Inlet is dominated by tides and generally follows bathymetric contours. Tidal current velocities exceed 4 knots in the central and lower inlet and exceed about 7 knots at the Forelands. The central part of lower Cook Inlet is a region of high tidal energy, especially on the eastern side but the Coriolis effect results in reduced tidal energy on the west side. Several features of mean flow (nontidal) are disputed but highly silty fresh water enters in the upper inlet, flows out primarily along the west side in the lower inlet and replacement inflow of entrained marine waters flows north along the east side of the inlet. Marine water enters through Kennedy Entrance and part of it exists through Shelikof Strait. The waters of Kachemak Bay are exchanged little with the water of the inlet (Science Applications Inc. 1977).

In Shelikof Strait the mean water flow is constantly to the southwest (Science Applications Inc. 1979) and the freshwater that exists in lower Cook Inlet is found along the western side of Shelikof, with a gradual widening of the plume to the southwest (Marine Coastal Habitat Management, 1978). In the summer this water is of relatively low salinity and high in temperature while the suspended sediment load remains sufficient for the water to be identified from satellite imagery (Marine Coastal Habitat Management, 1978).

SOURCES, METHODS AND RATIONALE OF DATA COLLECTION

The field collections for this study were made in part of Kachemak Bay and northern Kamishak Bay. The work in Kamishak Bay was conducted continously from May through September. Collections were made with beach seine, try net, gill net, trammel net and surface tow net. These are described in detail below. Temperature and salinity were measured with a Yellow Springs Instrument Co. Model 33 Temperature/Salinity meter. Sampling locations are illustrated in Figures 31 and 32.

The field crew consisted of four people who were housed in camp facilities in Cottonwood Bay during May through September. During April and November they stayed in Homer and the Kasitsna Bay field station respectively. Two outboard skiffs, one 17 ft. (5 m) and one 21 ft. (6.4 m) in length were used for sampling and the M/V HUMDINGER was irregularly available for tow net and try net sampling beginning in May.

Beach Seine

The beach seine was constructed as shown in Figure 33. Approximately [illegible] ft. (15 m) longlines of rope with small anchors were attached to each end. The net was set in an arc such that each end of the net was usually within 10 ft. (3 m) of the beach and the net was immediately retrieved. Sampling stations were informally selected on suitable beaches so as to evenly cover the study area. Once stations were selected, they were visited on each successive cruise. Stations sampled by Blackburn (1978) were resampled.

Try Net

The try net was a standard 20 ft. (6.1 m) try net purchased from McNeir Net and Supply Co. It had a 22 ft. (7 m) foot rope, a 20 ft. (6.1 m) headrope, and was made with 1-1/2" (38 mm) #9 webbing throughout with a 1-1/2" (38 mm) #18 bag and was dipped in green gard. Otter boards were 15" x 30" (38 cm x 76 cm). It was equipped with a tickler of 3/8" (9.5 mm) chain which was slightly shorter than the footrope so that it preceeded the footrope when the net was in operation. It was pulled at about 3.5 kph so that about 0.6 km were covered in one tow. The net was considered to open about 5.3 m horizontally and 0.7 m vertically so that one tow sampled about 3200 m of bottom. Sampling stations were selected in the field.

Gill Net

Gill nets were 6 ft. (1.8 m) deep and 100 ft. (30.4 m) long and each consisted of 25 ft. (7.6 m) long panels of 1", 1-1/2", 2" and 2-1/2" (25 mm, 38 mm, 51 mm and 64 mm) stretch mesh knotted nylon. The nets were hung to float, were anchored in the immediate vicinity of beach seine stations and retrieved after about a one hour soak.

Trammel Nets

The trammel nets were constructed of three adjacent panels (two outer and one inner) each 150 ft. (45.7 m) by 6 ft. (1.8 m). The two outer

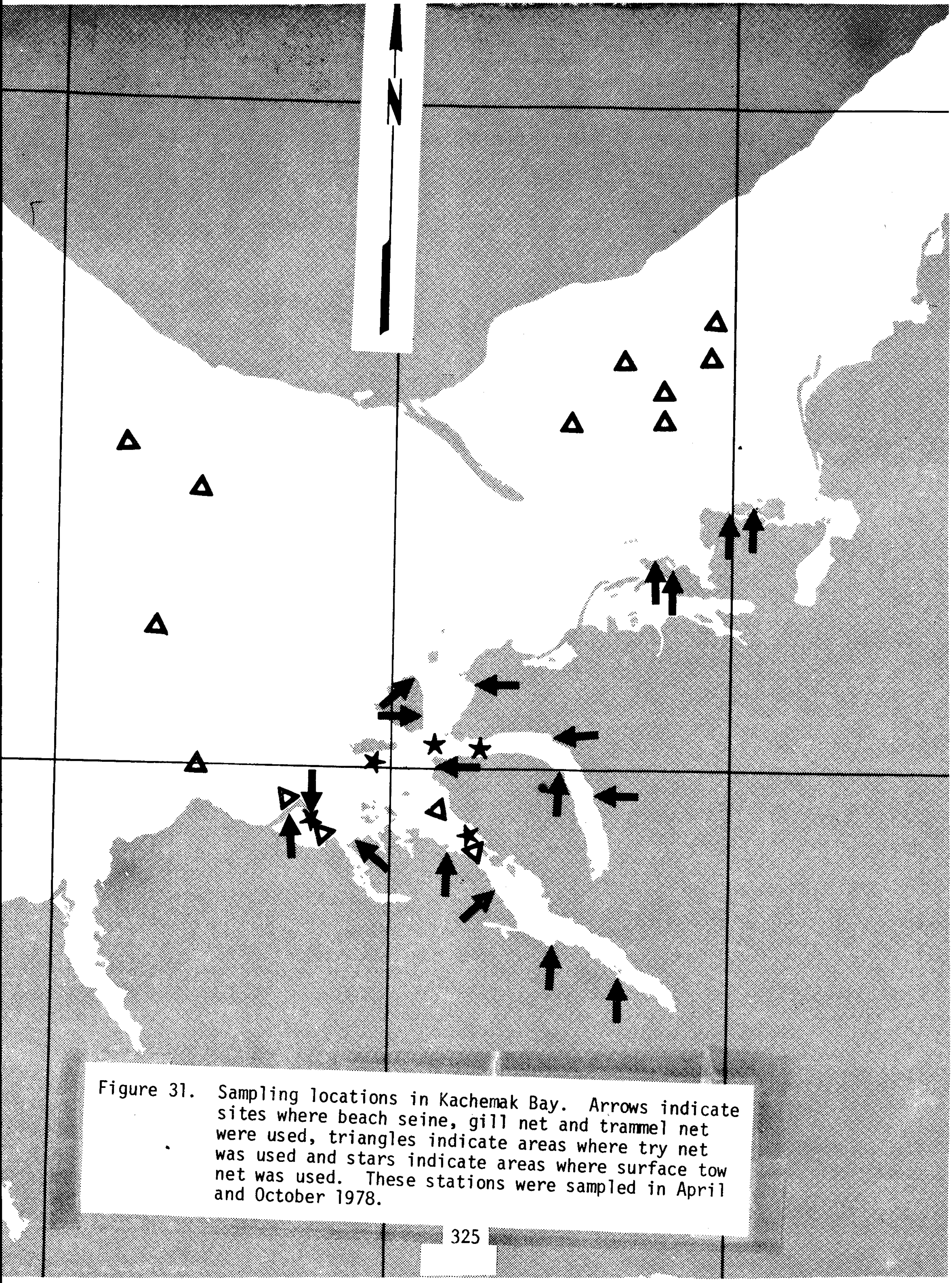


Figure 31. Sampling locations in Kachemak Bay. Arrows indicate sites where beach seine, gill net and trammel net were used, triangles indicate areas where try net was used and stars indicate areas where surface tow net was used. These stations were sampled in April and October 1978.

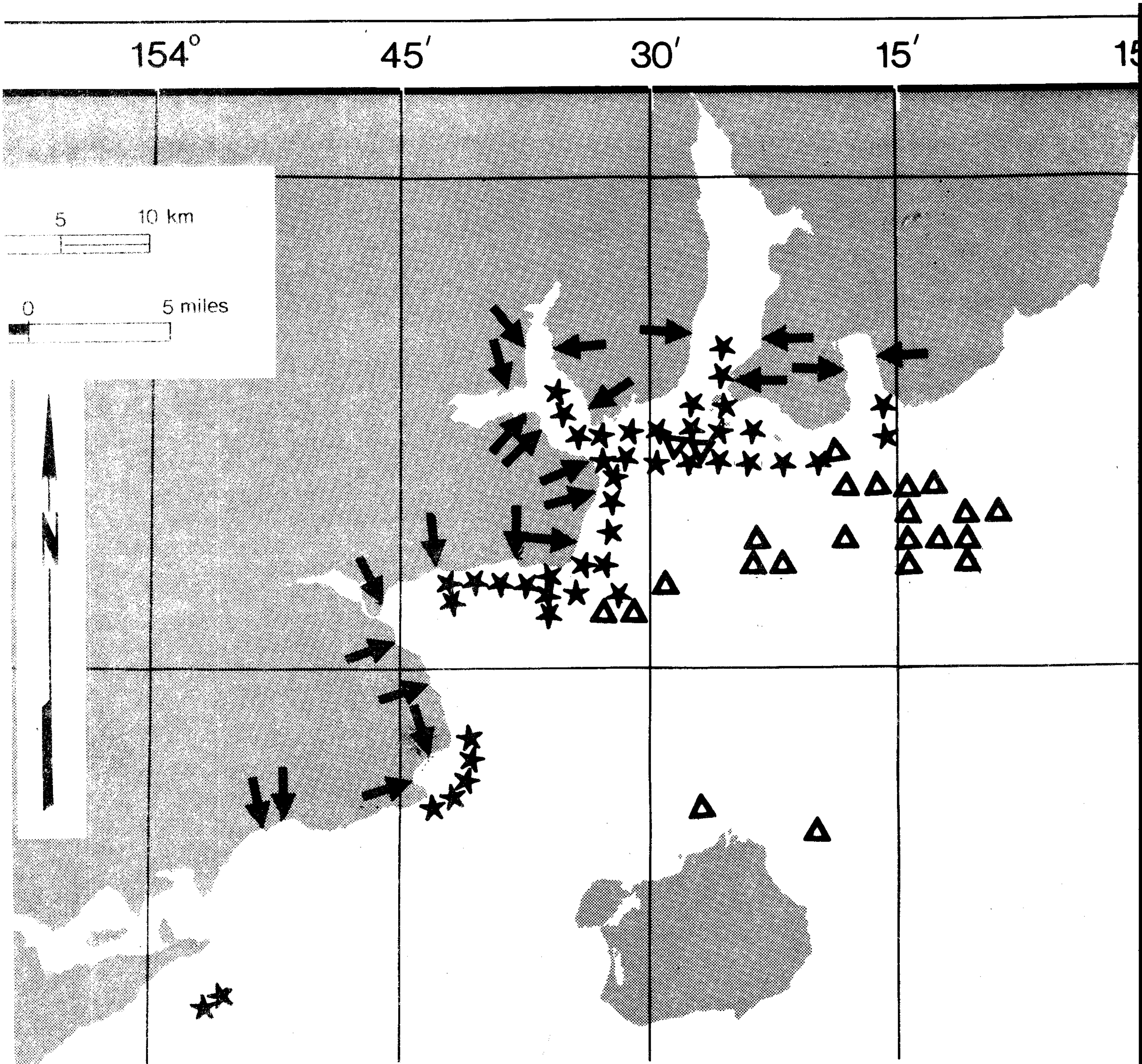


Figure 32. Sampling locations in Kamishak Bay. Arrows indicate sites where beach seine, gill net and trammel net were used, triangles indicate areas where try net was used and stars indicate areas where surface tow net was used. These stations were sampled in May through September 1978.

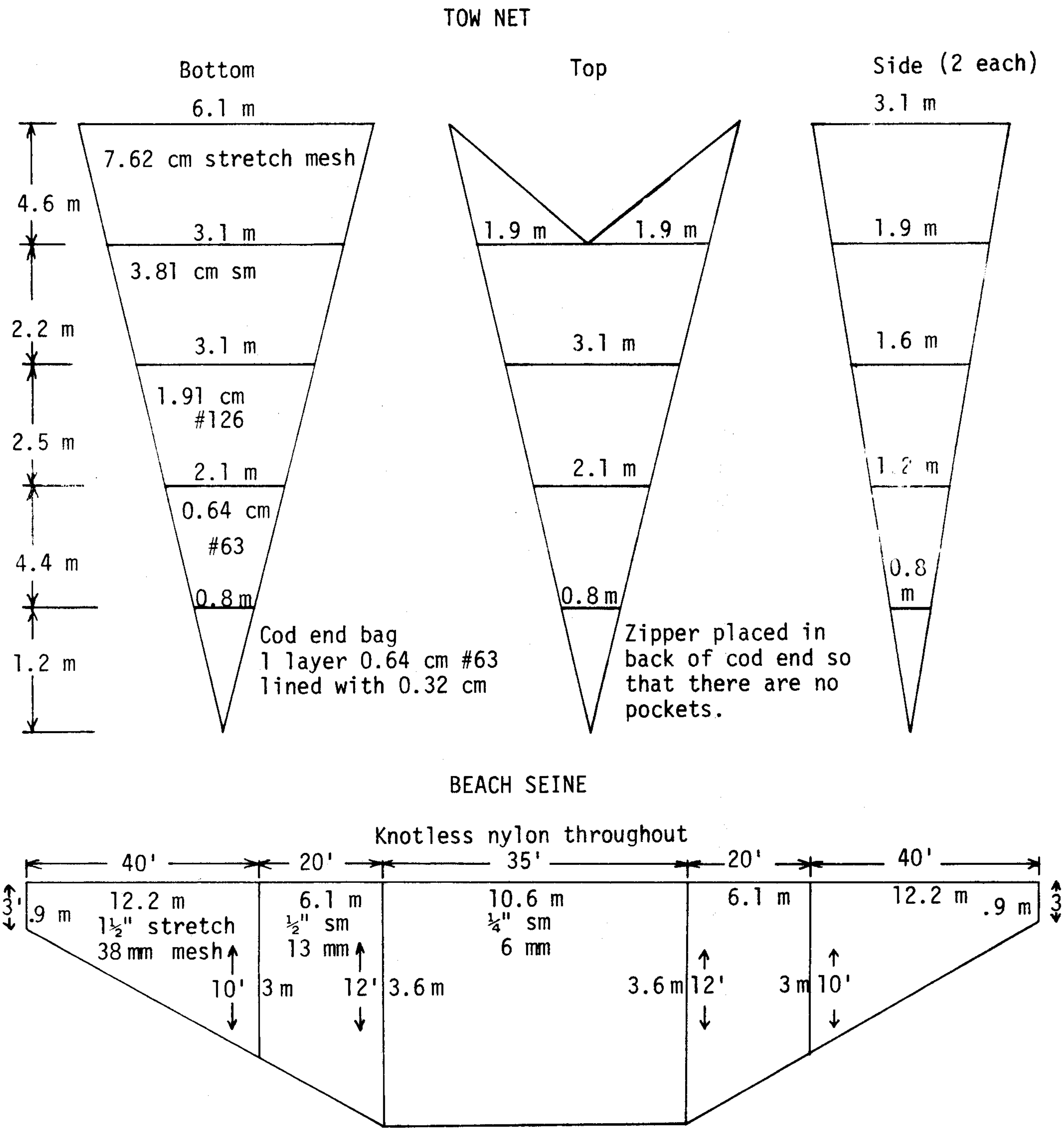


Figure 33. Specifications of the tow net and beach seine, diagrammatic.

panels were made with 20" (0.5 m) stretch mesh of #9 twine 8 mesh deep by 168 mesh long. The single inner panel was 2" (51 mm) stretch mesh of #139 twine, 68 mesh deep by 2016 mesh long. All panels were white knotted nylon. The lead line was 75 lb. lead core rope and the float-line was 1/2" (13 mm) poly foam core line.

The trammel nets were hung to sink and were fished on the bottom. A single net was anchored in the immediate vicinity of a beach seine station and was retrieved after approximately a one hour soak.

Tow Net

The tow net was constructed as illustrated in Figure 33. It was held open vertically by spreader bars of 2" (51 mm) galvanized water pipe and was held open horizontally by a towing vessel on each side. It opened approximately 10 ft. (3 m) vertically and 20 ft. (6.1 m) horizontally when fishing. It was towed at the surface between a skiff and the charter vessel on approximately 100 ft. (30.4 m) of line for 10 minutes at approximately 3.5 kph so that about 0.6 km were covered in one tow. Sampling stations were informally selected to cover the study area.

Sample Handling

Immediately after capture, catches were sorted to species when possible, counted, weighed and recorded. Life history stage was recorded when it was possible to determine and for some species the catches were sorted by life history stage, i.e. adult, juvenile and larval. The stomach was removed from large fish after they were weighed, measured and the data recorded. Small fish were preserved whole for food habits analysis and lengths of these were not taken in the field. Lengths were recorded from a large portion of the fish that were not used for food habits analysis.

Maturity state of adult fish was recorded when they were opened for stomach removal and in some cases samples of fish were opened expressly to determine maturity state. When sex products were observed to flow freely from fish this was recorded. Due to the lack of knowledge of the appearance of the gonads before and after spawning for the many species handled, the maturity state observations are considered of value only when freely flowing sex products were observed.

Data Limitations

The community of fishes observed during faunal surveys and the relative importance of species or species groups within the community is largely a function of the sampling tools employed. Try nets, beach seines, tow nets, and especially trammel nets and gill nets are selective. Sizes and even species of fish captured are influenced by such features as mesh size used, gear configuration, towing speed and method of employment (beach seine may be set far from the beach and pulled to shore or set with the ends nearly ashore, as it was in this study). Passive gear such as the trammel net and gill net depends upon the activity of the fish to

This section is adapted from a similar discussion for trawls by Alverson et al. (1964).

the presence of the net, body size and shape, presence of spines, behavior and other features. Even species within the size range which theoretically would be retained if engulfed by a towed net may differ in their ability to avoid the mouth of the net. The selective feature of all gears thus alters the species composition and sizes and quantities of species captured from that which occur in its path. The degree to which "apparent" distribution and relative abundance differs from the actual is unknown. Subsequent discussions of distribution and relative abundance of species reflect the results obtained with the sampling gear employed.

The beach seine and tow net each yielded large numbers of age 0 fish, including larval, post larval and early juvenile stages. The early stages were difficult to identify and too numerous for field crews to include in the data. However, samples were routinely taken, identifications made, and estimates of abundance (1, 10, 100 or 1,000) entered in the data. When these fish (almost exclusively herring and sand lance) became juveniles they were still coded as larvae to eliminate the problem of interpreting an increases in abundance over a short time period.

Food Habits Analysis

Specimens for food habits analysis were selected from those captured using the list of priorities and maximum number per cruise shown in Table 9. The total time available for food identification was allotted by cruise and as many specimens were examined as time allowed. During the sample analysis the project was extended and due to State of Alaska employment rules, the time available could not be extended without an extended delay, hence available time was less for analysis of later cruises.

Food habits analysis began with determination of the length, in mm and weight to the nearest 0.01 gm for fish less than about 300 gms and to the nearest 0.1 gm for larger fish. The stomach was removed, its fullness estimated and the weight of the total contents was determined to the nearest 0.01 gm. The gut contents of many of the small fish, especially the salmon, was so small that this was inadequate. The food items were separated, identified to the lowest possible taxon, counted and the weight determined by weighing or by estimating proportions.

Table 9. Priority list for selection of specimens for food habits analysis

PRIORITY		Maximum number analyzed per cruise
1	Sand lance	25
2	Herring	25
3	Dolly Varden	25
4	Chum Salmon Fry	25
5	Chinook Salmon Fry	15
6	Red Salmon Fry	15
7	Coho Salmon Fry	15
8	Pink Salmon Fry	15
9	Whitespotted Greenling Juvenile	15
10	Whitespotted Greenling Adult	10
11	Masked Greenling Juvenile	15
12	Masked Greenling Adult	10
13	Capelin	20
14	Eulachon	5
15	Longfin Smelt	10
16	Great Sculpin	20
17	Yellowfin Sole	10
18	Starry Flounder	10
19	Rock Sole	10
20	Staghorn Sculpin	10
21	Pollock	10
22	Pacific Cod	10

RESULTS

Catch Results

Identified in lower Cook Inlet were 21 families and 67 species of fish (Table 10). One species, the plain sculpin, common in try net hauls, constitutes a range extention. This species has been previously recorded in Japan, the Bering Sea, Sea of Okhotsk, the Aleutian Islands and as far east as Cold Bay on the south side of the Alaska Peninsula (Quast and Hall, 1972). This was one of the two taxa of Myoxocephalus that were identified in Cook Inlet. The buffalo sculpin was reported to occur from Monterey, California to the Gulf of Alaska and Kodiak by Hart (1973). This species was captured in Kachemak Bay.

Considerable confusion exists in the taxonomy of Myoxocephalus and Gymnocanthus. This was partially cleared up during this study. The Myoxocephalus were found to be great sculpin and plain sculpin in Cook Inlet and in Kodiak the warthead sculpin (M. niger) and a few specimens of an undescribed species were also captured. The Gymnocanthus were identified as threaded sculpin in Cook Inlet and Kodiak and armorhead sculpin (G. galealus) in Kodiak. Confusion in the identification of Bathymasterids was uncovered when obviously different taxa that keyed to the same species were sent to Norm Wilimovsky, who responded that several of the specimens were an undescribed species that has long been recognized to exist.

Relative Abundance

The numerically predominant taxa in the beach seine catches were Pacific sand lance, juvenile chum salmon, Dolly Varden, juvenile pink salmon, Pacific herring, longfin smelt, whitespotted greenling, Pacific staghorn sculpin, Myoxocephalus sp., and starry flounder (Table 11).

The weight predominant taxa in the try net catches were yellowfin sole, tanner crab, butter sole, flathead sole, Pacific halibut, rock sole, arrowtooth flounder, king crab, Myoxocephalus sp., and walleye pollock juveniles (Table 12).

The numerically predominant taxa in the tow net catches were Pacific sand lance, Pacific herring, whitespotted greenling, capelin, juvenile pink, sockeye, chum and chinook salmon (Table 13).

The numerically predominant species in the gill net catches were adult Pacific herring, chum salmon, Dolly Varden, and Bering cisco (Table 14). The numerically predominant species in the trammel net were adult Pacific herring, whitespotted greenling, sturgeon poacher, yellowfin sole, masked greenling and Pacific staghorn sculpin (Table 15).

Table 10. Fish species captured in Cook Inlet by beach seine, gill net, trammel net, tow net and try net April-October, 1978.

Petromyzontidae	
Arctic lamprey	*Lampetra japonica*
Squalidae	
Spiny dogfish	*Squalus acanthias*
Rajidae	
Big skate	*Raja binoculata*
Salmonidae	
Bering cisco	*Coregonus laurettae*
Pink salmon	*Oncorhynchus gorbuscha*
Chum salmon	*Oncorhynchus keta*
Coho salmon	*Oncorhynchus kisutch*
Sockeye salmon	*Oncorhynchus nerka*
Chinook salmon	*Oncorhynchus tshawytscha*
Dolly Varden	*Salvelinus malma*
Clupeidae	
Pacific herring	*Clupea harengus pallasi*
Osmeridae	
Surf smelt	*Hypomesus pretiosus*
Capelin	*Mallotus villosus*
Longfin smelt	*Spirinchus thaleichthys*
Gadidae	
Saffron cod	*Eleginus gracilis*
Pacific cod	*Gadus macrocephalus*
Pacific tomcod	*Microgadus proximus*
Walleye pollock	*Theragra chalcogramma*
Zoarcidae	
Wattled eelpout	*Lycodes palearis*
Gasterosteidae	
Threespine stickleback	*Gasterosteus aculeatus*
Scorpaenidae	
Rockfish	*Sebastes sp.*
Hexagrammidae	
Masked greenling	*Hexagrammos octogrammus*
Whitespotted greenling	*Hexagrammos stelleri*
Lingcod	*Ophiodon elongatus*

Table 10. (continued)

Anoplopomatidae	
Sablefish	*Anoplopoma fimbria*
Cottidae	
Padded sculpin	*Artedius fenestralis*
Crested sculpin	*Blepsias bilobus*
Sivlerspotted sculpin	*Blepsias cirrohosus*
Sharpnose sculpin	*Clinocottus acuticeps*
Spinyhead sculpin	*Dasycottus setiger*
Buffalo sculpin	*Enophrys bison*
Threaded sculpin	*Gymnocanthus pistiliger*
Irish Lord	*Hemilepidotus sp.*
Yellow Irish Lord	*Hemilepidotus jordani*
Bigmouth sculpin	*Hemitripterus bolini*
Northern sculpin	*Icelinus borealis*
Pacific staghorn sculpin	*Leptocottus armatus*
Plain sculpin	*Myoxocephalus jaok*
Great sculpin	*Myoxocephalus polyacanthocephalus*
Ribbed sculpin	*Triglops pingeli*
Agonidae	
Sturgeon poacher	*Agonus acipenserinus*
Smooth aligatorfish	*Anoplagonus inermis*
Fourhorn poacher	*Hypsagonus quadricornis*
Bering poacher	*Occella dodecaedron*
Tubenose poacher	*Pallasina barbata*
Cyclopteridae	
Ribbon snailfish	*Liparis cyclopus*
Tidepool snailfish	*Liparis florae*
Slipskin snailfish	*Liparis fucensis*
Showy snailfish	*Liparis pulchellus*
Ringtail snailfish	*Liparis rutteri*
Trichodontidae	
Pacific sandfish	*Trichodon trichodon*
Bathymasteridae	
Alaska ronquil	*Bathymaster caeruleofasciatus*
Searcher	*Bathymaster signatus*
Stichaeidae	
Snake prickleback	*Lumpenus sagitta*
Daubed shanny	*Lumpenus maculatus*
Pholidae	
Crescent gunnel	*Pholis laeta*

Table 10. (continued)

Ammodytidae	
Pacific sandlance	*Ammodytes hexapterus*
Pleuronectidae	
Arrowtooth flounder	*Atheresthes stomias*
Rex sole	*Glyptocephalus zachirus*
Flathead sole	*Hippoglossoides elassodon*
Pacific halibut	*Hippoglossus stenolepis*
Butter sole	*Isopsetta isolepis*
Rock sole	*Lepidopsetta bilineata*
Yellowfin sole	*Limanda aspera*
Dover sole	*Microstomus pacificus*
English sole	*Parophrys vetulus*
Starry flounder	*Platichthys stellatus*
Alaska plaice	*Pleuronectes quadrituberculatus*
Sand sole	*Psettichthys melanostictus*

Table 11. Relative abundance and rank of major taxa from beach seine catches in Cook Inlet, April-October, 1978 based on total number captured in all cruises, larval stages excluded.

Taxon	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	OVERALL Rank	OVERALL % of total
Pacific sandlance	5.4	6.5	43.7	39.7	2.4	12.7	10.8	12.1	1.5	80.8	54.3	77.7	1	38.5
Chum salmon		58.1	16.0	1.3	23.1	25.5	15.2	41.4	6.7	1.7			2	13.6
Dolly Varden		1.6	6.4	27.5	13.2	11.6	12.3	17.3	77.6	2.5	12.7	2.0	3	11.8
Pink salmon	84.8	8.1	6.8	0.5	8.4	38.8	2.5	11.8	0.2				4	8.3
Pacific herring			0.5	0.3	30.7	1.1	1.9	3.2		1.1	2.0		5	7.2
Longfin smelt		1.6	15.5	10.1	1.0	1.6	17.4	0.5		3.0	9.4		6	4.7
Whitespotted greenling	4.4		0.9	2.1	10.9	3.5	13.8	6.1	1.7	0.6	0.5		7	4.2
Pacific staghorn sculpin		4.8	0.5	2.1	1.0	0.3	3.5	0.5	2.7	3.7	5.6	0.4	8	2.0
Myoxocephalus sp.	5.4	12.9	2.5	2.7	0.1	0.5	1.0	0.5	1.1	0.7	4.5	15.1	9	1.7
Starry flounder		1.6	1.0	1.6	1.8	0.7	3.8	0.8	0.4	0.7	5.6		10	1.3
Snake prickleback			0.4	1.1	3.6	0.8	2.7	0.9	0.2	0.1			11	1.1
Rock sole		3.2	1.4	3.2	1.3	0.9	3.6	0.8	0.8	0.3	0.2	1.6	12	1.1
Pacific sandfish				0.3			0.2			3.1	0.2		13	0.9
Tubenose poacher					0.1	0.3	0.5	0.9	2.5	0.9		1.6	14	0.5
Bering cisco			0.2	1.3	1.0	0.1	1.7	0.9	1.1	0.1	0.5		15	0.5
Sturgeon poacher			0.9	0.8	0.4	0.1	1.0				0.2		16	0.3
Surf smelt			0.1	0.3	<0.1	0.2	0.3	0.6	0.2	0.3	0.7	1.2	17	0.3
Coho salmon				1.1	0.4	0.2		0.2	1.9			0.2	18	0.2
Threespine stickleback		1.6	1.0	2.4		0.1	0.3			<0.1			19	0.2
Saffron cod			0.3	0.5	0.2	0.8	0.5			<0.1			20	0.2
Sand sole			0.9		<0.1		0.5	0.3	0.2	<0.1			21	0.2
Masked greenling					0.1		1.1			0.1	1.1		22	0.1
Chinook salmon					0.1	0.2		1.1	0.6	<0.1			23	0.1
Hexagrammidae							2.1						24	0.1
Padded sculpin			0.1	0.3			0.2		0.2	0.2	0.2		25	0.1
Pacific tomcod			0.4	0.3	<0.1	0.1							26	0.1
Bering poacher				0.3			0.5		0.2		0.5		27	[illegible]
Sharpnose sculpin										<0.1	[illegible]		28	
Crescent gunnel			0.2				0.3			<0.1			29	[illegible]
Alaska plaice			0.1		0.1		0.2			<0.1			30	0.1

Table 12. Relative abundance and rank of major taxa from try net catches in Cook Inlet, April-October 1978. The weight percent of total and rank are based on the total kg captured in all cruises.

Taxon	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	OVERALL Rank	OVERALL Wt. % of total
Yellowfin sole	15.4		72.0	39.4	30.2		20.1	42.0	43.8			44.6	1	39.3
Tanner crab			15.7	20.9	17.9		60.9	21.8	5.4			19.6	2	23.0
Butter sole			7.2	24.0	21.3		2.4	2.8	4.3				3	8.8
Flathead sole				2.7	5.1		5.7	12.5	17.6			6.2	4	7.8
Pacific halibut				2.5	2.9		0.9	5.8	10.1			T	5	3.4
Rock sole	84.6		0.6	0.6	3.4		0.3	1.4	2.2			5.4	6	2.3
Arrowtooth flounder					0.8		2.6	3.3	5.5				7	1.8
King crab				4.4	7.2								8	1.8
Myoxocephalus sp.				0.5	1.3			0.5				6.4	9	1.6
Walleye pollock			1.1	0.9	2.3		2.2	3.8	1.0			T	10	1.6
Whitespotted greenling			0.4	0.3	1.8		0.8	3.0	2.0			1.6	11	1.5
Yellow Irish Lord					1.0		1.3	0.9	1.2			2.7	12	1.2
Threaded sculpin					0.5							4.4	13	0.9
Ribbed sculpin					0.7		0.3	1.3	2.0			0.5	14	0.8
Dungeness crab												3.6	15	0.7
Starry flounder				2.2					1.9				16	0.7
Searcher					0.9		0.1		0.8			0.4	17	0.3
Wattled eelpout					0.8		1.1		0.1			T	18	0.3
Unid. crab												1.3	19	0.3
Sturgeon poacher					0.4		0.1	0.5	0.4				20	0.2
Unid. sculpin									1.3				21	0.2
English sole												0.9	22	0.2
Pacific tomcod			0.8	0.6	0.2		0.1					T	23	0.2
Unid. crab												0.8	24	0.2
Longfin smelt			0.5	0.4	0.1		T		0.2			T	25	0.1
Pacific staghorn sculpin												0.7	26	0.1
Capelin			1.7										27	0.1
Pacific cod					0.3		0.2					T	28	0.1
Sablefish							0.6						29	0.1
Pacific sandfish				0.4	0.1								30	0.1
Alaskan ronquil					0.4								31	0.1
Big skate								0.2	0.1				32	0.1
Dover sole					0.1		T	0.1				0.1	33	0.1

Table 13. Relative abundance and rank of major taxa from tow net catches in Cook Inlet, April-October, 1978 based on total number captured in all cruises, larval stage excluded.[1]

Taxon	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	OVERALL	
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	Rank	% of total
Pacific sandlance			12.1	94.2		1.8							1	41.3
Pacific herring			70.7	0.4	34.8	28.8	7.8	33.3					2	28.6
Whitespotted greenling				1.7	50.0	3.6	5.6	7.8	3.9				3	6.3
Capelin			17.2					2.0					4	5.2
Pink salmon						1.8	45.6	19.6	30.8				5	4.7
Sockeye salmon				0.2	13.6	37.8							6	4.5
Chum salmon						16.2	15.6	25.5	3.9				7	3.5
Chinook salmon						9.0	15.6	9.8	50.0			100.0	8	3.3
Hemilepidotus sp.				3.1									9	1.2
Coho salmon					0.9		4.4						10	0.4
Arctic lamprey							2.2		3.9				11	0.2
Pacific sandfish							3.3						12	0.2
Starry flounder						0.9			3.9				13	0.2
Dolly Varden				0.2									14	0.1
Threespine stickleback					0.9								15	0.1
Ling cod								2.0					16	0.1
Bathymasteridae				0.2									17	0.1
Rock sole									3.9				18	0.1

[1] If larval stages are included the rank and percent of total catch of the top four taxa is: Pacific herring, 1, 49.4%; Pacific sandlance, 2, 30.1%; Capelin, 3, 7.0% and Whitespotted greenling, 4, 3.0%.

Table 14. Relative abundance and rank of major taxa from gill net catches in Cook Inlet, April-October, 1978 based on total number captured in all cruises, larval stages excluded.

Taxon	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	OVERALL	
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	Rank	% of total
Pacific herring			85.7	25.0		20.0	58.3			25.0			1	43.5
Chum salmon						60.0	11.1	33.3	100.0				2	17.4
Dolly Varden				50.0		20.0	8.3	33.3		25.0			3	15.9
Bering cisco			14.3				2.8	8.3		25.0			4	5.8
Spiny dogfish							5.6						5	2.9
Pink salmon								16.7					6	2.9
Sockeye salmon							2.8	8.3					7	2.9
Pacific staghorn sculpin							2.8			25.0			8	2.9
Starry flounder							5.6						9	2.9
Whitespotted greenling							2.8						10	1.5
Unid. Salmonid				25.0									11	1.5

Table 15. Relative abundance and rank of major taxa from trammel net catches in Cook Inlet, April-October, 1978 based on total number captured in all cruises, larval stage excluded.

Taxon	April	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	OVERALL	
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	Rank	% of total
Pacific herring		34.6	1.4	54.9	5.3			2.3		7.1			1	25.3
Whitespotted greenling		3.9	36.5	15.4	10.5	33.3	22.2	63.6	34.8	14.3	20.0		2	25.3
Sturgeon poacher		26.9	25.7	3.7	21.1	16.7		6.8		17.9			3	11.3
Yellowfin sole			24.3	9.3		16.7		4.6		3.6	10.0		4	9.6
Masked greenling				4.9	21.1	8.3	11.1	2.3	21.8	20.0			5	5.4
Pacific staghorn sculpin		15.4	2.7	3.7			33.3	2.3	17.4	7.1			6	5.4
Saffron cod			2.7	3.7	31.6			2.3					7	3.7
Rock sole		11.5	1.4	1.2	10.5	16.7		2.3	8.7		10.0		8	3.4
Dungeness crab									8.7	35.7			9	3.0
Pacific tomcod								11.4	8.7				10	1.7
Bering cisco			1.4				11.1				20.0		11	1.0
Butter sole				1.9			11.1						12	1.0
Spiny dogfish			2.7	0.6									13	0.7
Sand sole						8.3				7.1			14	0.7
Walleye pollock		7.7											15	0.5
Starry flounder								2.3		3.6			16	0.5
Unid. crab										3.6	10.0		17	0.5
Octopus											10.0		18	0.3
Big skate							11.1						19	0.3
Dolly Varden				0.6									20	0.3
Crested sculpin			1.4										21	0.3

Table 16. Beach seine catch in numbers of individuals[1] per tow and standard error, by taxon and cruise in Cook Inlet, 1978.

Taxon	APRIL[2] 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER[2] 1-31	MEAN
Pacific herring			0.2±0.1	0.1±0.1	26.2±19.1	0.7± 0.4	0.6±0.4	0.8±0.7		1.2±1.0	0.3±[illegible]		3.3±2.1
Bering Cisco			0.1±0.1	0.4±0.3	0.9± 0.3	0.1± 0.1	0.6±0.3	0.2±0.1	0.2± 0.1	0.1±0.0	0.1±[illegible]		0.2±0.1
Pink salmon	11.1±6.3	0.8±0.8	2.9±1.1	0.2±0.1	7.2± 5.1	26.3±25.2	0.8±0.4	2.9±1.5	T[3]	T			3.8±2.0
Chum salmon		6.0±3.3	6.9±2.1	0.4±0.3	19.7± 7.7	17.3± 7.2	4.8±2.7	10.1±5.0	1.5± 1.1	1.9±0.8			6.2±1.2
Coho salmon				0.3±0.3	0.3± 0.1	0.2± 0.1		T	0.4± 0.3			T	0.1±T
Sockeye salmon			T	0.1±0.1									T
Chinook salmon					0.1± 0.1	0.1± 0.1		0.3±0.1	0.1± 0.1	T			0.1±T
Dolly Varden		0.2±0.2	2.8±0.8	8.7±5.5	11.3± 3.4	7.9± 3.1	3.9±1.1	4.2±1.4	17.6±13.9	2.7±1.3	2.1±1.9	0.4±0.3	5.3±1.3
Surf smelt			T	0.1±0.1	T	0.1± 0.1	0.1±0.1	0.2±0.1	T	0.3±0.2	0.1±0.1	0.2±0.1	0.1±T
Longfin smelt		0.2±0.2	6.7±4.8	3.2±2.1	0.9± 0.6	1.1± 1.1	5.5±3.6	0.1±0.1		3.2±2.0	1.6±1.3		2.1±0.7
Saffron cod			0.1±0.1	0.2±0.1	0.1± 0.1	0.5± 0.4	0.2±0.1			T			0.1±T
Pacific cod							0.1±0.1						T
Pacific tomcod			0.2±0.1	0.1±0.1	T	0.1± 0.1							T
Walleye pollock			0.1±0.1		T	0.1± 0.1							T
Threespine stickleback		0.2±0.2	0.4±0.3	0.7±0.6		0.1± 0.1	0.1±0.1			T			0.1±T
Rockfish												T	T
Greenling							0.6±0.6						0.1±0.1
Masked greenling					0.1± 0.1		0.3±0.3			0.1±0.1	0.2±0.2		0.1±T
Whitespotted greenling	0.6±0.4		0.4±0.1	0.7±0.6	9.3± 2.2	2.4± 0.4	4.3±1.9	1.5±0.5	0.4± 0.2	0.6±0.3	0.1±0.1		1.9±0.3
Ling cod										T			T
Padded sculpin			T	0.1±0.1			0.1±0.1		T	0.2±0.1	T		T
Silverspotted sculpin							0.1±0.1						T
Sharpnose sculpin										T	0.2±0.1		T
Buffalo sculpin												T	T
Irish lord				0.1±0.1									T
Yellow Irish lord							0.1±0.1						T
Northern sculpin											0.1±0.1		T
Pacific staghorn sculpin		0.5±0.2	0.2±0.1	0.7±0.4	0.8± 0.3	0.2± 0.1	1.1±0.5	0.1±0.1	0.6± 0.4	4.1±2.5	0.9±0.7	0.1±0.1	0.9±0.3
Myoxocephalus sp.	0.7±0.4	1.3±0.3	1.1±0.4	0.8±0.4	0.1± 0.1	0.3± 0.2	0.3±0.2	0.1±0.1	0.2± 0.1	0.8±0.3	0.7±0.3	2.7±0.8	0.8±0.1
Sturgeon poacher			0.4±0.2	0.2±0.2	0.3± 0.2	0.1± 0.1	0.3±0.3				T		0.1±T
Bering poacher				0.1±0.1			0.2±0.2		T		[illegible]		T
Tubenose poacher						0.2± 0.2	0.2±0.1	0.2±0.1	0.6± 0.3	0.9±0.6		0.3±0.1	0.2±0.1
Ringtail snailfish											T		T
Pacific sandfish				0.1±0.1			0.1±0.1			3.4±3.4	T		0.4±0.4
Snake prickleback			0.2±0.1	0.3±0.2	3.0±2.0	0.5± 0.3	0.9±0.3	0.2±0.1	T	0.1±0.1			[illegible]
Crescent gunnel			0.1±0.1				0.1±0.1			T	0.1±0.1		[illegible]
Pacific sandlance	0.7±0.6	0.7±0.5	18.9±18.7	12.5±12.5	2.1±2.0	8.6± 5.8	3.4±3.4	3.0±2.6	0.3±0.3	88.3±82.4	9.0±6.6	[illegible]	17.5±10.3
Butter sole							0.1±0.1			T			T
Rock sole		0.3±0.2	0.6±0.2	1.0±0.4	1.1±0.3	0.6± 0.4	1.1±0.4	0.2±0.1	0.2±0.1	0.3±0.1	T	0.3±0.1	0.5±0.1
Yellowfin sole			0.1±0.1				0.1±0.1						T
Starry flounder		0.2±0.2	0.4±0.2	0.5±0.2	1.5±0.6	0.5± 0.3	1.2±0.5	0.2±0.1	0.1±0.1	0.8±0.4	0.9±0.6		0.6±0.1
Alaska plaice			T		0.1±0.1		0.1±0.1			T			T
Sand sole			0.4±0.3		T		0.2±0.1	0.1±0.1	T	T			0.1±T
Pacific halibut					0.1±0.1						T		T
Dungeness crab					T		0.1±0.1		T	T			T
Number of hauls	7	6	30	12	28	19	20	26	21	31	27	28	255

[1] Juveniles and adults only
[2] Samples in April and October were in Kachemak Bay, all others were in Kamishak Bay
[3] T < 0.05 individuals

Table 17. Try net catch in kg per 10 minute tow and standard error by taxon and cruise in Cook Inlet, 1978.

Taxon	APRIL[1] 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER[1] 1-31	MEAN
King crab	125[2,3]			0.4±0.4	0.5±0.5							16.1±16.1[2]	7.4±5.4
Tanner crab			2.2	1.9±0.5	1.3±0.8		5.5±1.5	0.8±0.4	0.2±0.1			1.3±0.6	1.4±0.3
Dungeness crab												0.1±0.1	T[4]
Capelin			0.2										T
Longfin smelt			0.1	T	T				T				T
Pacific cod					T		T						T
Pacific tomcod			0.1	T	T		T						T
Walleye pollock			0.2	0.1±T	0.2±0.1		0.2±0.1	0.2±0.1	T				0.1±T
Wattled eelpout					0.1±T		0.1±T		T				T
Whitespotted greenling			0.1	T	0.1±0.1		0.1±0.1	0.1±T	0.1±T			0.1±T	0.1±T
Sablefish							T						T
Threaded sculpin					T							0.2±T	T
Yellow Irish Lord					0.1±T		0.1±T	T	0.1±T			0.1±T	0.1±T
Pacific staghorn sculpin												T	T
Myoxocephalus sp.				T	0.1±0.1			T				0.2±0.1	0.1±T
Ribbed sculpin					T		T	T	0.1±T				T
Smooth alligatorfish					T							T	T
Sturgeon poacher					T		T	T	T				T
Slipskin snailfish							T						T
Showy snailfish				T									T
Pacific sandfish				T	T								T
Alaskan ronquil					T								T
Searcher					0.1±T		T		T			T	T
Arrowtooth flounder					0.1±T		0.2±0.2	0.1±T	0.3±0.1				0.1±T
Rex sole												T	T
Flathead sole				0.2±0.1	0.4±0.1		0.5±0.2	0.5±0.2	0.8±0.1			0.2±0.1	0.4±0.1
Butter sole			1.0	2.2±1.3	1.6±1.4		0.2±0.1	0.1±T	0.2±T				0.5±0.2
Rock sole	0.1		0.1	T	0.2±0.2		T	0.1±T	0.1±T			0.2±0.1	0.1±T
Yellowfin sole	T		10.1	3.6±1.0	2.3±0.4		1.8±0.8	1.7±0.6	2.1±0.5			1.5±0.9	2.1±0.4
English sole												T	T
Starry flounder				0.2±0.2					0.1±0.1				T
Pacific halibut				0.2±0.1	0.2±0.2		0.1±0.1	0.2±0.1	0.5±0.2				0.2±T
Number of hauls	1	0	1	5	5	0	4	10	9	0	0	15	50

[1] Samples in April and October were in Kachemak Bay, all others were in Kamishak Bay
[2] Weight estimated at 1.0 kg/crab
[3] Standard error not possible with a single sample
[4] T < 0.05 individuals

Nearshore Habitat

The nearshore habitat was sampled primarily by beach seine, gill net and trammel net (Tables 16, 19 and 20). This zone is the first marine area occupied by juvenile pink and chum salmon when they enter salt water in the spring. These two species were the most abundant taxa in April and early May beach seine catches. Dolly Varden were the predominant species in the nearshore habitat in terms of biomass. They constituted 30% of the weight of the beach seine catches throughout the study. This species did not appear in April; the first Dollies were captured in early May and they increased in abundance until at least early June, since they spend the winter in streams as well as intermittent periods during the summer in streams. Dollies are generally restricted to the immediate nearshore zone. They only occurred in abundance in the beach seine and gill net.

Sand lance were the numerically predominant species in the beach seine catches. They are primarily a pelagic species that also occurs nearshore. During April and early May they tended to occur singly, which is unusual for this schooling species.

A small number of Myoxocephalus sp. juveniles (essentially all great sculpin) about 5 to 12 cm in length and one year of age occurred regularly in the nearshore zone during April, May and early June. These same fish were found in the nearshore zone in Kodiak at the same time (Blackburn, 1 1979a). A few whitespotted greenling occurred in the April nearshore samples that were pelagic phase juveniles less than one year of age.

Although it does not appear in the samples, herring use the nearshore zone during the April through early June time period to spawn. A considerable herring fishery occurs each year in the immediate vicinity of the field studies in Kamishak and also in Kachemak bays, as was discussed in Status of Knowledge. In the Kamishak area the spawning period of herring was accompanied by the greatest mammal predator activity seen during the summer. Seals and porpoise were common throughout the area traversed by the field crews in late May.

During June through early September the nearshore zone was utilized more than at any other time period. This is associated with the movement to shallower water during summer by virtually every fish species (Blackburn, 1978 and 1979). Sand lance occurred in modest numbers through most of this time, being more abundant in early June and much more abundant in early September.

Larval herring were abundant throughout the summer, particularly in the latter half as they became large enough to be retained by the net and also be seen. They were abundant at all locations and seemed to be largest at stations located inside bays.

As in the spring, juvenile chum and pink salmon continued to be abundant in the nearshore zone through the summer. Chums were present in abundance later than were the pinks. Dolly Varden continued to be abundant in the

Table 18. Tow net catch in number of individuals per km and standard error by taxon and cruise in Cook Inlet, 1978.[1]

Taxon	APRIL[2] 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER[2] 1-31	MEAN
Arctic lamprey							0.3±0.2		0.1±0.1				T[3]
Pacific herring			229.2±229.2	0.2± 0.1	6.2±5.9	3.0±2.7	0.9±0.6	1.9±1.9					5.8±4.3
Pink salmon						0.2±0.2	5.3±3.7	1.1±0.5	0.7±0.5				1.0±0.5
Chum salmon						1.7±0.7	1.8±1.1	1.4±0.5	0.1±0.1				0.7±0.2
Coho salmon					0.2±0.2		0.5±0.5						0.1±0.1
Sockeye salmon				0.1± 0.1	2.4±1.5	3.9±3.6							0.9±0.6
Chinook salmon						0.9±0.6	1.8±1.3	0.5±0.4	1.1±0.5			0.2±0.2	0.7±0.2
Dolly Varden				0.1± 0.1									T
Capelin			55.8±5.8					0.1±0.1					1.1±0.7
Threespine stickleback					0.2±0.2								T
Whitespotted greenling[4]				0.9± 0.6	8.9±5.5	0.4±0.2	0.6±0.6	0.4±0.4	0.1±0.1				1.3±0.6
Ling cod[4]								0.1±0.1					T
Irish Lord[4]				1.5± 1.5									0.3±0.3
Pacific sandfish[4]							0.4±0.4						T
Ronquils[4]				0.1± 0.1									T
Pacific sandlance			39.2±15.8	45.5±45.5		0.2±0.1							8.4±7.7
Rock sole									0.1±0.1				T
Starry flounder						0.1±0.1			0.1±0.1				T
Number of tows	0	0	2	18	11	18	13	15	20	0	0	10	107

[1]Juveniles and adults only
[2]Samples in April and October were in Kachemak Bay, all others were in Kamishak Bay
[3]T <0.05 individuals
[4]Late larval to early pelagic juvenile stage

Table 19. Gill net catch in numbers of individuals per set and standard error by taxon and cruise in Cook Inlet, 1978.

Taxon	APRIL[1] 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	MEAN
Spiny dogfish							0.5±0.5						0.1±0.1
Pacific herring			3.0±3.0	0.3±0.3		0.2±0.2	5.3±4.6			0.5±0.5			1.6±1.0
Bering cisco			0.5±0.1				0.2±0.2	1.0		0.5±0.5			0.2±0.1
Salmonidae				0.3±0.3									0.1±0.1
Pink salmon								2.0					0.1±0.1
Chum salmon						0.7±0.7	1.0±0.7	4.0	1.0				0.6±0.3
Sockeye salmon							0.2±0.2	1.0					0.1±0.1
Dolly Varden				0.7±0.3		0.2±0.2	0.7±0.5	4.0		0.5±0.5			0.6±0.2
Whitespotted greenling							0.2±0.2						0.1±0.1
Pacific staghorn sculpin							0.2±0.2			0.5±0.5			0.1±0.1
Starry flounder							0.5±0.5						0.1±0.1
Number of sets			2	3		4	4	1	1	2	2		19

[1]Samples in April and October were in Kachemak Bay, all others were in Kamishak Bay

Table 20. Trammel net catch in numbers of individuals per set and standard error by taxon and cruise in Cook Inlet, 1978.

Taxon	APRIL[1] 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER[1] 1-31	MEAN
Octopus											0.2±0.2		T[2]
Unid crab										0.5±0.5	0.2±0.2		0.1±T
Dungeness crab									0.4±0.4	5.0±5.0			0.3±0.3
Spiny dogfish			0.3±0.2	0.2± 0.2				0.3±0.3					0.1±T
Big skate							1.0						T
Pacific herring		9.0	0.1±0.1	14.8±10.6	0.3±0.3			0.2±0.2		1.0±1.0			2.7±1.8
Bering cisco			0.1±0.1				1.0				0.5±0.5		0.1±0.1
Dolly Varden				0.2± 0.2									T
Saffron cod			0.3±0.2	1.0± 0.5	2.0±0.6			0.2±0.2					0.4±0.1
Pacific tomcod								0.5±0.3	0.4±0.4				0.2±0.1
Walleye pollock		2.0											0.1±0.1
Masked greenling				1.3± 1.3	1.3±1.3	0.5±0.5	1.0	0.2±0.2	1.0±0.8		0.5±0.5		0.6±0.3
Whitespotted greenling		1.0	3.9±1.3	4.2± 2.1	0.7±0.7	2.0±2.0	2.0	4.7±4.3	1.6±0.9	2.0±2.0	0.5±0.5		2.7±0.8
Crested sculpin			0.1±0.1										T
Pacific staghorn sculpin		4.0	0.3±0.2	1.0± 0.8			3.0	0.2±0.2	0.8±0.8	1.0±1.0			0.6±0.2
Sturgeon poacher		7.0	2.7±2.1	1.0± 0.8	1.3±1.3	1.0±1.0		0.5±0.3		2.5±2.5			1.2±0.5
Butter sole				0.5± 0.5			1.0						0.1±0.8
Rock sole		3.0	0.1±0.1	0.3± 0.2	0.7±0.3	1.0±1.0		0.2±0.2	0.4±0.2		0.2±0.2		0.4±0.1
Yellowfin sole			2.6±1.9	2.5± 1.8		1.0±1.0		0.3±0.2		0.5±0.5	0.2±0.2		1.0±0.5
Starry flounder								0.2±0.2		0.5±0.5			0.1±T
Sand sole						0.5±0.5				1.0±1.0			0.1±0.1
Number of hauls	0	1	7	6	3	2	1	6	5	2	4	1	38

[1] Samples in April and October were in Kachemak Bay, all others were in Kamishak Bay
[2] T <0.05 individuals

summer but the juvenile great sculpin decreased in abundance in the summer. Both longfin smelt and saffron cod were common through the summer. These fish were found to be more abundant further north in the inlet, at least on the east side, in 1976 (Blackburn, 1978). Bering cisco were most abundant in June and July. This species was found only nearshore and in bays near stream mouths. It was not taken south of Bruin Bay or in Kodiak waters (Blackburn, 1978 and 1979a). Staghorn sculpin and starry flounder were both common summer inhabitants of the nearshore zone, and both are known to enter fresh water (Hart, 1973). Preliminary work on species association conducted on beach seine catches made in 1976 and on samples from this study suggests that staghorn sculpin and starry flounder occur together but rarely with rock sole. Observations suggest that staghorn sculpin and starry flounder tend to occur in muddy habitats near stream mouths while rock sole occur in rocky areas.

During early autumn most of the fish species depart the nearshore zone, however, sand lance apparently move into it in greater numbers. This influx of sand lance was found in Kachemak Bay and off Kodiak (Blackburn, 1978, 1979a and b; Harris and Hartt, 1977), however, sand lance were never as abundant in Kamishak Bay as in Kachemak Bay and off Kodiak while evidence of an autumn movement to inshore waters of Kamishak Bay consists of a single large catch in early September. Thus, the autumn inshore movement of sand lance into Kamishak Bay apparently is not as important as it is in other areas.

Most of the juvenile salmon depart the nearshore zone in late summer or early autumn. Juvenile pinks were much less abundant after mid-July and were present in trace amounts after mid-August. This agrees with timing found by other investigators (Blackburn, 1978; Harris and Hartt, 1977; Stern, 1977). Juvenile chum salmon were relatively abundant in the nearshore zone until mid-August and common through mid-September. Dolly Varden were common through September in Kamishak, but their numbers were somewhat reduced in September, and considerably lower in Kamishak Bay in October. Longfin smelt were common through late September, which is as late as sampling was conducted where they were found. The adults were filling with spawn in preparation for winter, when they ascend rivers to spawn; they probably remain common in the marine nearshore zone of the upper inlet through much of the winter, depending upon the duration of their freshwater existence, but this is not known. Pelagic whitespotted greenling juveniles were much less abundant after mid-August. The juveniles are all young-of-the-year which are pelagic in early summer. They become demersal in mid-summer and apparently are mature in their following summer. Juvenile <u>Myoxocephalus</u> (virtually all great sculpin in the beach seine) were more common in the autumn than they had been in summer. In the autumn these are young-of-the-year which are 45 to 65 mm in length, after occurring as larvae in mid-summer. This taxon apparently is one of the few that is common in the nearshore zone through the winter.

ı important feature of the nearshore habitat is its relationship to tides. In the lower Cook Inlet area where these studies were conducted the beaches were nearly all cobble or gravel in the upper half of the intertidal zone but the lower portion of the beach was very gently sloped mud. The mud made low tide sampling very difficult and it was generally avoided. Regardless, the beach seine catches were summarized for the entire summer by the tidal stage at which they were made; high tide plus or minus one hour, low tide plus or minus one hour, flood tide or ebb tide. Catches were considerably lower on low tide (25 fish per set), intermediate on ebb tide (42 fish per set) and greatest on flood (84 fish per set) and high tide (82 fish per set).

For the different species there are a number of apparent trends, some of which may be spurious. The catch of herring (including larvae and mostly larvae) was the greatest on flood (34 per haul) and least on low (0.6 per haul) with intermediate values on the other stages. Pink salmon (mostly juveniles) catches were much greater on flood tide (11.3 per haul), least on low (0.1 per haul) and intermediate on high (0.7 per haul) and ebb (2.1 per haul). Chum salmon juveniles showed the same trend, particularly the low abundance on the low tide (0.5 per haul). Dolly Varden were markedly more abundant on flood tide (8.7 per haul) than on the other tides (3.9 to 4.6 per haul). Longfin smelt were most abundant on high tide (6.0 per haul) and absent on low tide. Staghorn sculpin were much more abundant on flood tide while juvenile great sculpins were most common on ebb tide. Pacific sand lance catches were 48.3 per haul on high tide, 9.7 on flood, 14.1 on low and 3.1 on ebb tide. The other species either showed no differences or were insufficiently abundant to produce reliable results. The data from Kodiak, taken during this same time period yielded essentially identical trends for each species mentioned above except for herring and staghorn sculpin for which there was insufficient data and longfin smelt which were not captured in Kodiak (Blackburn, 1979b).

Pelagic Habitat

The pelagic habitat is quite different in many respects from the demersal or nearshore habitat. Hydrographic features are much more important as they constitute the primary structure that exists in the pelagic zone. Geographic features, however, considerably affect the nearshore pelagic habitat.

The well-known schooling of fishes is a feature of pelagic species, and this presents the greatest difference in sampling pelagic and demersal fishes. The haul to haul catch variability of pelagic species is much greater than it is for demersal or nearshore species.

The tow net sampled the pelagic zone and this gear is directed primarily at smaller fish. Pacific sand lance and Pacific herring greatly predominated the tow net catches and larval herring were especially abundant (Table 18). During certain cruises the following species occurred in significant proportions of the total catch: young-of-the-year whitespotted greenling, adult capelin, juvenile pink salmon, juvenile sockeye salmon, juvenile chum salmon and juvenile chinook salmon.

During the early summer a couple of relatively large catches of sand lance occurred, as well as some large catches of juvenile herring and adult capelin with flowing sex products. The young-of-the-year white-spotted greenling were common in small numbers (they apparently are not a schooling fish) through the summer. Juvenile sockeye salmon were common in June and early July. In July and August juvenile pink, chum and chinook salmon were relatively common.

Demersal Habitat

The demersal habitat was sampled primarily by try net. In April one trawl in Kachemak Bay behind the Homer Spit yielded a large catch of king crab. In Kamishak Bay, yellowfin sole were the predominant species (Tables 12 and 17) with the largest catches in late May and early June. It was hypothesized from work in 1976 (Blackburn, 1978) that yellowfin sole were most common in Kamishak Bay in June and July and moved to deeper water in August. The current data supports that hypothesis. Tanner crab were quite abundant in Kamishak Bay, with greatest abundance in June and July and lesser abundance in late August. It is hypothesized that this is the result of relatively warm water (11.5° C at 14 m on August 15, 1978) present in Kamishak Bay in late summer. Butter sole were much more abundant in late May and June than they were later in the summer. Flathead sole were present in progressively greater abundance through the summer while halibut, rock sole and arrowtooth flounder showed no meaningful trends of abundance through the summer.

In October, sampling was conducted in Kachemak Bay and one try net haul behind the Homer Spit resulted in another large catch of king crab.

Food Habits

Species examined for food habits had generally taken advantage of a variety of prey in more than one prey group; i.e., small zooplankters, large zooplankters, fish, insects, epibenthic crustaceans, and benthic invertebrates.

Small zooplankters were eaten by young fishes and small mouthed fishes. Copepods were the most important of these plankters, and were eaten by pink fry, herring and sand lance all season, by chum, sockeye and greenling juveniles early in the season, and by a surf smelt and a small rock sole.

Larger zooplankters were eaten by most fish examined except flounders. Decapod larvae were the most important, eaten especially by chinook, sockeye, coho and Dolly Varden juveniles, surf smelt, longfin smelt and pollock. Chaetognaths and euphausiids were especially important to cohos.

Fish eggs and larvae were eaten by most species examined, and either became a part of the food composition, or the dominant food. The most important fish feeders were chinook, coho, sockeye and chum juveniles, Dolly Varden (especially adults), staghorn sculpins, and a yellowfin sole.

Insect larvae and adults were important all season to all salmons and Dolly Varden juveniles.

Epibenthic crustaceans, especially gammarid amphipods, were eaten by all species examined. Gammarids were most important to chum juveniles, adult whitespotted greenling, Dolly Varden juveniles, longfin smelt, saffron cod, small great sculpins and starry flounders.

Benthic invertebrates were food for flounders, especially rock sole and butter sole, which ate clams and polychaetes.

Water Temperature

The water temperatures increased from about 6.5° C in late May to peak values of over 16° C in early to mid-August and declined thereafter (Figures 34 and 35). The temperatures were higher near the beach than offshore.

Temperature profiles were made at two offshore sampling locations on August 15, 1978 with the resulting observation that even at 14 m depth water was about 11.5° C (Table 21).

Table 21. Temperature profiles for two sample locations on August 15, 1978.

	LOCATIONS	
	59° 33' 15" N 153° 12' 00" W	59° 32' 15" N 153° 09' 00" W
Depth, m	Temperature C°	Temperature C°
0.5	12.2	13.0
1	11.9	12.9
3	12.0	12.4
5	11.8	12.1
10	11.5	12.0
14	11.5	11.4

These temperatures are relatively high and are due to the hydrography of lower Cook Inlet. The water in the upper inlet flows south on the west side and is replaced with northerly flow on the east. Thus the water on the west side of the inlet has been heated by exposure to the vast intertidal mud flats of Cook Inlet. This feature undoubtedly makes the water temperature on the west side of the inlet unusually sensitive to seasonal changes in air temperature and insolation.

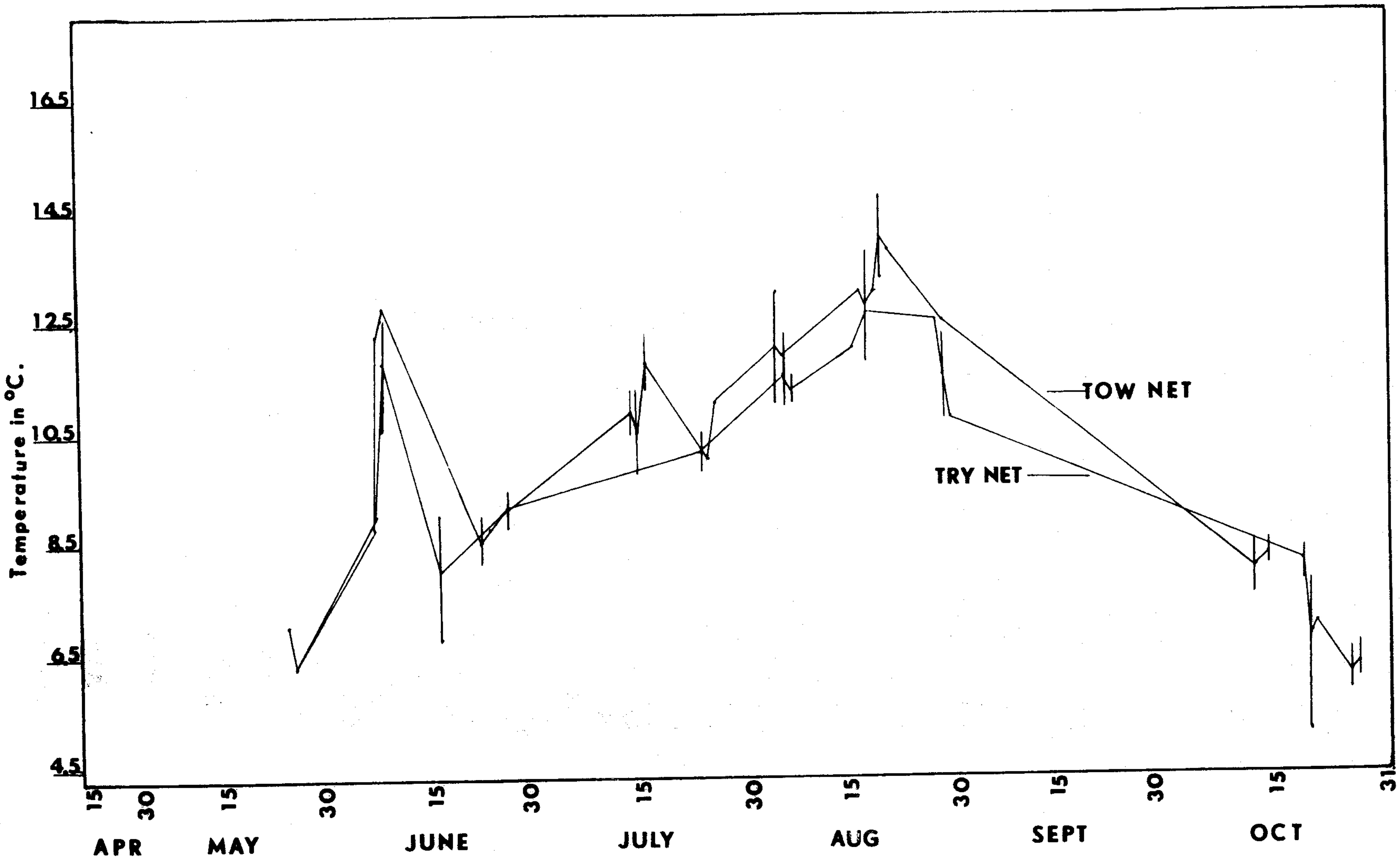


Figure 34. Summary of surface temperatures taken concurrently with tow net and try net samples in 1978. The daily mean temperature and its range are shown by date.

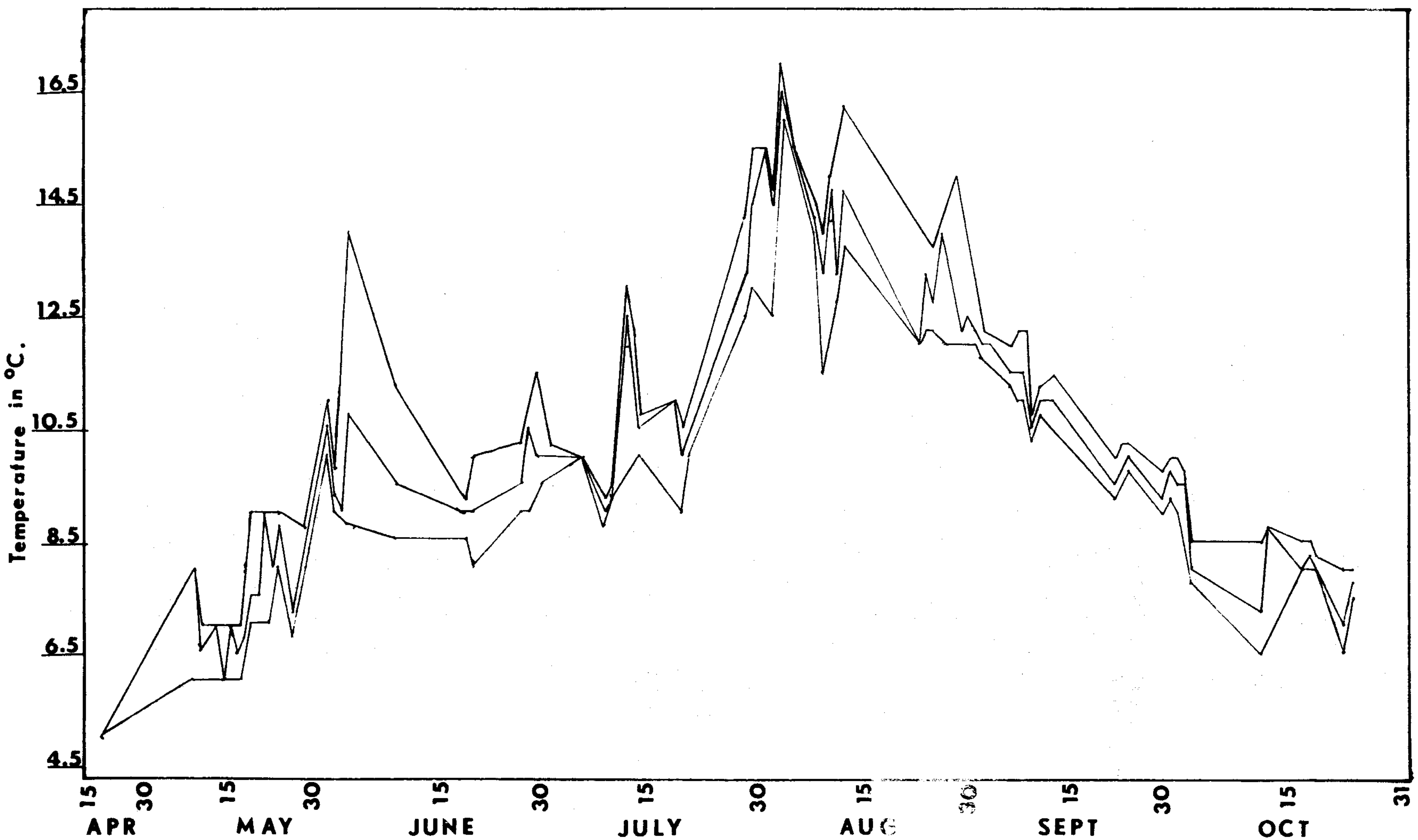


Figure 35. Summary of surface temperatures taken concurrently with beach seine samples in 1978. The daily mean temperature and its range are shown by date.

Relative Abundance, Spatial-Temporal Distribution and Growth, by Species

The beach seine and tow net effort by geographic areas is presented in Tables 22 and 23 for comparison with similarly prepared catch tables that follow.

King Crab (*Paralithodes camtschatica*)

King crab were not examined for food habits in this study. Fish and epibenthic invertebrates were eaten by king crab in other studies (Feder, et al., 1979). Bering Sea king crab ate pelecypods, gastropods, asteroids, ophiuroids, echinoids, decapods, polychaetes, algae, crustaceans and coelenterates (McLaughlin and Hebard, 1961). Kodiak king crab ate mollusks, crustaceans and fish (Feder and Jewett, 1977).

Predators of king crab included halibut (Gray, 1964), Pacific cod (Kasahara, 1961), and sculpins, cod and halibut (Rosenthal et al., 1978). King crab larvae were eaten by sand lance, Dolly Varden and juvenile sockeye salmon in this study.

Tanner Crab (*Chinoecetes bairdi*)

Tanner crab ranked second in weight abundance in the try net (a figure which excludes two large catches of king crab in Kachemak Bay). They were common throughout the summer but catches were considerably lower in August. It is hypothesized that they departed the shallows of Kamishak Bay to avoid warm water, since they were considerably less abundant in August and water temperatures were high.

The large majority of the Tanner crab captured were very small.

Tanner crab were not examined for food habits in this study; epibenthic crustaceans and invertebrates were prey items in other studies.

Yasuda (1967) reported Tanner crab consumed echinoderms, decapods, amphipods and bivalves in Japan. McLean et al. (1976) reported juvenile Tanners consumed dead and decaying mollusks, crustaceans and fish remains in Cook Inlet and Kodiak. Feder et al. (1977b) reported they consumed clams, hermit crabs, barnacles and crangonid shrimp in Kodiak. Feder and Jewett (1977) reported Tanner crab ate polychaetes, clams, fish and plant material.

Kodiak Tanner crab were preyed on by great sculpins, rock sole, starry flounder and halibut (Hunter, 1979), and Yellow Irish Lords (ADF&G staff). Cook Inlet Tanner crab were preyed on by halibut (Feder et al., 1977a), and Tanner larvae were preyed on by Dolly Varden, longfin smelt and pollock in this study.

Dungeness Crab (*Cancer magister*)

Dungeness crab were not examined for food habits in this study. McLean et al. (1976) reported dungeness fed on crustaceans, mollusks, worms, seaweed, and young dungeness in Kodiak and Cook Inlet.

Table 22. Number of beach seine hauls by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	Mean
Oil Bay			3	3	2	1	3	3	5	[illegible]	1		24
Iniskin Bay			4	1	2	2	2	3	1	8	5		28
Cottonwood Bay		5	10	2	3	5	4	3	2	4	2		40
Iliamna Bay		1	8	3	12	5	6	10	6	4	5		60
Ursus Cove			5	3	7	4	4	4	3	10	5		45
Rocky Cove					2	2	1	1	2	2	4		14
Bruin Bay to Rocky Cove								2	2		4		8
Kachemak Bay	7											29	36

Table 23. Number of tow net samples by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	Total
Oil Bay						3							3
Oil Bay to Iliamna Bay			2	12	11	15		15	9				[illegible]
Ursus Cove				6			4		11				[illegible]
Rocky Cove							7						7
Contact Point							2						2
Kachemak Bay												10	10

Table 24. Pacific herring catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October, 1978.

Location	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	Mean
Oil Bay			0.3	0	0	0	3.3	0.3	0	0.7	0		0.6
Iniskin Bay			0	0	0	0	0.5	0	0	0.1	0		0.1
Cottonwood Bay		0	0.2	0	182.7	0	0	0	0	0	0		13.8
Iliamna Bay		0	0.1	0	15.0	0.2	0.2	0.2	0	0	0		3.1
Ursus Cove			0.4	0.3	0.9	3.2	0	0	0	3.5	1.6		1.4
Rocky Cove					0	0	0	0	0	0	0.2		0.1
Bruin Bay to Rocky Cove								0	0		0		0
Kachemak Bay	0											0	0

T < 0.05

Table 25. Juvenile Pacific herring catch in numbers per km towed by the tow net by geographic location and time. Sampling conducted in Cook Inlet from April through October, 1978.

Location	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	Mean
Oil Bay						0							0
Oil Bay to Iliamna Bay			229.2	0.1	6.1	3.5		1.8	0				9.5
Ursus Cove				0.2			1.2		0				0.3
Rocky Cove							0.9						0.9
Contact Point							0						0
Kachemak Bay	0											0	0

Table 26. Juvenile pink salmon catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October, 1978.

Location	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	Mean
Oil Bay			0.3	0	0	0	0	0	0.2	0	0		0.1
Iniskin Bay			8.5	0	0	0	0	12.3	0	0	0		2.5
Cottonwood Bay		0	1.0	0.5	0.3	0.2	1.0	0.3	0	0	0		0.4
Iliamna Bay		5.0	2.4	0.3	4.2	2.2	1.3	2.2	0	0	0		2.0
Ursus Cove			4.8	0	1.3	2.0	0.2	1.7	0	0.1	0		1.1
Rocky Cove					70.0	240.0	0	0	0	0	0		44.3
Bruin Bay to Rocky Cove								0	0		0		0
Kachemak Bay	11.1											0	2.2

Shrimp

Shrimp food habits were not examined in this study. Other studies reported plankters were eaten by larval shrimp and detritus and epibenthic crustaceans and invertebrates by adult shrimp.

McLean et al. (1976) cited Berkeley's 1929 study in which shrimp consumed dead animal material and living amphipods, euphausiids, limpets, annelids and other shrimp. Crow (1976) reported shrimp in Kachemak Bay consumed detritus, algae, and fragments that appeared to be shrimp, copepods, and crabs. Feder et al. (1978) reported the sand shrimp, *Crangon dalli* consumed polychaetes, benthic foraminifera, amphipods and other crustaceans. Stickney (1979) reported *Pandalus borealis* larvae consumed diatoms, eggs, invertebrate larvae (especially calanoid and copepod nauplii), and spionid polychaetes.

Shrimp larvae and young were preyed on by pink, sockeye and coho juvenile salmon, sand lance, walleye pollock, longfin smelt, surf smelt, small great sculpin, starry flounder, and rock sole in this study. Kodiak shrimp were preyed on by Pacific cod, great sculpin, rock sole, sand sole, and halibut (Hunter, 1979). Shrimp in the Cook Inlet-Kodiak survey (McLean et al., 1976) were consumed by Pacific hake, Pacific cod, sablefish, lingcod, flounders, rock fish, skates, rays, halibut, salmon and harbor seals. MacDonald and Petersen (1976) reported Beluga whales, Steller's sea lions and harbor seals preyed on shrimp, and Hatch et al. (1978) reported glaucous-winged gulls, kittiwakes, and tufted puffins preyed on shrimp.

Pacific Herring

Pacific herring ranked second in numerical abundance in the tow net, first in the gill and trammel nets and fifth in the beach seine. They were taken throughout the sampling season in Kamishak Bay but were taken only as young-of-the-year in Kachemak Bay. Single large catches occurred in late May in the tow net and late June in the beach seine.

Herring are known to spawn in Kamishak Bay as discussed in Status of Knowledge During May there were over 50 vessels in Kamishak Bay either fishing or tendering (buying for a processor) herring and there was a large floating processor, the YARDARM KNOT, anchored in Iniskin Bay. There were also a considerable number of seals, porpoise, and birds in the area, apparently to feed on herring. After the herring completed spawning in late May or early June, the level of activity diminished considerably.

Herring larvae were captured in abundance throughout the Kamishak Bay area. The tow net caught from a few to thousands of herring larvae on virtually ever haul. The beach seine also caught considerable numbers of herring larvae. Interestingly, very few larvae of any other species were captured. The earliest larval herring was taken from a fish stomach in about mid-May and was about 8-10 mm, suggesting it resulted from a mid-April spawn.

Distribution of catches did not suggest that there were locations of greatest abundance (Tables 24 and 25).

Herring grew from about 2 cm in late May to 4 to 5 cm in late September. One-year old herring were about 8 to 9 cm in late June and grew to about 9 to 12 cm by early August. Two-year old herring apparently were not captured (Figure 36).

Herring from mid-May through October were examined for stomach contents. The 134 specimens had consumed 20 prey items (Figure 37).

Copepods were an important food in eight time periods. In late May 89% copepods (mostly non-calanoid) were consumed, in late June 74% (mostly calanoid), in July 15% (mostly calanoid) and 21% (calanoid), in late August 38% (calanoid), in September 74% (calanoid) and 76% (mostly calanoid), and in October 78% (mostly calanoid).

In late May 5% barnacle larvae (mostly cyprids) were consumed, in late June 35% (mostly nauplii), in July 64% (mostly nauplii) and 9% (nauplii and cyprids) and in early September 10% (nauplii).

Fish and larvae were 8% of the early June diet, 9% and 21% of the July diet and 88% of the early August diet. Gammarid amphipods were 91% of contents of the two stomachs examined in early June, 10% and 24% in September, and 1% or less in other time periods. Mysids were 24% of the late July diet and 54% of the late August diet. Gastropod veligers were 5% and 20% of the July diets and 12% and 8% of the August diets. Chaetognaths were consumed by the one herring examined in October, comprising 21% of its diet.

Zooplankton, fish and epibenthic crustaceans were also herring foods in other studies. Forsberg et al. (1977) found small planktonic organisms, Callianassa larvae, harpaticoid copepods, and amphipods were prey for herring in Tillamook Bay, Oregon. Kron and Yuen (1976) found juvenile salmon were prey for herring in Tutka Bay.

Predators of herring included Pacific cod and halibut (Hunter, 1979); great sculpins and rock sole (Rogers et al., 1979); and king salmon, sockeye and coho smolt (McLean et al., 1976). Larval herring in this study were eaten by other herring, sand lance, Dolly Varden, pink, chum, sockeye and chinook salmon juveniles, eulachon and staghorn sculpins. Herring were eaten by murres (Hatch, 1978) and Steller's sea lions and harbor seals. (MacDonald and Peterson, 1976).

Bering Cisco

Bering cisco consistently occurred in low abundance in the beach seine, gill net and trammel net. Largest catches were in inner Oil Bay and inner Iliamna Bay, near or in freshwater influence.

The stomach of one Bering cisco caught in late June contained 60,320 calanoid copepods, weighing 4.6 gms.

Pink Salmon

Juvenile pink salmon ranked fourth in numerical abundance in the beach seine and fifth in the tow net. They were captured in the beach seine from April through early September with greatest catches in April in

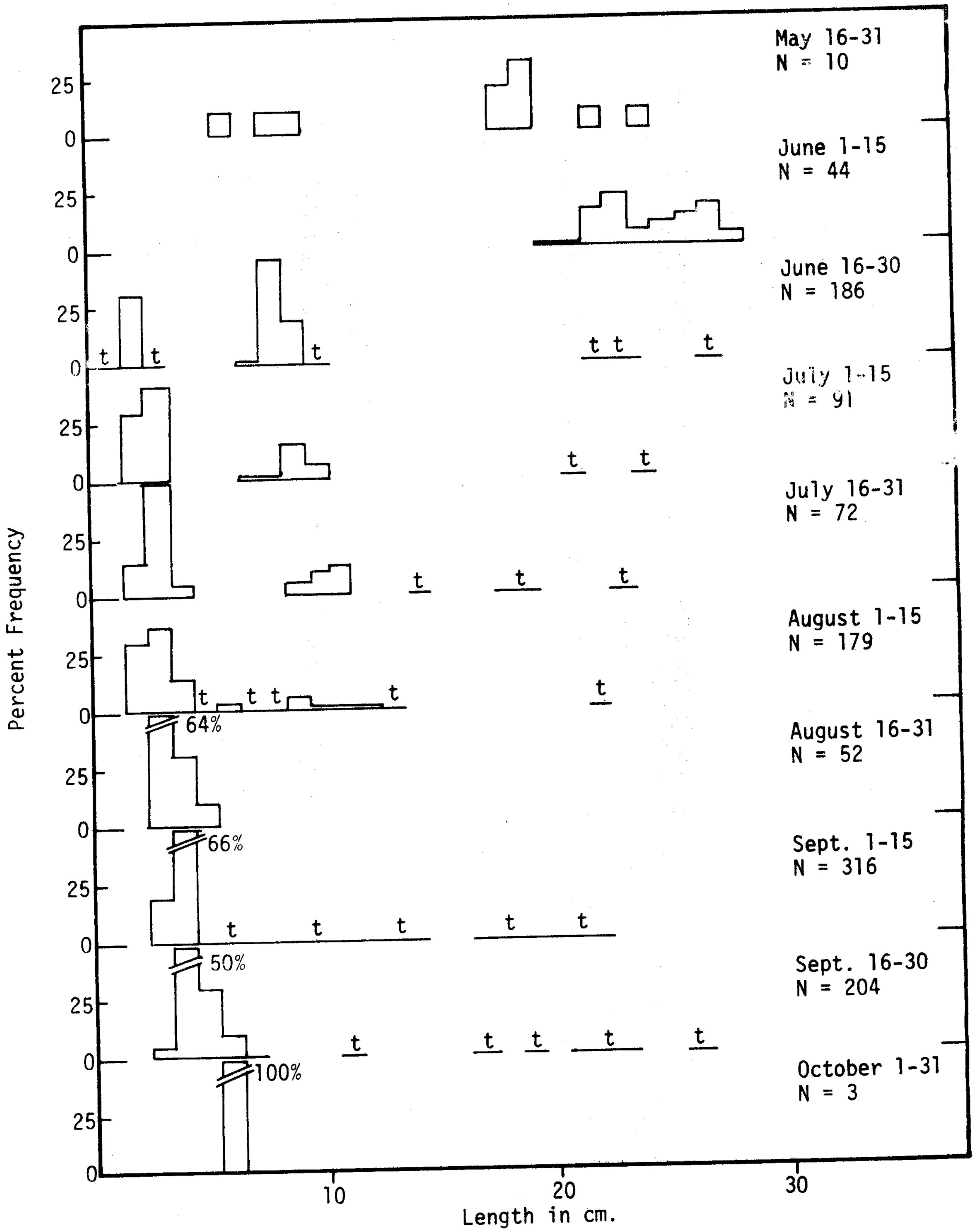


Figure 36. Relative length frequency of Pacific herring by time of capture. The catch by all gears and areas is combined; April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay.

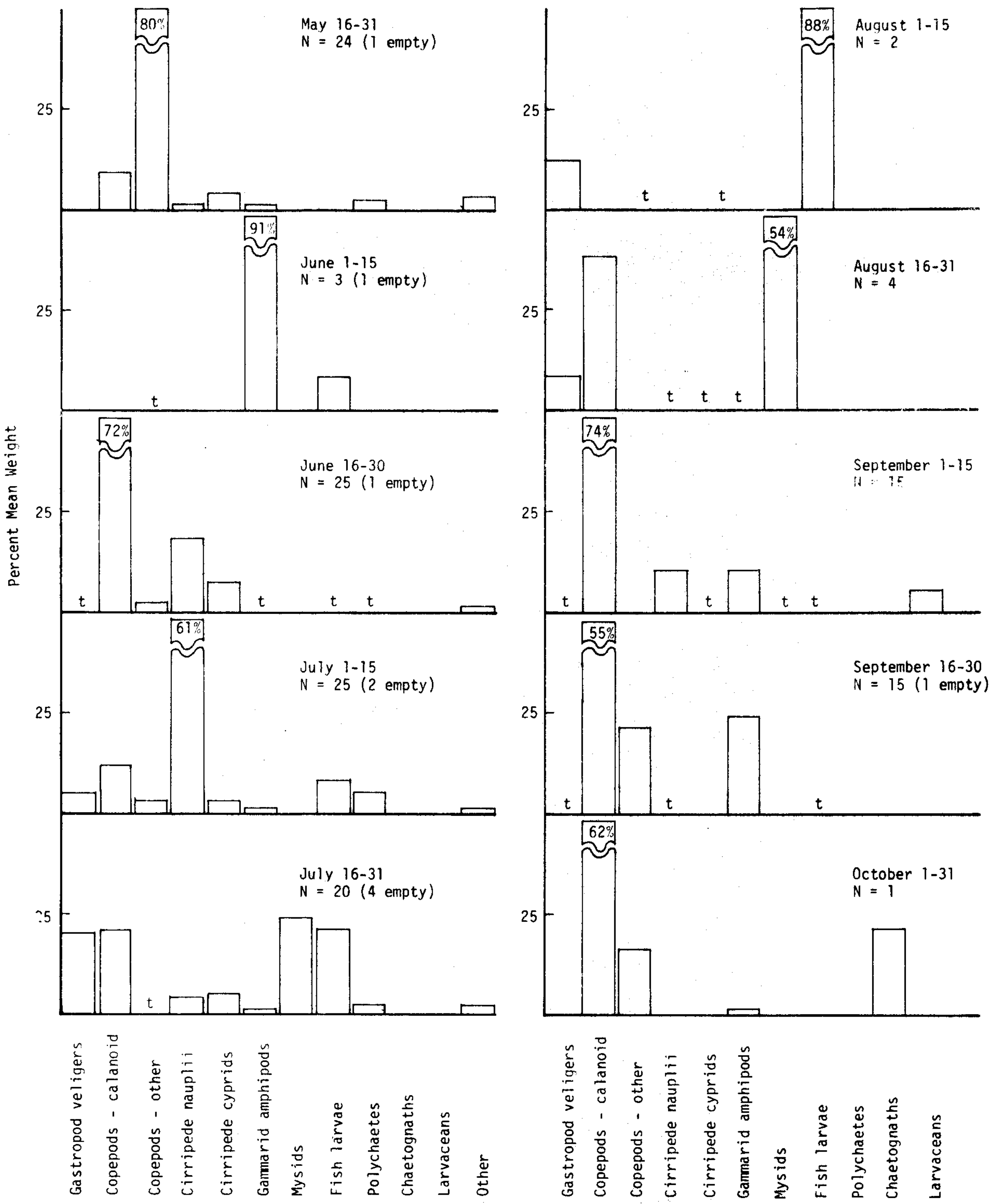


Figure 37. Pacific herring diet composition by major food item and time. May through September 1978 catches were in Kamishak Bay and October catches were in Kachemak Bay. N = number of stomachs examined; t = trace.

Kachemak Bay and late June - early July in Kamishak Bay (Table 16). Tow net catch of juvenile pinks was greatest in late July and early August, as they began to move offshore. The timing of peak abundance is identical to that determined in 1976 but this data set contains half monthly frequency while the former provided monthly frequency.

Beach seine catches of juvenile pink salmon were much greater in Rocky Cove than elsewhere (Table 26), a feature also seen in 1976. Tow net catches were primarily in Ursus Cove and Rocky Cove (Table 27) but this feature is questionable as the tow net catches were highly variable and did not clearly cover all areas when juvenile pinks were abundant.

Juvenile pink salmon grew from 30 to 40 mm in April and May and to about 80 mm in late August and September (Figure 38).

Eighty-four pink salmon fry and juveniles caught in April and from June to mid-September were examined for stomach contents; 22 prey items were identified (Figure 39).

Copepods comprised 30% to 100% of the stomach content weight in time periods before September; none were eaten in this month. More non-calanoid copepods were consumed in April and June and more calanoids in July and August. Shrimp larvae comprised 6% of contents in April and 10% in late June. Gastropod veligers comprised 4% in late July and 8% in early August. Insect larvae comprised 6% of stomach contents in April and insect adults up to 37% during and after July.

Gammarid amphipods comprised 3% to 8% of stomach contents before September and 66% of the contents of the one juvenile examined in this month. Cumaceans were present in stomachs from mid-June to mid-August, comprising 1% to 7% during three cruise periods and 50% during early July.

Herring larvae (13%) were consumed by pinks in late June. In a Cook Inlet study by ADF&G in 1976 pinks over 80 mm changed to a fish larvae diet. In the present study pinks were 80 mm by August, but no fish larvae were found during or after this month.

Hermit crab larvae, polychaete larvae and barnacle larvae were also consumed.

Food habits in this study were similar to those in other studies where pinks consumed plankters, insects, fish larvae and epibenthic crustaceans. Annan (1958) found young pinks preyed on copepods and diptera. Manzer (1969) found juvenile pinks preyed on copepods and larvaceans in Chatham Sound. Bailey et al. (1975) found Traitor's Cove pink fry fed on copepods, barnacle nauplii and cladocerans.

Juvenile pink salmon in Kodiak fed on calanoid and harpacticoid copepods, eggs, zoeae, fish larvae, and insects (Gosho, 1977), and calanoid and harpacticoid copepods and gammarid amphipods (Rogers et al., 1979). Pink fry in Tutka Bay fed on copepods, decapods, invertebrate eggs, barnacle nauplii and cyprids, insect larvae, and gammarids (Kron and Yuen, 1976). Northeastern Pacific pinks over 40 cm preyed on amphipods, euphausiids and fish (Le Brasseur, 1966), and Kodiak adult pinks preyed on fish (Rogers et al., 1979).

Table 27. Juvenile pink salmon catch in numbers per km towed by the tow net by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	Mean
Oil Bay						0							0
Oil Bay to Iliamna Bay			0	0	0	0.2		1.1	0.4				0.4
Ursus Cove							10.8		0.9				2.5
Rocky Cove							3.6						3.6
Contact Point							0						0
Kachemak Bay												0	0

Table 28. Juvenile chum salmon catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October, 1978.

Location	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	Mean
Oil Bay			0	0	4.5	0	1.7	0.3	0.2	0	0		0.7
Iniskin Bay			2.2	0	0.5	21.0	1.5	0.3	2.0	0.1	0		2.1
Cottonwood Bay		4.0	9.9	1.5	50.0	4.2	0	1.0	0.5	0.2	0		7.4
Iliamna Bay		16.0	4.6	0	22.7	7.4	1.5	0.6	0	0.2	0		5.3
Ursus Cove			12.4	0.7	14.0	22.8	19.2	26.8	1.3	5.5	0		11.0
Rocky Cove					11.0	64.0	1.0	0	0	0	0		10.8
Bruin Bay to Rocky Cove								65.0	0.5		0		16.4
Kachemak Bay	0											0	0

Table 29. Juvenile chum salmon catch in numbers per km towed by the tow net by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	Mean
Oil Bay						0							0
Oil Bay to Iliamna Bay			0	0	0	2.0		1.4	0.2				0.8
Ursus Cove				0			1.7		0				0.3
Rocky Cove							2.4						2.4
Contact Point							0						0
Kachemak Bay												0	0

Table 30. Juvenile coho salmon catch in numbers per km towed by the tow net by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	Mean
Oil Bay						0							0
Oil Bay to Iliamna Bay			0	0	0.2	0		0	0				T
Ursus Cove				0			0		0				0
Rocky Cove							1.0						1.0
Contact Point							0						0
Kachemak Bay												0	0

T < 0.05

Table 31. Juvenile coho salmon catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	Mean
Oil Bay			0	0	1.0	0	0	0	0	0	0		0.1
Iniskin Bay			0	1.0	1.5	0.5	0	0	0	0	0		0.2
Cottonwood Bay		0	0	1.5	0.3	0	0	0	0	0	0		0.1
Iliamna Bay		0	0	0	0.1	0.2	0	0	0	0	0		T
Ursus Cove			0	0	0.1	0.2	0	0	0	0	0		T
Rocky Cove					0.5	0	0	0	0	0	0		0.1
Bruin Bay to Rocky Cove								0	0		0		0
Kachemak Bay	0											T	T

T < 0.05

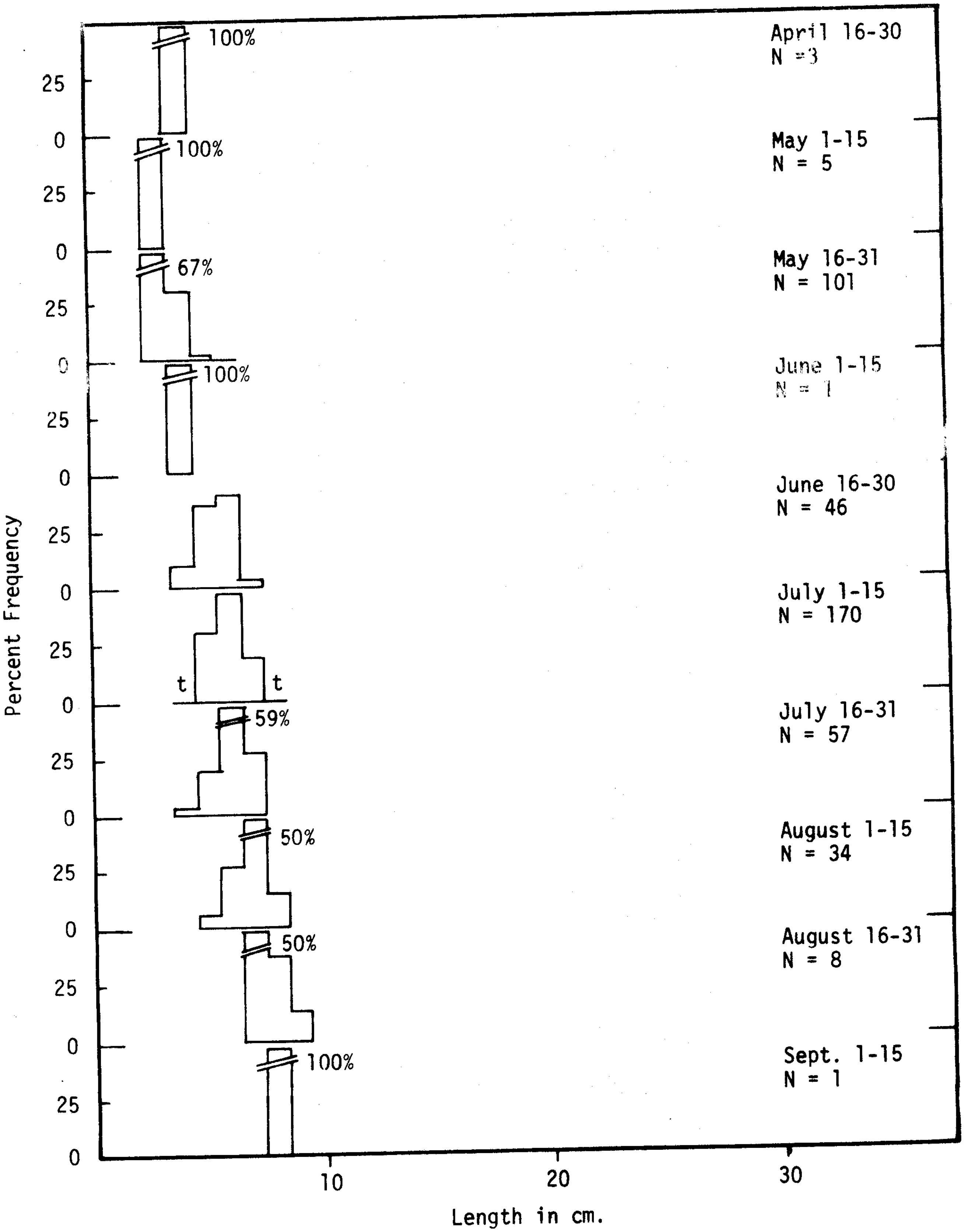


Figure 38. Relative length frequency of pink salmon by time of capture. The catch by all gears and areas is combined; April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay.

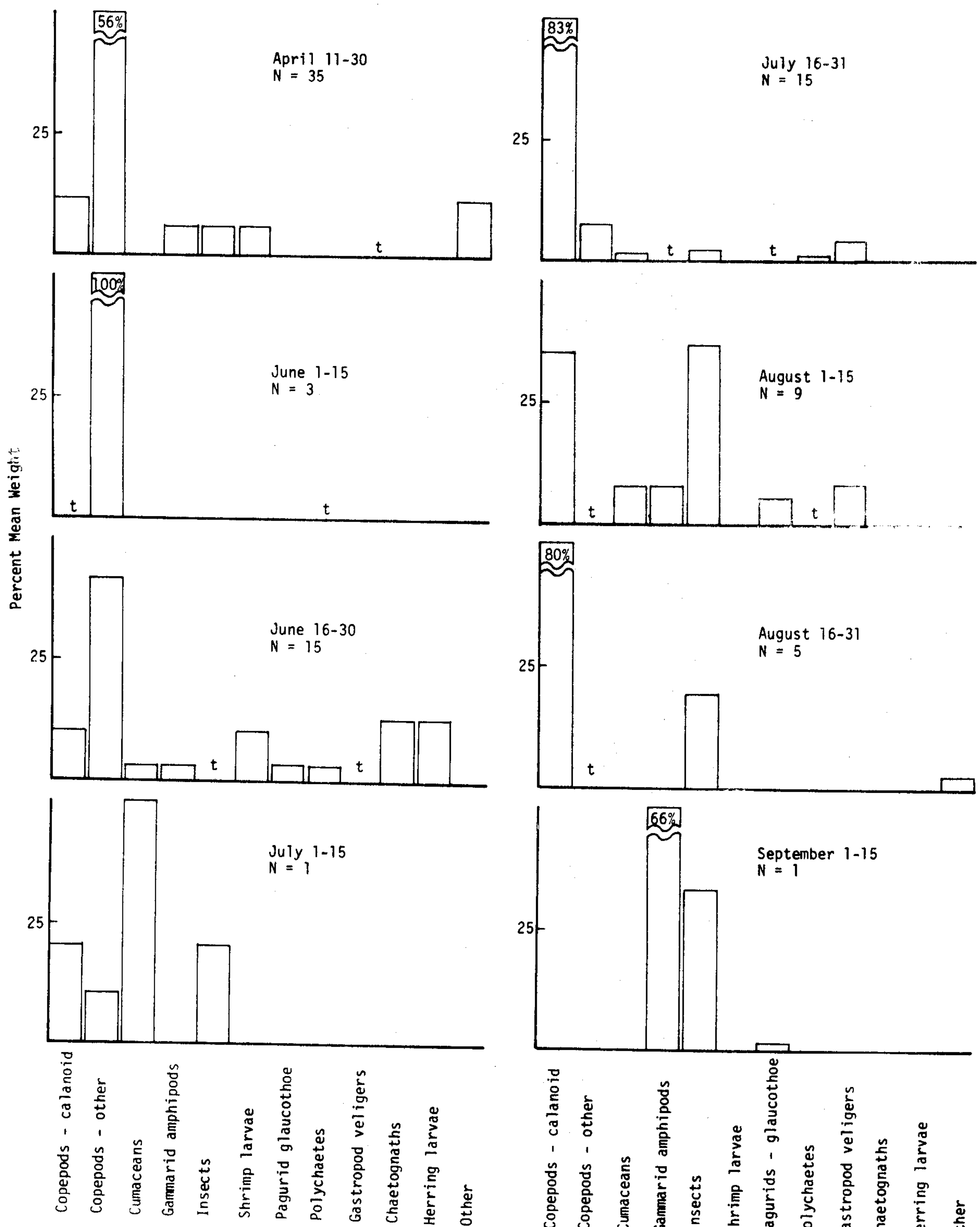


Figure 39. Juvenile pink salmon diet composition by major food item and time. April catches were in Kachemak Bay and others were in Kamishak Bay. N = number of stomachs; t = trace.

Bailey et al. (1975) found pink fry selected for decapod zoeae, larvaceans, cladocerans, mysids, cumaceans, isopods, amphipods and insects, and against barnacle nauplii.

Predators of pink salmon fry were Dolly Varden and small great sculpins in this study, and Dolly Varden and herring in Kron and Yuen's study (1976). Parker (1971) reported juvenile coho salmon were significant predators of pink fry in British Columbia.

Chum Salmon

Chum salmon ranked second in numerical abundance in the beach seine catches and seventh in the tow net catches. Juvenile chum salmon were most abundant in beach seine catches in late June and early July. They occurred in measurable abundance from early May through mid-September, a little longer than juvenile pink salmon. They occured in July and August in the tow net.

Juvenile pink salmon were slightly more numerous in the tow net catches and less numerous in the beach seine catches than chums, which supports the hypothesis that chums spent a little more time near shore than did juvenile pinks. Walker (1968 ms, as cited in Stern, 1977) reported this as a possibility but no evidence was found in 1976 to support the hypothesis. In contrast, I think it is clear that juvenile chums are present in the nearshore zone during a greater portion of the year than juvenile pinks. They were both captured during the same times (except April, but chums are not common in Kachemak and juveniles would not be expected at any time) but chums were more abundant, especially later. In Kodiak chums were captured into November and as early as March. In addition, juvenile chums of 100 mm were captured as early as late June and 30 mm chums were captured as late as early July and 40 mm chums as late as early August (Figure 40). Juvenile pinks were much more uniform in size than the chums.

The beach seine catches of juvenile chum salmon were apparently greater in Ursus Cove, Rocky Cove and Bruin Bay to Rocky Cove (Table 28) and less in Oil Bay and Iniskin Bay. These trends may be affected somewhat by the sampling pattern. The distribution of juvenile chums in the tow net appears to reflect the locations sampled when chums were present (Table 29).

The length frequency of juvenile chums (Figure 40) suggest mean size increased from 40 mm in May to about 80 mm in early September, however, the possibility of emigration of larger fish and immigration of smaller ones during the summer seems likely. This could have a considerable impact on apparent growth and the figures should be considered as descriptive of the fish present rather than strictly representative of growth rate.

Stomachs of 179 chum salmon fry and juveniles collected from May to mid-September were examined for food habits and 30 prey items were found (Figure 41).

Copepods decreased in importance as the season progressed. In the two time periods in May, 85% non-calanoid copepods by weight and 83% calanoid and non-calanoid copepods were present in chum stomachs. In June to mid-August 47% to 10% copepods were present, and 1% copepods were present in both late August and early September.

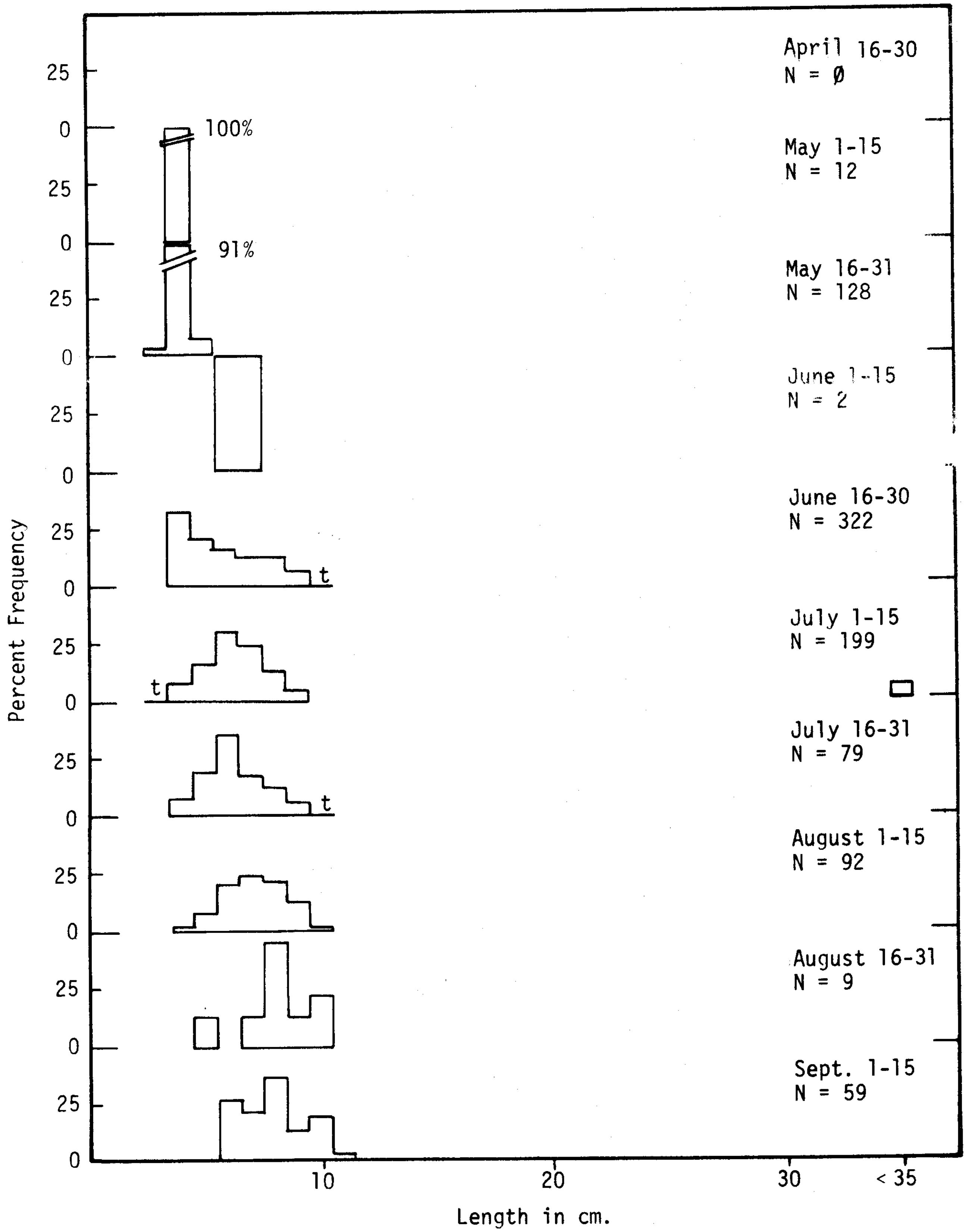


Figure 40. Relative length frequency of chum salmon by time of capture. The catch by all gears and areas is combined; April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay.

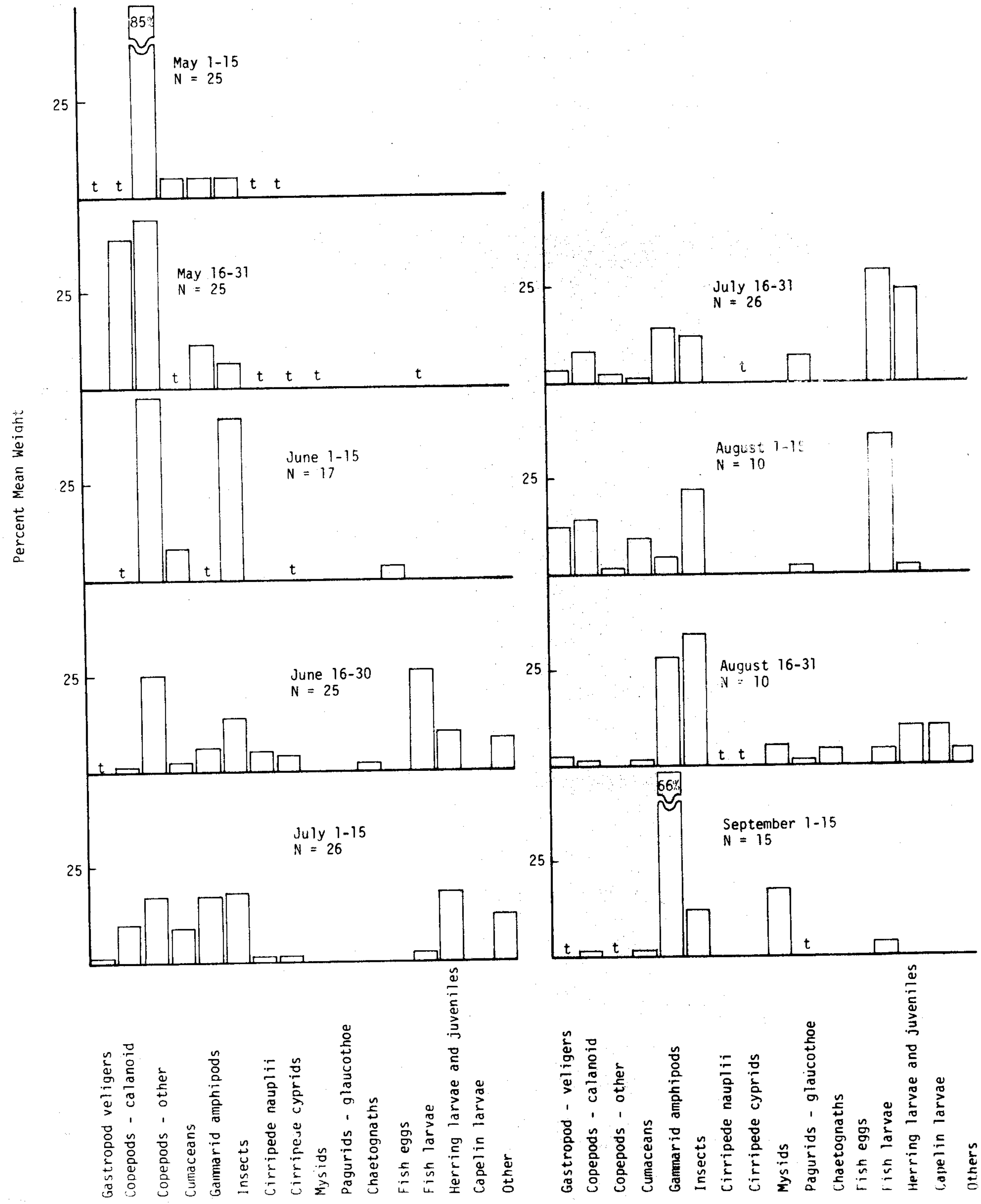


Figure 41. Juvenile chum salmon diet composition by major food item and time. Catches were in Kamishak Bay. N = number of stomachs examined; t= trace.

In late June 36% of the diet was fish (10% herring, and trace amounts of cottid, flounder and stichaeid larvae), in early July 20% (18% herring larvae and juveniles), in late July 53% (24% herring larvae), in early August 38% (2% herring larvae), in late August 24% (10% herring larvae and 10% capelin larvae) and in September 3% (unidentified). Insects were 5% to 42% of the diet in each time period. Gammarids and cumaceans comprised up to 28% of diets before September, and gammarids comprised 66% of the diet in this month. Mysids comprised 5% of the diet in late August and 17% in early September. Barnacle larvae, gastropod veligers, hermit crab larvae, chaetognaths, polychaete larvae, and fish eggs were also consumed.

Food habits in this study were similar to those in other studies where zooplankters, insects, fish larvae, and epibenthic crustaceans were eaten. Annan (1958) reported young chums ate copepods, diptera larvae, isopods and amphipods. Manzer (1969) reported juvenile chums in Chatham Sound ate copepods and larvaceans. Forsberg et al. (1977) reported juveniles in Tillamook Bay, Oregon ate insect larvae and adults, and fish larvae. Bailey et al. (1975) reported chum fry in Traitor's Cove ate copepods, larvaceans, dipteran larvae cladocerans and invertebrate eggs. They [illegible] found chums selected for cladocerans, decapod zoeae, larvaceans and benthic and intertidal animals, and against barnacle nauplii. Rogers et al. (1979) reported chum juveniles in Kodiak ate insects, harpacticoid copepods and gammarids.

Chum salmon fry were preyed on by sand lance and staghorn sculpins (this study) and by juvenile cohos (Parker, 1971). Chums were also eaten by murres (Hatch et al., 1978).

<u>Coho Salmon</u>

Coho salmon ranked tenth in numerical abundance in the tow net catches and 18th in the beach seine catches. They were taken from June through October with peak abundance of juveniles in early June through early July and peak abundance of adults in late August (Tables 16 and 18).

The tow net catches did not show distributional features (Table 30) but the beach seine catches tended to be greatest in Iniskin and Cottonwood bays and to a lesser extent in Iliamna Bay and Ursus Cove, based primarily on repeated catches and abundance (Table 31). Known runs in the study area include 500 coho in the Iniskin River, 2,000 coho in Dutton Creek at the head of Cottonwood Bay, about 1,500 in the stream's tributary to Ursus Cove and less than 500 in the Amakdedori River.

Juvenile coho ranged from 8 to 15 cm in length with a mean of 10.7 cm.

Eight coho salmon juveniles from mid-June, July and October hauls were examined for stomach contents (Figure 42). Of the 13 prey items found, fish were important in each month. The one coho examined in June had eaten 26% unidentified fish larvae by weight. The four coho in late July had eaten 56% fish larvae, mostly sand lance, and the one coho in October had eaten 47% fish larvae, mostly snake pricklebacks.

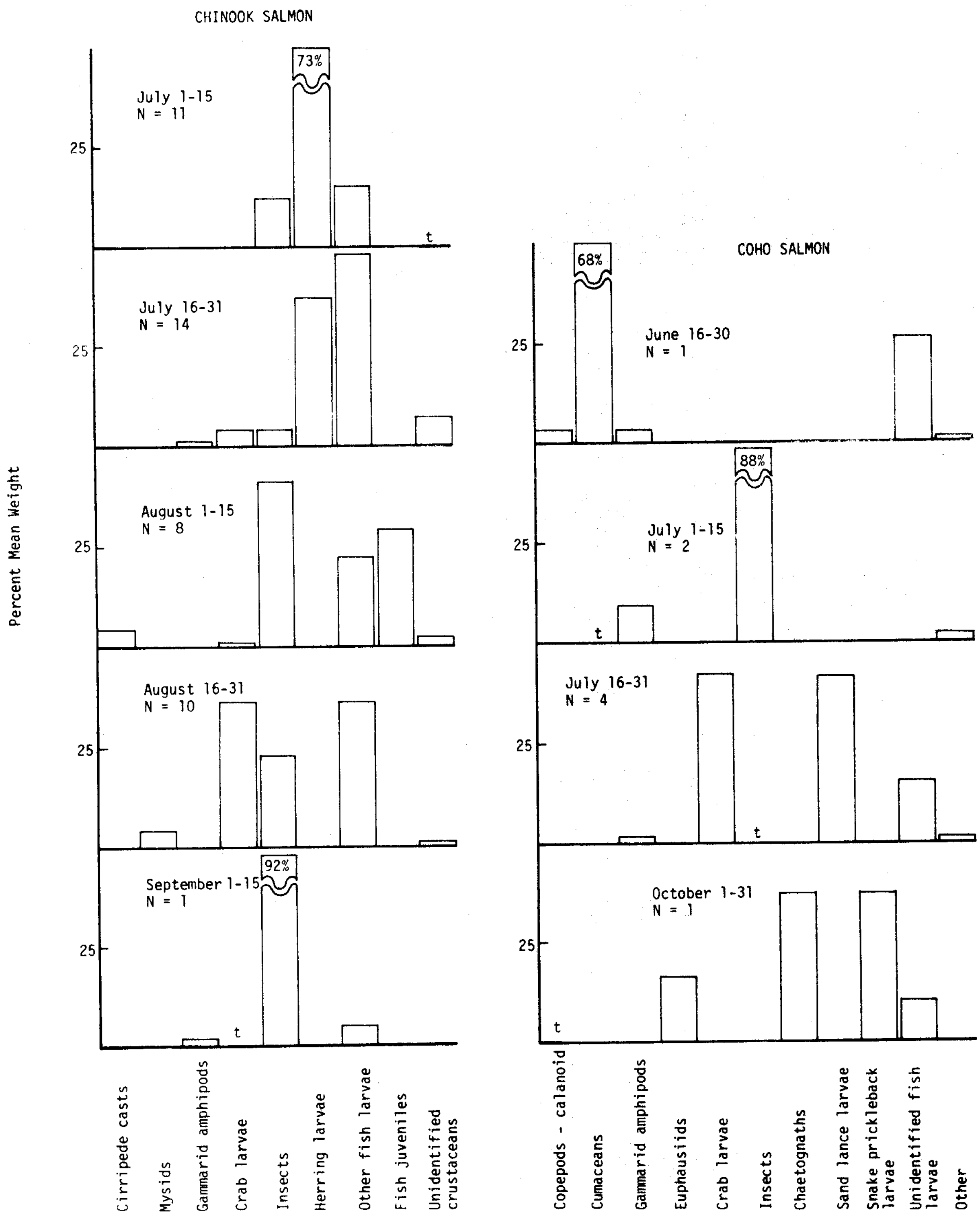


Figure 42. Juvenile chinook and coho salmon diet compositions by major food item and time. July through September 1978 catches were in Kamishak Bay and October catches were in Kachemak Bay. N = number of stomachs examined; t = trace

Cumaceans were 68% of the mid-June diet. Insect larvae and adults were 88% of the diet of the two coho's sampled in early July. Crab larvae were 42% of the late July diet. Euphausiids and chaetognaths were 16% and 37% of the October diet. Gammarid amphipods and calanoid copepods were 3% to 9% of diets in two time periods.

Food habits in this study were similar to those in other studies, where fish, plankters, insects and epibenthic crustaceans were eaten. Forsberg et al. (1977) reported cohos ate fish larvae, decapods and amphipods in Oregon. Manzer (1969) reported juvenile cohos in Chatham Sound ate herring and sand lance larvae. McLean et al. (1976) reported coho smolt ate herring larvae, sand lance, greenling, rock fish, eulachon, insects, copepods, amphipods, barnacles, crab larvae, and euphausiids in Cook Inlet and Kodiak. Rogers et al. (1979) reported juvenile cohos ate calanoid and harpacticoid copepods, crab larvae, gammarids and fish in Kodiak. Parker (1971) reported juvenile cohos preyed on pink and chum fry in British Columbia.

Sockeye Salmon

Juvenile sockeye salmon ranked sixth in numerical abundance in the tow net catches but were rarely captured in the beach seine (Table 12). They occurred from early June through early July. They ranged from 7 to 10 cm in length with a mean of 8.5 cm. The area that they were captured in the tow net, Oil Bay to Iliamna Bay, reflects the area sampled during the period of their occurrence (Table 32).

There are a few streams on the west side of Cook Inlet with small runs of sockeye but by far the majority of the sockeye return to rivers on the east side of the inlet. The fish captured were not taken in proximity to a known spawning stream and it appears most likely that they were from other areas of Cook Inlet.

Stomachs of 32 juvenile sockeye salmon collected in June and early July were examined for contents. Twenty prey items were present (Figure 43).

The one sockeye sampled in early June had consumed 78% non-calanoid copepods by weight. Sockeyes in late June and early July had consumed 6% and 4% calanoid copepods. Insects comprised 7%, 8% and 29% of stomach contents in the three time periods.

Fish eggs comprised 50% and unidentified fish larvae comprised 7% of stomach contents in late June. Fish larvae comprised 26% of stomach contents in early July; 7% of this was sand lance larvae, and 8% was herring larvae.

Shrimp larvae formed 30% of the diet in early July, crab larvae formed 10% in late June, gammarid amphipods formed 7% in early June, and cumaceans formed 7% and 12% in early July.

Zooplankton, insects, fish and epibenthic crustaceans were also prey found in other studies. Le Brasseur (1966) reported mature sockeyes from the Northeast Pacific consumed amphipods, euphausiids, and squid, and immature sockeyes consumed planktonic species, especially copepods and larvaceans.

Table 32. Juvenile sockeye salmon catch in numbers per km towed by the tow net by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay						0							0
Oil Bay to Iliamna Bay			0	0	2.6	4.7		0	0				1.5
Ursus Cove				0			0		0				0
Rocky Cove							0						0
Contact Point							0						0
Kachemak Bay												0	0

Table 33. Juvenile chinook salmon catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			0	0	0	0	0	0.3	0.2	0	0		0.1
Iniskin Bay			0	0	0	0	0	0	0	0	0		0
Cottonwood Bay		0	0	0	0	0	0	1.0	0	0	0		0.1
Iliamna Bay		0	0	0	0.1	0	0	0.3	0.2	0	0		0.1
Ursus Cove			0	0	0	0.2	0	0	0.3	0.1	0		0.1
Rocky Cove					0.5	0.5	0	0	0	0	0		0.1
Bruin Bay to Rocky Cove								0	0		0		0
Kachemak Bay	0											0	0

Table 34. Juvenile chinook salmon catch in numbers per km towed by the tow net by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay						0							0
Oil Bay to Iliamna			0	0	0	1.1		0.6	0.9				0.5
Ursus Cove				0			4.2		1.2				1.4
Rocky Cove							1.0						1.0
Contact Point							0						0
Kachemak Bay												0.2	0.2

Table 35. Juvenile Dolly Varden catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October, 1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			8.3	3.3	6.5	1.0	1.0	6.3	0.2	2.0	0		3.2
Iniskin Bay			2.0	11.0	22.0	27.5	1.0	3.3	0	5.6	0		6.2
Cottonwood Bay		0	2.1	1.5	2.7	1.6	1.0	3.7	0	0	0		1.4
Iliamna Bay		0	2.2	22.7	8.6	4.2	5.7	1.3	0.7	2.2	0		4.5
Ursus Cove			0	3.7	15.9	3.5	3.0	9.2	20.0	0.7	4.2		6.1
Rocky Cove					16.0	22.5	14.0	1.0	140.5	0	0		26.6
Bruin Bay to Rocky Cove								3.5	0		0.2		0.9
Kachemak Bay	0											0	0

Table 36. Adult Dolly Varden catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October, 1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			1.0	0	0	0	1.7	2.3	0.2	3.0	0		1.0
Iniskin Bay			1.2	1.0	1.0	0	0	0	1.0	0	0		0.3
Cottonwood Bay		0.2	0.2	0	0	0	0.8	0.3	0	0	0.5		0.2
Iliamna Bay		0	0.2	0	0.1	0.2	0	0.2	0.2	0	0.4		0.1
Ursus Cove			0	0	0.4	0.2	0.2	0	2.3	0.6	5.6		1.0
Rocky Cove					0	2.0	0	2.0	4.0	1.0	0		1.1
Bruin Bay to Rocky Cove								0	3.0		0.5		1.0
Kachemak Bay	0											0.3	0.3

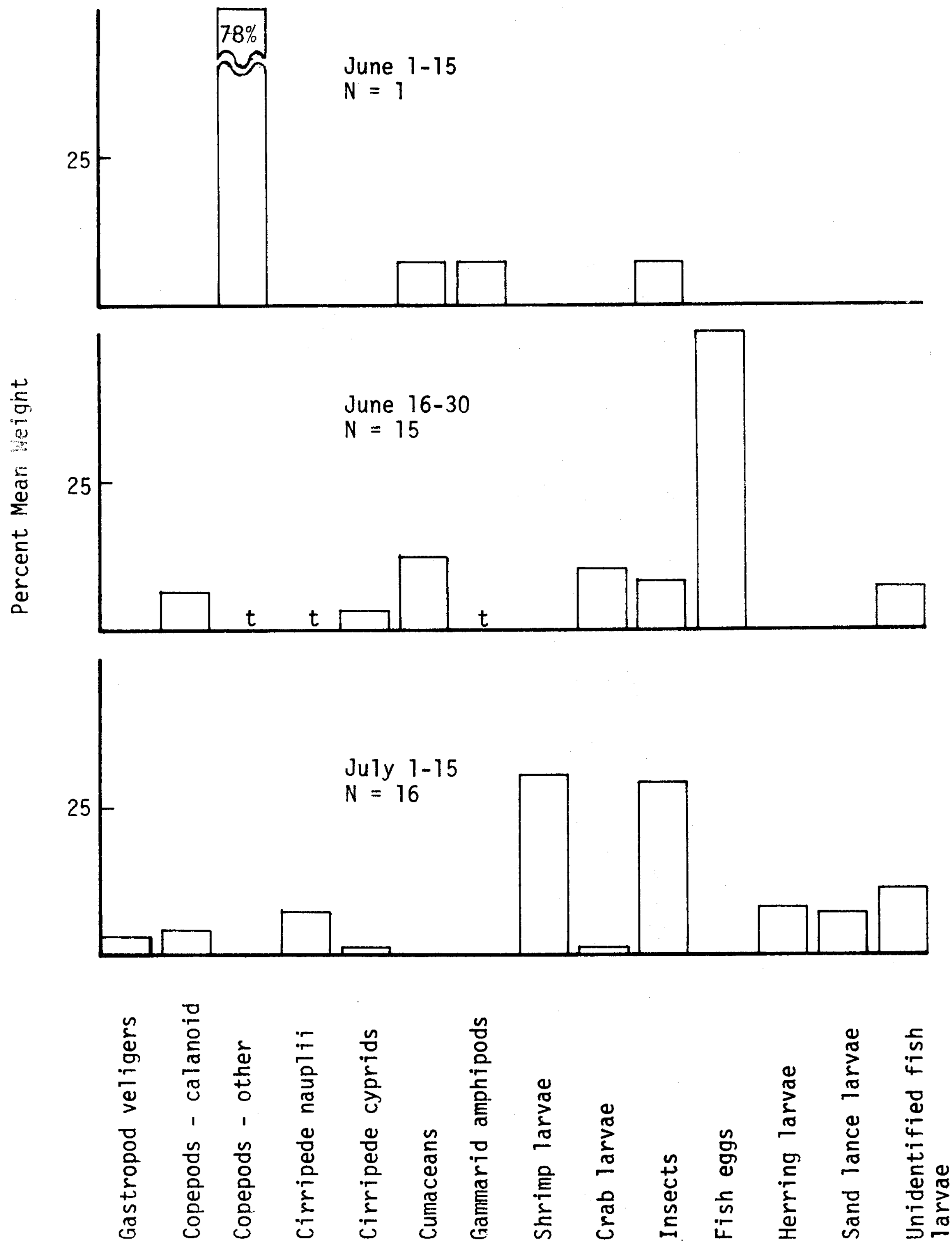


Figure 43. Juvenile sockeye salmon diet composition by major food item and time. Catches were in Kamishak Bay. N = number of stomachs examined; t = trace.

Dell (1963) reported immature Aleutian sockeyes preyed on larval fishes, euphausiids, amphipods and squid. He also cited earlier studies in which sockeyes preyed on euphausiids, amphipods, calanoid copepods, and molluscs (Andrievskaya, 1958), and euphausiids, amphipods, crab larvae and copepods (Synkova, 1961).

McLean et al. (1976) listed insects, copepods, amphipods, decapods, barnacle larvae, ostracods, euphausiids, and larval and juvenile sand lance, rock fish, eulachon, starry flounder, herring, and prickleheads as prey items for sockeye smolt in the Cook Inlet and Kodiak areas. Carlson (1963) reported insects, copepods, amphipods, euphausiids, anomuran larvae and sand lance as prey items for Bristol Bay sockeye juveniles. Simenstad and Nakatani (1977) reported harpacticoid copepods as the major prey and gammarid amphipods, mysids, and fish as minor prey of juvenile Attu sockeye.

Sockeye fry were preyed on by Dolly Varden, Arctic char, squawfish (in freshwater), prickly sculpins (in freshwater), rainbow trout, and coho salmon (McLean et al., 1976), and tufted puffins (Hatch et al., 1978).

Chinook Salmon

Juvenile chinook salmon ranked eighth in numerical abundance in the tow net and 23rd in the beach seine catches. They occurred from late June through October and appeared to be most abundant in July and August (Tables 16 and 18). The distribution within the sampling area is not clear as they were too infrequently captured (Tables 33 and 34).

A total of 47 juvenile chinook salmon were measured and they ranged from 7 to 18 cm. Two fish in late June averaged 90 mm, 14 in late July averaged 95 mm, 11 in early August averaged 96 mm and 15 in late August averaged 115 mm.

There are a few streams on the west side of Cook Inlet with small runs of chinooks but by far the majority of them spawn in streams on the east side of the inlet. It appears most likely that these fish were from other portions of Cook Inlet.

Stomach contents of 44 juvenile chinook salmon caught from July to mid-September were examined. Ten prey items were found (Figure 42).

Fish was 88% by weight of stomach contents in early July; 73% of that was herring larvae and 2% was stichaeid larvae. Fish was 85% of contents in late July; 37% of that was herring larvae. Unidentified fish larvae and juveniles were 51%, 36% and 5% of contents in the following time periods.

Insects formed 12%, 4%, 41% and 23% of diets in July and August, and 92% of the diet of one fish examined in September. Crab larvae occurred in stomachs in July and August, forming 4%, 1%, and 3 to 6% of the contents. Mysids and gammarid amphipods were 4% or less of contents when present.

Food habits in this study were similar to those in other studies where fish, plankters, insects, and epibenthic crustaceans were eaten. Young chinook ate copepods and dipterans (Annan, 1958), and dipterans, decapods, amphipods, isopods and herring and smelt juveniles (Forsberg et al., 1977).

Maturing chinook ate herring, sand lance, rock fish, eulachon, amphipods, copepods, euphausiids and crab and barnacle larvae in Cook Inlet and Kodiak (McLean et al., 1976). Mature chinook ate herring, anchovies, rock fish, euphausiids, crab megalops and squid in California (Merkel, 1957).

Dolly Varden

Dolly Varden were captured primarily in the beach seine in which they ranked third in numerical abundance. They occurred in greatest numbers in June through August (Table 16). They were widely distributed with juveniles most abundant in Rocky Cove and adults less abundant in Iniskin, Cottonwood, and Iliamna bays (Tables 35 and 36).

Most of the Dolly Varden were juveniles and their growth during their first year at sea is clearly evident, with 130 mm fish (90 to 170 mm) in late May growing to 150 mm (110 to 180 mm) in late July and about 200 mm (140 to 240 in late September (Figure 44). The size of other age classes cannot be determined from the length frequency data.

Dolly Varden juveniles caught from May through October were examined for stomach contents. The one Dolly Varden examined in early May had an empty stomach. All but three of the 177 Dollies from the remaining catches had consumed 36 prey items (Figure 45).

Fish larvae and juveniles were a major food in each time period. Fish was 33% of the diet in late May (15% sand lance juveniles, 6% longfin smelt larvae, 6% chum salmon fry, and 5% unidentified salmon fry), 19% in early June (Irish Lord larvae), 16% in late June (8% salmon fry and 2% greenling juveniles), 7% in early July (snake prickleback larvae) 11% in late July (unidentified larvae), 16% in early August (5% herring larvae), 23% in late August (12% herring larvae), 44% in early September (18% herring larvae, 6% herring juveniles and 8% sand lance juveniles), 26% in late September (23% herring larvae), and 78% in October (24% sand lance juveniles, 52% salmon fry and a trace was staghorn sculpin larvae).

Gammarid amphipods were 22% to 80% of the diets from mid-May through October. _Telmessus cheiragonus_ (horse crab) megalops were 13% and Dungeness megalops were 14% of the early June diet, and _T. cheiragonus_ was 18% of the late June diet. Cumaceans were consumed from mid-May to mid-August and were 2-18% of the diets. Mysids were consumed from mid-May to October, and were 8% of the contents or less before September, and 30% and 17% in this month.

Insects were consumed from mid-May through October, especially; in late July and early August when they were 42% and 66% of the diets. Copepods, isopods, euphausiids, shrimp and polychaetes were also consumed.

Eight adult Dolly Varden in late May and early June were also examined for food habits (Figure 46). In May 58% of the diet by weight was sand lance juveniles, 6% was capelin larvae and 36% was polychaetes. In June, 76% of the diet was herring juveniles, 10% sand lance juveniles, and 12% walleye pollock juveniles.

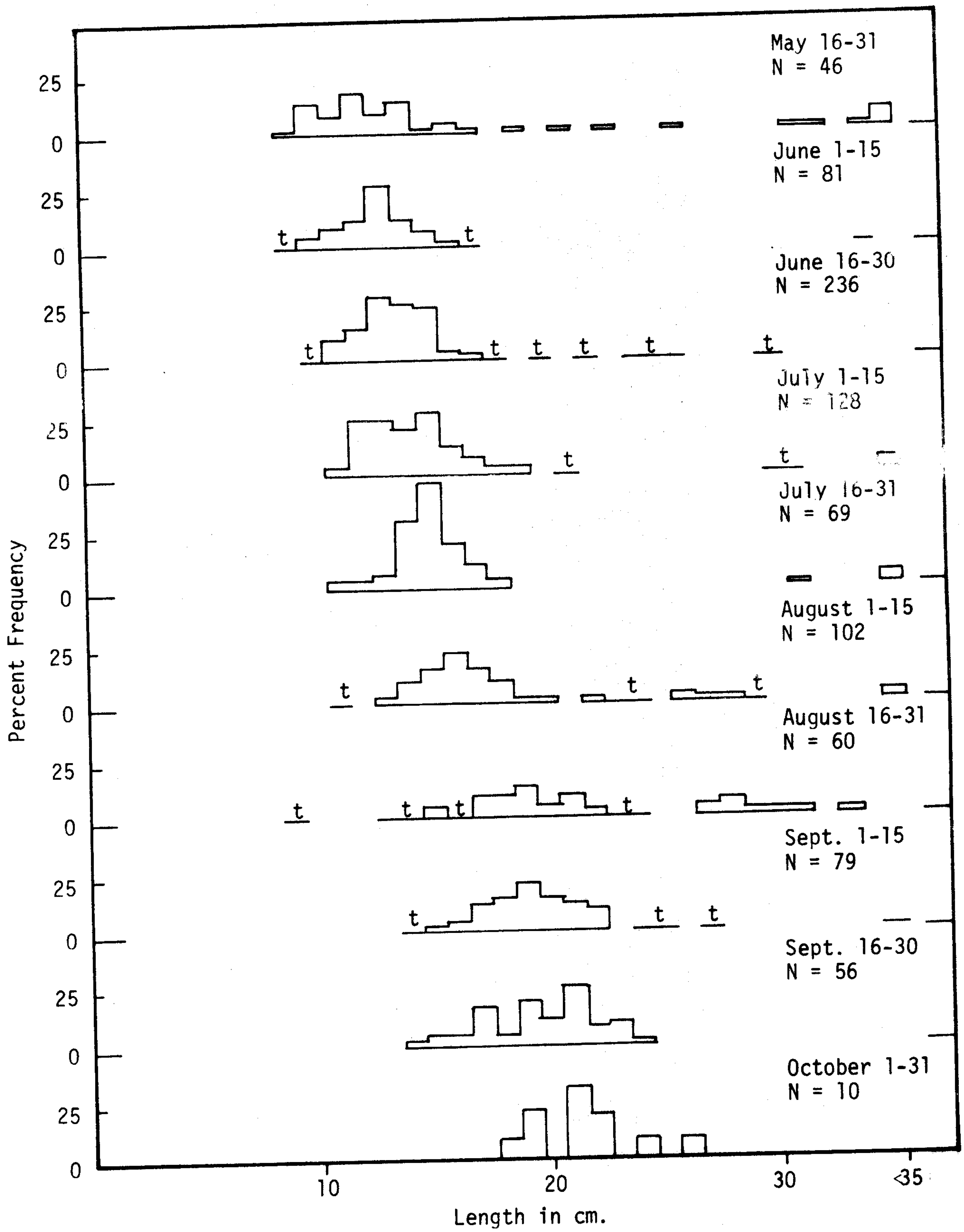


Figure 44. Relative length frequency of Dolly Varden by time of capture. The catch by all gears and areas is combined; April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay.

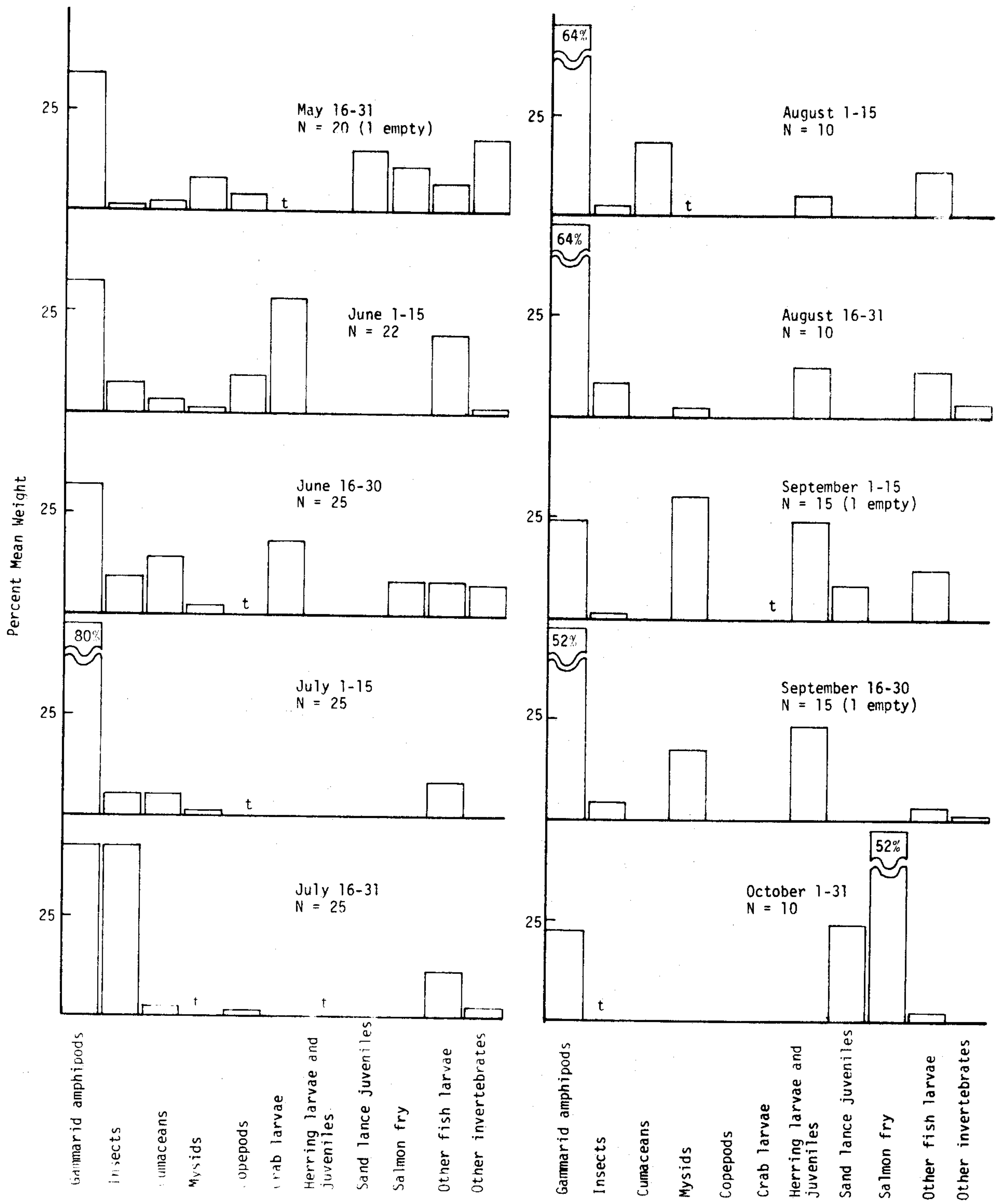


Figure 45. Juvenile Dolly Varden diet composition by major food item and time. May through September 1978 catches were in Kamishak Bay and October 1978 catches were in Kachemak Bay. N = number of stomachs examined; t = trace.

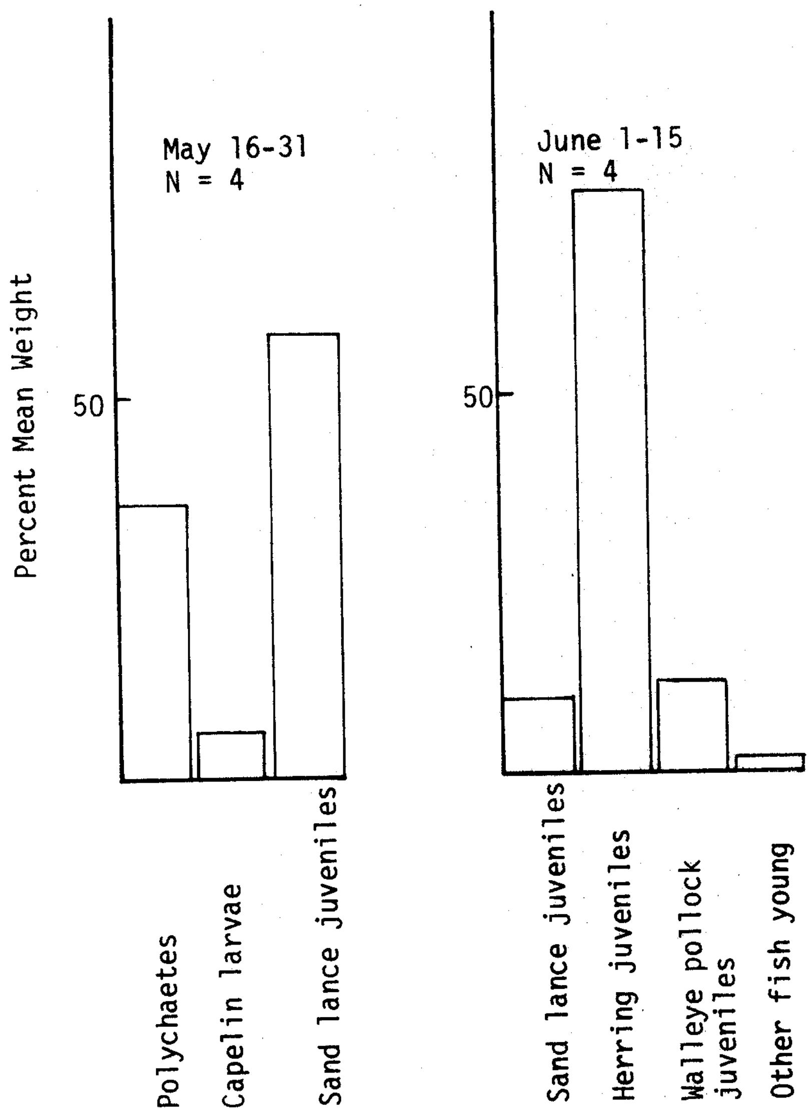


Figure 46. Adult Dolly Varden diet composition by major food item and time. Catches were in Kamishak Bay. N = number of stomachs examined.

Fish, epibenthic crustaceans and insects were also eaten in other studies. Simenstad and Nakatani (1977) reported juvenile Dolly Varden ate harpacticoid copepods, gammarid amphipods, insects, mysids and fish at Attu, and adult Dolly Varden ate mysids and fish at Amchitka. Kron and Yuen (1976) reported Dolly Varden ate juvenile salmon and capelin in Tutka Bay.

Capelin

Capelin ranked fourth in numerical abundance in the tow net catches and 27th in the try net catches. The catches were almost exclusively in late May when tows of both gear types were made in the mouth of Iniskin Bay within a few minutes of each other. The capelin were adults with ripe and running sex products. In addition larval capelin were relatively abundant in Kachemak Bay in October sampling when both the beach seine and tow net captured about 20 per haul.

The adult capelin were 9 to 12 cm (mean 10.7 cm) standard length and the larvae captured in October ranged from 2 to 5 cm (mean 4.0 cm) in standard length.

The length composition of larval capelin was bimodal, with peak numbers at 2 to 3 cm and at 5 cm, suggesting either prolonged spawning or two different spawning times.

Capelin are a forage fish that occurs in tremendous quantities in some areas. They spawn from the last week of May until perhaps as late as mid-July (Blackburn, 1979b). Their eggs are deposited in coarse sand or fine gravel on beaches where they ride the crests of waves ashore on high tides at night to spawn (Templeman, 1948). They may also spawn subtidally, however.

Ten adult capelin stomachs in late May were examined for contents; nine were empty, and one contained mostly barnacle nauplii (Figure 47). Capelin consumed small plankters in other studies as well as larger plankters and crustaceans. Templeman (1948) reported immature capelin fed on copepods, and mature capelin on copepods, amphipods, euphausiids, shrimp, and capelin eggs. Rogers et al. (1979) reported capelin fed on calanoid copepods.

Capelin were prey for Pacific cod and halibut (Hunter, 1979), Dolly Varden (Kron and Yuen, 1976), Dolly Varden, chum salmon juveniles and yellowfin sole (this study), herring, cod, salmon, seals, whales, murres, puffins, gulls, terns, shearwaters and sea pigeons (Templeman, 1948) and cormorants, glaucous-winged gulls, kittiwakes, horned and tufted puffins, Artic and Aleutian terns and murres (Hatch et al., 1978).

The young reach about 40 to 60 mm during their first winter and are an important food for some sea birds during winter. Sanger et al. (1979) found marbled murrelets specialized on juvenile capelin in the winter and common murres feed to a limited extent on capelin.

Longfin Smelt

Longfin smelt ranked sixth in numerical abundance in the beach seine and 25th in the try net. They occurred throughout the summer in Kamishak Bay and their abundance was strongly related, on a cruise by cruise basis, to the water transparency. They only occurred at greater than 1.0 fish per haul in

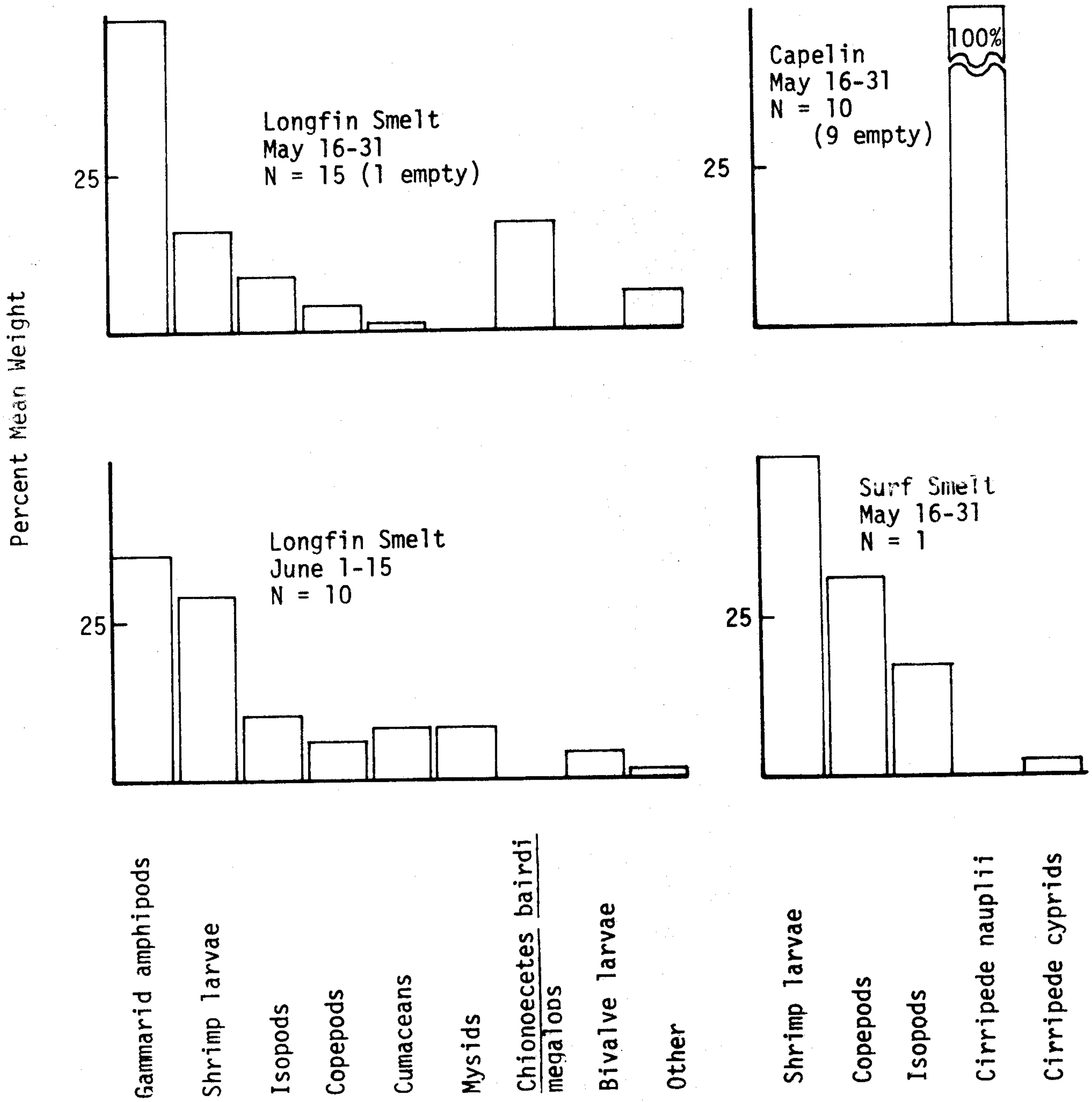


Figure 47. Smelt diet composition by major food item, species and time. Catches wer in Kamishak Bay. N = number of stomachs examined.

cruises that also had water with less than 1.5 m visibility and on the only cruise in which visibility greater than four meters occurred, longfin smelt were not captured. They were also much more abundant in Oil Bay, the most northern area sampled, than elsewhere in the study area (Table 37).

Neither of the above distribution features are surprising since these fish were found to be primarily inhabitants of the upper portion of lower Cook Inlet by sampling in 1976 (Blackburn, 1979). Their occurrence in the study area is strongly related to hydrographic features that affect the boundary of their primary habitat area.

The age 1 longfin smelt appeared in late May at 5 to 6 cm and grew to about 8 to 9 cm by late September. Age 0 longfin smelt appeared at 3 to 5 cm in early September. Age 2 and older were 8 to 15 cm in late May with a mode at 11 cm (Figure 48). Longfin smelt are considered to spawn at the end of their second year and are not known to survive to spawn a second time. Some of the larger individuals may be age 3 smelt.

Stomachs of 25 longfin smelt caught in late May and early June contained 17 prey items (Figure 47). Gammarid amphipods comprised 49% and 35% of stomach contents by weight for the two time periods, shrimp larvae comprised 16% and 29%, and isopods comprised 9% and 10%. Tanner crab megalops (Chionoecetes bairdi) comprised 17% of the diet in late May and mysids and cumaceans each comprised 8% in early June. In addition to epibenthic crustaceans and decapod larvae, small plankters, and fish eggs and larvae were consumed.

Longfin smelt from an ADF&G Cook Inlet study in 1976 were examined for food habits. The 100 fish had eaten amphipods, copepods, and mysids, and to a lesser extent, barnacle larvae, crab larvae, cumaceans, and chaetognaths.

Larval longfin smelt were eaten by sand lance in this study.

Surf Smelt

Very few surf smelt were captured and all were in the beach seine. The stomach of one surf smelt in late May contained shrimp larvae, copepods, isopods and a few barnacle cyprids (Figure 47). Plankters and epibenthic crustaceans were also smelt prey in a study by Forsberg et al. (1977), who reported surf smelt in Tillamook Bay, Oregon ate decapod larvae, copepods, larvaceans, barnacle cyprids and amphipods. Osmerids were preyed on by Pacific cod, great sculpin, rock sole and yellowfin sole in Kodiak (Rogers et al., 1979).

Saffron Cod

Saffron cod were captured in modest numbers throughout the study area, in the nearshore zone. The stomach of one saffron cod in late May contained 52% isopods by weight and 48% gammarid amphipods (Figure 49). During one beach seine, several saffron cod had longfin smelt in their mouths.

Table 37. Longfin smelt catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October, 1978. This table includes all life history stages.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			108.0	12.3	5.5	21.0	32.0	1.0	0	27.7	40.0		25.6
Iniskin Bay			0.2	10.0	0	0	2.5	0	0	0	0.2		0.6
Cottonwood Bay		0.2	0	0	1.7	0	0	0	0	0	0.5		0.2
Iliamna Bay		0	0	0	5.1	0	1.5	0	0	0	0		1.2
Ursus Cove			0	0	0	0	0	0	0	0.2	0.8		0.5
Rocky Cove					0	0	0	0	0	0	0		0
Bruin Bay to Rocky Cove								0	0		0		0
Kachemak Bay	0											0	0

Table 38. Juvenile whitespotted greenling catch in numbers per km towed by the tow net by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay						0							0
Oil Bay to Iliamna Bay			0	0	8.9	0.5		0.4	0.2				1.8
Ursus Cove				2.5			0		0				0.7
Rocky Cove							1.2						1.2
Contact Point							0						0
Kachemak Bay												0	0

Table 39. Juvenile whitespotted greenling catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			0	0	0.5	0	0.7	0	0	0	0		0.1
Iniskin Bay			0	0	7.5	1.0	0	1.3	0	1.6	0		1.2
Cottonwood Bay		0	0.5	4.0	25.7	3.4	7.0	1.0	1.0	0.2	0		3.5
Iliamna Bay		0	0.1	0	9.3	2.8	7.8	2.4	0.3	0.5	0.2		3.4
Ursus Cove			0.4	0	3.1	1.0	1.2	0.5	0	0.3	0.2		0.9
Rocky Cove					10.5	3.0	1.0	0	2.0	0	0		2.3
Bruin Bay to Rocky Cove								1.0	0		0		0.2
Kachemak Bay	0.6											0	0.1

Table 40. Adult whitespotted greenling catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			0	0	0	0	0	0	0	0	0		0
Iniskin Bay			0.5	0	1.5	0	0.5	0.3	0	0	0		0.2
Cottonwood Bay		0	0.1	0	0.3	0.2	0.2	0	0	0	0		0.1
Iliamna Bay		0	0	0	0.5	0	0.3	0.5	0	0	0		0.2
Ursus Cove			0	0	0.3	0.2	0	0	0	0	0		0.1
Rocky Cove					0	0	0	0	0	0	0		0
Bruin Bay to Rocky Cove								0	0		0		0
Kachemak Bay	0											0	0

Table 41. Staghorn sculpin catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October, 1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			0.3	1.7	0.5	0	0.7	0	0.6	6.3	2.0		1.4
Iniskin Bay			0	0	0	0	3.0	0.3	0	1.5	0		0.8
Cottonwood Bay		0.6	0.5	1.0	0	0.6	0.2	0	0	0.5	0.5		0.4
Iliamna Bay		0	0.1	0	0.9	0	1.3	0.1	0	0	0		0.4
Ursus Cove			0	0.3	1.6	0.2	0.2	1.2	2.7	8.1	0		2.8
Rocky Cove					0	0	0	0	0	6.0	0		0.9
Bruin Bay to Rocky Cove								0	1.0		0		0.2
Kachemak Bay	0											0.3	0.2

T < 0.05

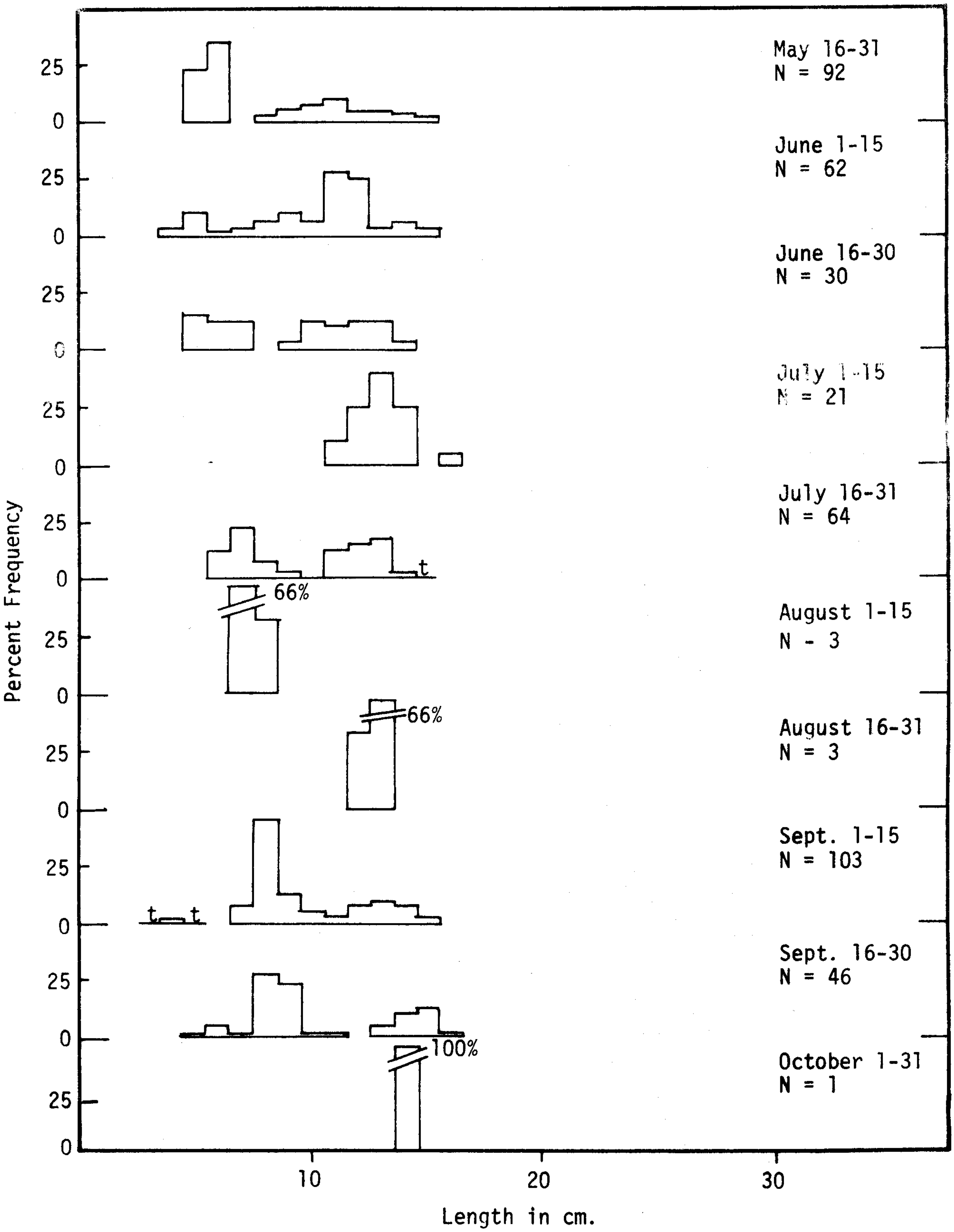


Figure 48. Relative length frequency of longfin smelt by time of capture. The catch by all gears and areas is combined; April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay.

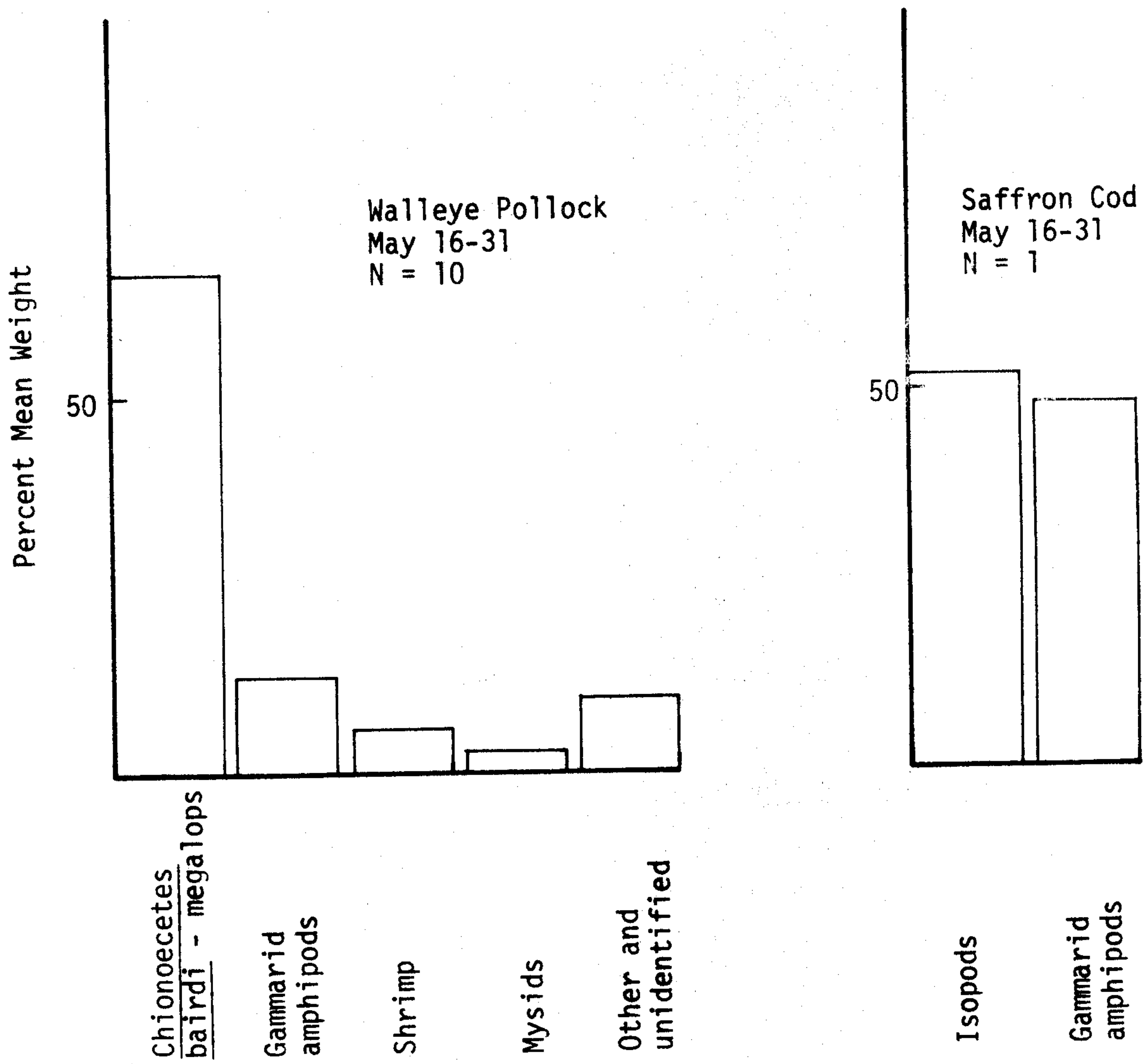


Figure 49. Walleye pollock and saffron cod diet compositions by major food item and time. Catches were in Kamishak Bay. N = number of stomachs examined.

Pacific Cod

Only four individuals of Pacific cod were captured. They ranged from 5 to 24 cm and all but the smallest one were captured in the try net. The primary habitat of the adults of this commercially utilized species is in water deeper than 40 fathoms but the juveniles are common in shallow water in some areas.

Pacific cod stomachs were not examined for prey items in this study. Other studies reported cod ate fish and epibenthic crustaceans and other invertebrates.

Kasahara (1961) reported on studies in the North Pacific Ocean. In Kamchatka and the Bering Sea, small Pacific cod ate small crustaceans, including amphipods, and other invertebrates. Adult cod ate herring, sand lance, pollock, tanner crab, king crab, flounder, salmon, greenling, capelin, cottids, young cod and mollusks (squid and octopus).

Simenstad and Nakatani (1977) found juvenile Pacific cod consumed gammarid amphipods, isopods, sand lance and other fish, polychaetes and sea cucumbers in their Attu study, and adult cod ate decapods, gammarids, polychaetes and fish in their Amchitka study. Feder et al. (1977a) reported cod consumed mollusks, *C. bairdi*, shrimp, amphipods, euphausiids, isopods, eelpouts, flatfish, sand lance, herring, cod and cottids in the Gulf and Bering Sea. Simenstad (1977) reported cod ate euphausiids, shrimp (*Pandalus* and *Crangon* spp.), Irish Lord, flounders, osmerids, and stichaeids in Cook Inlet and Kodiak.

Other Kodiak studies reported cod ate *C. bairdi*, hermit crabs, mysids, euphausiids, pollock, sand lance and flatfish (Feder and Jewett, 1977), *P. borealis* and other shrimp, *C. bairdi* and other crabs, herring, walleye pollock, eelpouts, cottids, searchers, sand lance, arrowtooth flounder and flathead sole (Hunter, 1979), and *P. borealis* and other shrimp, gammarids, sand lance, herring, cottids, osmerids, flounder and salmon (Rogers et al., 1979).

Pacific cod were eaten by other cod (Kasahara, 1961), and birds, including glaucous-winged gulls, horned puffins and tufted puffins (Hatch et al., 1978).

Walleye Pollock

Walleye pollock ranked 15th in abundance and were captured in 44% of the try net hauls. They occurred only occasionaly in other gears. All pollock captured were juveniles apparently of age 0 or 1 (Figure 50). Age 0 pollock grew from about 4 cm in July to 12 cm in October (based on six fish) and age 1 pollock grew from about 12 cm in early June to 18 or 19 cm by late August.

Ten walleye pollock in late May were examined for food habits (Figure 49). They had eaten 66% tanner crab megalops (*Chionocetes bairdi*) by weight, 13% gammarid amphipods, 6% shrimp, 3% mysids, and less than 1% plankters and

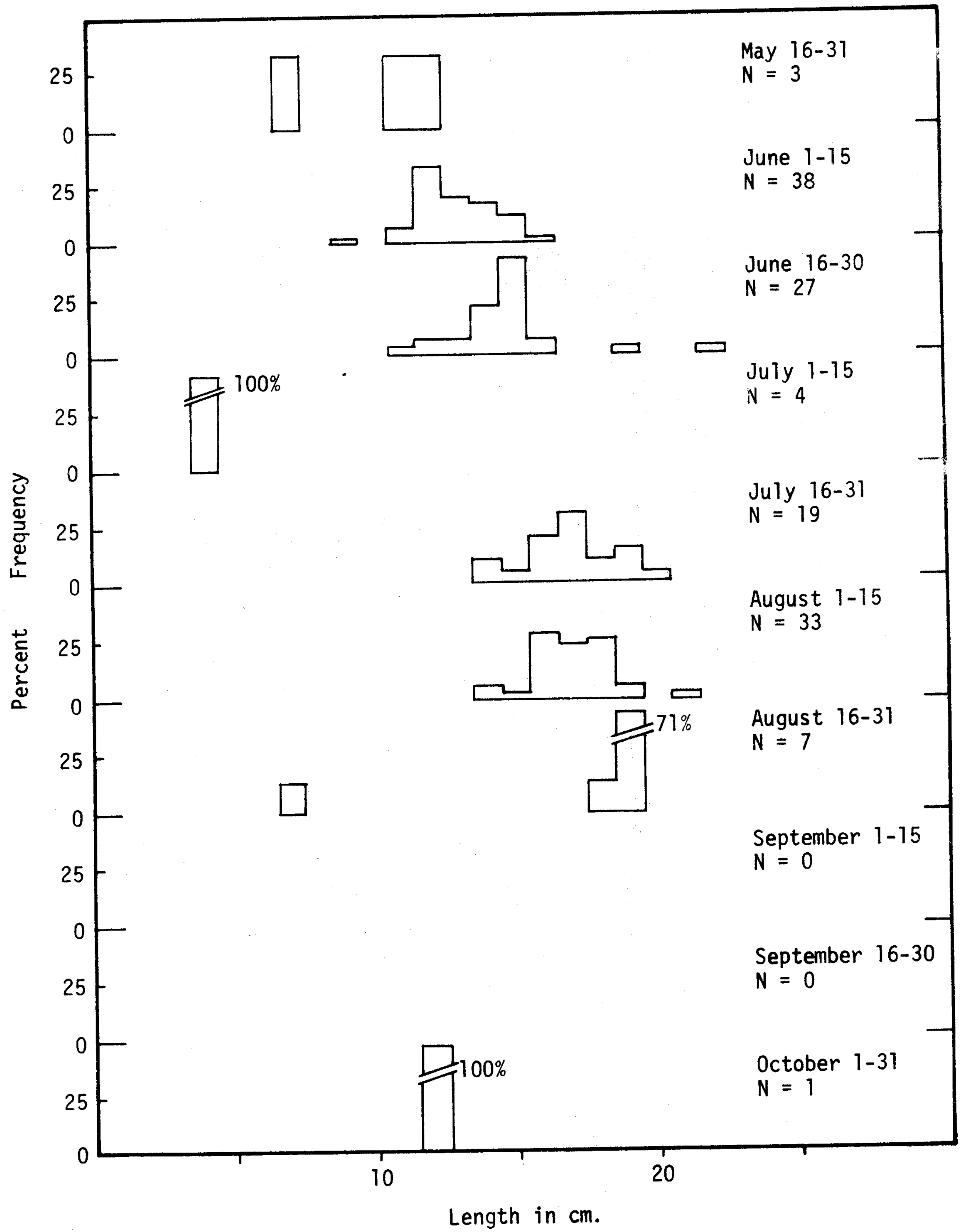


Figure 50. Relative length frequency of walleye pollock by time of capture. The catch by all gears and areas is combined; April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay.

fish larvae. Epibenthic crustaceans, fish and plankters were also prey found in other studies. Kasahara (1961) summarized previous studies in the North Pacific, reporting pollock fed on euphausiids, amphipods, large copepods, shrimp, small fish and squid. In Gulf of Alaska and Bering Sea studies Smith et al.(1977) reported pollock fed on euphausiids, fish, shrimp, cephalopods, amphipods and C. bairdi, and Feder et al. (1977a) reported pollock ate smaller pollock, plankton, shrimp and small fish.

Cooney et al. (1978) reported small Bering Sea pollock larvae ate copepod nauplii and eggs, larger pollock larvae ate small copepods, and post larval pollock ate large copepods, amphipods and euphausiids. Simenstad (1977) reported pollock in Cook Inlet and Kodiak ate mysids, shrimp, euphausiids and cottids. Rogers et al. (1979) reported juvenile pollock in Kodiak ate chaetognaths, calanoid copepods, euphausiids, and shrimp, and adult pollock ate euphausiids, shrimp, sand lance and other fish.

Larval walleye pollock were eaten by Dolly Varden in this study. Pollock were also eaten by Pacific cod and halibut (Hunter, 1979; IPHC, 1978), larger pollock (Feder et al., 1977a), kittiwakes, murres and tufted puffins (Hatch, 1978), and harbor seals (MacDonald and Petersen, 1976).

Pacific Ocean Perch

Pacific ocean perch were not examined for food habits in this study. Zooplankton, fish and epibenthic crustaceans were eaten by perch in other studies.

Carlson and Haight (1976) reported SE Alaskan perch juveniles consumed copepods and euphausiids and, to a lesser extent, amphipods, chaetognaths, larval and adult shrimp, pteropods and fish. Smith et al. (1977) reported perch juveniles consumed planktonic crustacea, euphausiids and pandalid shrimp, and adults consumed euphausiids, pandalids, squid and fish in the Gulf of Alaska. In the same study, Smith reported Bering Sea perch consumed euphausiids, mysids and squid.

MacDonald and Petersen (1976) reported predation on rock fish by Steller sea lions and harbor seals.

Whitespotted Greenling

Whitespotted greenling ranked second in trammel net catches, third in tow net catches, seventh in beach seine catches, tenth in gill net and 11th in the try net. Its appearance in all the gears is due to the presence of both pelagic juveniles and demersal adults. The trammel net captured adults and its catches displayed no significant seasonal feature. The try net captured primarily adults, including a considerable portion of age 1 (about 13 to 18 cm) whitespotted greenling, which apparently were more abundant late in the summer. The tow net captured pelagic juveniles (age 0) which were most abundant during June through early August with a peak abundance in late June (Table 38). The beach seine captured primarily juvenile and a few adult whitespotted greenling. The seasonality of juvenile whitespotted greenling in the beach seine was the same as in the tow net. Distribution of juvenile and adult whitespotted greenling show little but a decreased abundance in Oil Bay (Tables 39 and 40).

Juvenile, age 0 whitespotted greenling grew from about 4 to 5 cm in late May to about 7 to 8 cm in early August and about 9 or 10 cm in September. In Kachemak they apparently were a bit larger in October, about 10 to 15 cm. Age 1 whitespots were about 13 cm in late May or early June and grew to about 18 cm by late August (Figure 51). Larger sizes could not be assigned ages based on length frequency. Based on examination of a few fish, it appears all age 1 whitespotted greenling were sexually mature, however this determination may be in error. Examination of gonads of maturing greenling in Kodiak revealed two size modes of ova. Just before spawning the larger ova segregated to the posterior portion of the ovary. This strongly suggests that these fish spawn more than once per year and thus over an extended time period. However, the second batch of eggs was not followed through a second spawning thus they may be for the following year.

A total of 12 whitespotted greenling with flowing sex products were observed. All of these were over 20 cm in length and two were seen on July 15, nine on August 7 and one on September 6.

The masked greenling was the only other species of the genus *Hexagrammos* captured in Kamishak Bay. This contrasts drastically with Kodiak where five species were taken. In addition, the abundance of greenlings was much greater in Kodiak. Simenstad et al. (1978) established the importance of kelp beds to the abundance of this group and the general absence of kelp in Kamishak Bay probably plays a part in greenling abundance.

Stomachs of 31 juvenile and two adult whitespotted greenling were examined for contents (Figure 52). The juveniles, from April, late May and June catches, had preyed on 12 food items. Copepods made up 100% (mostly non-calanoid) of the diet in April, 93% (mostly calanoid) in late May, and 80% (non-calanoid) in early June. Gammarid amphipods were 7% of the late May diet and 71% of the late June diet. Barnacle cyprids, cumaceans, decapod larvae, polychaete larvae and fish eggs and larvae were also consumed in June.

The two adults in late May had preyed on gammarids and mysids. Their stomachs also contained 67% unidentified invertebrates.

Zooplankters, fish and epibenthic crustaceans were food for greenling in other studies also. Rogers et al. (1979) found Kodiak whitespotted greenling juveniles and adults consumed larval shrimp and crabs, polychaetes, gammarid and caprellid amphipods, harpacticoids, and larval fish including sand lance, cottids, hexagrammids, flounder, rock fish and stichaeids. Rosenthal (1978) found whitespotted greenling (10.5-31.0 cm) in the Gulf of Alaska consumed amphipods, gastropods, shrimp, brachyuran crabs, isopods, mussels and fish eggs.

Whitespotted greenling were preyed on by horned puffins (Hatch et al., 1978) and Steller's sea lions (MacDonald and Peterson, 1976).

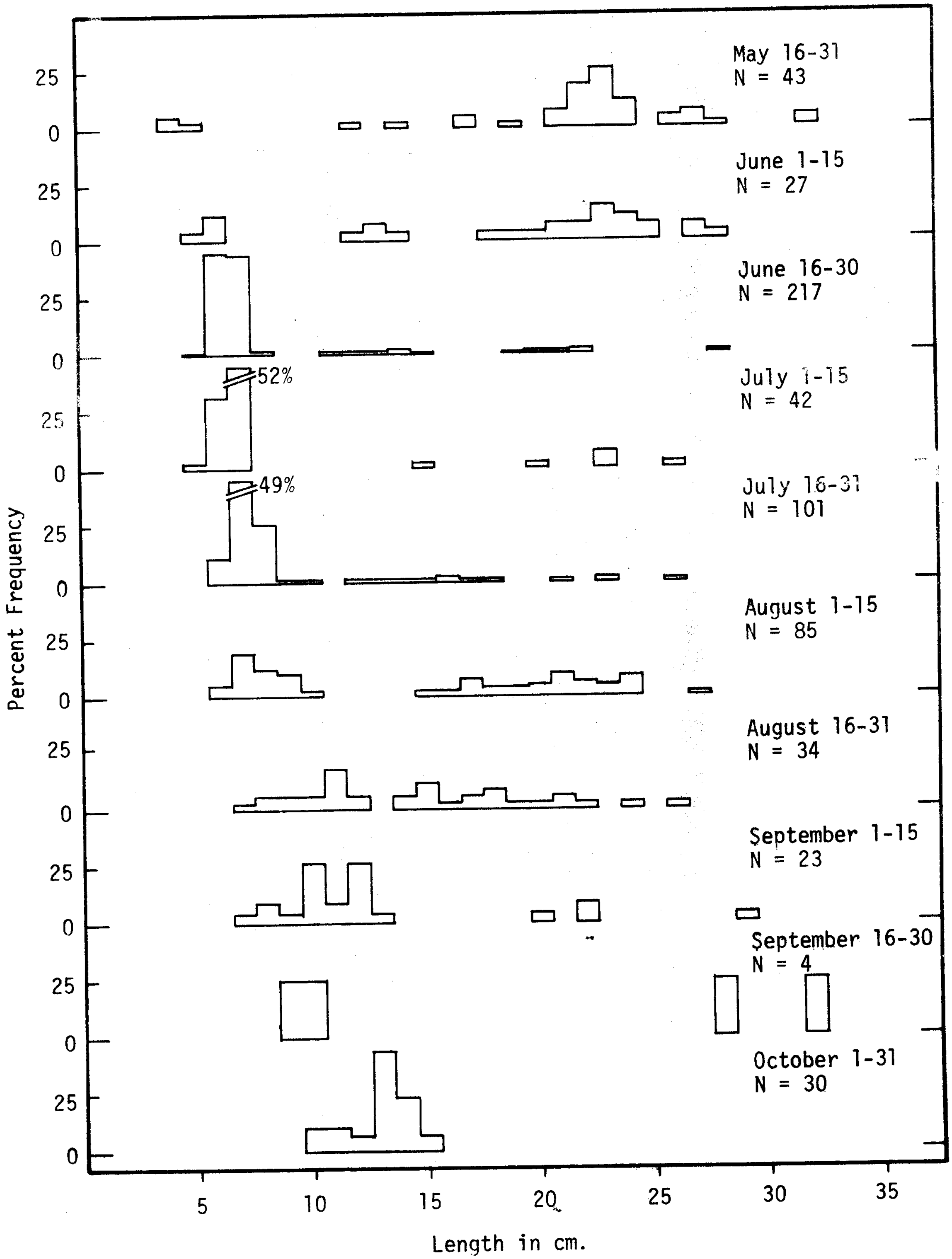


Figure 51. Relative length frequency of whitespotted greenling by time of capture. The catch by all gears and areas is combined; April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay.

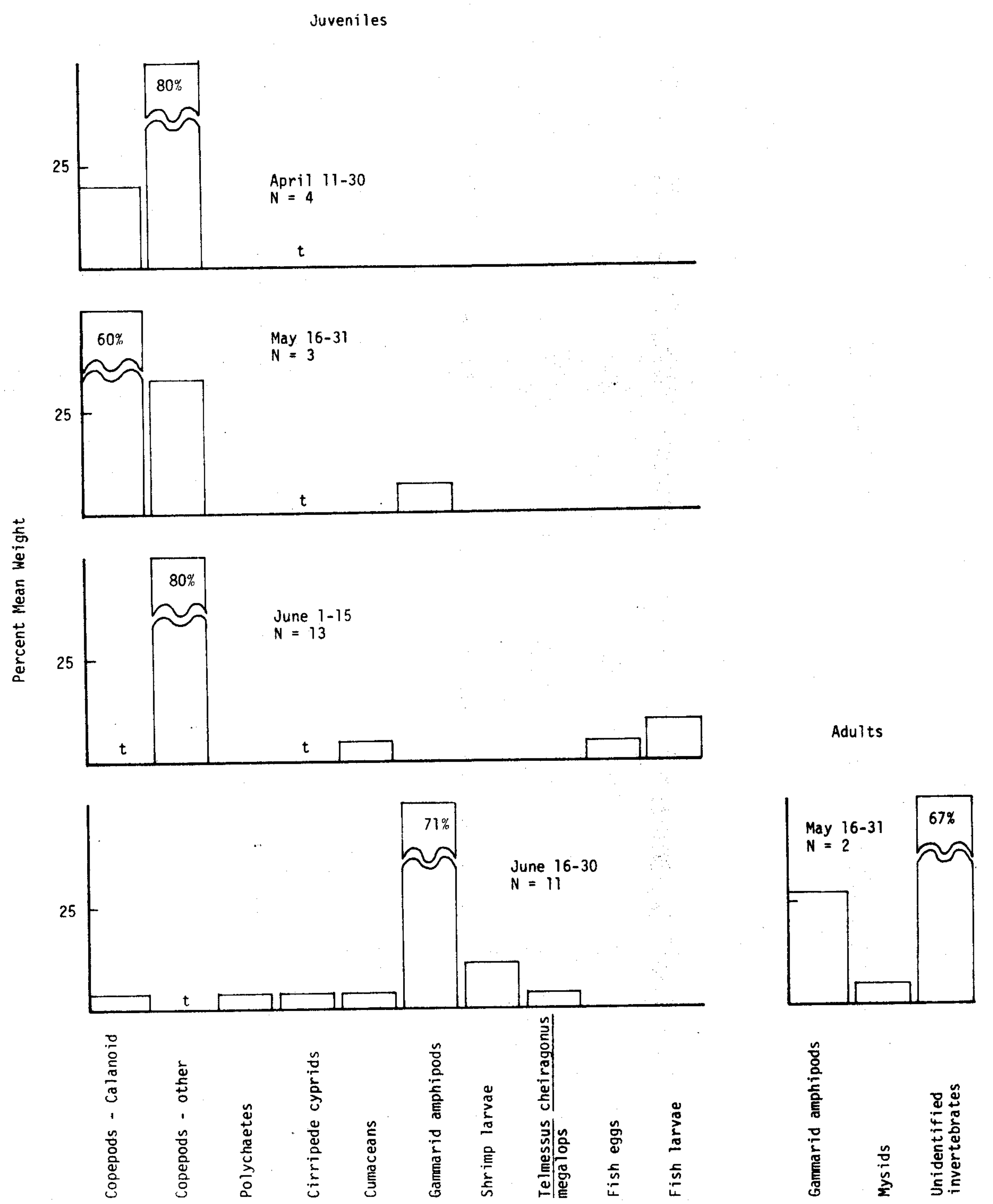


Figure 52. Juvenile and adult whitespotted greenling diet composition by major food item and time. April 1978 catches were in Kachemak Bay and others were in Kamishak Bay. N = number of stomachs examined; t = trace.

Pacific Staghorn Sculpin

Staghorn sculpin ranked sixth in the trammel net catches, and eighth in the beach seine and gill net catches. Seasonal features are not clear, but they were more abundant in September than earlier. They were most abundant in beach seine catches at the same locations starry flounder were most abundant, those near stream or river mouths and the CPUE by area was very similar to that of the starry flounder (Table 41). This species is a common and in some areas abundant member of the nearshore community (Phinney, 1972).

Juvenile staghorn sculpin appeared at 1 and 2 cm in late June, 2 to 4 cm in late July and 4 to 10 cm with a mode at 8 to 10 cm in early September. A second age class appeared to grow from about 10 cm in early summer to about 18 cm in late summer.

Stomachs of eight staghorn sculpins from May catches were examined for prey items (Figure 53). Only one of the three in early May contained food, and this was all unidentified. Stomachs in late May contained 62% sand lance larvae by weight, 14% herring larvae, 8% chum salmon fry, 7% isopods, 4% mysids, and 3% polychaetes.

Myoxocephalus spp.

Myoxocephalus sculpins ranked ninth in both the beach seine and try net catches. The beach seine catches were almost exclusively great sculpin and try net catches were almost exclusively plain sculpin. The beach seine catches showed a lower abundance from late June through August with greater abundance both earlier and later (Table 16). The distribution features showed primarily a complete absence in Oil Bay (Table 42). In 1976, this taxon was not found in the inlet north of Anchor Point (Blackburn, 1978), a feature consistent with their absence in Oil Bay.

Age 0 *Myoxocephalus* appeared in late May and early June at 1 to 2 cm and grew to 4 to 7 cm in late September. Age 1 *Myoxocephalus* were present in April and May at 5 to 12 cm but this age class was too infrequent later to follow its growth.

It is felt that great sculpin juveniles are common nearshore inhabitants during winter since age 1 great sculpin were common in April, before other fish occurred, age 0 were common in the fall and during summer this taxon was less abundant.

Forty-one great sculpins (50-100 mm) from April to mid-June catches were examined for stomach contents; eight food items were found (Figure 53). Gammarid amphipods were 75% to 98% of the diets in each time period. Pink salmon fry were 17% and mysids were 5% of the diet in April.

Epibenthic crustaceans and fish were also prey for juvenile and adult great sculpins in other studies. Simenstad and Nakatani (1977) reported fish, crabs, gammarid amphipods and isopods as prey for adult Attu great sculpins. Feder et al. (1977a) reported crabs (*Chionoecetes bairdi* and *Hyas*), and *Crangon dalli* as prey for lower Cook Inlet great sculpins. Simenstad (1977) reported fish, shrimp, and euphausiids as prey for great sculpins in lower Cook Inlet and Kodiak.

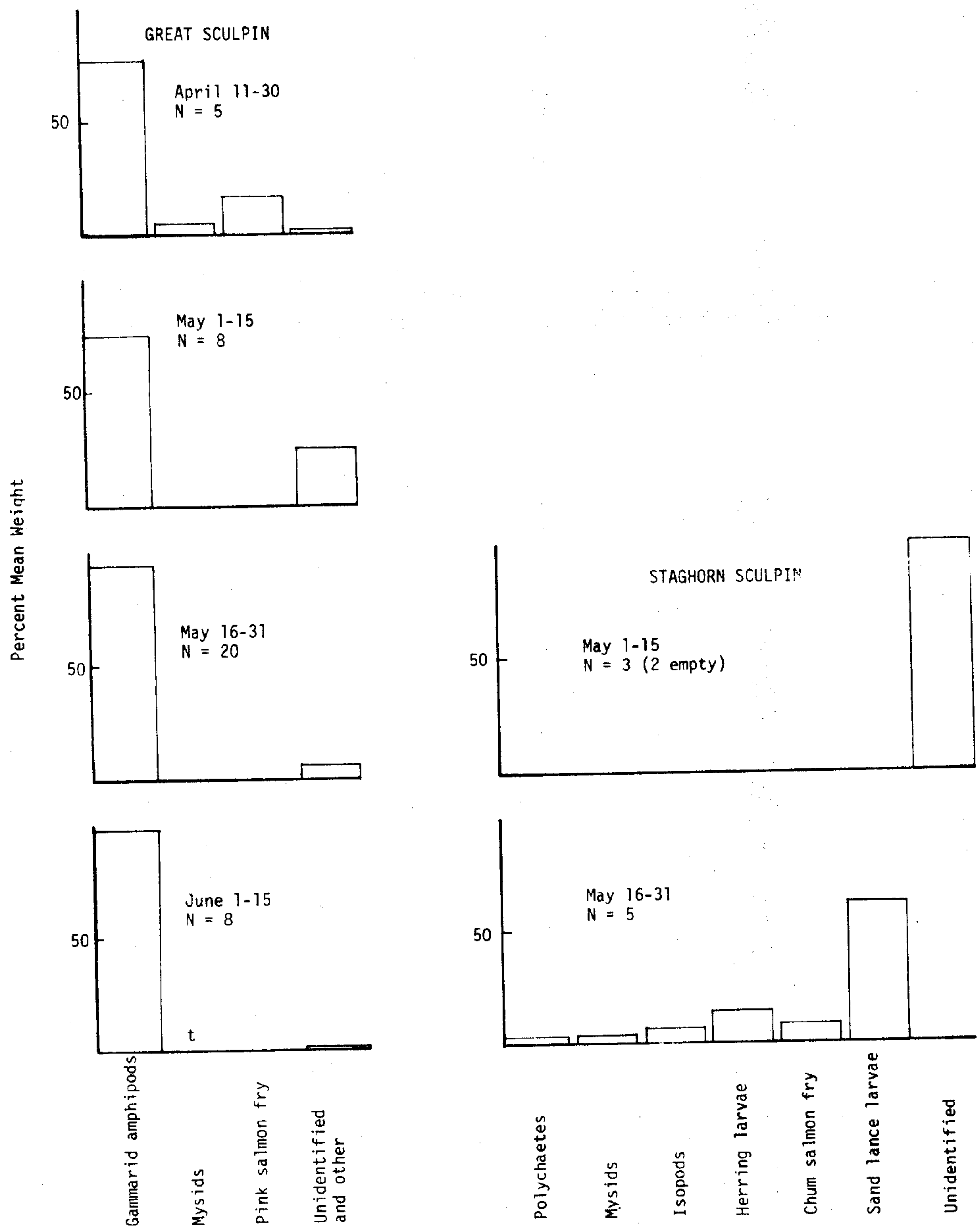


Figure 53. Great sculpin and staghorn sculpin diet compositions by major food item and time. April 1978 catches were in Kachemak Bay and others were in Kamishak Bay. N = number of stomachs examined; t = trace.

Table 42. Myoxocephalus sp. catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978. This taxon is almost exclusively great sculpin juveniles.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			0	0	0	0	0	0	0	0	0		0
Iniskin Bay			3.8	2.0	0	0	1.0	0.3	0	0.9	0.4		1.0
Cottonwood Bay		1.2	0.4	1.0	0	0	0.5	0	1.0	0.2	1.0		0.5
Iliamna Bay		2.0	0.9	0.3	0.2	0.2	0.3	0.1	0.3	0.2	1.0		0.4
Ursus Cove			1.2	1.7	0	1.0	0	0.2	0.3	1.5	1.6		0.9
Rocky Cove					0	0.5	0	0	0	0.5	0.2		0.2
Bruin Bay to Rocky Cove								0	0		0.5		0.2
Kachemak Bay	0.7											2.6	2.2

Table 43. Pacific sandlance catch in numbers per km towed by the tow net by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978. This table includes larvae.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay						111.1							111.1
Oil Bay to Iliamna Bay			39.2	68.3	6.8	3.6		0	0				16.0
Ursus Cove				0.3			0		0				T
Rocky Cove							0						0
Contact Point							0						0
Kachemak Bay												0	0

T < 0.05

Table 44. Pacific sandlance catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October 1978. This table includes larvae.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			1.0	0	0	0	0	0	1.2	58.0	0		7.6
Iniskin Bay		0	0	0	0	0	0	0	6.0	0.1	1.8		0.6
Cottonwood Bay		0.8	0	0	0.3	0.6	0.2	0.7	1.5	0.2	0		0.4
Iliamna Bay		0	70.4	50.0	0.8	22.4	11.8	7.9	4.2	0.5	3.0		17.1
Ursus Cove			0	0	10.0	17.0	0	0.5	0.3	256.1	0.2		60.1
Rocky Cove					0	0	0	0	0	0	0		0
Bruin Bay to Rocky Cove								0.5	0		58.0		29.1
Kachemak Bay	0.7											14.0	11.4

Table 45. Rocksole catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October,1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			0.3	0	0.5	6.0	0.3	0	0.6	0	0		0.5
Iniskin Bay			0.8	2.0	1.5	0	2.0	0.3	0	0.6	0		0.6
Cottonwood Bay		0.4	1.1	0.5	2.0	0.6	1.2	0	0	0	0		0.7
Iliamna Bay		0	0.1	2.3	1.0	0.2	0.3	0.1	0	0	0		0.4
Ursus Cove			0.4	0.7	1.1	0	2.5	0.8	0	0.4	0.2		0.7
Rocky Cove					1.0	1.0	1.0	0	0.5	0.5	0		0.5
Bruin Bay to Rocky Cove								0	0		0		0
Kachemak Bay	0											0.3	0.2

Table 46. Starry flounder catch in numbers per beach seine haul by geographic location and time. Sampling conducted in Cook Inlet from April through October, 1978.

Location	APRIL	MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	Mean
	11-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-31	
Oil Bay			1.3	1.3	3.5	5.0	1.7	1.0	0	2.0	2.0		1.5
Iniskin Bay			0.2	1.0	0	0.5	2.0	0.3	0	0.6	0		0.5
Cotton Wood Bay		0.2	0.2	0	0	0	2.5	0	0	0	0		0.3
Iliamna Bay		0	0	0	1.7	0	0	0.1	0	0	0		0.4
Ursus Cove			1.2	0.3	2.0	0.8	1.2	0	0	1.4	2.8		1.3
Rocky Cove					0.5	0	0	0	1.0	0	2.2		0.9
Bruin Bay to Rocky Cove								0	0		0		0
Kachemak Bay	0											0	0

T < 0.05

Adult great sculpins in Kodiak ate C. bairdi (some over 40 mm) and other crabs, yellow Irish Lords, Pacific sand fish, butter sole, rock sole, shrimp and medium-sized gastropods (Hunter, 1979). Juvenile sculpins in Kodiak ate gammarids, fish and brachyuran crabs, and adults ate sand lance, herring, cottids, cod, osmerids, flounders, salmon, crab and shrimp (Rogers et al., 1979).

Rosenthal (1978) reported large great sculpins ate brachyuran crabs and herring eggs and adults in the northeast Gulf of Alaska.

Great sculpins were preyed upon by Pacific cod in Hunter's 1979 study.

Sand Lance

Sand lance were captured in greatest numbers in early summer, before about mid-June, and in late summer after September 1 (Tables 16 and 18). The catch distribution strongly suggests that sand lance were most common between the mouth of Iliamna Bay and Oil Bay. Virtually all the sand lance captured in the tow net were in Oil Bay and between Oil Bay and Iliamna Bay (Table 43). The beach seine yielded them in more areas, with single large catches in Ursus Cove and between Bruin Bay and Rocky Cove. The most consistent beach seine catches of sand lance were in Iliamna Bay, at one station at the mouth of the bay. Within Iniskin, Cottonwood and Iliamna bays, sand lance were infrequent (Table 44).

Previous studies have shown that nearshore sand lance are more abundant in early summer than in mid-summer and are much more abundant after about September 1 (Blackburn, 1978). The studies this year also show this feature and suggest that they are primarily taking refuge in sand in nearshore areas in the spring, moving offshore somewhat during summer and moving inshore in very large numbers in September.

The extent of their distribution is not clear but they are reported to be more abundant in shallow water fairly close to land (from an oceanic point of view)(Macy et al., 1978). They were reported to range from 0 to 100 m, and be most common above the 50 m depth in the summer in the Bering Sea (Figure 54; Macy et al., 1978). A plankton survey on the east side of Kodiak (Dunn et al.,1979) found larvae at nearly all stations within about 30 miles of land, except in Kennedy Entrance. They reportedly have a preference for coarse sand bottoms, with which they have been associated; which may be expected since they bury in sand for refuge and apparently bury their eggs in sand (Macy et al., 1978).

The spawning of sand lance is thought to occur in winter. Based on the growth rate of larvae and juveniles the hatching of sand lance in Cook Inlet appears to occur over an extended period, lasting at least as late as March and perhaps April (Figure 55). They grew to about 60 mm by late August and 70 mm in late September. As was reported previously (Blackburn, 1978) different groups showed considerably different sizes beginning in September and sizes in late September and October ranged from 40 to 100 mm. The one-year old sand lance apparently were about 90 to 100 mm in late May through June and about 100 to 130 mm in July, but assignment of age cannot be reliably based on size after about one year of age (Figure 55).

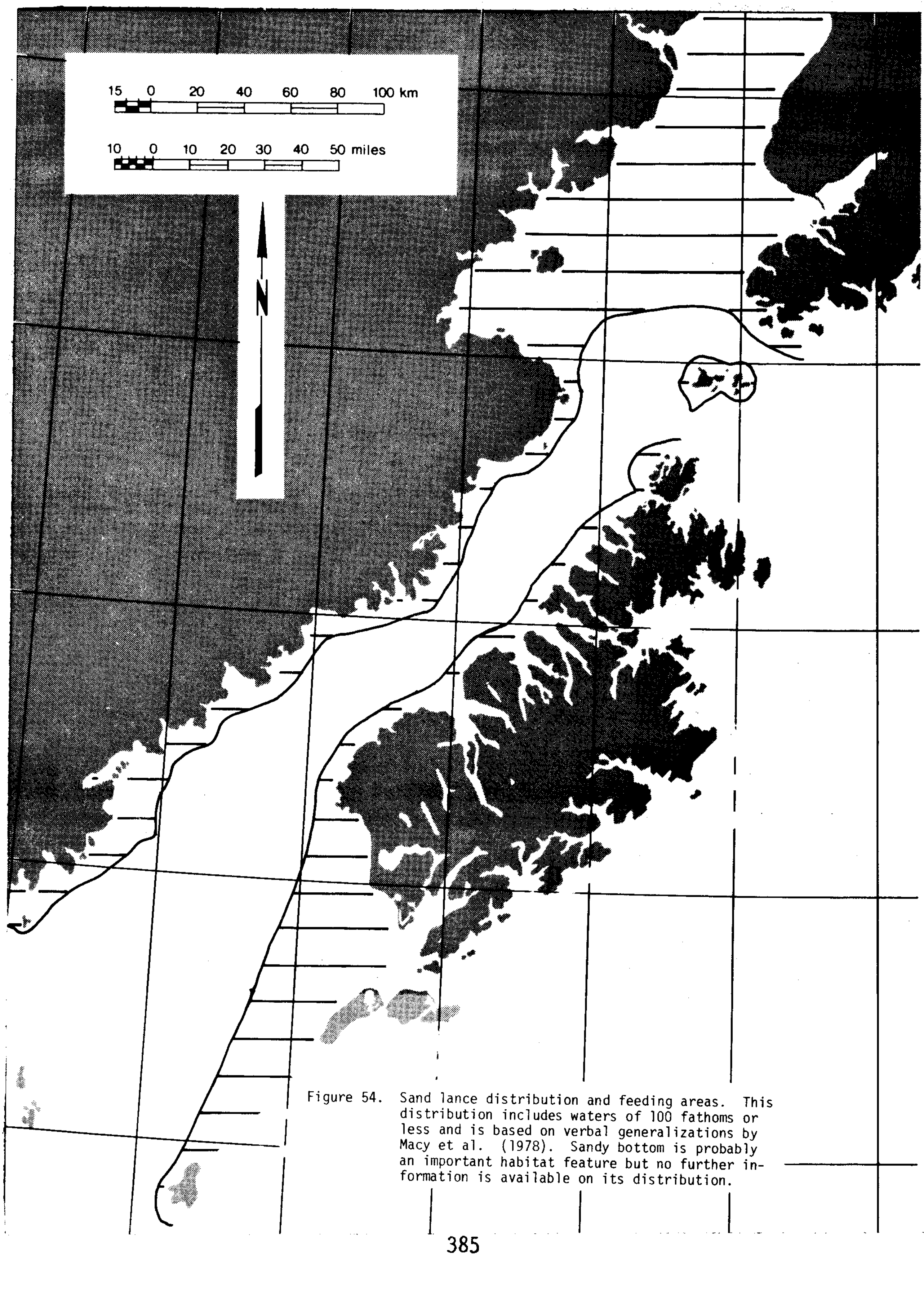


Figure 54. Sand lance distribution and feeding areas. This distribution includes waters of 100 fathoms or less and is based on verbal generalizations by Macy et al. (1978). Sandy bottom is probably an important habitat feature but no further information is available on its distribution.

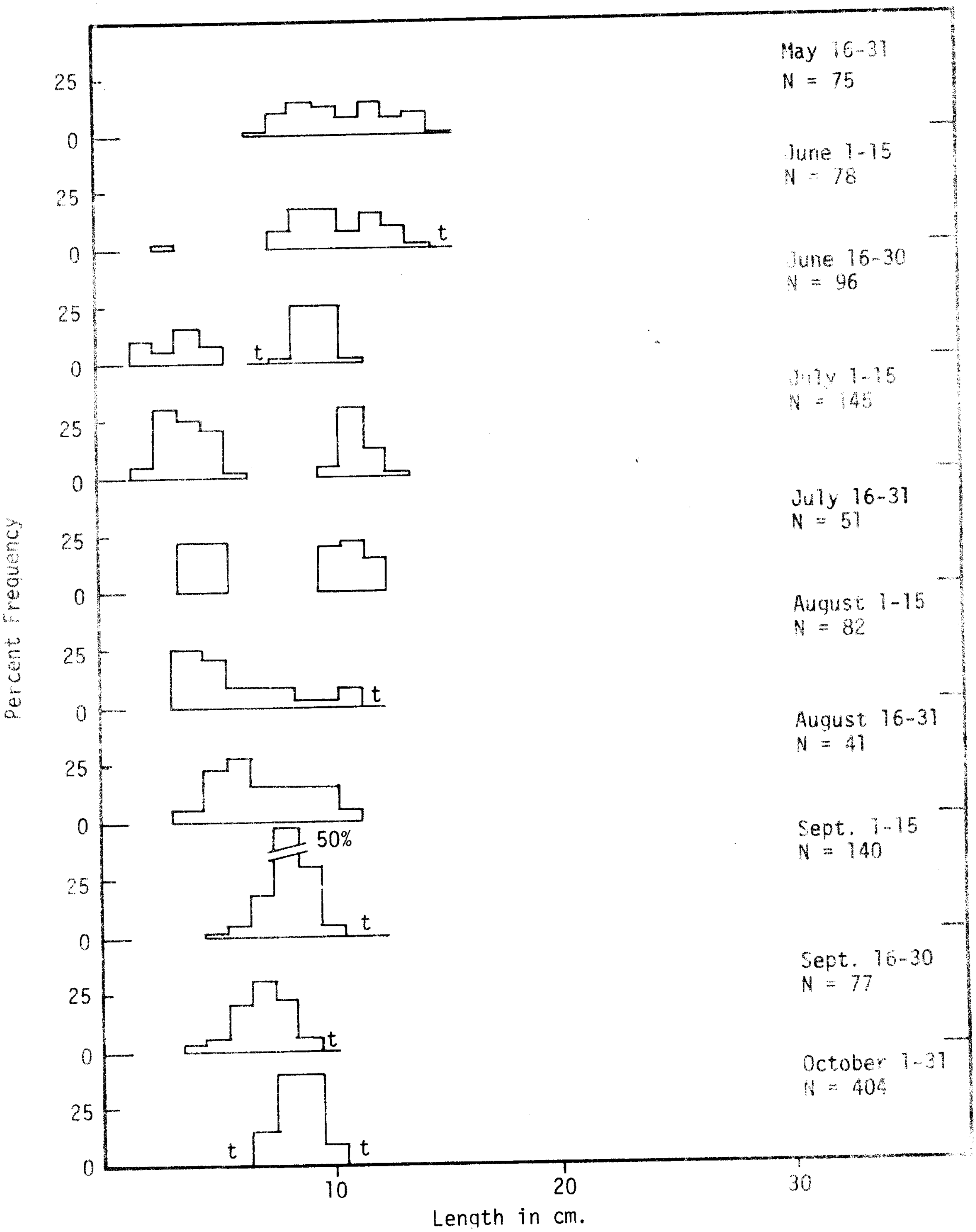


Figure 55. Relative length frequency of Pacific sandlance by time of capture. The catch by all gears and areas is combined; April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay.

Sand lance from each time period were sampled for food habits. The 191 pecimens had consumed 20 prey items (Figure 56).

Copepods comprised 41 to 98% by weight of the diets; non-calanoids were eaten in April, and mostly calanoids from May through October. Barnacle (cirripede) nauplii comprised 17% of the diet in late May, 17% and 6% in June, and 24% in late August. Barnacle cyprids comprised 6% of the diet in late May, 4% and 3% in June and 3% in early July. Larvaceans comprised 41%, 4% and 5% of the diets in September and October.

Shrimp larvae were 15% of the diet in April, 27% in early May, 31% in early June, 10% in early August, and 5% in October. Fish larvae comprised 28% of the April diet and chaetognaths comprised 19% of the October diet. Diatoms, gammarid amphipods, crab larvae, gastropod veligers, polychaete larvae and fish eggs were 6% or less of diets when present.

Sand lance from an ADF&G Cook Inlet study in 1976 were examined for food habits. The 100 fish had fed on copepods, barnacle larvae, larvaceans, and cladocerans, and to a lesser extent on amphipods, gastropod veligers, mysids, crab larvae and chaetognaths.

Plankton, fish larvae and epibenthic crustaceans were also food for sand lance in other studies. Trumble (1973) reported small sand lance larvae in the eastern North Pacific consumed diatoms and dinoflagellates, and larger sand lance consumed copepods, nauplii, chaetognaths, fish larvae, amphipods and annelids. Simenstad and Nakatani (1977) reported sand lance in Attu waters consumed copepods, chaetognaths, gammarid amphipods, and polychaetes. Rogers et al. (1979) reported Kodiak sand lance consumed calanoid copepods, gammarids, barnacle larvae and, to a lesser extent, shrimp, harpacticoids, cladocerans (Podon), and eggs.

Sand lance were food for Pacific cod, rock sole, sand sole and halibut (Hunter, 1979), pollock, whitespotted greenling, great sculpins and yellowfin sole (Rogers et al., 1979), king salmon, sockeye and coho smolt (McLean et al., 1976), herring (Trumble, 1973), and Dolly Varden, sockeye and coho juveniles, and staghorn sculpins (this study).

Rock Sole

Rock sole ranked sixth in abundance in the try net, eighth in the trammel net and twelfth in the beach seine. Seasonal features are only apparent in the beach seine catches which indicated greatest abundance from late May through July. Nearshore sampling in Kodiak during this same time indicated the same pattern, a peak abundnace in early summer and a gradual decline later. They have been observed by divers in Kodiak to enter the nearshore zone in about March or April in abundance and their age zero young, less than an inch in length are abundant in early June and later.

Distributional features of abundance are not apparent in the beach seine catches (Table 45). Growth of rock sole from the length frequency data requires a bit of imagination but is apparent. Modes at 5 and 10 cm in October mark the size of age 0 and 1 rock sole and weak modes for age one

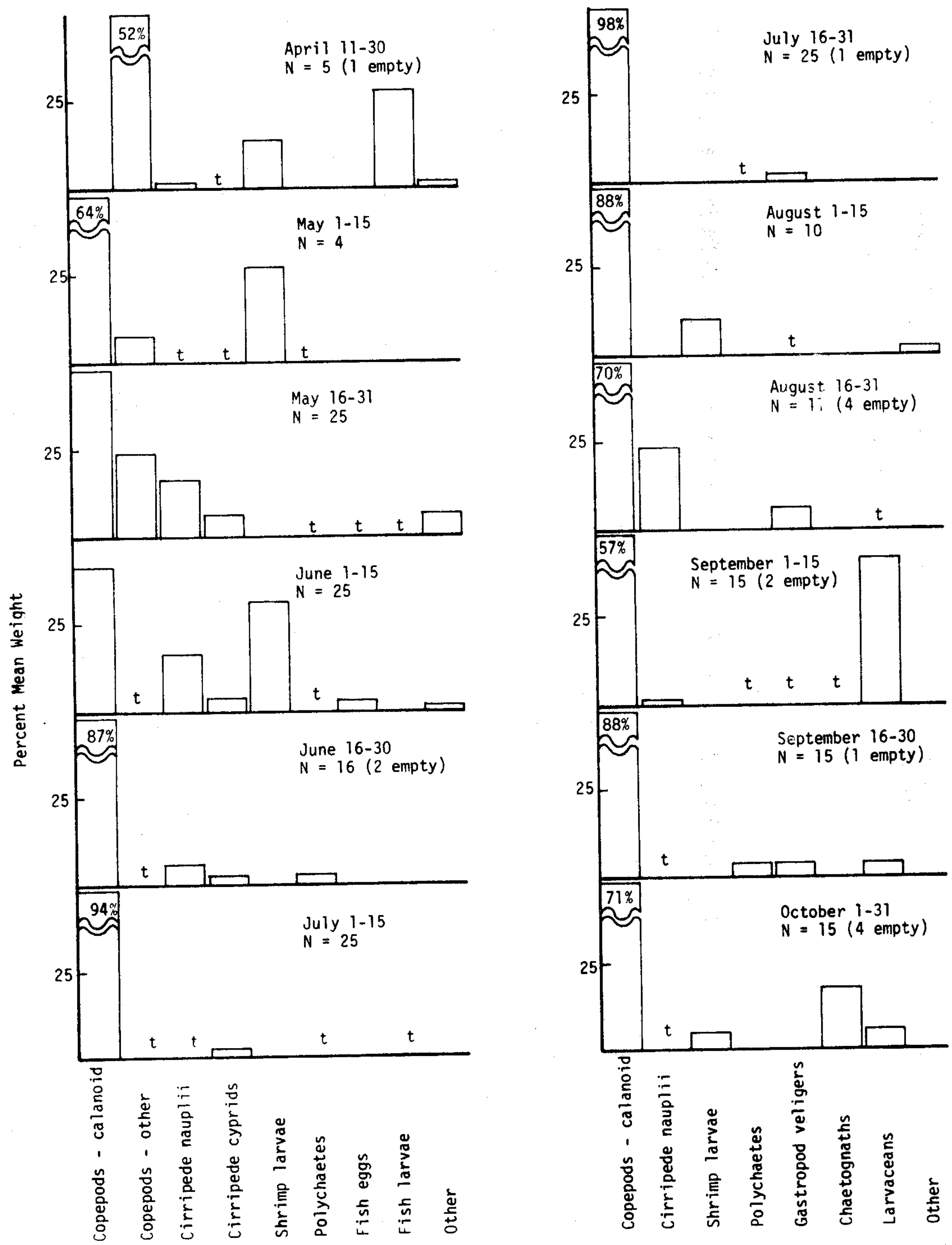


Figure 56. Sand lance diet composition by major food item and time. April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay. N = number of stomachs examined; t = trace.

appear to grow from about 5 to 6 cm in early June through 8 to 9 cm in late August. Modes representing age 2 rock sole appear in May and June at about 10 cm and increase in size to perhaps 14 or 15 cm by the end of the summer but this year class is much less common at this time (Figure 57). The suggested growth rate is about 5 cm per year. Other age classes cannot be identified.

Ten rock sole caught in May had eaten 12 prey items (Figure 58). One juvenile (56 mm) in early May had consumed 25% calanoid copepods by weight and 75% non-calanoid copepods. Algae formed 49% of the nine adult diets in late May, and gammarid amphipods, limpets, chitons, bivalves, and polychaetes were also present.

Rock sole in other studies preyed on benthic and epibenthic invertebrates as in this study, and also on fish. Bering Sea rock sole fed on polychaetes, mollusks, shrimp, sand lance and echinoderms (Shubnikov and Lisovenko, 1964), polychaetes and mollusks (Skalkin, 1963) and polychaetes, pelecypods and amphipods (Smith et al., 1977).

Rosenthal (1978) reported rock sole ate sand lance, amphipods, opisthobranch snails, bivalves, polychaetes and herring eggs in the NE Gulf of Alaska. Simenstad (1977) reported lower Cook Inlet rock sole ate polychaetes and gastropods, and to a lesser extent bivalves, mysids and shrimp.

Kodiak rock sole fed on polychaetes and clams (Feder and Jewett, 1977); and polychaetes, sand lance and other fish, amphipods, clam siphons, and whole clams (Hunter, 1979). Polychaetes, clam siphons, and gammarids were eaten by juveniles and adults and sand lance, herrring cottids, hexagrammids, osmerids, stichaeids, and flounder by adults in Kodiak (Rogers et al., 1979).

Rock sole are preyed on by great sculpins, sand sole and halibut (Hunter, 1979).

Yellowfin Sole

Yellowfin sole ranked first in abundance in the try net, fourth in the trammel net and were rare in the beach seine. This indicates that they are less frequent in the 10 to 30 ft. depths where trammel nets were set than a little deeper and further offshore and were rare in the intertidal zone. They were most abundant in late May and early June in the try net, which supports the migration pattern hypothesized from work in 1976 and 1977 (Blackburn, 1978). They were abundant in deeper water south east of Augustine Island in August through March and almost absent in June. They apparently move into the shallows of Kamishak between March and May, probably for spawning as this species is a summer spawner (June and July) in the Bering Sea (Pereyra et al., 1976) and one ripe male was captured in mid-June.

Growth of yellowfin sole is not clear from the length frequency data. One age class appears to have grown from about 5 to 6 cm in June to 9 cm in October (Figure 59). Growth cannot be identified from larger fish, however.

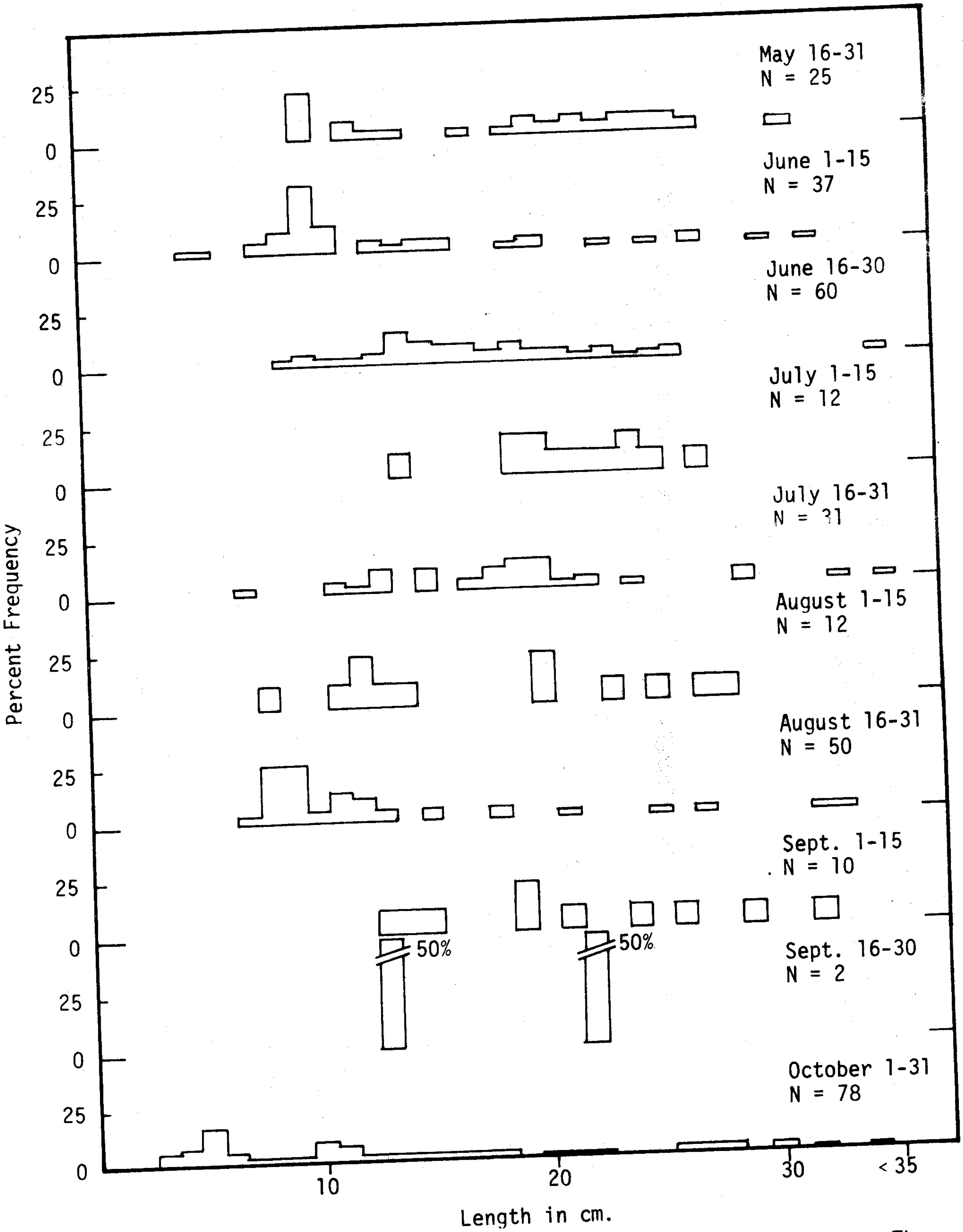


Figure 57. Relative length frequency of rock sole by time of capture. The catch by all gears and areas is combined; April 1978 and October 1978 catche were in Kachemak Bay and others were in Kamishak Bay.

Figure 58. Flounder diet composition by major food item, species and time. Catches were in Kamishak Bay. N = number of stomachs examined; t = trace.

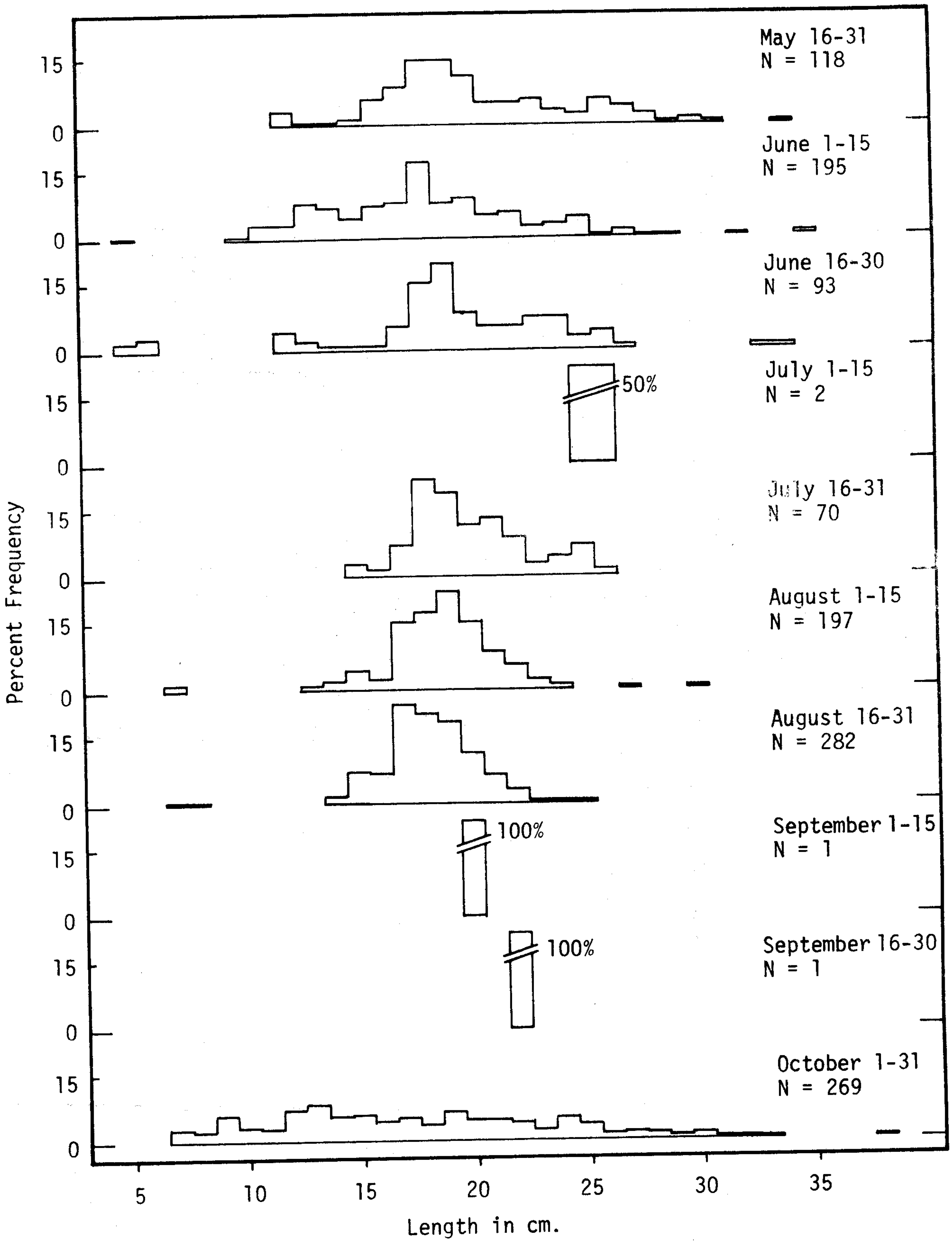


Figure 59. Relative length frequency of yellowfin sole by time of capture. The catch by all gears and areas is combined, April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay.

Nineteen yellowfin sole were examined for food habits (Figure 58). In ate May four stomachs were empty, but five contained 64% capelin juveniles by weight, 22% gammarid amphipods, 11% algae, and 1% or less bivalves and brachyuran crab larvae. Ten stomachs in early June contained 26% algae, 10% bivalves, 4% or less gastropods, barnacles, gammarids, and polychaetes and 48% unidentified invertebrates.

Similar food items, fish and benthic and epibenthic crustaceans and invertebrates, were reported for yellowfin sole in other studies. Skalkin (1963) reported Bering Sea yellowfin sole ate amphipods, mysids, euphausiids, bivalves, and polychaetes. Smith (1977) reported euphausiids were the major food of soles in the Gulf and Bering Sea. Feder et al. (1977a) reported Cook Inlet soles ate pelecypods. Simenstad (1977) reported soles ate fishes, polychaetes and shrimp in his Cook Inlet-Kodiak study. Feder et al. (1977b) reported Kodiak yellowfin soles ate fishes, clams and tanners (Chionocetes bairdi). Rogers et al. (1979) reported juvenile and adult Kodiak yellowfin soles ate clam siphons, unidentified eggs, polychaetes, shrimp, and fish larvae including cottids, osmerids, flounder, sand lance and stichaeids.

Starry Flounder

Starry flounder ranked tenth in the beach seine catches and occurred infrequently in all other gears. They were most abundant in beach seine catches during approximately late June through September in Kamishak, except during the month of August (Table 16). They were much more abundant at some sampling sites than at others. In general, the locations of highest abundance were in very close proximity to the stream or river mouths. When the beach seine data is grouped by area they appear more abundant in Oil Bay and Ursus Cove than elsewhere (Table 46) but specific sites in Rocky Cove, Iliamna Bay and Iniskin Bay yielded high catches of starry flounder.

Since this species is known to ascend rivers (Hart, 1973) it seem appropriate to speculate that the decrease in abundance in August is the reflection of their excursion into fresh water.

Length information has not been reproduced since it is about the most difficult to interpret of any of the fishes. A total of 158 measurements were spread among nine cruises and 39 length classes from 4 to 46 cm. Age 0 starry flounder did appear in late August and September at 4 to 5 cm but older age classes cannot be identified.

Eleven starry flounder in late May were examined for stomach contents (Figure 58). Gammarid amphipods were 86% of the diet by weight, isopods were 11% and bivalves, mysids, shrimp, algae and insect larvae were 2% or less.

Benthic and epibenthic crustaceans and other invertebrates were also prey items found in other studies. Larval starry flounder in California fed on plankton, larger flounder fed on clams and worms, and mature flounder fed on shellfish and echinoderms (Orcutt, 1950). Juvenile flounder in Tillamook Bay, Oregon fed on amphipods, juvenile clams, polychaetes and isopods (Forsberg et al., 1977).

Rosenthal (1978) reported starry flounder fed on herring eggs attached to seaweed, clam siphons, brittle stars, and crab in the NE Gulf of Alaska and Feder et al. (1977a) reported flounder fed on clams and sand shrimp (*Crangon dalli*) in Cook Inlet. Hunter (1979) reported starry flounder ate razor and surf clams (.5-4 cm) in Kodiak.

Larval starry flounder were preyed on by sockeye smolt (McLean et al., 1976). Flounder were eaten by harbor seals (MacDonald and Peterson, 1976).

Sand Sole

Sand sole were occasionally captured in the beach seine and trammel net exclusively in bays or near a river but never in the try net.

One sand sole in late May was examined for food habits; it had eaten 75% mysids by weight and 25% gammarid amphipods (Figure 58). Hunter (1977) found Kodiak sand sole ate mostly fish, including 0+ age rock sole and adult sand lance. Miller (1967) found Puget Sound sand sole ate fish and epibenthic crustaceans, including shrimp and mysids.

Pacific Halibut

Pacific halibut ranked fifth in abundance in the try net and composed 3.4% of the catch by weight (Table 12). There was no time of greatest abundance apparent (Table 17) nor any location of greater abundance.

All halibut were smaller than 35 cm but one, which was 49 cm (Figure 60). The length frequency does not clearly demonstrate age or growth but with information on size at age it is interpretable. On Portlock Bank, age 1 halibut have been about 7 cm, age 2 halibut about 17 cm and age 3 halibut about 30 cm (IPHC, 1978a). Although this information lacks a time scale which makes interpretation a little more difficult, it appears that age 1 halibut in Kamishak Bay were about 10 to 15 cm, age 2 halibut were about 15 to 25 cm and age halibut were infrequent but between about 25 and 34 cm. Most of the halibut captured were apparently age 2.

Halibut were not examined for food habits in this study. Other studies reported halibut ate epibenthic crustaceans and other invertebrates, and fish.

Cook Inlet halibut (Feder et al. 1977a) fed on fishes, including stichaeids and sandfish, and crabs, including *Chionoecetes bairdi*. Northeastern Gulf halibut (Rosenthal, 1978) fed on crabs, snails, octopus and algae.

Kodiak halibut prey items included whole king crab, Dungeness, and *C. bairdi* (Gray, 1964), euphausiids and caridean shrimps (Feder and Jewett, 1977) and shrimp, sand lance, and herring (Rogers et al., 1979). In Hunter's (1979) study, prey items for halibut under 300 mm were *Crangon* shrimp (the major prey), 0 + age rock sole, sand lance and larval cottids; for halibut 300-599 mm prey items were pollock, sand lance, herring, flatfish, sandfish, capelin, *C. bairdi*, other crabs and shrimp; and for halibut 599-790 mm prey items were pollock and *C. bairdi*.

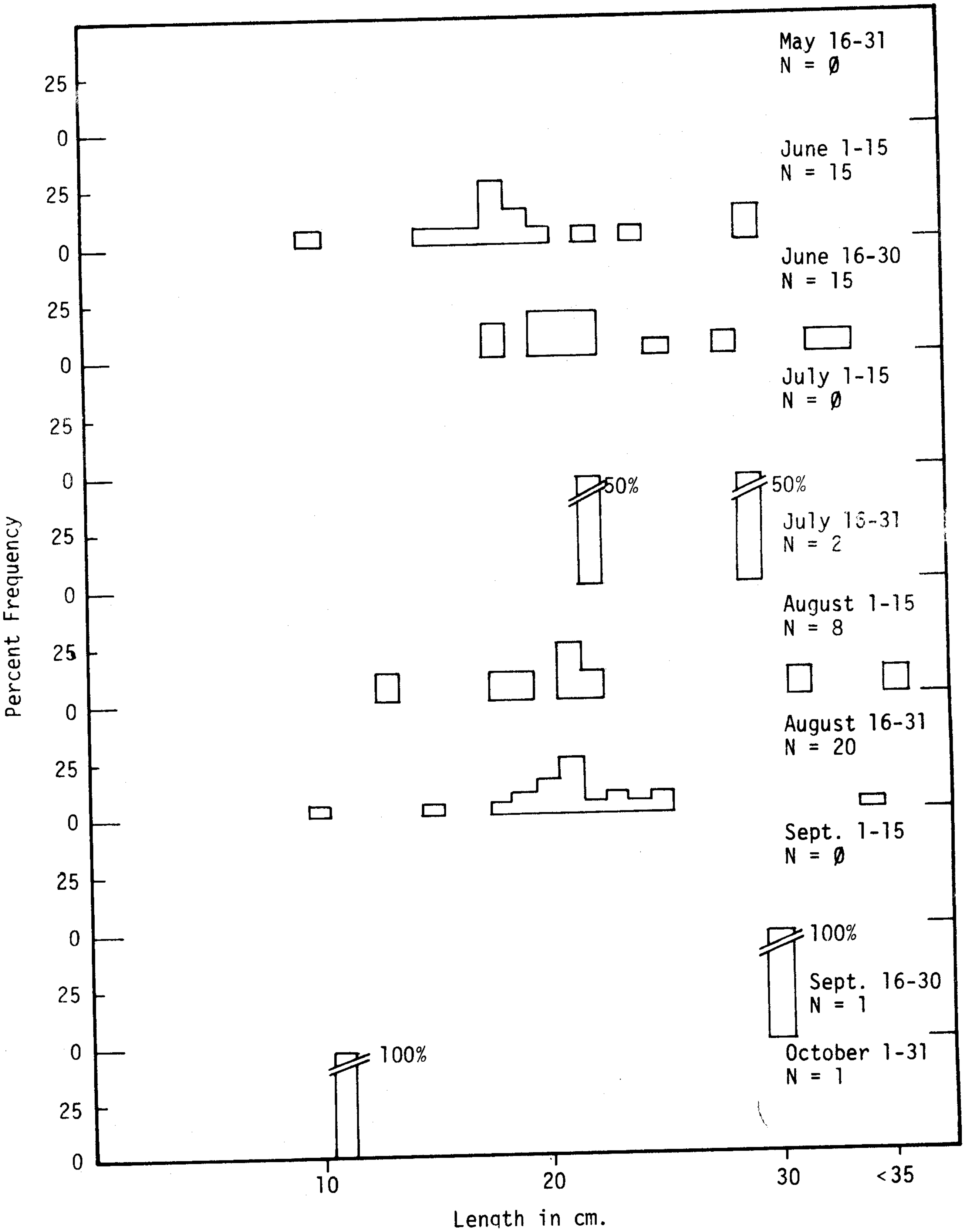


Figure 60. Relative length frequency of Pacific halibut by time of capture. The catch by all gears and areas is combined; April 1978 and October 1978 catches were in Kachemak Bay and others were in Kamishak Bay.

McLean et al. (1976) reported Kodiak and Cook Inlet halibut consumed fishes, crabs, clams, squid and other invertebrates. IPHC (1978) reported halibut young ate *C. bairdi*, hermit crabs, sand lance, pollock and zero-age rock sole. Smith et al. (1977) reported small halibut ate small crustaceans and larger halibut ate shrimp, crab and fish, including sand lance.

Amchitka halibut consumed Pacific cod and *Erimacrus* (horse crab) (Isakson et al., 1971), and armorhead sculpins, pollock, sand lance, and rock sole (Simenstad, 1977).

Halibut were preyed on by Pacific cod, sand sole and other halibut (Hunter, 1979), and Steller's sea lion (MacDonald and Petersen, 1976).

Butter Sole

Butter sole were captured throughout the summer in the try net, in which they were the third most abundant taxon. They were most abundant in May and June and catches were greater within about four miles of the Oil Bay to Iniskin Bay shoreline than at similar depths off Ursus Cove, during May and June.

One butter sole in late May was examined for food habits; it had eaten 56% polychaetes by weight, 25% bivalves, and 19% gammarid amphipods (Figure 58).

Benthic and epibenthic invertebrates were also food items for butter sole in Kodiak (Hunter, 1979), where bivalve siphons, small crabs, polychaetes, whole bivalves, and gastropods were consumed. One large sole had eaten a sea cucumber in Hunter's study. Simenstad's (1977) Cook Inlet Kodiak study found shrimp, mysids, bivalves, gastropods, fish, and polychaetes were food items of butter sole.

Area by Area

Kachemak Bay

The following species are considered critical based on their direct commercial utilization within the area: king crab, tanner crab, Dungeness crab, herring, shrimp, halibut, and pink, chum and sockeye salmon. Coho and chinook salmon are less common in Kachemak Bay but should be considered critical species based on their high sport and commercial value and, independently, on the presence of both juveniles and adults feeding and migrating in the area. Pacific sand lance and capelin are considered critical species as food fish for a wide variety of organisms. Razor clams are found in this area, are utilized for sport and subsistence and should be considered critical. Dolly Varden are common in Kachemak Bay and are used for sport, subsistence and a small amount is commercially harvested thus they sould be considered a critical species. Rockfish are utilized to some extent for sport, subsistence and are sold to a limited extent thus they should be considered at least an important species. Pacific cod and walleye pollock are used for crab bait and are fairly common in Kachemak Bay and must be considered as important. Flounders should collectively be considered important as they are quite common in the demersal zone and some undoubtedly spawn in Kachemak Bay.

Lower Central Zone

The following species are considered critical based on their direct commercial utilization within the area: king crab, tanner crab, halibut, herring, and salmon. Salmon also utilize this area as a migratory pathway both into and out of the inlet and for feeding. Sand lance must be considered critical as a forage fish species. Razor clams are found in this area, are probably utilized to some extent and should be considered important. Pollock and cod are found in the deeper part of this area and should be considered important. Dungeness crabs are harvested to some extent in this area and should be considered important. Flounders should collectively be considered important as they are quite common in the demersal zone.

The food organisms listed as critical in Kachemak Bay are also critical in this area.

Kamishak Bay

The following species are considered critical based on their direct commercial utilization within the area: king crab, tanner crab, Dungeness crab, herring, halibut, and pink, chum and silver salmon. Sockeye salmon and king salmon adults must be considered to migrate throughout the inlet on their return and juveniles were found to feed in this area. Therefore both sockeye and king salmon are also considered critical species. Pacific sand lance are considered critical species as a food fish for a wide variety of organisms. Razor clams are found in this area, are probably exploited to some extent and should be considered an important species. Flounders should collectively be considered important as they are quite common in the demersal zone and at least some apparently spawn in Kamishak Bay.

The food organisms listed as critical in Kachemak Bay are also critical in this area.

Kennedy Entrance

The following species are considered critical based on their direct utilizaiton within the area: king crab, tanner crab, halibut, pink salmon and chum salmon. All five salmon species migrate through this area on their way into Cook Inlet and to Kodiak and thus they must be considered critical. Sand lance apparently use this area and must be considered a critical species based on their use as a food. Capelin use of this area is not known but could be extensive; in which case it would be a critical species. Dungeness crab are harvested to some extent in this area and must be considered important. Pollock and cod are found in this area and should be considered important. Flounders should collectively be considered important as they are quite common in the demersal zone.

The food organisms listed as critical in Kachemak Bay are also critical in this area.

Kalgin Island

The following species are considered critical in this area based on their commercial utilization: halibut, all five species of Pacific salmon and Pacific herring. Razor clams are extensively utilized for sport and are therefore a critical species. Sand lance, longfin smelt and saffron cod are not known to be of direct food value but may be important as food of beluga whales which are common in the inlet. Longfin smelt, saffron cod and herring occur in considerable abundance and are probably grouped or schooled during winter and provide a likely food source for belugas.

The food items listed as critical in Kachemak Bay are also critical in this area.

Shelikof Strait

The following species are considered critical species in Shelikof Strait due to their commercial utilization: king crab, Tanner crab, halibut, all five species of Pacific salmon, Pacific herring, shrimp, walleye pollock, Pacific cod, dungeness crab and black cod. In addition sand lance and capelin are considered critical as food. There is no specific knowledge of their presence in Shelikof Strait but all available evidence suggests they are abundant. Razor clams are abundant along the shores of Shelikof, are commercial exploited and should be considered critical.

Various rockfish including the valuable Pacific Ocean Perch may be critically important in Shelikof Strait, but there is no specific knowledge of their distribution or abundance there. Thus they are classed as important.

The food items listed as critical in Kachemak Bay are also critical in this area.

DISCUSSION

The discussion addresses six geographic areas separately. They are Kachemak Bay, the Lower Central Zone, Kamishak Bay, Kennedy Entrance, Kalgin Island area and Shelikof Strait. The boundaries of these areas are shown in Figure 61.

Drilling Platforms

Acute Oil Spills

Kachemak Bay

Habitat location and type. Three habitat types will be addressed. These are demersal, pelagic and nearshore. The demersal habitat is located on, in or very near bottom. The pelagic habitat is the entire water column and the nearshore habitat type is both pelagic and demersal but in the immediate vicinity of shore.

Use by key species including life history stages. Critical and important species which use the demersal habitat within Kachemak Bay are juvenile and adult king crab, tanner crab, Dungeness crab, shrimp, halibut, flounders, walleye pollock, Pacific cod and rock fish. Adult capelin, normally considered a pelagic species, are found near or on bottom in the April-June period before their spawning.

The major catch area for king crab, tanner crab, Dungeness crab and shrimp is in the western half of the outer bay, although some catch occurs in virtually all of the bay. According to Trasky et al. (1977):

> "Outer Kachemak Bay was shown to be a major area for both release and settling of several species of commercially important shellfish larvae. Initial release of king crab and pink and humpy shrimp occurred primarily in the central and southern portions of the outer bay. King crab larvae were primarily distributed from the central part of the bay towards Anchor Point while humpy shrimp larvae were distributed westward toward the mid-portion of the lower inlet. Areas of settling for king crab larvae included the entire mouth of Kachemak Bay, however, the highest density was found along the northern shore off Bluff Point.
>
> The distribution of larvae is partially related to water movement patterns and may reflect entraiment in the gyres found in outer Kachemak Bay. Larval abundance was especially high at stations within the central area of outer Kachemak Bay in the vicinity of the gyres...
>
> Sampling conducted throughout Kachemak Bay and along the coast of the lower Kenai Peninsula indicated the importance of rocky, relatively shallow (less than 30 m; 90 ft. depth)

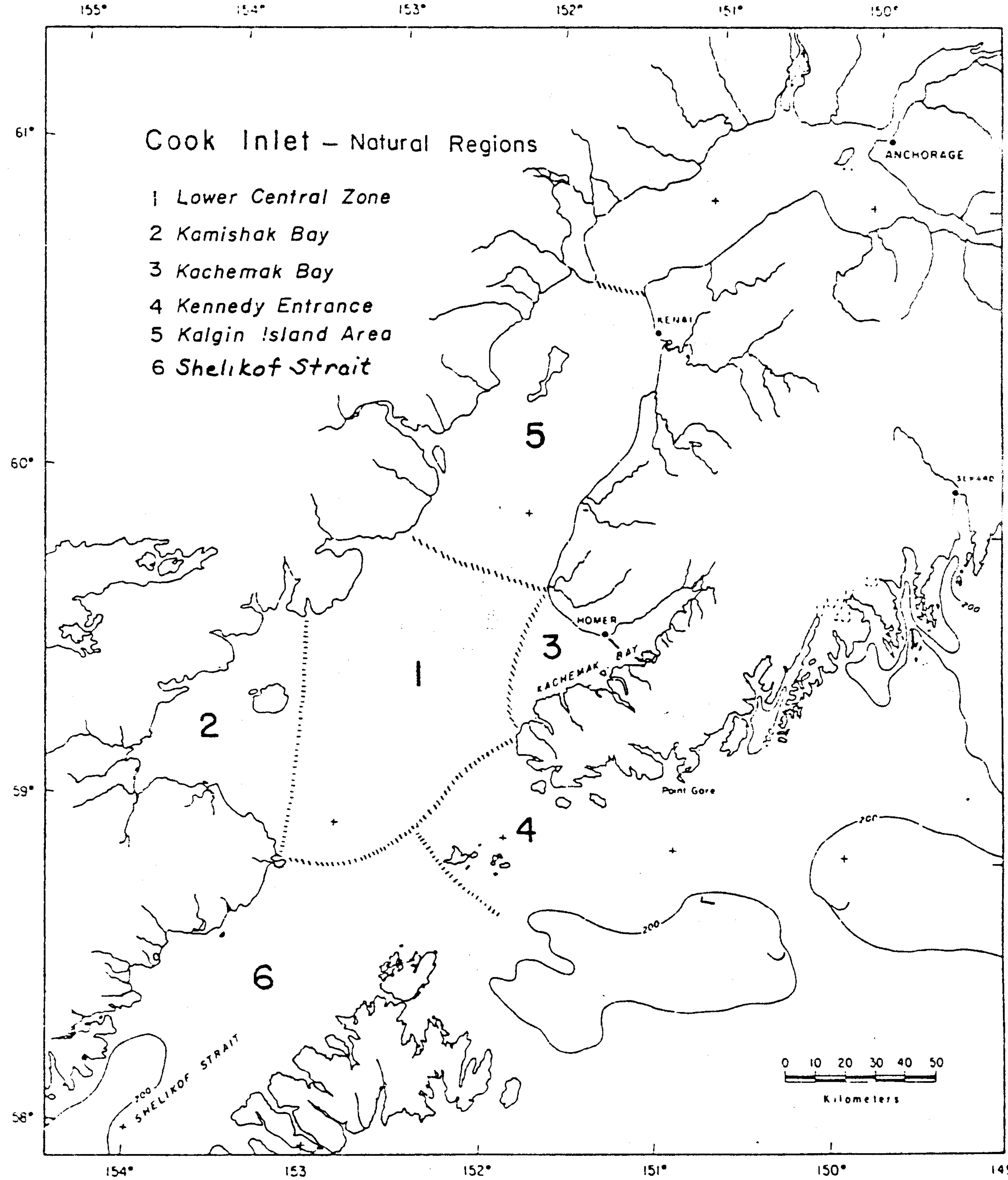


Figure 61. Cook Inlet natural regions.

habitat for post-larval king crabs...The Anchor Point to Bluff Point area, in particular is considered critical to the maintenance of king crab stocks within the Bay."

The major catch area for halibut is the 10 to 30 fathom deep zone (Trasky et al., 1977) and the halibut commission has identified an area in the vicinity of Bluff Point to Anchor Point and another off the south Kenai Peninsula where greatest effort is expended for halibut (Figure 16).

Flounders occur virtually everywhere on the continental shelf but areas of higher abundance within Kachemak Bay are not known. Adult Pacific cod and walleye pollock are commonly found deeper than 40 fathoms but juveniles also occur shallower. Modest numbers of both occur in Kachemak Bay but distribution features are not known.

Critical and important species which use the pelagic habitat within Kachemak Bay are: adult salmon of all five species migrating to their home stream and also feeding; juvenile salmon of all five species feeding and migrating to sea; larval, juvenile and adult herring, capelin and sand lance, all feeding; larval king crab, tanner crab, Dungeness crab, shrimp, flatfish and razor clams, all feeding; larval, juvenile and adult pollock, Pacific cod and rock fish, all feeding.

The salmon catches in Kachemak Bay are greatest along the southern shore where pinks and reds are caught in greatest abundance. These species plus king, chums and cohos are harvested throughout the bay (Figures 1, 6, 8, 10 and 12). Pink salmon spawning streams are numerous on the south side of Kachemak Bay. There is a run of 15,000 reds in the English River and several rivers with modest runs of cohos and chums on the south side of Kachemak Bay (Figure 3). Areas where spawning of pink and chum salmon occurs within tidal influence are common on the south side of Kachemak Bay (Figure 15). These are extremely important as they provide the most predictable production of any of the spawning areas. This is due to the influence of the ocean waters which moderate the effects of extremely cold waters which freeze spawn deposited upstream.

Juvenile salmon enter the pelagic zone in early summer where they can be found through at least early Autumn. Some of the areas of Kachemak, especially the bays on the south side are used by large numbers of juvenile pink salmon. These fish typically use protected bays extensively in early summer.

Herring spawn in the intertidal zone in the late April through early June time period and their larvae hatch in about two weeks and disperse through the upper layers of the pelagic zone. They feed in the pelagic zone throughout the summer and attain about 30 mm and metamorphose to juveniles in middle September. Juveniles and adults also are dispersed throughout the pelagic zone of Kachemak Bay throughout the summer. Through the autumn and winter months herring move to deeper water, still within the pelagic zone. They are commonly captured by shrimp trawls during winter months.

Capelin spawn in the intertidal zone beginning in late May through about mid-July. Eggs are deposited in sand and small gravel (Templeman, 1948). They hatch in about two weeks and disperse through the surface layers of the pelagic zone. They reach about 20 to 45 mm by September - October, but remain larval through their first winter. They are smaller than herring juveniles in September due to their thin larval form. They apparently remain in surface waters through the winter where they provide important forage for birds (Sanger et al., 1979). They metamorphose to juveniles in the spring at about 12 months of age and 65 to 70 mm. They remain in the pelagic zone in their second summer and possibly in the following winter. As they approach 24 months of age they mature and occur in large concentrations and may be found in surface waters and near bottom, before spawning. They may survive and spawn repeatedly as some larger capelin do occur.

Sand lance spawn probably in midwinter and probably subtidally in sand, but this is not based on knowledge from the Pacific Ocean. The larvae hatch apparently in midwinter and are 20 to 50 mm by late June (Figure 54). All age classes are found in surface waters of the pelagic habitat. Large catches of larvae were made in Kachemak Bay (Blackburn, 1978). The young-of-the-year grow to about 60 to 90 mm by September and apparently mature at 24 months of age. Sand lance seem to be common in intertidal habitat during winter where they bury in sand for protection.

Most all marine species are found in the pelagic zone at some time in their life history. The larvae of crab, shrimp, razor clams, flatfish, walleye pollock, Pacific cod and rockfish are included. In addition, juvenile and adult pollock, cod and rockfish commonly feed in the pelagic zone.

Critical and important species which use the nearshore habitat within Kachemak Bay include a large portion of both the demersal and pelagic species. They are: adult salmon of all five species migrating to their home stream and feeding; juvenile salmon of all five species feeding and migrating from rivers to sea; salmon eggs and alevins in intertidal portions of streams; herring eggs, larvae, and adults during spawning; sand lance perhaps for spawning in winter, for protection in winter and for feeding throughout the year; juvenile king and tanner crab for feeding and adult king crab during winter; Dungeness crab juveniles and adults for feeding in summer; some flatfish species; Dolly Varden for feeding the nearshore zone throughout the summer; rockfish juveniles and adults reside in kelpy and rocky areas which include the nearshore zone; and razor clams are found in the nearshore zone.

Of special importance in the nearshore zone are the spawning areas of herring, capelin and salmon. Salmon eggs, since they are actually in streams are not as exposed but this is an area where polutants may reside a long time once they come to rest.

The following organisms were found to be very important food items from food habits analyses: copepods, gammarid amphipods, decapod larvae, chaetognaths, euphausiids and fish eggs and larvae. Copepods were separated into calanoid and other. Other copepods were not positively identified but most were probably harpacticoid copepods. Calanoid copepods predominate the zooplankton (Damkaer, 1977). They are generally short lived and numbers respond rapidly to food supply so that generally abundance is greatest during the seasons of high productivity, that is spring, summer and possibly into fall. The most abundant calanoids are common in the inlet and the open ocean and in Kachemak Bay calanoids migrate to the surface at night contributing to a considerable night increase in plankton (Damkaer, 1977).

Harpacticoid copepods are generally epibenthic and are utilized most in the nearshore zone. No information is available on distribution, abundance or seasonality of harpacticoids.

Gammarid amphipods are epibenthic and generally live for more than a year. They are ubiquitious, as are copepods and no specific information is available on distribution, abundance or seasonality.

Decapod larvae and fish eggs and larvae are ephemeral taxa and are discussed above. Chaetognaths are ubiquitous and short lived predatory plankters. Data is not available on distribution, abundance or seasonality but the likely pattern involves spring and summer abundance with lesser numbers throughout the year. Euphausiids are planktonic and most live for a year or more. Information on distribution and abundance is not existent in the Cook Inlet area but Dunn et al. (1979) found larval, juvenile or adult forms virtually everywhere on the east side of Kodiak in October-November, March-April and June-July cruises. The adults tend to be more spotty in distribution and the different species are in somewhat different areas.

Fish eggs were not identified but some were definitely planktonic such as flounders and cod release. These species are discussed above. Larval fish include a wide variety of types but the most abundant are capelin, smelt sp., and sand lance in Kachemak Bay (English, 1979). Some flounder and cod larvae were important in numbers (English, 1979) and herring larvae are locally abundant, as they were found to be in Kamishak Bay in this study.

Seasonality-critical periods of use. The demersal zone in Kachemak Bay is utilized by juvenile and adult king crab, Tanner crab, dungeness crab, shrimp, halibut, flounders, walleye pollock, Pacific cod, rock fish and others during the entire year. There is no time when the demersal habitat is any less critical, based on presence of resource.

The pelagic habitat in Kachemak Bay is used intensively by juvenile salmon during about June through at least September and by adult salmon during the same time period. Herring use the pelagic habitat in Kachemak Bay throughout the year although during winter they probably are somewhat restricted to the deeper zones while during summer all life history stages are present in the surface layers. Sand lance and capelin use the pelagic zone throughout the year.

Larval stages of a large number of marine organisms are ephemeral inhabitants of the pelagic zone and data on season of occurrence is scarce. Shrimp larvae are reported to hatch in March and April and require two to three months of planktonic life (McLean et al., 1976). Haynes (1977) found larvae of Pandalid shrimp in Kachemak Bay to be abundant in early May 1976 in early developmental stages. By mid-July they were still common but in late developmental stages. Based on that information the best guess for time of larval shrimp occurrence in the plankton is about April 1 through July 31.

King crab larvae were found in the plankton of Kachemak Bay from early May through mid-July but by late June a large proportion of the larvae were glaucothoe larvae, the stage at which settling occurs and by mid-July the abundance was considerably reduced (Haynes, 1977). In early May a considerable portion of the larvae were advanced beyond the first larval stage. Based on this information larvae of king crab are probably present from about early April through early July.

Existing information on Tanner crab is quite sparse. They are reported to release larvae from April through July (Kaiser, personal communication) and require two months for larval development (McLean et al., 1976). Based on that information they should be present during April through September.

The larval release period for dungeness crab is not known. Existing information from a number of sources states that eggs are released during time periods from early October through late May (Kaiser, personal communication). English (1979) found few dungeness larvae in Kachemak during summer sampling thus will probably shed little light on this problem when his data is fully analyzed. The larval stage is reported to last four to five months (McLean et al., 1976).

Walleye pollock and Pacific cod spawn planktonic eggs in the spring. The eggs hatch in a few days to planktonic larvae. The duration of the planktonic stage is not known but the duration of presence in the pelagic zone encompasses the entire life cycle of these species. Eggs and larvae are probably present from late March through early June. Juveniles and adults are present year round.

Flounders also spawn pelagic eggs which hatch into planktonic larvae. Specific studies have not been conducted in this area but the general time for flounder spawning is spring and early summer, at least. Thus flounder eggs and larvae are probably present during the time from late March through at least September. Rock fish larvae are present within this time period also and further refinement is not possible.

Razor clams are reported to spawn when surface water temperatures reach 13° C. In Cook Inlet this is reported to be mid-July (McLean et al., 1976).

The nearshore habitat is used by many of the same species as the pelagic habitat and also by some of the demersal species. Time of use by the species common to these habitats is the same as presented above.

Juvenile salmon use the nearshore habitat during March through July. Dolly Varden are present from about mid-May through September or early October. Herring spawn is present during late April, May and early June. Capelin spawn is present from late May through probably about mid-July. Halibut occur occassionally in the nearshore habitat during mid to late summer. King crab occur in the nearshore habitat during late winter and spring. Sand lance are present in the nearshore zone year round and eggs may be present in mid-winter. Dungeness crab use the nearshore zone in summer.

The time of use by the important food organisms is discussed in the previous section.

Potential for long residence time of contaminant.

Weathering of oil. Every year 80,000 metric tons of petroleum are introduced into the marine environment during oil and gas drilling and production operations. Of this total, approximately 60,000 metric tons or 3/4 of the total input is lost during major accidents resulting from blowouts, pipeline repture and other unpredictable happenings. Minor spills and discharge of formation waters (brines) during normal drilling and production operations account for the remaining 20,000 metric tons. As worldwide petroleum production increases, so will the loss of oil. By 1980, if the rates of losses remain the same, the total input of oil into the marine environment from offshore drilling and production may reach 200,000 metric tons per year (Clark & MacLeod, 1977).

Petroleum or petroleum products released on the surface of marine waters immediately undergo weathering processes which disperse and break down hydrocarbons by physical, chemical and biological means. Physical and chemical weathering processes involve spreading, evaporation, dissolution, emulsification, sedimentation and photochemical modification (Clark and MacLeod, 1977). Biological processes involve the degradation of oil by microorganisms (biodegradation) and possible uptake by larger organisms.

The weathering of oil is affected by a variety of factors, such as location of the spill, wind, waves, currents, water depth, salinity, organisms, nutrients and kind of oil spilled (McAuliffe, 1977).

Spreading. Spreading, the dissipation of oil on the sea surface to form slicks, will greatly enlarge the area of a surface oil slick. The extent of spreading is primarily dependent upon the chemical and physical nature of the spilled oil although winds, waves and currents are also contributing factors (NAS, 1975).

According to an oil spill trajectory study by Dames and Moore, 1979, wind drift factor current is the primary driving force of oil slick movement. Net current and tidal current are secondary forces.

Spreading and dispersion accelerate the weathering process by increasing the surface area of the oil that is exposed to air, light and seawater. Generally, the lighter the oil the faster the oil will spread (Dames & Moore, 1975a). A representative calculation of oil spreading indicates that a 62,000 barrel oil spill would, after 11 days, spread to a diameter of 9.8 n.mi. (18.2 km.) (ADF&G, 1978a).

In calm water, gravity and surface tension cause oil to spread over the surface in a thin, continuous layer and in a circular pattern. In open water, spreading is aided by waves, wind and water currents causing elongation and distortion of a surface slick (Clark & MacLeod, 1977). In areas where there is restricted circulation, such as a gyre in a bay, surface spreading alone would greatly increase the area of the bay which would be affected by a spill.

On a calm sea spreading oil passes through the following phases:

1. During the first hour gravitational and inertial forces increase the diameter of a spill. According to Fay's data, a 10,000 ton spill of oil could increase by a factor of eight in the first hour.

2. During the period from one hour to one week after the spill, gravity and viscosity cause the diameter of the spill to increase by five times that reached during the first (one hour) phase.

3. After one week, if any oil remains on the water surface, it would be spread over an area in a thickness of approximately 8 mm. (Clark and MacLeod, 1977).

Crude oil and most types of refined products which spread across the surface of quiet or confined waters can be cleaned up or at least dispersed. However, no satisfactory method has been found for cleaning up heavy fuel oil that tends to solidify when spilled into cold seawater (Clark & MacLeod, 1977).

After oil is spilled at sea, components of oil that have low molecular weights immediately begin to vaporize into the atmosphere or are leached into the seawater (NAS, 1975).

Evaporation. After a spill the first changes to take place are evaporation of the volatile components and alteration of the physical properties of the remaining slick. The rate and extent of these changes depend upon the chemical and physical nature of the components of the spilled petroleum, the wave action, wind velocity, and water temperature. Weathering studies show that most hydrocarbons smaller than C15 (boiling point less than 250 C) will volatilize from the sea surface within ten days; lighter petroleum components evaporate within hours. Hydrocarbons from C15 to C25 (boiling point range 250 to 400 C) will evaporate in limited amounts and will tend to remain in the slick. Hydrocarbons above C25 will be retained (Clark and MacLeod, 1977). A study by Kinney et al. (1970) showed that hydrocarbon compounds below C12 are significantly reduced in 8 hours principally due to evaporation.

Between 30 and 50% of the hydrocarbons in a typical crude petroleum spill on the sea surface will be removed by evaporation. Bunker C fuel oil would probably lose about 10% of its hydrocarbons. About 75% of the hydrocarbons of a No. 2 fuel oil and almost 100% of the hydrocarbons of gasoline or kerosene will vaporize (Clark & MacLeod, 1977). Dames & Moore, 1975b stated that significant quanitites of spilled oil may be removed from the surface waters by evaporation. An oil spill or blowout in Kachemak Bay and in Chinitna Bay might behave similarly to light Arabian crude oil in which as much as 20 to 40% of the oil may evaporate in several days depending on the temperature of the oil and the wind conditions.

If petroleum is spilled in an open ocean, evaporation may be complete before the slick reaches the shoreline. Wind and waves tend to increase evaporation rates because of sea spray and bursting bubbles will inject petroleum components into the marine atmosphere. In most areas, these hydrocarbons remain in the atmosphere only temporarily and are then redeposited in the ocean at a distance anywhere from a few meters to several hundred kilometers from the area of injection (Clark & MacLeod, 1977).

Dissolution. After a spill, soluble components of a slick are lost from the sea surface to the water column by a process called dissolution. This process starts immeidately upon contact of the oil with seawater. Low molecular weight aliphatic and aromatic hydrocarbons, also lost by evaporation to the atmosphere, are removed from an oil slick by dissolution into the seawater. The rate of dissolution depends on ambient weather conditions (e.g. air and water temperatures, wind velocity, sea state, currents and waves) and on the physical characteristics and chemical composition of the petroleum (Clark and MacLeod, 1977). Hydrocarbons with higher molecular weights are less water soluble and are not as rapidly removed from the slick, as are the lighter molecular weight hydrocarbons, although gradually they will be leached out by seawater (NAS, 1975).

Emulsification. Whereas evaporation and dissolution help disperse the soluble parts of an oil spill, emulsification is an important method of dispersion for the insoluble components of petroleum. Emulsions can be of two types: oil in water or water in oil.

Oil in seawater emulsions are relatively unstable and are easily disbursed by currents and rough seas. Following the Arrow spill in Chedabucto Bay in Nova Scotia, Canada, fine particles of oil ranging from 5 micromillimeters to several millimeters were found in the water column and dispersed as far as 250 km away from the spill site. The eventual fate of oil in water emulsions appears to be dissolution in the water column or association with solid particulate matter or detritus and then eventual biodegradation or incorporation into the sediments (NAS, 1975). Oil in water emulsions disperse in the sea and degrade more rapidly than a continuous oil slick (CIRO, 1978). Seawater in oil emulsions eventually break up or combine with particulate matter, sand or other detritus and are subsequently biodegraded or incorporated into sediments (Clark and MacLeod, 1977).

Water in oil emulsions usually form when the more viscous oil such as high asphalt crude petroleums and residual oils are spilled. These emulsions form semi-solid gel-like lumps referred to as "chocolate mousse" in reports following the Torrey Canyon incident. Crude petroleum containing high levels of asphaltenes such as those from Kuwait and Venezuela, can produce a mousse that is stable for several months whereas petroleum containing low levels of asphaltenes, including those from Libya and Nigeria, produce a relatively unstable mousse (Clark and MacLeod, 1977).

The fate of water in oil emulsions has been indicated as a source of tar ball formation (NAS, 1975). During large spills, thick layers of oil persist for long periods of time and large aggregates of mousse can be produced. Mousse washed ashore becomes incorporated with sand and debris eventually forming thick balls of oil called tar balls. Tar balls appear to be fairly resistant to dispersal, oxidation and bacterial attack and thus degrade very slowly. Wave action and turbid waters, both characteristic of Cook Inlet, aid in the formation of tar balls (Dames and Moore).

Sedimentation. Another process that removes oil from the surface of seawater is sedimentation, a process which involves the sinking of petroleum components. Petroleum sinks when its density becomes greater than that of seawater. Evaporation and dissolution, which have been discussed previously, combined with other processes such as oxidation cause oil to sink. The surface of tar balls formed by this process undergo degradation into many, small dense particles of oil which can then sink (Clark and MacLeod, 1977).

Oil also sinks when it adheres to particulate matter such as organic materials, clays, silt, sand, glacial flour, and shell fragments suspended in the water column. Turbelent waters agitate the petroleum and particulate matter causing the oil and particles to agglutinate. During calm seas these particles sink to the bottom. Large quantities of suspended sediments are found in coastal bays and estuaries. When an oil spill in these areas is agitated by wind and waves, adsorption will occur and particulate matter coated with oil will sink to the bottom (Clark and MacLeod, 1977).

The rate of sedimentation in the environment is not known although observation shows that a considerable amount of sinking can take place within a few weeks after a spill. Lateral spreading of sedimented petroleum can occur for several months after spills. Sedimented petroleum is likely to be concentrated rather than dispersed in estuaries because of the method in which water moves into and out of the estuary. The long residence time of oil in intertidal areas depends upon wave action in the area and upon sediment and substrate types (Hayes et al., 1977). Oil spilled in shallow offshore areas can sink and then be rolled along the bottom by waves and currents. The oil accumulates particles of sand, shells, rocks and pebbles forming hard, tarry masses (Clark & MacLeod, 1977).

Photochemical modification. Another method of oxidizing spilled oil is by photochemical processes. Compared to spreading and evaporation, photochemical modification is a slow process (McAuliffe, 1977). Oil spread in a thin film or in dispersed droplets near the surface of the water generally photooxidize more quickly over a long period of time than "chocolate mousse" or tar balls (Clark and MacLeod, 1977).

Freegarde and Hatchett estimated that an oil slick 2.5 micromillimeters thick (2 metric tons per km2) could be degraded by photochemical processes in 100 hours of continuous exposure to sunlight. Thus assuming 8 hours of sunlight per day an average oil slick in the open ocean could decompose in a few days (Clark & MacLeod, 1977).

Biodegradation. Microorganisms including bacteria, yeast, and fungi that are capable of oxidizing hydrocarbons are present in almost all natural waters (Clark and MacLeod, 1977). Studies by Kinney et al., 1970, showed that Cook Inlet water degrades Cook Inlet crude oil. Cook Inlet waters appear to have a large capacity for degrading crude oil. Biodegradation is essentially complete within one to two months. Their studies found that microorganisms that are capable of oxidizing hydrocarbons are found throughout Cook Inlet numbering about 103 per liter or about 10% of the total population. It appears that biodegradation is more important than physical flushing in removing hydrocarbons from the marine environment.

Once a spill has occurred, the dispersed oil becomes an increased food source for these aquatic organisms. The rate at which oil is degraded depends on environmental conditions, the type of oil spilled, and the number and types of microbial populations present (Clark &MacLeod, 1977). Biodegradation appears to be the major method of removing hydrocarbons from the marine environment (McAuliffe, 1977).

Hydrocarbons may also be ingested by larger organisms. Fish tend to eliminate ingested hydrocarbons more quickly than clams or oysters (McAuliffe, 1977). The ingested material may either be incorporated into the tissues or eliminated in the feces (Clark & MacLeod, 1977).

Long residence time of oil. The potential for long residence time of oil spill contamination in Lower Cook Inlet and Shelikof Strait depends upon the retention of oil in the water column, in coastal sediments, and along the shoreline. The various environmental conditions affecting the retention of oil in the marine environment include circulation, tidal range, suspended sediments, bathymetry, bottom type, coastal morphology, and winds.

The following charts discuss the physical processes and environmental conditions which will determine the long residence time of oil or other contaminants in Lower Cook Inlet as a whole as well as in each of the natural regions of Lower Cook Inlet and Shelikof Strait as designated by OCSEAP (Figure 61). These regions include 1) Lower Central Zone, 2) Kamishak Bay, 3) Kachemak Bay, 4) Kennedy Entrance, 5) Kalgin Island

Area, and 6) Shelikof Strait. Also discussed is each region's vulnerability to oil spills and retention of oil contamination as determined by scientific research.

Relative sensitivities of key species. These are discussed in Table 51.

Lower Central Zone. All the subsections for this zone are addressed under Kachemak Bay. Critical species for this area are identified in Results under Area by Area. Potential for long residence times of contaminants is addressed specific to this area in Chart III.

Kamishak Bay. All the subsections for this zone are addressed under Kachemak Bay. Critical species for this area are identified in Results under Area by Area. Potential for long residence times of contaminants is addressed specific to this area in Chart IV.

Kennedy Entrance. All the subsections for this zone are addressed under Kachemak Bay. Critical species for this area are identified in Results under Area by Area. Potential for long residence times of contaminants is addressed specific to this area in Chart V.

Kalgin Island Area. All the subsections for this zone are addressed under Kachemak Bay. Critical species for this area are identified in Results under Area by Area. Potential for long residence times of contaminants is addressed specific to this area in Chart VI.

In addition, longfin smelt and saffron cod use the pelagic and nearshore zones of this area for feeding. Longfin smelt are anadromous with eggs hatching in winter or spring. Larvae or jueveniles were 30 to 50 mm in early September (Figure 48) thus larvae are present all summer, and juveniles and adults are present year round.

Saffron cod apparently spawn in December to February and larvae hatch in April and are planktonic for two to three months (Andriyashev, 1954). Thus larval saffron cod are probably present in this area during April, May and June and juveniles and adults are present throughout the year.

Shelikof Strait. All subsections for this zone are addressed under Kachemak Bay. Critical species for this area are identified in Results under Area by Area. Potential for long residence times of contaminants is addressed specific to this area in Chart VII.

In addition, black cod juveniles and all life history stages of Pacific Ocean Perch use the pelagic and demersal habitats in Shelikof Strait for feeding throughout the year.

CHART I . LOWER COOK INLET

CIRCULATION

ADF&G, 1978

The following discussion of Lower Cook Inlet circulation is taken from Resource Report for Cook Inlet Sale No. 60, ADF&G, 1978. Further detail may be obtained from Burbank (1977), Circulation Studies in Kachemak Bay and Lower Cook Inlet.

Lower Cook Inlet circulation is exceptionally complex due to the large tidal range and seasonally variable freshwater runoff and winds. During the spring, summer and early fall the freshwater runoff from the upper Inlet is high and southerly winds are more frequent.

Intruding seawater from the Alaska Current enters Cook Inlet through Kennedy Entrance (Figure 62). Coastal divergence causes upwelling northwest of the Chugach Islands, and these upwelled waters subsequently enter outer Kachemak Bay and are incorporated into the eastern counterclockwise (CCW) gyre. As a consequence of offshore divergence, intruding Gulf of Alaska surface waters are diverted offshore and bypass outer Kachemak Bay, although at least some of this water is incorporated into the clockwise (CW) gyre in western outer Kachemak Bay.

After reaching Anchor Point, the northward intrusion of seawater is diverted strongly to the west. A CCW gyre is apparently produced in the central lower Inlet south of this westward diversion. Strong westward flow has also been observed immediately south of the CCW gyre.

A significant amount of the intruding seawater continues north and northwest of Anchor Point where it encounters the strong southward flow of turbid, low salinity water from the upper Inlet. Net northward flow may extend significantly farther north to the vicinity of the East and West Forelands. Strong north-south mixing is apparent in the area west of Ninilchik. This partially mixed water is carried west into the Mid-channel Rip.

The most intense southward flow of turbid, low salinity water from the upper Inlet occurs in a relatively narrow stream between the Mid-channel and West Rips. The convergence of the intruding seawater with this strong southward flow produces a frontal zone (the Mid-channel Rip) along which the more dense seawater flows under the less dense southward flow of turbid water. Convergence along the Mid-channel Rip is most intense between the latitudes of Anchor Point and Kasilof. In the channel south of the South Kalgin Island Shoal the intruding seawater, after flowing under the strong southward flowing stream of turbid water, apparently surfaces again in the channel west of the South Kalgin Island Shoal.

After convergence and intense mixing along the Mid-channel Rip between Anchor Point and Kasilof, intruding seawater is carried south in the western half of the lower Inlet. In the lower Inlet south of Ninilchik, the southward outflow of turbid, low salinity water from the upper Inlet is mostly constrained to west of the Mid-channel Rip. After passage through Kamishak Bay, the turbid water outflow is eventually discharged into Shelikof Strait. The frontal zone defined by by the Mid-channel Rip continues south through Kamishak Bay and into Shelikof Strait; however, it is rather weak and frequently very ill-defined in southern Lower Cook Inlet.

Convergence along the Mid-channel Rip collects considerable debris from surface waters in eastern Lower Cook Inlet. Evidence suggests much of this debris may be held in the rip (primarily between the latitudes of Anchor Point and Kasilof) for considerable (several months or more) periods of time.

Most of this debris is eventually carried south along the rip and into Kamishak Bay. Sizeable accumulations of debris are found in Kamishak Bay where it apparently lingers in gyres or eddies until blown ashore. Amakdedori Beach and the south shores of Kamishak Bay are the eventual depositional sites of much of this debris, although significant amounts are probably carried into Shelikof Strait.

Major alterations in surface transport can be produced by persistent moderate to strong winds. Strong winds have been observed to eliminate the Kachemak Bay gyre systems, and other gyres within the Inlet are probably also susceptible. Persistent (2-3 day) strong southerly winds have been observed to greatly increase northward surface transport in the lower Inlet and, as a consequence, generate a strong southward flowing countercurrent at depth. Correlation of most regional scale perturbations of Lower Cook Inlet circulation with winds, however, has been severely inhibited by lack of accurate offshore weather data.

As observed in Kachemak Bay, the larger tidal ranges seem to enhance circulation through coastal embayments and other areas which, during periods of smaller tides, contain gyres or a relatively sluggish circulation.

The most significant initial transport mechanism in Lower Cook Inlet and Shelikof Strait is the tidal current. Typical tidal current velocities of approximately 1-4 knots are experienced throughout most of Lower Cook Inlet and many areas of Shelikof Strait, although velocities in Shelikof Strait are apparently somewhat less than in Cook Inlet. Tidal Current velocities much in excess of 4 knots are common locally in Lower Cook Inlet. The tidal current directions generally conform roughly with the morphology of the basin and shoreline.

U.S. Coast Pilot 9

At the entrance to Cook Inlet the tidal currents have an estimated velocity of 2 to 3 knots, and in general increase up the Inlet. Very large velocities occur in the vicinities of Harriet Point and the East and West Forelands. The current velocity has been measured at 5 knots near the East and West Forelands. It is estimated that the velocity during a large tide is as much as 8 knots between East and West Forelands and probably more between Harriet Point and the southern end of Kalgin Island.

In general, the direction of the current is approximately parallel to the trend of the nearest shore and, when flats are uncovered, parallel to their edges. Off the various bays a set may be expected, toward the bay on a flood current and from the bay on an ebb current.

TIDAL RANGE

Sharma & Burrell, 1970

The mean tidal range in Cook Inlet is of great magnitude. Tides up to 12 m are common at Anchorage.

U.S. Coast Pilot 9, 1977

The diurnal range of tide in Cook Inlet varies from 14.3 feet at Port Chatham to 29.0 feet at Anchorage.

SUSPENDED SEDIMENTS

Feeley & Cline, 1977

The distribution patterns of particulate material in Lower Cook Inlet show a direct relationship to water circulation. The inflowing relatively nonturbid Gulf of Alaska water moves along the eastern coastline until it reaches Kalgin Island where it mixes with the highly turbid brackish water from Upper Cook Inlet. Under the influence of tidal currents and coriolis forces, the turbid water moves southwest along the western coast into Shelikof Strait where the particulate matter disperses and settles to the bottom. This counterclockwise circulation pattern gives rise to extremely large horizontal gradients in suspended matter. However, tidal mixing is extensive and rapid; and, therefore, no vertical suspended matter gradients are observed during the winter months in the central regions of Lower Cook Inlet.

The surface and near-bottom suspended matter distribution patterns in Lower Cook Inlet are remarkably similar, indicating that Cook Inlet is characterized by unusually high horizontal gradients and no vertical gradients during the winter season. On the eastern side, the inflowing Gulf of Alaska water has suspended matter concentrations ranging between 0.5 and 5.0 mg/l. On the western side, the outflowing turbid water, which contains mechanically abraded rock debris from Upper Cook Inlet and has particulate concentrations ranging from 5.0 to 200 mg/l, is transported past Augustine Island to Kamishak Bay, where a portion of the suspended material settles out and the remaining material is transported around Cape Douglas into Shelikof Strait and is dispersed.

Burbank, 1974

Tidal currents within Cook Inlet, as interpreted from the bottom sediment distribution (Figure 63), are sufficiently strong to prevent deposition of material finer than sand. Facies 2 (gravel) probably represents a true equilibrium size distribution. The gravels are most likely palimpsest glacial till with more recent additions of ice-rafted gravel.

The Facies 1 sand in the upper Inlet is probably present only because the tremendous sediment input from Knik Arm overwhelms the capacity of the environment to remove it, since turbulence and current velocities in the Facies 1 region are comparable to areas farther south where gravel is the equilibrium product. The positive skewness of most Facies 1 sands, indicating a depositional environment, may be a summertime phenomenon. It is expected that during winter months, when sediment input is greatly reduced, net erosion would occur. Interestingly, the distribution pattern of Facies 1 sands conforms with the clockwise circulation pattern proposed for the upper Inlet; however, the pattern of the bottom sediment size distribution may be biased in this manner by the relatively low sediment input of the Susitna River.

The inlet broadens and deepens in the region of Facies 3 (sand with variable gravel and silt-clay), although current velocities appear to be sufficient to prevent deposition of significant amounts of finer material. Although no size distribution data are available for bottom sediments in Kamishak Bay, the extensive mudflats and a few notations of the bottom characteristics on USCGS chart 8554 indicate that a significant amount of the finer (suspended) material carried from the upper inlet is deposited in Kamishak Bay. A narrow and diminished plume of suspended sediments passes out of Kamishak Bay and into Shelikof Strait along the western shore.

BATHYMETRY

Muench et al., 1978

Cook Inlet is a broad (70-90 km), shallow (mean depth of 60 m or 33 fathoms) elongate embayment (Figure 64).

BOTTOM TYPE

Sharma & Burrell, 1970

Sediments in Cook Inlet consist predominantly of cobbles, pebbles and sand, with minor amounts of silt and clay. The boundaries of the three sedimentary environments are very well defined (Figure 63). During the summer months, large quantities of glacially derived sediment are added to the upper reaches of Cook Inlet. Strong currents prevent early deposition of most of the silt and clay which are transported seaward toward the Forelands. In this area intense tidal flushing removes almost all material of less than gravel size. The rate of sediment supply to the Inlet is minimal during the extended winter season, and sediments are reworked predominantly by ice rafting.

WINDS

Muench et al., 1978

Cook Inlet is subject to large climatological variations. During winter, regional weather is controlled by deepening of the Aleutian Low atmospheric pressure system, which brings predominantly northerly winds and concurrent low temperatures (below $0^{o}C$) over the Inlet. These low temperatures cause extensive ice formation in the shoal reaches of upper Cook Inlet. This ice then moves southward along the western shore, often as far as Cape Douglas. Deepening of the Aleutian Low also leads to predominantly easterly winds offshore along the Gulf of Alaska coast. These easterly winds cause a coastal sea level set-up and a downwelling tendency. During summer the climate ameliorates somewhat as the effects of the North Pacific atmospheric high become dominant. Air temperatures rise to $10\text{-}12^{o}C$, winds are variable, predominantly southerly over the Inlet; and storm frequency decreases. Offshore winds become primarily westerly, leading to a weak upwelling tendency in the Gulf of Alaska.

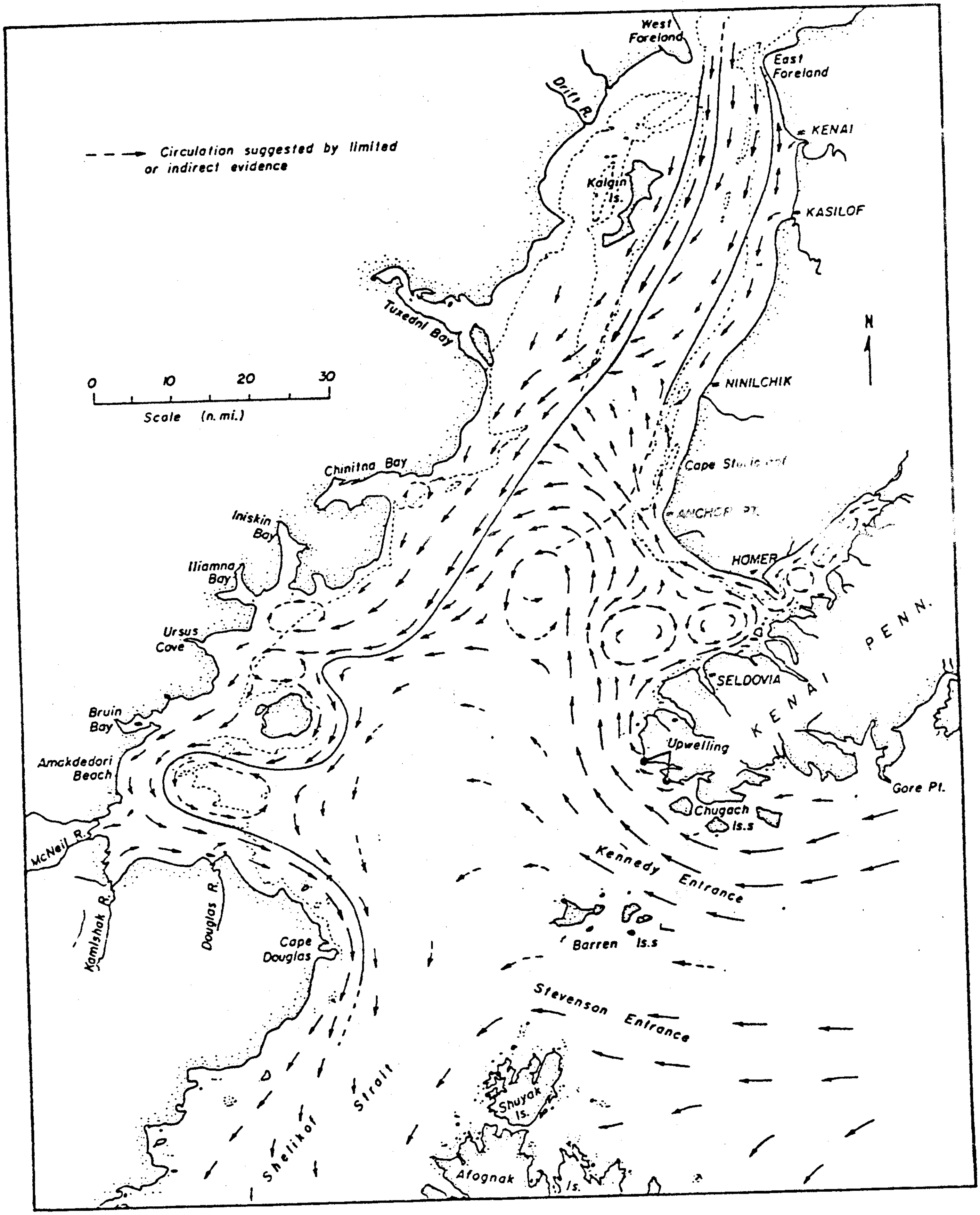


Figure 62. Net surface circulation in Lower Cook Inlet, based primarily on data collected during the spring and summer seasons. (Burbank, 1977)

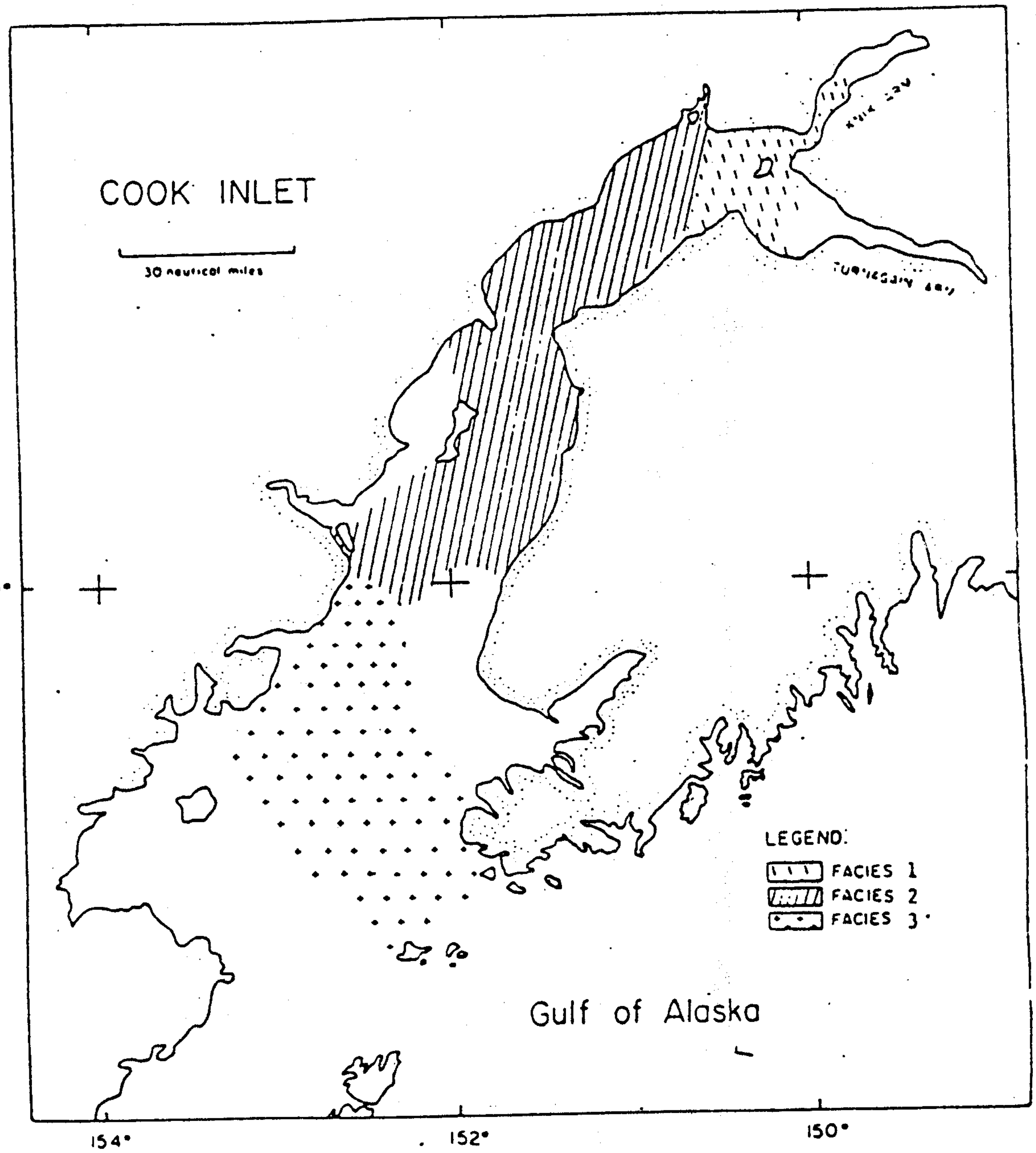


Figure 63. Bottom sediment facies of Cook Inlet (after Sharma and Burrell, 1970).

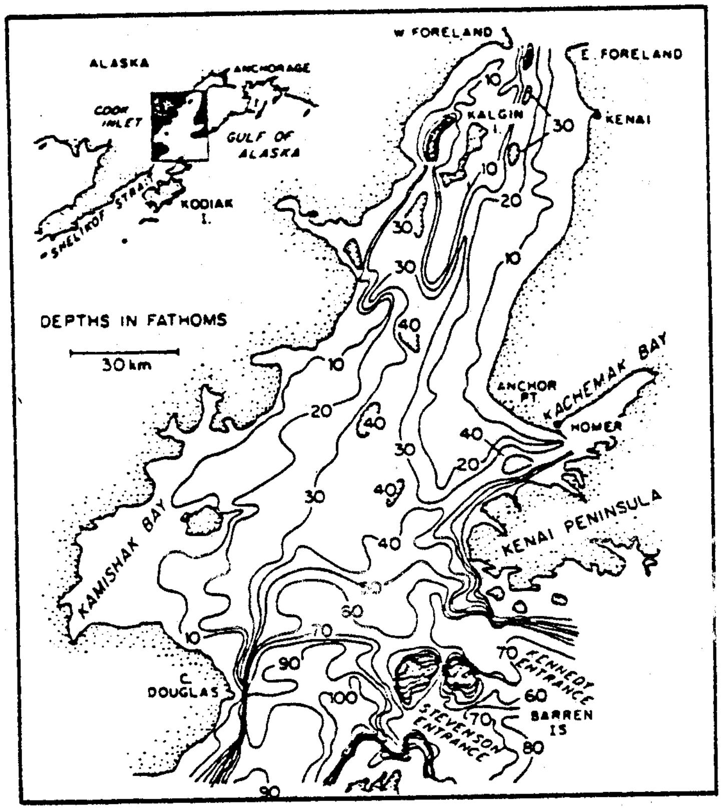


Figure 64 Location and bottom topography of Lower Cook Inlet. Muench et al., 1977.

VULNERABILITY OF LOWER COOK INLET COASTLINES TO OIL SPILLS

Hayes et al., 1977

Hayes et al. (1977) studied the relationship between coastal morphology and the longevity of spilled contaminants. Based on studies of the spill from the tanker Metula in the Strait of Magellan neutral and depostional shorelines rather than erosional shorelines will retain oil longer in the advent of a spill in Lower Cook Inlet. Especially vulnerable will be the salt marshes and tideflat areas of the west side of the Inlet as well as the gravel intertidal zone of the lower shoreline of Kachemak Bay.

Generally, Lower Cook Inlet is a high risk area for the long residence time of oil from spills (Figure 65). A total of 41.5% of the shoreline is classified as having high risk values with 39% of this being areas where the residence time would be 10 years or more if no cleanup procedures were initiated.

The following table shows the risk ratings and oil spill vulnerability of various coastal environments in Lower Cook Inlet. The oil spill vulnerability scale of 1-10 is based primarily on the expected longevity of oil in the sediments of each environment if no cleanup procedures are initiated.

Table 47. Risk rating and oil spill vulnerability of various coastal environments in Lower Cook Inlet.

Risk Rating	Discussion	Longevity of Spilled Oil
1-2	Erosional shorelines with high (over 330 ft, 100 m) vertical bluffs of bedrock faces of variable heights, beaches coarse gravel or bedrock platforms. Oil easily removed by wave erosion; some problems in areas where gravel beaches occur. 13% of the coastline has a risk rating of 1-2.	Oil that goes ashore could be expected to be dispersed within a few weeks.
2-4	Erosional shorelines with vertical bluffs less than 300 ft. (100 m) or low bluffs in glacial or deltaic deposits. Beaches are mixes of sand and gravel flanked in places by wide tidal flats for bedrock platforms. Generally low-risk area except where depositional berms exist; gravel and boulder low-tide terraces subject to long-term oiling; burial possible on beach faces. 32% of the coastline has a risk rating of 2-4.	Areas would probably be free of oil within 6 months.
4-6	Depostional shorelines: spits, formed by sediment deposition from longshore transport; bayhead beach-ridge plains, consisting of parallel beach ridges formed by wave action in the upper reaches of bays; and deltas at the mouths of heavy sediment laden streams entering an exposed high energy coast. Beaches are mixed of sand and gravel. Dunes are common in areas where bayhead beach-ridges are forming. Penetration and burial of oil possible; if buried, would remain longer. Gravel beaches more susceptible than sandy areas; oil would tend to accumulate here because of position at head of bay. 13% of coastline has risk rating of 4-6.	Pollution is possible up to one year.

6-8	Deltas of heavy sediment laden streams entering areas of low wave energy and deltas of smaller streams. Low wave energy conditions and coarse grain size would allow oil to remain for years; fresh water plume would probably keep oil off delta during periods of high run-off. 2.5% of coastline has a risk rating of 6-8.	Oil could remain in place for several years.
8-10	Stable shorelines (some low erosional bluffs and minor depositional features) and tide dominated bayhead depositional systems. Stable mountainous shorelines are dominated by steep valley walls, pocket beaches of mixed sand and gravel and extensive tidal flats. Stable lowland and hilly shorelines are generally sediment starved and fronted by thin tidal flat deposits covering wide rock platforms. Extensive sand waves and shoals, mud flats and salt marshes are found in the depositional zone at the head of tidally dominated bays. Almost all areas subject to long-term oil spill damage, especially salt marsh areas and tidal flats; fewer problems at mouth than at head of embayment. Lower parts of intertidal areas would be flushed by tidal currents; oil may not enter area if fresh water run-off is high. 39% of the coastline has a risk rating of 8-10.	Long-term pollution of 10 years or longer can be expected in these areas.

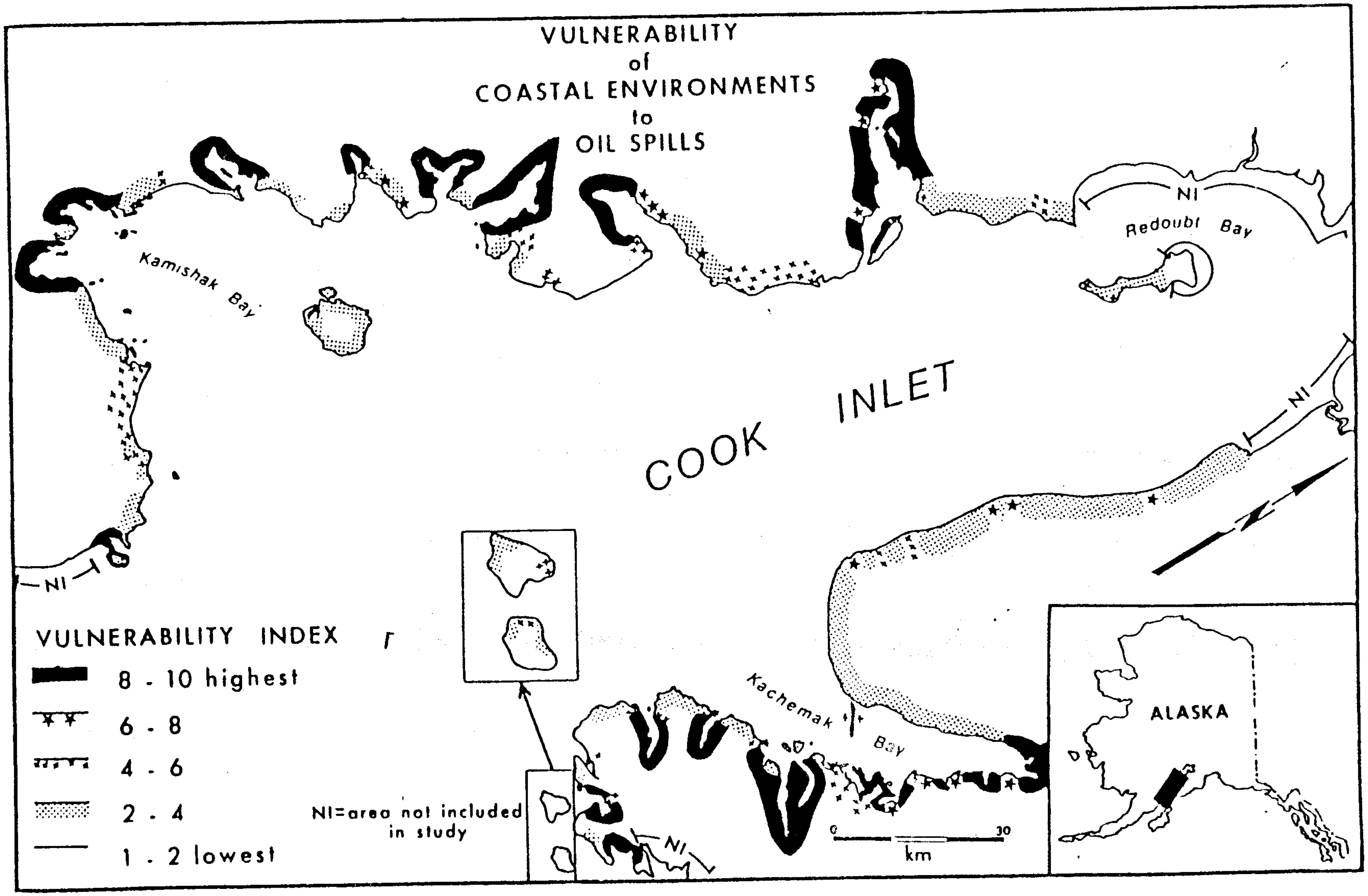


Figure 65. Vulnerability of coastal environments to oil spi''s. (Hayes et al., 1977)

Chart II . Kachemak Bay

CIRCULATION

Burbank, 1977

Outer Kachemak Bay - Circulation in outer Kachemak Bay (Figure 66) is dominated by two large gyres, a counterclockwise (CCW) rotating gyre in the eastern half and a clockwise (CW) rotating gyre in the western half. The two-gyre system appears relatively stable unless altered by strong winds. Net transport in outer Kachemak Bay is generally northward whether or not the gyres are present.

Variation in the tidal range causes a variation in the size and shape of the two-gyre system. Extreme tidal ranges may cause enlargement of the CW gyre with concommitant diminuation or destruction of the CCW gyre. Increase in the tidal range, accompanied by increasing tidal current velocities, tends to increase net northward transport of surface waters throughout the outer bay.

Surface waters in outer Kachemak Bay are apparently derived largely from coastal upwelling (divergence) northwest of the Chugach Islands. This may significantly increase available nutrient concentrations and greatly enhance biological productivity in outer Kachemak Bay.

Water in the gyres has a typical residence time of roughly 1-2 weeks, although longer residence times are possible. Northward flowing seawater is incorporated into the gyres along their southern periphery while a loss of water is incurred along the northern periphery of the gyres.

Intrusion of seawater into Kachemak Bay occurs primarily along the southeastern shore. Near the entrance to the inner bay the flow turns north, normally (during periods of high freshwater runoff) bypassing the inner bay. Strong surface outflow from the inner bay (during spring and summer) also turns north and flows along the northeast shore of the outer bay.

Major changes in the Kachemak Bay circulation pattern are comparatively infrequent during the more quiescent spring and summer months, specifically May to August. Beginning in later summer (September) and continuing through winter, strong seasonable storms tend to frequently alter this circulation. Indirect evidence suggests that east or southeastward surface transport from central Lower Cook Inlet into outer Kachemak Bay can occur, however, the oceanographic or meteorologic conditions required to induce such transport are not known.

Surface and subsurface (100 ft; 30 m depth) circulation is generally similar unless the surface currents are altered by persistent strong winds in either Kachemak Bay or Lower Cook Inlet. In such cases, subsurface compensatory currents which differ markedly from the surface currents have developed.

Inner Kachemak Bay - Inner Kachemak Bay is a positive, partially mixed estuary wherein fresh water input (from rivers and precipitation) is greater that evaporation, and tidal currents cause considerable vertical mixing. The horizontal circulation (Figs. 67 and 68) is characterized by two counterclockwise (CCW) rotating gyres. The northeastern gyre is elongated whereas the southwestern gyre is fairly symmetrical.

Fresh water, introduced primarily by the Fox, Bradley and Martin Rivers at the head of the bay, flows out of the bay along the northwest shore. A significant amount of this outflow is diverted offshore in the region where the two gyres meet. The gyre movements and horizontal mixing processes tend to distribute the fresh water layer throughout the inner bay.

Vertical and horizontal mixing processes increase the salinity of the surface water outflow near the mouth of the bay and greatly increase the volume of the surface water outflow from the inner bay. Surface outflow into the outer bay occurs across the entire entrance to the inner bay; subsequent transport is northwest along the northeast shore of the outer bay. The intensity of the surface outflow from the inner bay is probably greatly diminished during fall and winter when river runoff is low.

Seawater intrusion into the inner bay apparently occurs primarily below 100 ft (30 m) depth in the vicinity of the entrance. Vertical mixing occurs throughout the water column within the inner bay.

CURRENTS

Dames & Moore, 1975

Outer Kachemak Bay - Information available from the National Ocean Survey (1973) and the Alaska Department of Fish & Game (1975) indicate that the surface currents in outer Kachemak Bay are highly variable, but generally less than 1 knot. Both the current direction and magnitude appear to be a function primarily of the range of tidal fluctuation over any given tide. Tidal currents outside the mouth of the Bay appear to be slightly higher and more uniform, possibly in absence of boundary effects from the shoreline.

The tidal traverse, or distance which a water particle may move during a flood or ebb tide, varies as a function of location within the Bay as well as the duration and amplitude of the tidal fluctuation. Tidal traverses may be less than 2 miles or greater than 10 miles.

TIDAL RANGE

Dames & Moore, 1975a

Table 48. SUMMARY OF TIDAL DATUM FOR KACHEMAK BAY

Datum	Seldovia[a] Elevation (feet)	Halibut Cove[b] Elevation (feet)	Homer[c] Elevation (feet)	Anchor Pt[d] Elevation (feet)
Estimated Highest Water	23.0	24.0	24.8[e]	25.0
Mean Higher High Water	17.8	18.2	18.1	18.7
Mean High Water	17.0	17.5	17.3	18.0
Mean Tide Level	9.3	9.55	9.45	9.9
Mean Low Water	1.6	1.6	1.6	1.8
Mean Lower Low Water	0.0	0.0	0.0	0.0
Estimated Lowest Water	-5.5	-6.0	-5.6[e]	-6.0

(a) Lat. 59°26.6'; Long. 151°43.0'
(b) Lat. 59°36.0'; Long. 151°09.7'
(c) Lat. 59°36'; Long. 151°25'
(d) Lat. 59°49'; Long. 151°50'
(e) Highest and lowest levels observed

SUSPENDED SEDIMENTS

Dames & Moore, 1975a

The oceanic waters which flow past the entrance to Kachemak Bay are relatively clear, having suspended sediment concentrations in the order of 1 to 2 mg/l. Consequently, waters within Kachemak Bay are similarly clear. Available measurements indicate the suspended sediment concentrations are generally 3 mg/l or less throughout the year. Where glacial streams flow into Kachemak Bay, such as in the vicinity of China Poot Bay, the water may be relatively turbid, especially during the summer months when streamflow is greatest. Suspended sediment concentrations may also be higher along the beaches due to turbulent mixing and resuspension of sediments in the nearshore zone. Burbank (1974) reports that this nearshore turbid water is generally limited to areas with water depths less than 18 feet. This nearshore turbid zone may enhance the attachment and deposition of oil of it moves toward shore.

Kinney et al., 1970

A suspended particle of sediment has approximately a 90% chance of being flushed out of Cook Inlet because of river input and entrained flow.

Dames & Moore, 1975a

The suspended matter that is characteristic to much of Cook Inlet water is an important factor for oil spills occurring within the Cook Inlet area. If oil becomes attached to sediment particles the specific gravity of the oil and sediment becomes greater than the specific gravity of salt water and the particles sink into the water column (where they would be influenced by currents) or to the bottom substrate. Where waters were clearer, such as in Kachemak Bay, this sedimentation process would not be as apparent.

BATHYMETRY

Burbank, 1977

Water depths in Outer Kachemak Bay are from 20 to 40 fathoms (120 to 240 feet) and water depths in Inner Kachemak Bay vary between less than 10 fathoms to approximately 50 fathoms (60 to 300 feet) (Figure 69).

BOTTOM TYPE

Shaw & Lotspeich, 1977

Shaw and Lotspeich noted that in general, the presence of smaller sediment particles in the substrate indicates calmer waters from which suspended organic materials will settle out and which will favor the growth of organisms. Thus, substrates composed of silts and clays typically contain more organic material including hydrocarbons than do sands.

Driskell & Dames & Moore, 1977

Bottom types in Kachemak Bay were identified during a study to determine the composition and distribution of major infaunal organisms in Kachemak Bay. The study found that the four major substrate types, namely, rock, sand, silt and shell debris, combine to form six major geological facies in outer Kachemak Bay (Figure 70).

Boulder - Large Cobble Facies - This facies predominates over a substantial portion of the intertidal and subtidal regions of outer Kachemak Bay down to approximately 10 fathom (18 m) depths (Figure 70).

Northern Shell Debris Facies - This facies spans the northern portion of the outer bay at depths from 10 fathoms to between 20 and 30 fathoms (Figure 70). Besides shell debris, the substrate contains varying quantities of silt, sand and rubble.

Southern Shell Debris Facies - In subtidal areas along the southwestern edge of the bay is another facies characterized by fine to coarse shell debris (Figure 70). The area is exposed to strong currents. Depths range from 10 to 4[illegible] fathoms. This area is considered distinct from the northern shell region because of differences between the infaunal assemblages.

Sand Facies - Sand dominates the substrate in the western central portion of the outer bay (Figure 70). Generally, the area appears swept by weaker currents than the shell debris regions. Circulation studies indicate the occasional presence of a large clockwise gyre over this area (Burbank, 1976). The substrate surface is mainly characterized by ripple marks. In conflict with the hypothesis suggesting weaker currents, however, was the presence of sand waves approximately six feet high at one station. The crests were oriented generally in a magnetic east-west direction. These waves appeared to consist of coarse sand, gravel and shell debris. The substrate becomes increasingly silty to the east, near the muddy sand facies. Toward the northern and western margins of the facies, fine shell debris becomes more abundant.

Muddy Sand Facies - The muddy sand (or sandy mud) facies is centrally located in the outer bay and varies in depth from 15 to 40 fathoms (Figure 70). The bottom is flat and smooth, indicating fairly weak currents. Shell debris is generally lacking.

Silt Facies - This facies occupies the deep troughs (deeper than 30 fathoms) leading from the inner bay to Lower Cook Inlet (Figure 70). Microrelief varies, appearing either flat, slightly rippled or pitted with burrows. The substrate varies from a cohesive anoxic clay to a loose silt mixed with slight amounts of shell debris or fine sand.

WINDS

Dames & Moore, 1975a

Normally, in sheltered areas, such as Kachemak Bay, locally generated wind drift currents are not felt below depths greater than 5 feet from the water surface. Winds are not as strong in Kachemak Bay as in Cook Inlet proper or the Gulf of Alaska due to the presence of the Kenai Mountains to the east and southeast. Kachemak Bay is oriented northeast to southwest, while Cook Inlet is situated north to northeast to south-southwest. Northwest winds at the mouth of the Bay are not obstructed by land and are estimated to be 30 to 100% greater than those at Homer. Winds at Homer are predominantly from the north and northeast and also from the west and southwest. Maximum monthly wind speed at Homer is 7.8 knots.

VULNERABILITY OF KACHEMAK BAY TO OIL SPILLS

Dames & Moore, 1979

A study by Dames & Moore was initiated to provide information on shoreline areas that would probably be impacted by hypothetical oil spills from nine selected locations in Lower Cook Inlet. These sites correspond to recently leased tracts and probable future pipeline locations. The analysis was based primarily on an oil spill trajectory model with winds and net and tidal currents being the environmental factors affecting the spill. The results of this study showed that Kachemak Bay would be impacted within three days after an oil spill from any of the nine spill locations (Figure 71). The probability that Kachemak Bay would be impacted was 3% (Figure 72). The short time that it will take the spilled oil to reach Kachemak Bay means that the oil will have minimally dispersed, therefore, more oil will be available to impact the shoreline and the toxic constituents will not have been degraded. These factors will greatly affect fish and wildlife resources in Kachemak Bay. The rapid movement from spill site to shoreline impact makes containment and control difficult unless the necessary resources are in the immediate vicinity and are mobilized quickly once a spill release occurs.

Dames & Moore, 1975a

This study indicated that oil entering the two gyre systems along the southern half of Outer Kachemak Bay could retain oil for several tidal cycles before being transported elsewhere which could potentially affect the valuable fishery resources in this area. These resources include shrimp, herring, Dungeness crab, tanner crab and king crab. Once the oil breaks loose from the gyre, it could potentially flow to the north or south margin of Kachemak Bay depending on the stage of the tide and the wind conditions.

Figures 73 and 74 show predicted oil spill trajectory for both varying winds at Homer and with a 10 know northwest wind at Homer.

Trasky et al., 1977

Coastal Morphology - The shores of Lower Cook Inlet, indluding Kachemak Bay, were classified according to their environmental susceptibility to oil spills (Figure 65). Based upon the potential residence time of oil which might impinge upon the shoreline, a total of 41.5% of the shoreline was classified as having a high risk value (6-10) in which deposited oil could potentially remain in place for several to over 10 years. Shore areas within embayments would be the most severely affected by an oil spill and would have the longest oil residence time. Salt marshes and tidal flats along the west shore of the Inlet and the intertidal zone of the lower shoreline of Kachemak Bay are also considered particularly susceptible. Studies of geomorphic indicators show that the general trend of coarse-grained sediment transport by wave-induced longshore currents is primarily into both the large embayments (Kachemak and Kamishak Bays) and the smaller embayments (Figure 75). This transport increases the potential for contamination of embayed shores. Conventional oil spill cleanup procedures were deemed to be ineffective on a major portion of susceptible shorelines in Lower Cook Inlet.

Circulation - Net northward transport of clear oceanic waters entering Lower Cook Inlet was shown to occur primarily along the east side of Cook Inlet (Figure 62). Turbid, relatively fresh water, originating largely in Upper Cook Inlet, is carried out of the Inlet along the western side. A strong westward deflection of the intruding seawater occurs at the latitude of Anchor Point.

Gyre systems were found in both inner and outer Kachemak Bay. The outer Bay gyre system typically retains water within the gyres for periods of 1-2 weeks, and may be of key importance to the development and survival of commercially important shellfish larvae. Because the gyres contain tremendous numbers of larvae they are also potential hazard areas. If oil or other pollutants entered the gyre system during the spring or early summer months when larval concentrations are high the result could be the mortality of substantial numbers of larvae as they come in contact with the pollutant. The gyre system would also enhance dispersion of oil and other pollutants throughout outer Kachemak Bay, increasing the potential for contamination of shore areas.

Larval Shellfish - Outer Kachemak Bay was shown to be a major area for both release and settling of several species of commercially important shellfish larvae. Initial release of king crab and pink and humpy shrimp occurred primarily in the central and southern portions of the outer Bay. King crab larvae were primarily distributed from the central part of the Bay toward Anchor Point while humpy shrimp larvae were distributed westward toward the mid-portion of the lower Inlet. Areas of settling for king crab larvae included the entire mouth of Kachemak Bay, however, the highest density was found along the northern shore off Bluff Point.

The distribution of larvae is partially related to water movement patterns (Figure 66) and may reflect entrainment in the gyres found in outer Kachemak Bay. Larval abundance was especially high at stations within the central area of outer Kachemak Bay in the vicinity of the gyres.

An oil spill anywhere within the outer Bay could eventually disperse throughout the gyres, resulting in mixing of oil with the high concentrations of shellfish larvae. Since the larval stages are highly sensitive to low levels of oil, the result could be the reduction or elimination of an entire year class of commercially important shellfish larvae.

Shrimp - The majority of the diatoms and some of the macrophytes found in the stomachs of commercially important shrimp (pink, coonstripe and sidestripe) in Kachemak Bay are species common in the marsh/mud flat areas along the south side of Kachemak Bay. Pollution of these marsh areas by oil could have an adverse impact on the shrimp resource of Kachemak Bay by destroying potential food organisms or the productive capability of the marshes themselves.

Prediction of Pollution Transport - Prediction of pollution transport within Kachemak Bay or Lower Cook Inlet involves a number of transport mechanisms, all of which are variable with time and with location within the Inlet. The tidal stage at which a spill occurred would normally be the most significant initial variable in determination of a pollutant's trajectory. Depending on the range of the tide and the tidal stage at the time of initiation of a continuous spill, the spill could be expected to produce a surface slick 5-10 n.mi. (9.3-18.5 km) long within about 6-12 hours.

Spreading and horizontal mixing processes would also tend to enlarge the area of the spill. Surface spreading of an oil slick would be a particularly significant process in areas such as the gyres in outer Kachemak Bay where the surface slick could be retained for 1-2 weeks or more.

In the absence of winds, the net circulation will be the dominant control of long range transport. In outer Kachemak Bay, the typical net surface current velocities of 0.15-0.3 kts (7.5-15 cm/sec) (Figure 66) would carry a slick roughly 3.6-7.2 n.mi. (6.7-13.3 km)/day either within or outside of the gyres. Oil along the southern shore of outer Kachemak Bay would normally be carried eastward along the southern coast, with a high probability of coastal impingement and transport into the various embayments along the southern coast. The strong surface water outflow from inner Kachemak Bay during the spring and summer would normally prevent intrusion of surface oil into the inner Bay. However, reduction in fresh water runoff during fall and winter may greatly increase the vulnerability of the inner Bay to intrusion of surface pollutants.

The surface water outflow from inner Kachemak Bay, which flows northwest along the northern shore of the outer Bay, may provide the northeast shore with some degree of protection from impingement of oil by holding oil contaminated water offshore, however, marked separation of nearshore fresh water from the more saline offshore water is essentially a summertime (high runoff period) phenomenon. The increased suspended sediment concentrations found along the northern shore would probably enhance deposition of oil by adsorption on suspended sediments. The bottom environment along the northern shore is a critical nursery area for settling crab larvae.

Oil retention within the outer Kachemak Bay gyre system could normally be expected and would be particularly deleterious during the crab and shrimp spawning period. The highest concentrations of larvae in outer Kachemak Bay are typically found in the region of the eastern (CCW) gyre.

Surface oil transported out of Kachemak Bay would normally be carried north and northwestward in eastern Lower Cook Inlet. The major tide rips (frontal zones) in central Lower Cook Inlet (primarily the Mid-channel Rip) would probably collect a considerable amount of surface oil originating in eastern Lower Cook Inlet. Extreme mixing processes along the Mid-channel Rip would likely also sink a large proportion of oil following adsorption on suspended sediments.

Wind influence can frequently overshadow all other transport and dispersion processes and may on the average, be the single most important force effecting surface oil transport in Lower Cook Inlet. Not only does the wind have a direct influence on transport of surface oil, but the net circulation itself may be altered by persistent winds. Impingement on shore areas frequently requires some onshore wind influence on either the net circulation or the surface slick. Favorable winds (northeast, east or southeast) could sweep the Bay clear of surface oil and might preclude any significant damage within Kachemak Bay. On the other hand, winds from other directions could readily drive an oil slick ashore anywhere in outer Kachemak Bay. For example, a moderate onshore wind with a speed of 15 kts (7.7 m/sec) would cause an oil slick to drift onshore at a speed of roughly 0.45 kts (23 cm/sec). Such a wind could drive an oil slick from the central outer Bay to any shore in outer Kachemak Bay in less than 24 hours.

Due to the great variability in wind directions during all seasons of the year, and the lack of adequate offshore wind data in outer Kachemak Bay and Lower Cook Inlet, it is difficult to characterize the probability of shore impingement due to wind-induced transport. Strong north and northwesterly winds during the winter raise the probability of onshore transport in Kachemak Bay. Southerly and southeasterly winds, more frequent during the summer months, afford outer Kachemak Bay a greater degree of protection from onshore transport.

Assessment of potential oil transport, retention and shore impingement in Kachemak Bay due to an oil spill can at present by treated only in terms of general probability of occurrence. There is little doubt that outer Kachemak Bay is highly vulnerable to the spreading of oil throughout the Bay and to retention of oil within the gyre system for significant periods of time. The typical net circulation would moreover carry a surface oil slick to within at least a few miles of most of the coastline, increasing the probability of shore impingement in the presence of onshore wind transport. The potential for ecological damage would be greatest if oil was to be introduced into the southern half of the outer Bay in the spring or summer months.

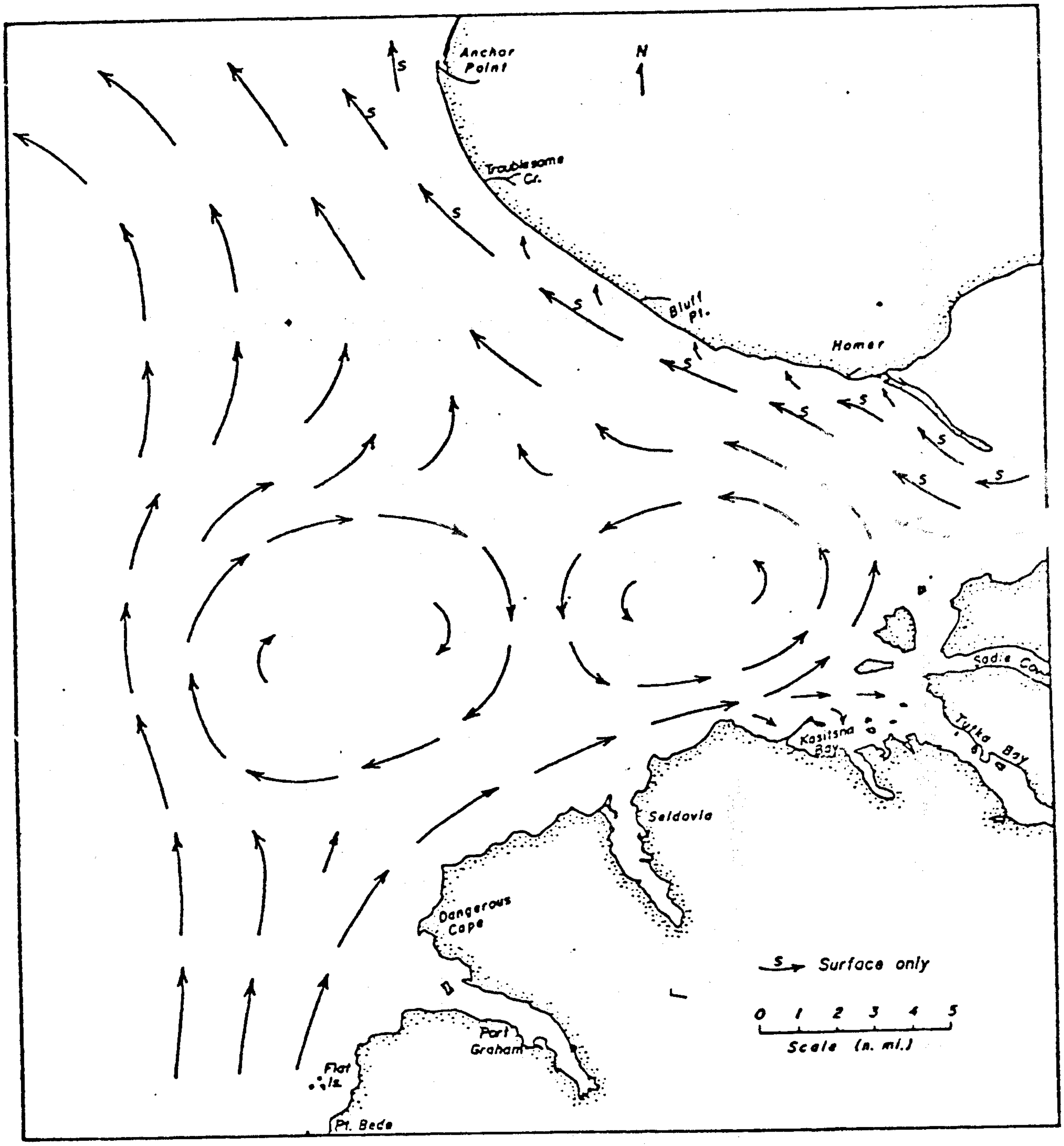


Figure 66. Net surface and subsurface (50-100 ft.; 15-30 m depth) circulation in outer Kachemak Bay. (Burbank, 1977)

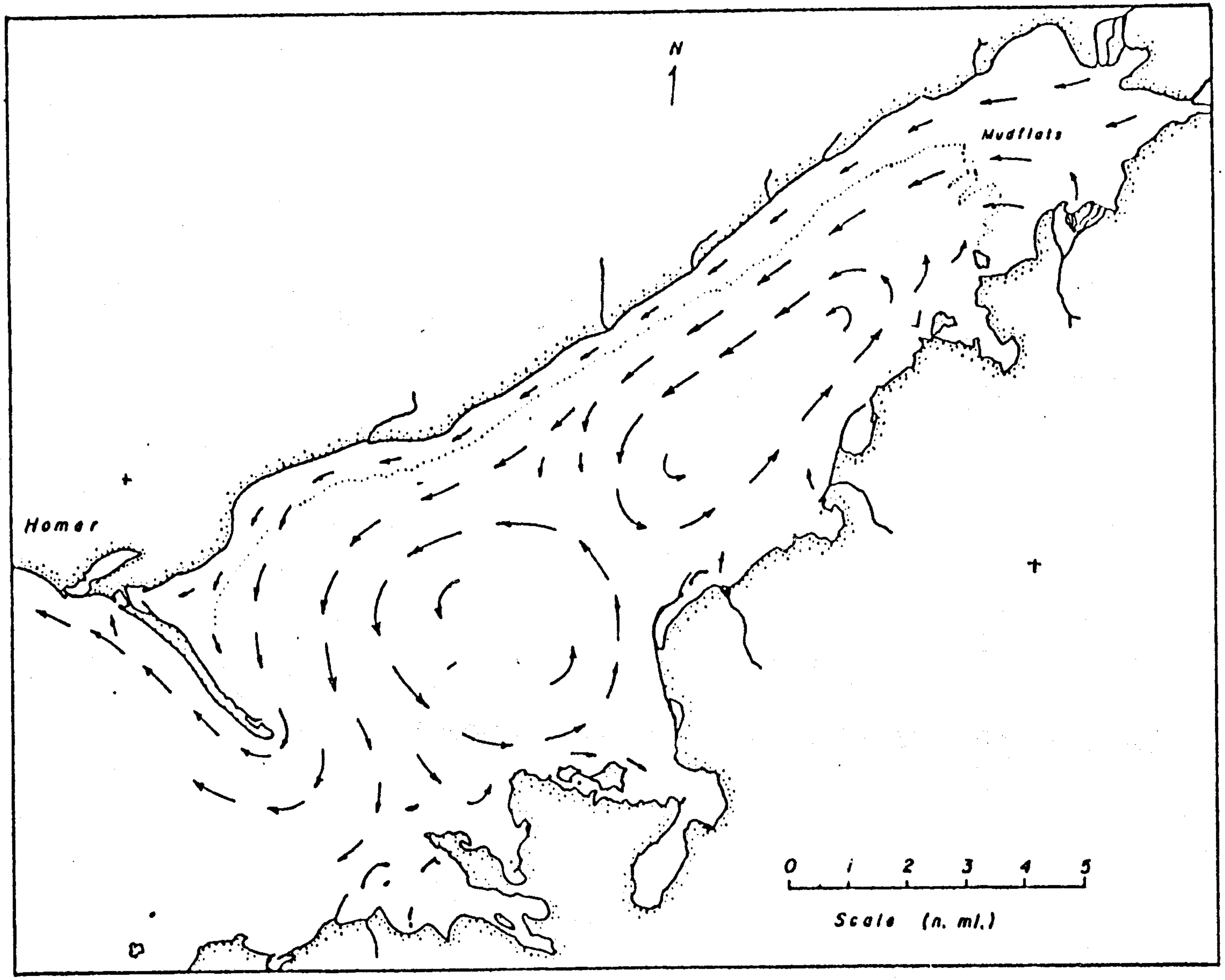


Figure 67. Surface currents in inner Kachemak Bay. (Burbank, 1977)

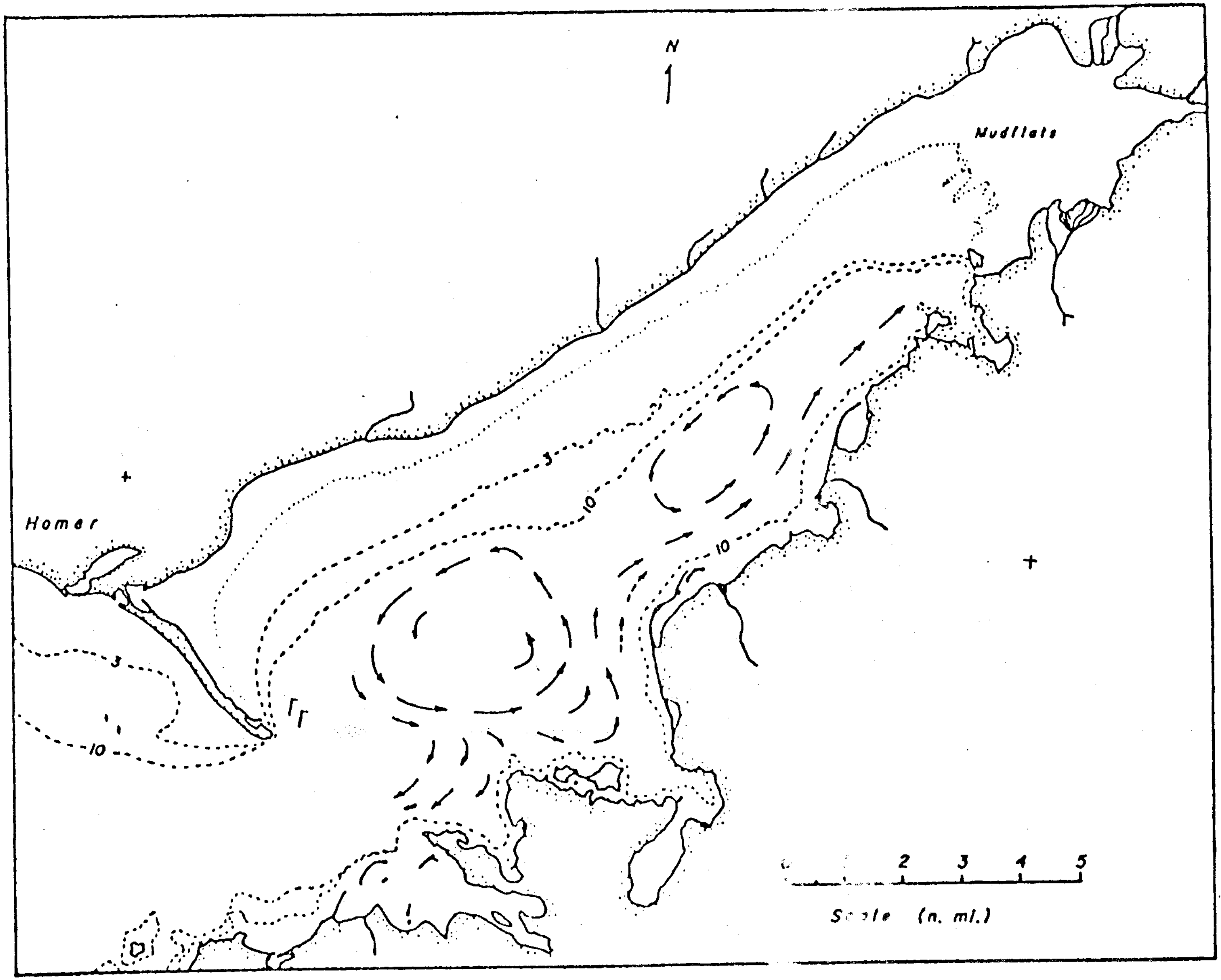


Figure 68. Subsurface (100 ft.; 30 m depth) currents n inner Kachemak Bay. Depth is in fathoms [1 fm = 6 ft. = 2 m (approx .]. Only the 3 and 10 fm depth contours are shown. (Burbank, 1977)

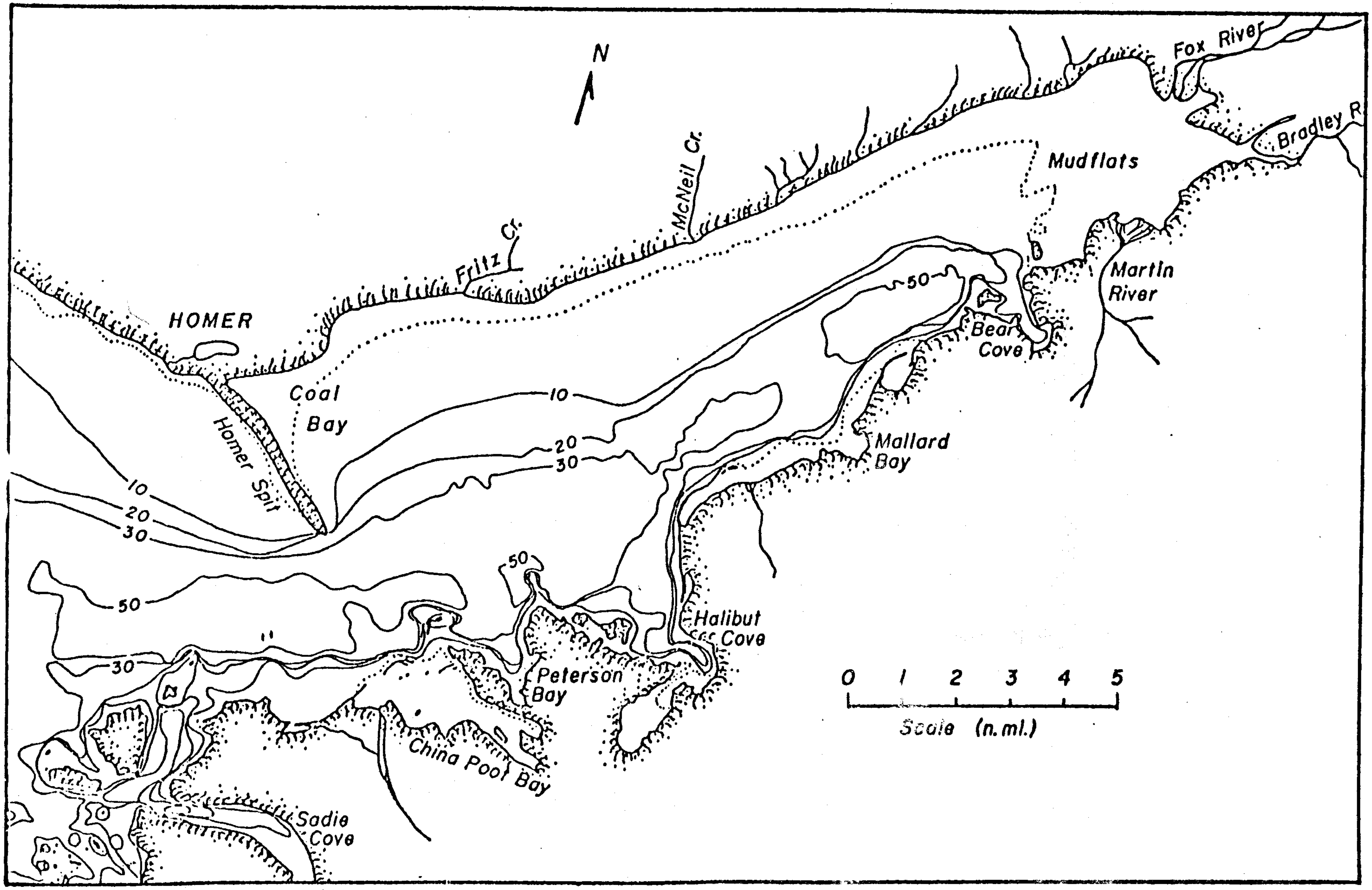


Figure 69. Bathymetry (fathoms) of inner Kachemak Bay [1 fm = 2 m (approx.)]. (Burbank, 1977)

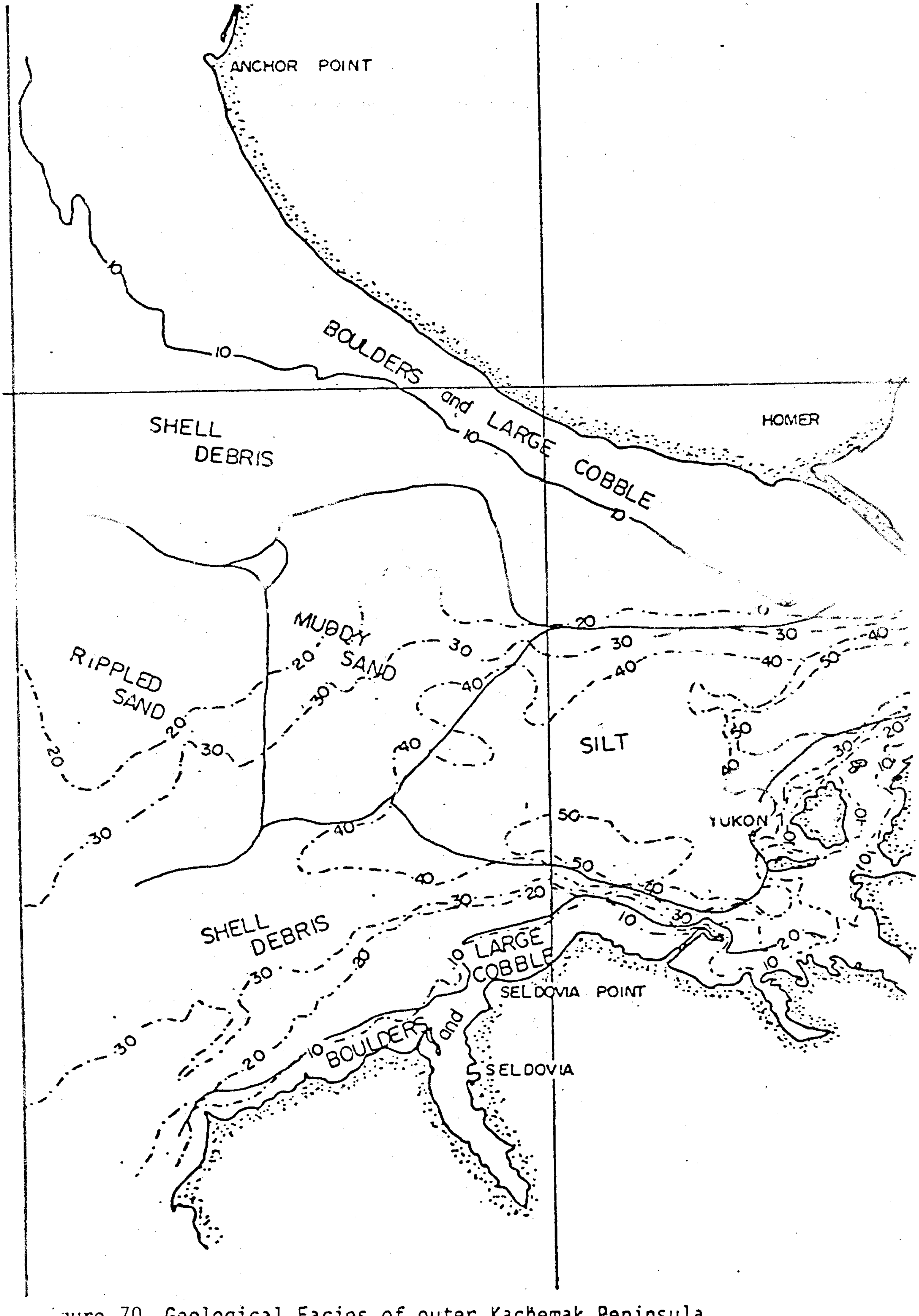


Figure 70. Geological Facies of outer Kachemak Peninsula (depth contours in fathoms) (Driskell and Dames and Moore, 1977)

CONTACT MADE WITHIN:

- ■ 1 DAY
- ⊞ 3 DAYS
- □ 6 DAYS

ALL SITES

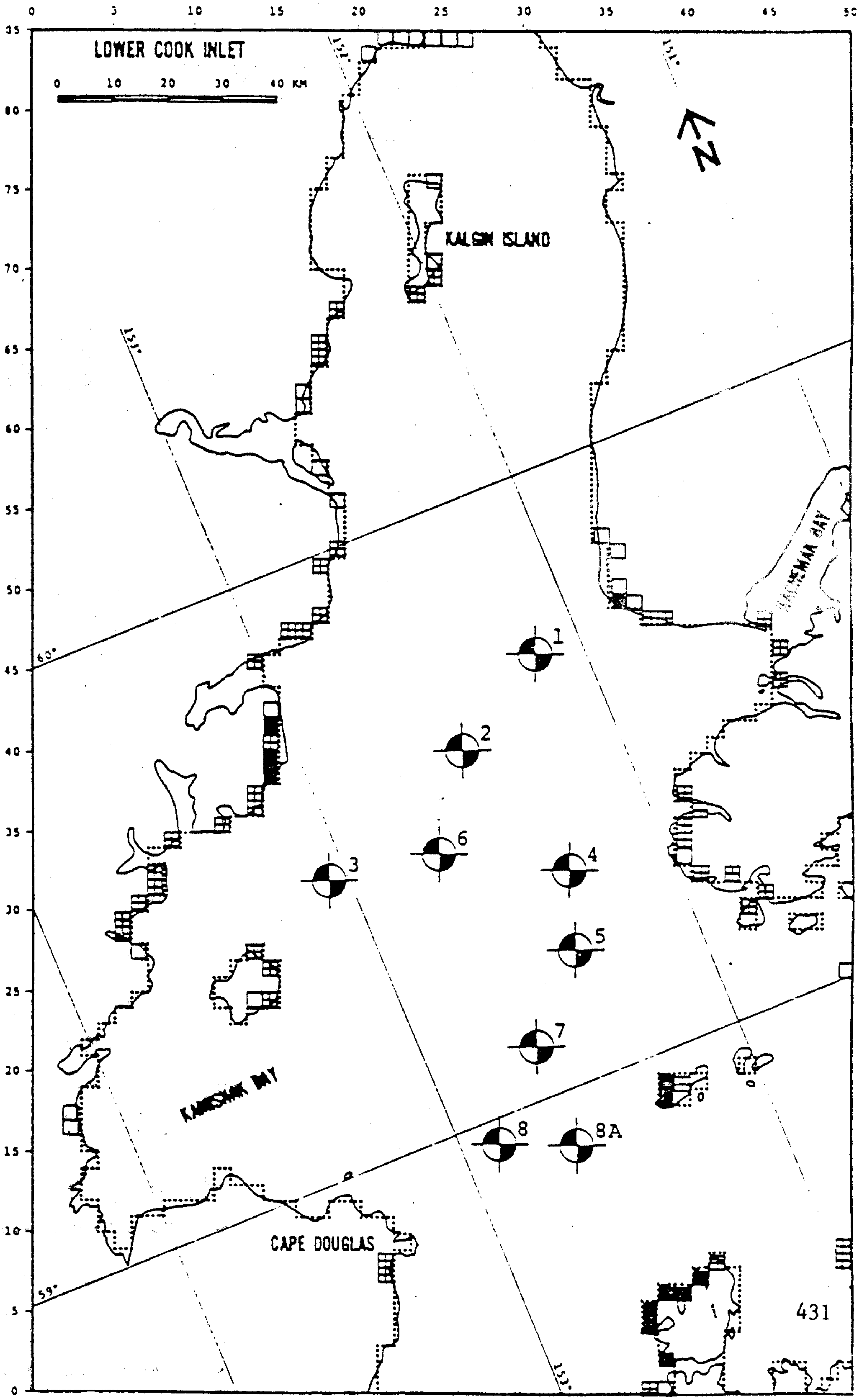


FIGURE 71 : POTENTIAL BOUNDARY CONTACT ZONES
(Dames and Moore. 1979)

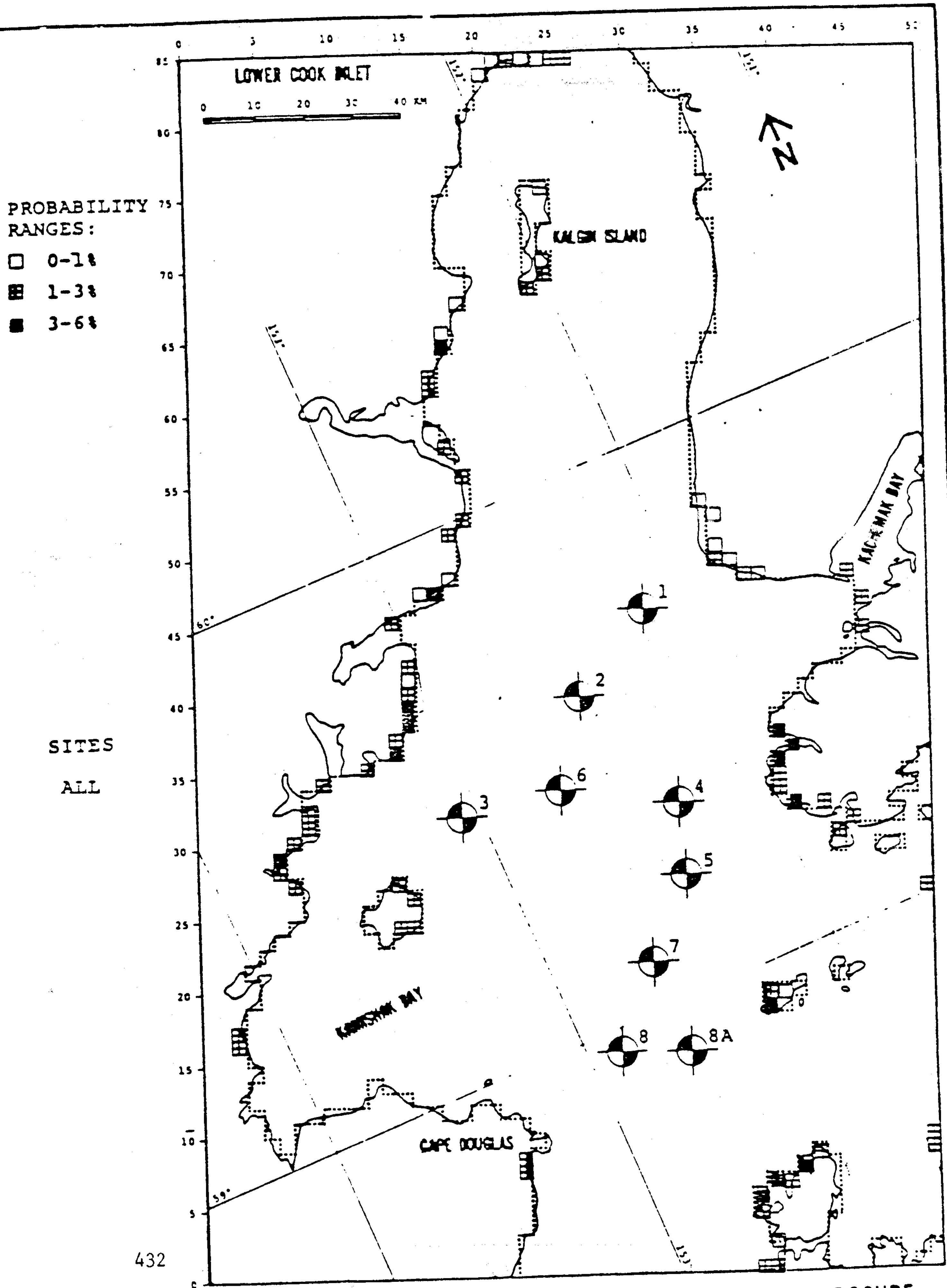


FIGURE 73 . ANNUAL PERCENT PROBABILITY OF EXPOSURE

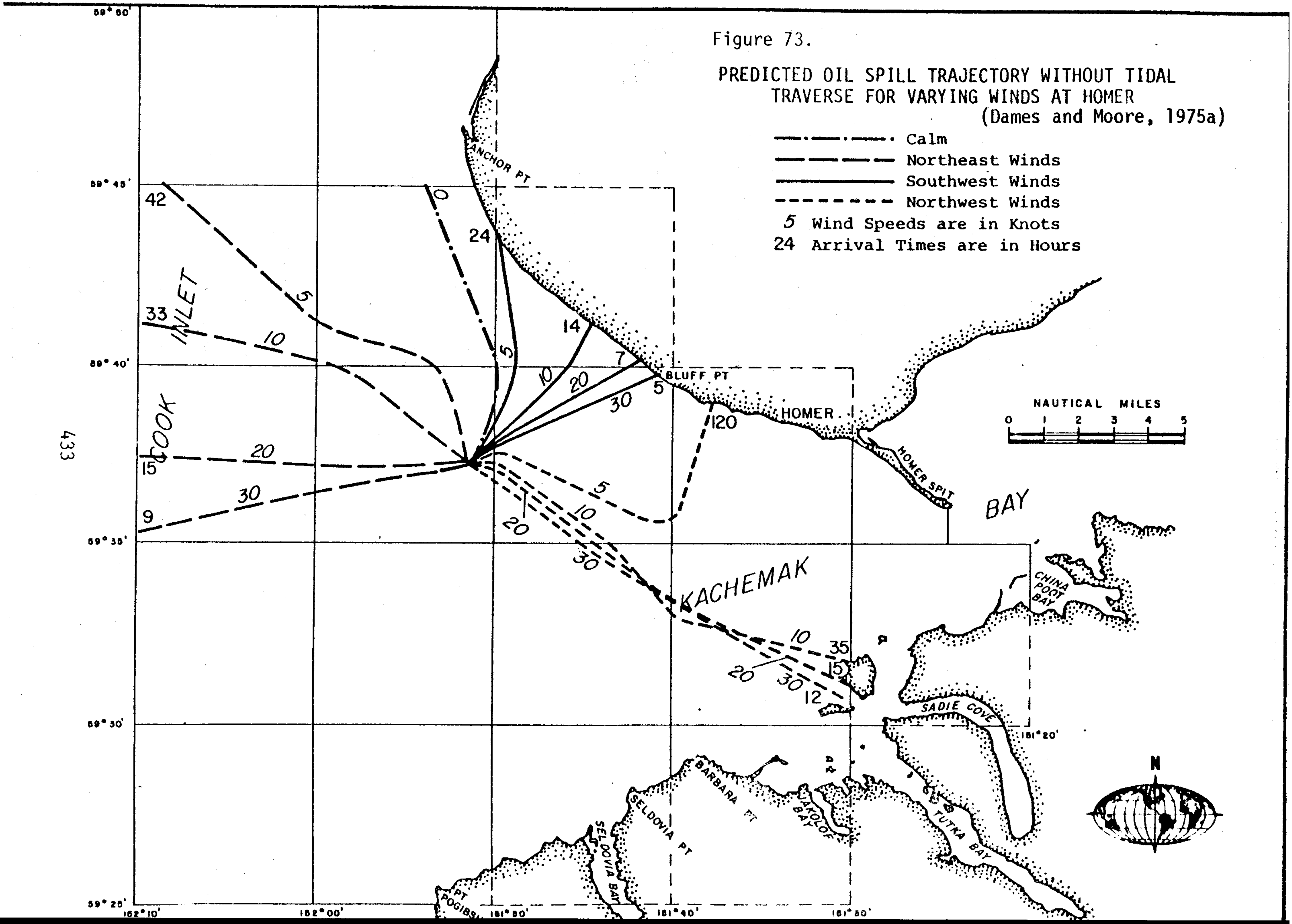


Figure 73.

PREDICTED OIL SPILL TRAJECTORY WITHOUT TIDAL TRAVERSE FOR VARYING WINDS AT HOMER (Dames and Moore, 1975a)

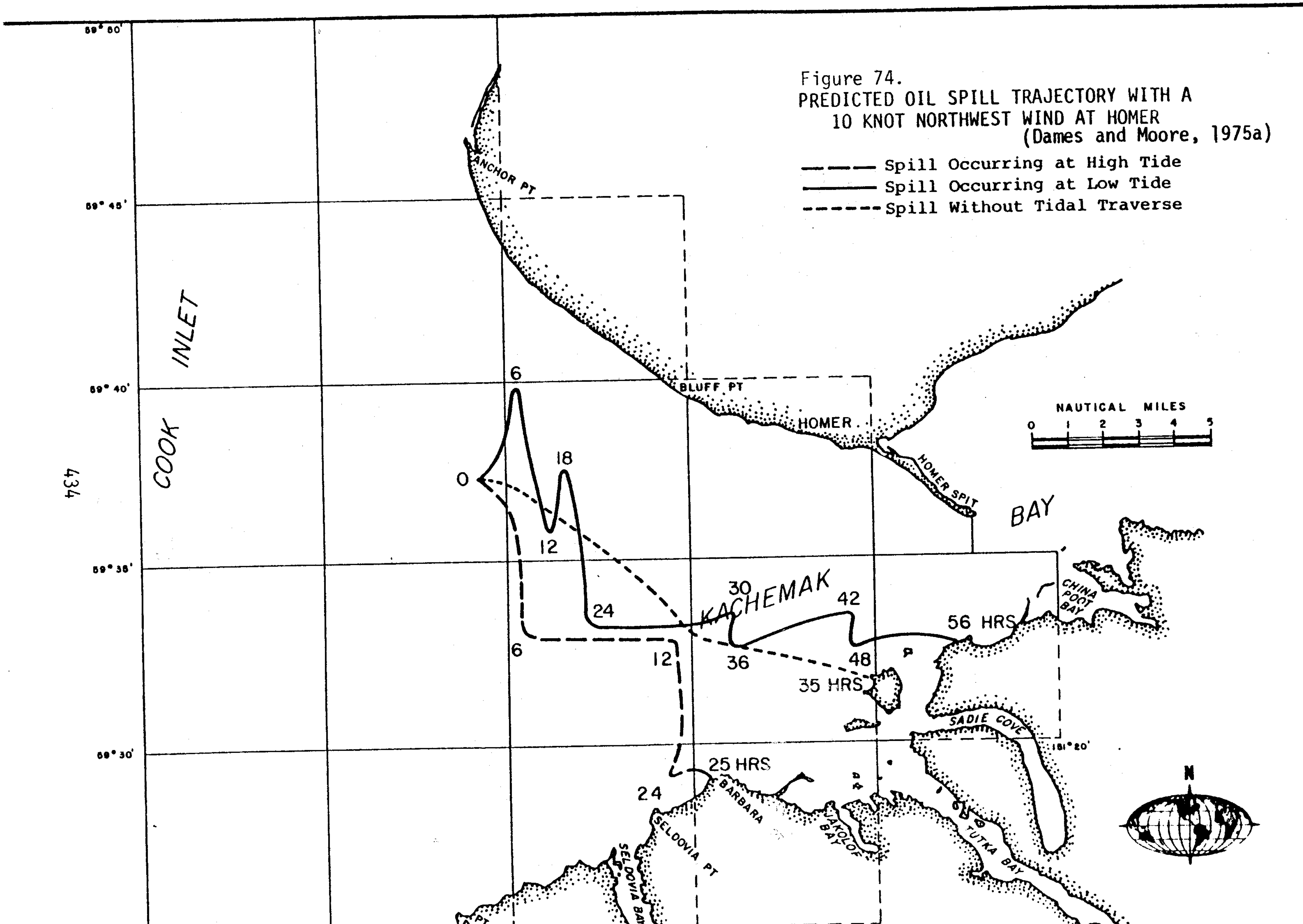


Figure 74.
PREDICTED OIL SPILL TRAJECTORY WITH A 10 KNOT NORTHWEST WIND AT HOMER
(Dames and Moore, 1975a)

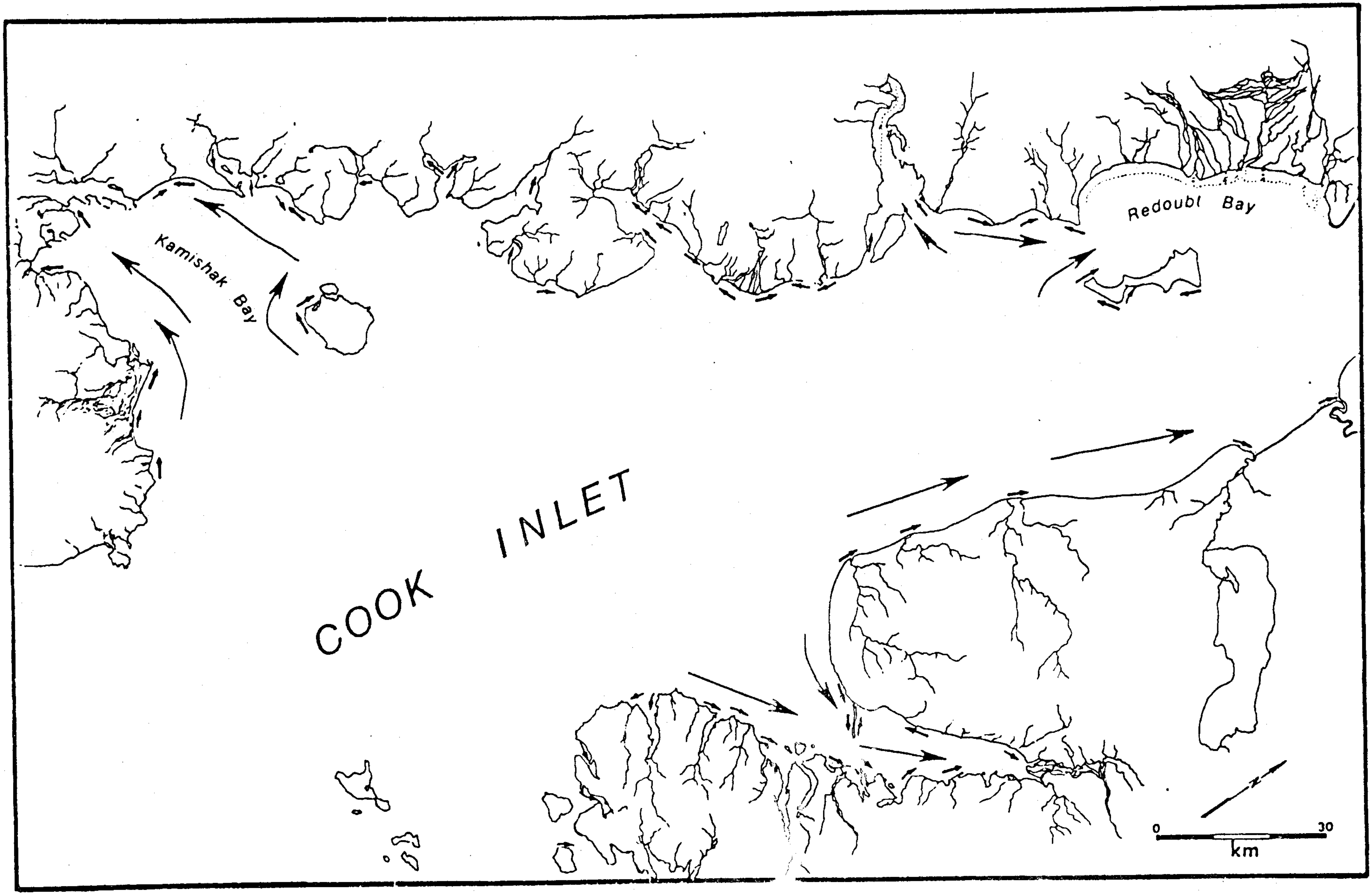


Figure 75. Longshore sediment transport patterns in lower Cook Inlet. Based on geomorphic evidence such as recurved spits, cuspate spits, and beach protuberances. (Hayes et al., 1977)

Chart III . Lower Central Zone

CIRCULATION

The Lower Central Zone primarily includes offshore waters (see Figure 61). The only shoreline area within this zone extends from approximately Oil Bay to, and including, Chinitna Bay. Therefore, most of the information regarding circulation in the Lower Central Zone is found on Chart I , Lower Cook Inlet.

Dames & Moore, 1975b

Dames and Moore studied the meterological and oceanographic effects of oil spills in Chinitna Bay, from which the following information was excerpted.

Virtually no quantitative data is available for circulation patterns in Chinitna Bay, although fishing gear and cargo lost north of Chinitna Bay and on the east side of Lower Cook Inlet have been recovered in Chinitna Bay.

Tidal currents generally flow parallel to the coastline and reverse directions approximately every six hours and traverse 6 to 12 mi during each flood or ebb tide. Tides are diurnal and maximum tidal currents are slightly greater than 3 knots during the flood and ebb tide.

Burbank, 1977

In the vicinity of Anchor Point surface and subsurface waters are transported westward. As they move offshore, the currents turn southwestward toward Kamishak Bay. Apparently, a gyre exists about 15 n. mi (28 km) westsouthwestward of Anchor Point (Figure 62).

The currents north of Anchor Point move in a north-northwestward direction.

Dames & Moore, 1979

The net current field in the middle portion of Lower Cook Inlet west of Kachemak Bay is relatively well defined compared to the southern portion of the Inlet.

TIDAL RANGE

Dames & Moore, 1975b

The tidal range and beach slope determine the areal extent of beach that may be affected by surface oil. Tides in the Chinitna Bay area are composed of diurnal and semi-diurnal components, both of which have a strong influence on tidal phase and amplitude. A summary of tidal datum for Chinitna Bay and adjacent waters is provided in Table 49 .

Table 49. SUMMARY OF TIDAL DATUM NEAR CHINITNA BAY

Datum	Iniskin Bay[a] Elevation (feet)	Chinitna Bay[b] Elevation (feet)	Snug Harbor[c] Elevation (feet)
Estimated Higher Water	20.0	20.0	21.0
Mean Higher High Water	14.5	14.4	15.7
Mean High Water	13.7	13.6	14.9
Mean Tide Level	7.6	7.5	8.3
Mean Low Water	1.4	1.4	1.7
Mean Lower Low Water	0.0	0.0	0.0
Estimated Lowest Water	-5.0	-5.0	-6.0

(a) Lat. 59°40.8'; Long. 153°23.8'
(b) Lat. 59°50.3'; Long. 153°00.0'
(c) Lat. 60°06.2'; Long. 152°34.3'

BATHYMETRY

Muench et al., 1978

Depths in the Lower Central Zone are variable, ranging from approximately 10 to 40 fathoms (Figure 64).

SUSPENDED SEDIMENTS

Dames & Moore, 1975b

The surface waters near Chinitna Bay are relatively clear. A geophysical survey conducted in this area during late August of 1975 measured surface visibility at 15 to 18 feet. According to Burbank (1974) surface suspended sediment loads in the nearby offshore regions ranged from 10 to 40 mg/l. Nearshore waters may exhibit relatively higher suspended sediment concentrations primarily due to inflows from silt-laden, glacier-fed streams such as Red River, and the East, Middle and West Glacier Creeks. Burbank (1974) also reports that nearshore waters may have increased turbulent mixing and thus higher sediment loads. This nearshore turbid zone may enhance the attachment and deposition of oil if it moves toward shore.

Feeley & Cline, 1977

The distribution of suspended matter from Kachemak Bay to Kamishak Bay in Lower Cook Inlet indicates that suspended matter concentrations are lowest in the center of Cook Inlet with particulate concentrations increasing rapidly near the coast, especially in the vicinity of Kamishak Bay. Particulate concentrations are uniform with depth throughout most of the region which suggests that the water column is vertically mixed. This is supported by the temperature and salinity distributions which are also uniform with depth. Apparently, the turbulence which is caused by tidal mixing is sufficient to keep the water column well mixed with respect to suspended matter.

BOTTOM TYPE

Sharma & Burrell, 1970

Sediments in the Lower Central Zone are primarily gravelly sand with minor silt and clay components (Figure 63).

WINDS

Dames & Moore, 1975b

The Chinitna Bay area is exposed to strong offshore winds from the northern, western and southern sectors and from the drainage winds of Mt. Iliamna. Winds are generally from the north, northeast, south and southwest. Maximum monthly wind speed is 10-15 knots. A 10-year extreme 1 minute wind speed is calculated to be 67 knots.

VULNERABILITY OF LOWER CENTRAL ZONE TO OIL SPILLS

Dames & Moore, 1979

A study by Dames & Moore was initiated to provide information on shoreline areas that would probably be impacted by hypothetical oil spills fron nine selected locations in Lower Cook Inlet. These sites correspond to recently leased tracts and probable future pipeline locations. The analysis was based primarily on an oil spill trajectory model with winds and net and tidal currents being the environmental factors affecting the spill. According to the study the shoreline on the west side of Lower Cook Inlet from Iliamna Bay northward to Chinitna Bay is a critical impact area both in terms of the amount of time for an oil spill to impact the coastline and the annual probability of exposure to an oil impact (see Figure 71). Anchor Point, on the east side of the Inlet, was considered an area of concern, although to a lesser degree. Figure 72 shows that oil would impact most of the western shoreline of the Lower Central Zone within 1 to 3 days and the probability that a spill could occur at any one of the potential oil spill sites was primarily 1-3% or 3-6%.

Hayes et al., 1977

Most of this coastline has a risk rating of 1-2 or 2-4 (Table 47 and Figure 75) although the heads of bays, such as Chinitna Bay, where salt marshes and tidal flats are located, have a risk rating of 8-10 which would subject areas to long term oil spill damage.

Dames & Moore, 1975b

This study by Dames & Moore, used to assess the behavior of a potential oil spill at the proposed drilling site of Phillips Petroleum Company just east of Chinitna Bay, showed that with a strong onshore wind, it would be possible for oil to reach the shore within several hours. Winds from a western direction will tend to propagate the oil further offshore while winds from an eastern direction will force the oil toward shore. Figures 76 , 77 , 78 and 79 show movement of oil from a spill occuring at low and high tide with winds from the northeas and southeast at 5 and 20 knots. Tidal currents generally flow parallel to the coastline, reverse directions approximately every six hours and traverse 6 to 12 miles during each flood or ebb tide.

If an oil spill occurs at high tide with onshore wind conditions, the orientation of Chinitna Bay is such that the net surface drift may carry the spill into the Bay and onto the beaches.

Suspended sediments present in the offshore area of Chinitna Bay may contribute to the formation of oil and sediment particles in which oil is absorbed to the sediment and the mixture sinks into the water column or onto the bottom substrate, thus contaminating it.

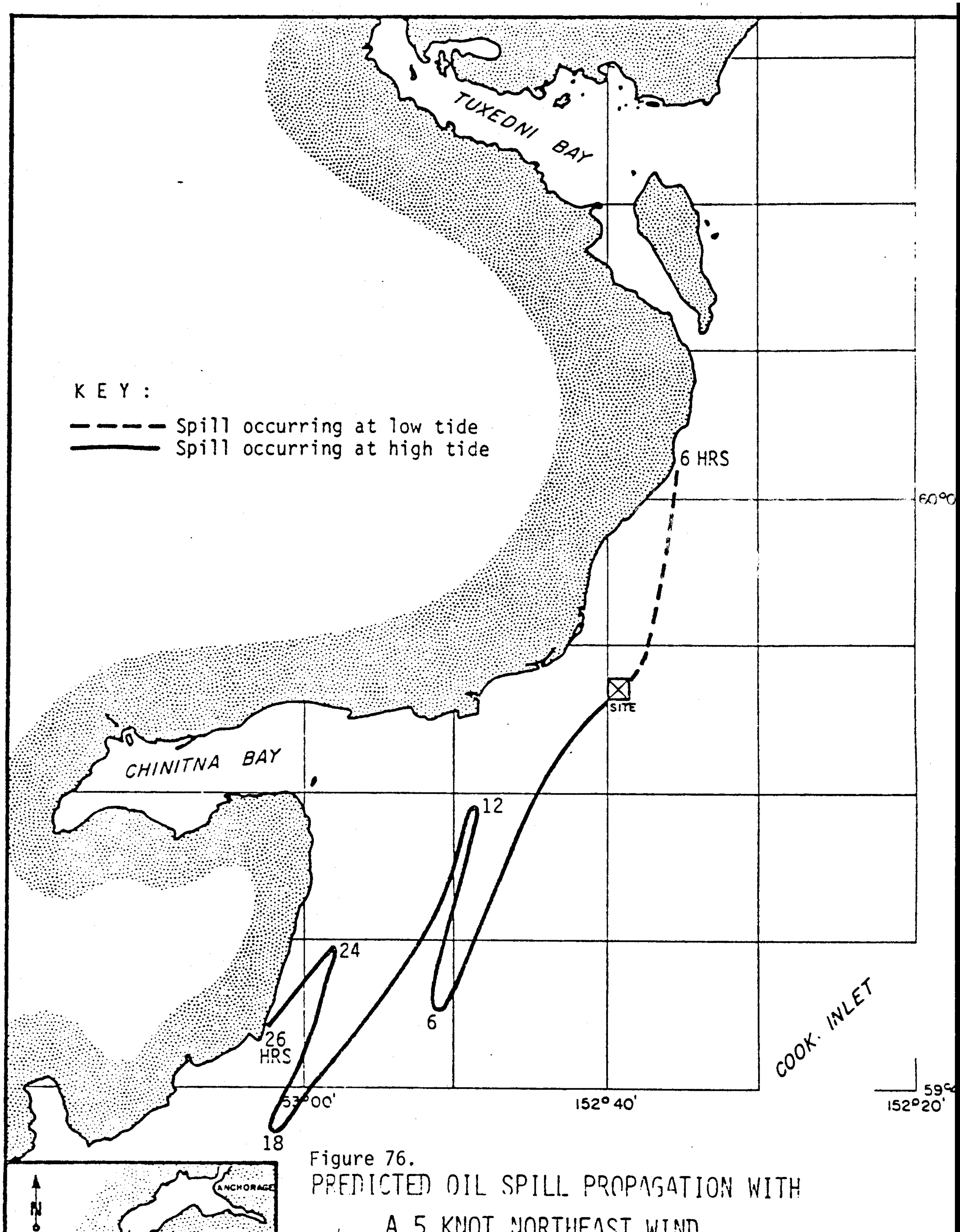


Figure 76.
PREDICTED OIL SPILL PROPAGATION WITH
A 5 KNOT NORTHEAST WIND
(Dames and Moore, 1975b)

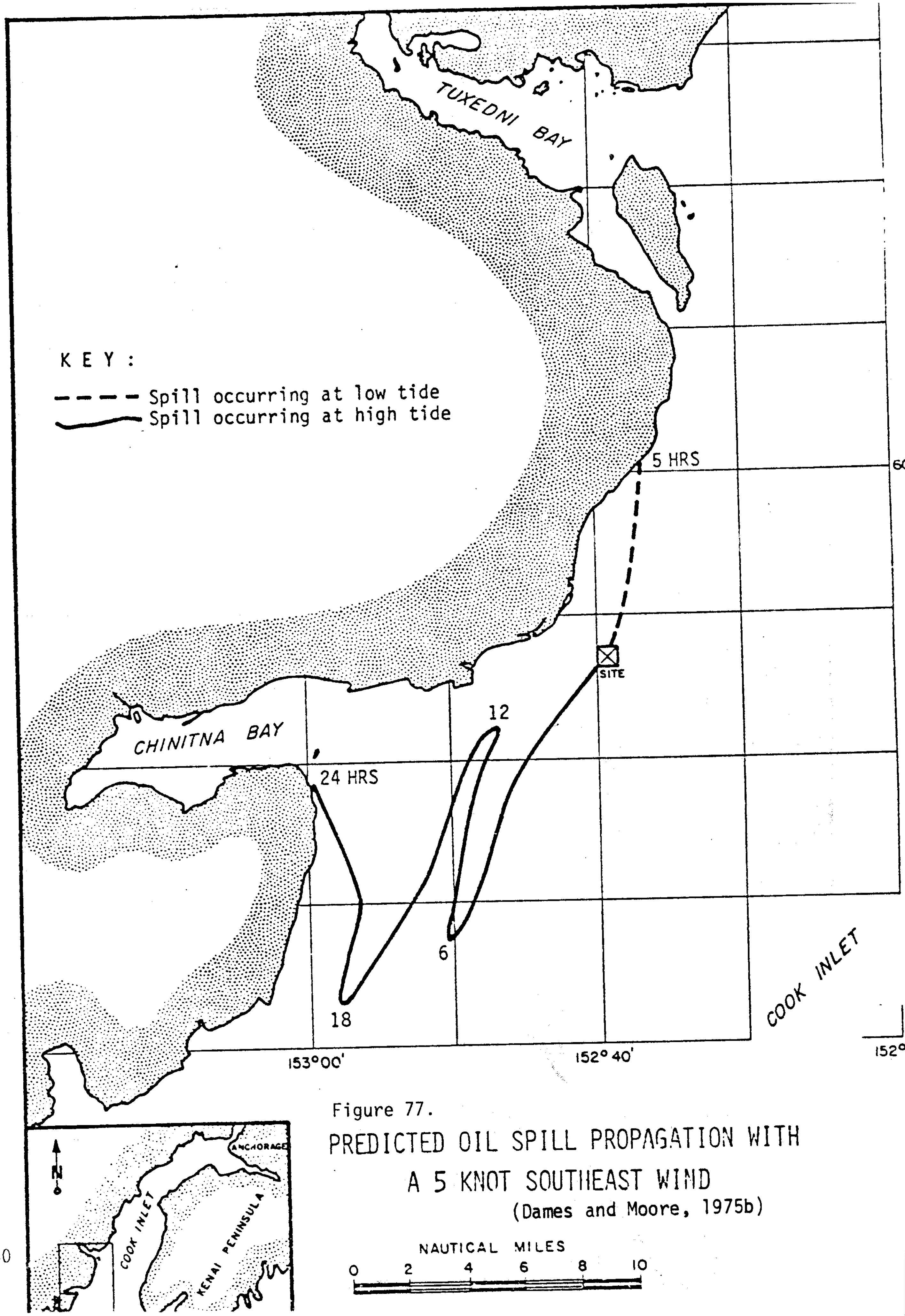
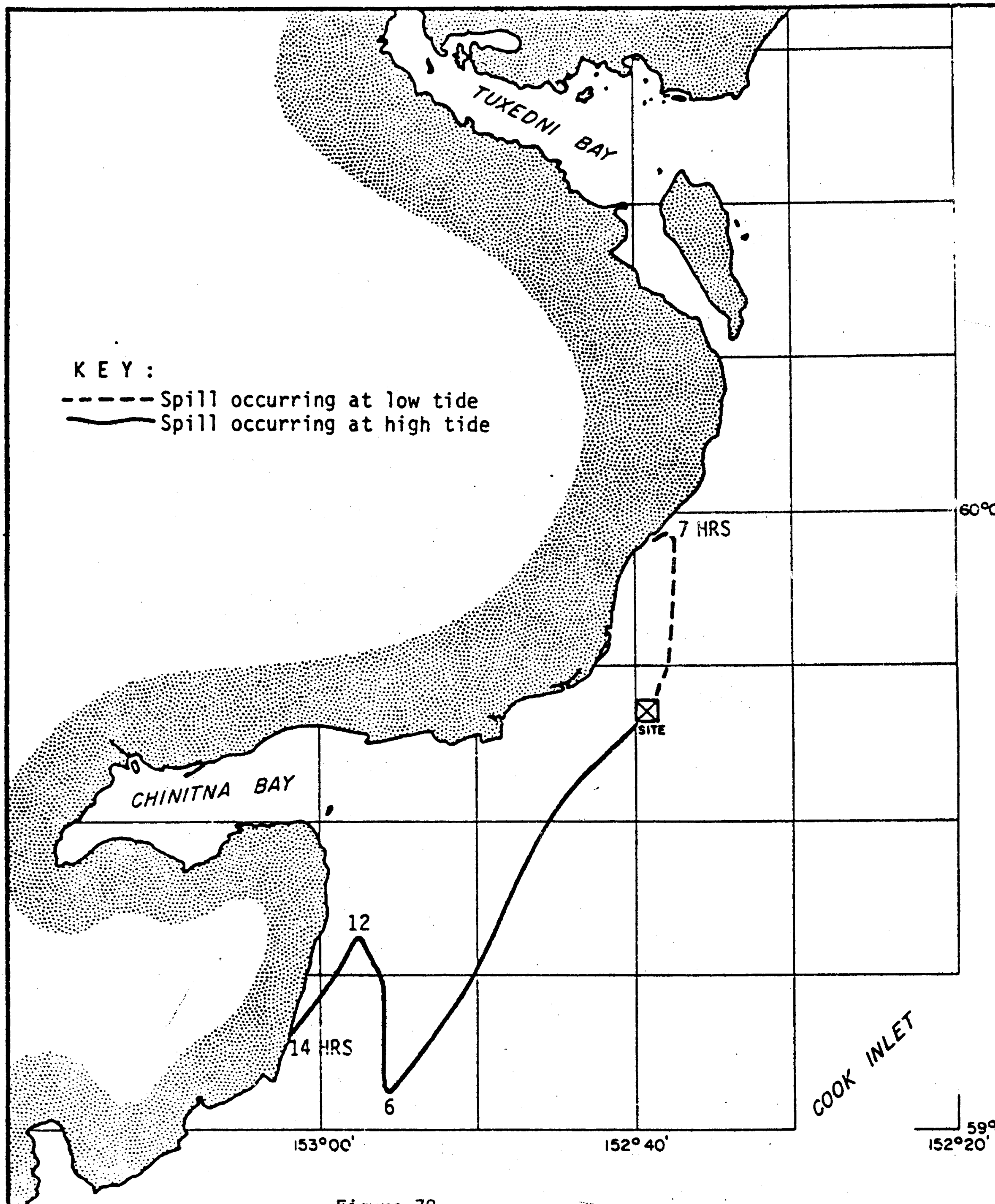


Figure 77.

PREDICTED OIL SPILL PROPAGATION WITH A 5 KNOT SOUTHEAST WIND

(Dames and Moore, 1975b)



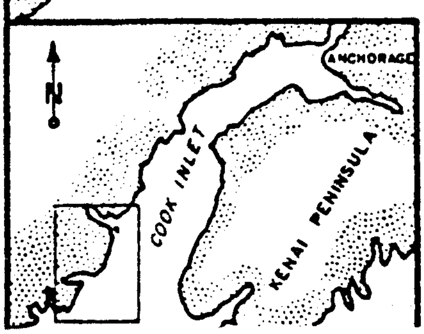


Figure 78.
PREDICTED OIL SPILL PROPAGATION WITH
A 20 KNOT NORTHEAST WIND
(Dames and Moore, 1975b)

NAUTICAL MILES
0 2 4 6 8 10

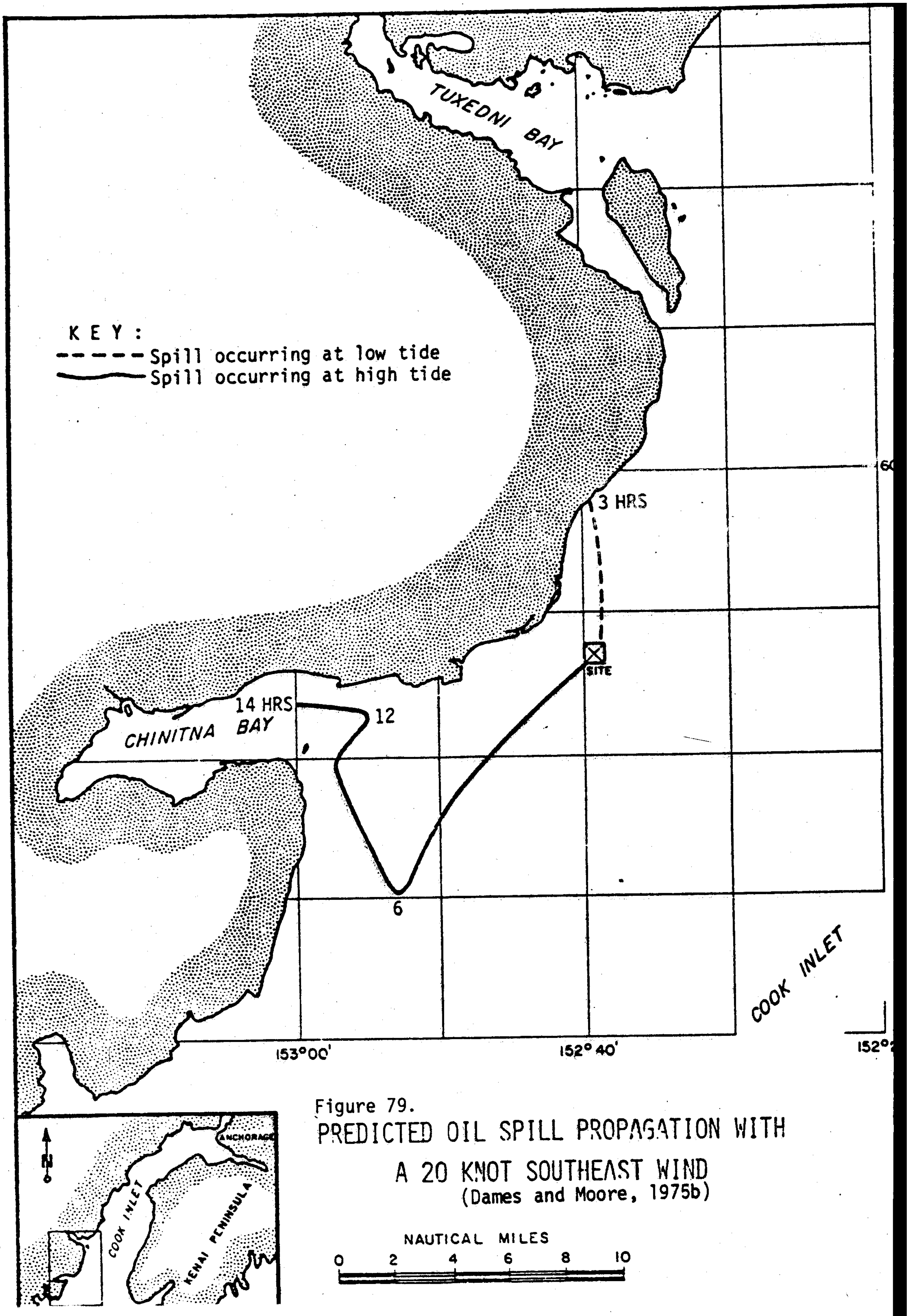


Figure 79.
PREDICTED OIL SPILL PROPAGATION WITH A 20 KNOT SOUTHEAST WIND
(Dames and Moore, 1975b)

Chart IV . Kamishak Bay

CIRCULATION

Refer to the discussion of general circulation in Lower Cook Inlet on chart 61 , Lower Cook Inlet for information regarding circulation patterns in Kamishak Bay.

Dames & Moore, 1979

Net currents in Kamishak Bay are generally weak but appear to be relatively stable.

Burbank, 1977

Fishermen, aircraft pilots and others familiar with Lower Cook Inlet all conclude that debris accumulated by the Mid-channel Rip is eventually carried south into Kamishak Bay where significant amounts of this debris are deposited on Amakdedori Beach. Barnacle-encrusted and abraded debris typical of the Mid-channel Rip, however, is also found washed ashore in the Kenai area following strong westerlies, therefore it is reasonable to assume that this debris may be carried ashore elsewhere in Lower Cook Inlet by storm winds from appropriate directions.

As the Mid-channel Rip debris collection and other debris in western Lower Cook Inlet is carried south into Kamishak Bay, significant amounts of this debris accumulate offshore in apparent eddies or gyres north and south of Augustine Island.

In addition to the two aforementioned possible gyres in Kamishak Bay, directions of drift-boat set on flood and ebb tide in the northernmost area of Kamishak Bay suggest a third (clockwise) gyre in this vicinity, however, supporting data is sketchy. No debris accumulations have been reported offshore in this northernmost area of northern Kamishak Bay.

The patterns of debris and suspended load distribution suggest a combined process of a weak extension of the frontal zone (Mid-channel Rip) into Kamishak Bay, accompanied by gyres north and south of Augustine Island. It is emphasized that the three gyres shown in Kamishak Bay are suggested only through indirect evidence and further study is necessary to substantiate their presence.

U.S. Coast Pilot 9, 1977

In the north part of Kamishak Bay, the currents follow the coast, flooding northeast and ebbing southwest at a rate of about 1 knot. The current is more noticeable near the shore. With a strong wind, tide rips occur about 2 to 4 miles north of Chinitna Point.

TIDAL RANGE

Specific tidal data for Kamishak Bay is unknown. Refer to Chart I , Tidal Range, Lower Cook Inlet for a general description of tides in Lower Cook Inlet.

SUSPENDED SEDIMENTS

Burbank, 1974

No size distribution data are available for bottom sediments in Kamishak Bay, althouth the extensive mudflats indicate that a significant amount of the finer, suspended material carried from Upper Cook Inlet is deposited in Kamishak Bay. A narrow and diminished plume of suspended sediments passes out of Kamishak Bay and into Shelikof Strait along the western shore.

Feeley & Cline, 1977

On the west side of Cook Inlet, the outflowing turbid water containing particulate matter ranging in concentrations from 5 to 200 mg/l is transported past Augustine Island into Kamishak Bay, where a portion of it settles out. The remaining suspended material is transported around Cape Douglas into Shelikof Strait and is dispersed.

BATHYMETRY

Muench et al., 1978

Water depths in Kamishak Bay range from 10 to 20 fathoms (Figure 64).

BOTTOM TYPE

Burbank, 1974

No size distribution data are available for bottom sediments in Kamishak Bay, although the extensive mudflats indicate that a significant amount of the finer, suspended material carried from Upper Cook Inlet is deposited in Kamishak Bay. A narrow and diminished plume of suspended sediments passes out of Kamishak Bay and into Shelikof Strait along the western shore.

Shaw & Lotspeich, 1977

This study was conducted to determine the amounts and types of hydrocarbons present in three selected locations in Lower Cook Inlet. The intertidal region of one of these areas, Douglas Bay, was found to have bottom sediments consisting of fine sand. Sands generally do not retain hydrocarbons as readily as do silts and clays.

WINDS

Refer to Chart I , Lower Cook Inlet, Winds for a general discussion of wind patterns. Specific data is not available.

VULNERABILITY OF KAMISHAK BAY TO OIL SPILLS

Dames & Moore, 1979

This oil spill trajectory study showed that the coastline from Iliamna Bay (the northern side of Kamishak Bay) to Chinitna Bay was a critical area due to both the short time that it would take oil to contact the shoreline (primarily 1 to 3 days) and the probability of oil from a spill impacting this area (1 to 3% and 3-6%) (See Figures 71 and 72). Augustine Island, located in Kamishak Bay, is also an area of concern but to a lesser degree than the critical areas.

The model did not show the shoreline areas of Kamishak Bay being greatly impacted by oil apparently because only one oil spill site located in the central portion of Lower Cook Inlet below Augustine Island was used in the model. If more than one site would have been considered in this area, there might have been more impact on Kamishak Bay. Wind from the east could drive a trajectory directly into Kamishak Bay if the spill site were located in the central portion of Lower Cook Inlet, reasonably close to and slightly south of Augustine Island.

ADF&G, 1978b

Drift card and bottle trajectories have shown that Kamishak Bay, especially between Ursus Cove and Amakdedori Beach, and Augustine Island are particularly susceptible to pollution from most areas in Lower Cook Inlet. Lease tracts northeast of Augustine Island pose the greatest threat to Kamishak Bay.

Hayes et al., 1977

The majority of shoreline in the Kamishak Bay region has a risk rating of 8-10, which is the highest rating. Coastal areas would be subject to long term oil damage. The majority of the remaining coastline is rated 2-4, and a few areas are ranked 4-6 and 6-8. Augustine Island is rated as 2-4. (See Figure 65 and Table 47 for explanation of risk ratings.)

The circulation pattern of Lower Cook Inlet is such that oil would probably be selectively transported into the Kamishak Bay area (Figure 75). Northerly and easterly winds would augment this pattern. The accumulation of tremendous quantities of flotsam in the Kamishak Bay region supports this assumption.

Chart V . Kennedy Entrance

Circulation

Refer to Chart I , Lower Cook Inlet, Circulation for general description of waters entering Cook Inlet through Kennedy Entrance.

Burbank, 1977

A large proportion of the seawater influx through Kennedy Entrance proceeds northward up the east side of the inlet (Figure 62). Some westward transport may occur immediately after passage through Kennedy Entrance, however, circulation between Augustine and the Barren Islands is poorly understood, although there is some indication that circulation may be very sluggish in part of this region. Coastal divergency or upwelling along the tip of the Kenai Peninsula northwest of the Chugach Islands diverts the inflowing Gulf of Alaska surface water offshore such that outer Kachemak Bay is largely bypassed. Surface water entering outer Kachemak Bay is comprised primarily of this upwelled water. The upwelled water, together with relatively fresh surface waters discharged from inner Kachemak Bay, is eventually carried out of Kachemak Bay along the northeast shore and continues north as far as Cape Starichkof.

Dames & Moore, 1979

The net current field in the Kennedy Entrance area is quite variable.

U.S. Coast Pilot 9, 1977

Currents in Kennedy Entrance have a velocity of 2 to 3 knots and generally do not exceed 4 knots. Tidal current velocities in the Barren Islands are estimated at 2-3 knots.

TIDAL RANGE

Refer to Chart I , Lower Cook Inlet, Tidal Range, for a general dsicussion of tidal range.

SUSPENDED SEDIMENTS

Feeley & Cline, 1977

Gulf of Alaska water, flowing into the east side of Cook Inlet through Kennedy Entrance, is relatively nonturbid having suspended matter concentrations ranging between 0.5 and 5.0 mg/l.

BATHYMETRY

Muench et al., 1978

Water depths in the vicinity of Kennedy Entrance range from 50 to 70 fathoms (Figure 64).

BOTTOM TYPE

Sharma & Burrell, 1970

The portion of the Kennedy Entrance area which is located north of a line drawn between the Chugach Islands and the Barren Islands (Figure 63) has bottom sediments composed of sand with variable amounts of gravel and silt-clay.

Shaw & Lotspeich, 1977

Koyuktolik Bay (Dogfish Bay) have bottom sediments composed of fine sand and silt.

WINDS

VULNERABILITY OF KENNEDY ENTRANCE TO OIL SPILLS

Dames & Moore, 1979

The study showed that the coastline from Dangerous Cape to Cape Elizabeth and the shorelines of the Barren Islands were critical areas from the nine potential oil spill sites selected for the model. According to the model, both areas would be impacted by the spill within 1 to 3 days, with a probability range of 1 to 3% or 3 to 6% (Figure 71 and 72). Trajectories from site 5, west of the Chugach Islands, were shown to impact the Chugach Islands. Trajectories from sites 7 and 8A were shown to extend into the Gulf of Alaska. Therefore, possibility of exposure to oil spills is seen on the eastern side of the Kenai Peninsula as well as Kodiak Island.

Hayes et al., 1977

Much of the coastline in the Kennedy Entrance is rated having a 1-2 or 2-4 risk rating (Figure 65 and Table 47). These areas are generally low risk areas where oil can be removed by wave erosion. Oil may be retained in these areas where gravel beaches occur, where depositional berms exist, and where low tide gravel and boulder terraces are found. Burial of oil is possible on beach faces. High risk (8-10) areas are found in Chugach Bay, Port Chatham and at the head of Koyuktolik (Dog Fish) Bay. Salt marshes and tide flats in these areas are subject to long term oil spill damage.

Chart VI . Kalgin Island Area

CIRCULATION

Refer to Chart I , Lower Cook Inlet, Circulation, for discussion of circulation in Lower Cook Inlet which also includes information on the movement of water in the Kalgin Island Area.

U.S. Coast Pilot 9, 1977

The tidal currents at the entrance to Cook Inlet have an estimated velocity of 2 to 3 knots, and in general increase up the inlet. Very large velocities have been measured in the vicinities of Harriet Point and the East and West Forelands and the entrances to Knik and Turnagain Arms. The current velocity was measured by the survey ship McARTHUR at 5 knots near the East and West Forelands, and it is estimated that the velocity of the current during a large tide is as much as 8 knots between East and West Forelands and probably more between Harriet Point and the southern end of Kalgin Island.

The currents on either side of Kalgin Island reach a velocity of 3 to 4 knots at times.

In Tuxedni Channel, the current floods northwest at a velocity of 1.1 knots and ebbs south at a velocity of 1.9 knots.

The currents are very swift at Harriet Point, exceeding 5 knots on large tides. With southern breezes dangerous tide rips occur between Harriet Point and Kalgin Island, extending some distance south.

In general, the direction of the current is approximately parallel to the trend of the nearest shore and, when flats are uncovered, parallel to their edges. Off the various bays a set may be expected, toward the bay on a flood current and from the bay on an ebb current.

TIDAL RANGE

U.S. Coast Pilot 9, 1977

The diurnal tidal range at Tuxedni Channel is 16.6 feet.

SUSPENDED SEDIMENTS

Feeley & Cline, 1977

On the eastern side of Lower Cook Inlet the inflowing Gulf of Alaska water has suspended matter concentrations ranging between 0.5 and 5.0 mg/l. On the western side of the Inlet, the outflowing turbid water, which contains mechanically abraded rock debris from Upper Cook Inlet and has particulate concentrations ranging from 5.0 to 200 mg/l, is transported past Augustine Island to Kamishak Bay, where a portion of the suspended material settles out. The remaining material is transported around Cape Douglas into Shelikof Strait and is dispersed.

Burbank, 1974

Clear seawater enters Cook Inlet from the east where it is carried into the Inlet mouth by the westward flowing Alaska Current. Driven by the tidal flux and Coriolis force, this water works its way up the lower Inlet along the eastern shore. In the region of the Forelands, basin geometry jets the flooding seawater to the west side of the Inlet to produce a net clockwise gyre in the region bounded by the East, West and North Forelands. This gyre appears to break down north of the North Forelands into a roughly northeast-southwest pulsation.

Fresh water input from the turbid Knik Arm and relatively clear Susitna River waters are partially mixed in the upper Inlet and carried in a general southwestward direction on the ebb tide. Although the outflow of turbid fresh water must certainly intrude into the region of relatively clear seawater between the North and West Forelands, the outflow in this area is apparently not as great as the inflow on the flood tide. This results in a net outflow of turbid fresh water on the east side of the upper Inlet.

The region between the East and West Forelands and Kalgin Island appears to have a highly variable circulation pattern, depending on the state of the tide. It seems to be an area of extreme mixing of outflowing turbid fresh water and intruding clear seawater, with no obvious circulation pattern. Below Kalgin Island the turbid water moves toward the west side of the Inlet and flows out of the Inlet along the western shore and into Shelikof Strait.

BATHYMETRY

Muench et al., 1978

The bathymentry throughout the Kalgin Island Area varies between 10 and 30 fathoms. Depths increase gradually to the south toward the mouth of Lower Cook Inlet (Figure 64).

BOTTOM TYPE

Sharma & Burrell, 1970

Bottom sediments in the Kalgin Island are primarily gravel (50 to 100%) with minor amounts of sand (Figure 63).

Current velocities at the head of Cook Inlet are sufficient to hold mud in suspension and to carry it toward the Forelands area. In addition, sediments are transported down the Inlet by ice-rafting during the winter season. With the incoming tide, turbulence and strong currents are generated by the constriction near the Forelands. The turbulence extends to the bottom, where sediment smaller than gravel is picked up and transported toward the head of the Inlet. As the distance from the Forelands increases, the energy of the water decreases and sediments are deposited. The grain-size distribution thus becomes a function of distance from the Forelands, and the ebb tide controls the distribution of sediments south of the Forelands.

WINDS

Refer to Chart I , Lower Cook Inlet, Winds, for a general discussion of winds in Cook Inlet.

VULNERABILITY OF KALGIN ISLAND AREA TO OIL SPILLS

Dames & Moore, 1979

The only coastal areas in the Kalgin Island area that were of concern because of impact from oil spills from the nine hypothetical spill sites in this model were Harriet Point and Anchor Point. Harriet Point would be impacted by a spill within three days and Anchor Point would be impacted within one day (see Figure 71). The model shows that the eastern shoreline north of Anchor Point is free of potential oil impact. This results from the selection of potential oil spill locations, all south of Anchor Point. The meteorologic and oceanographic input field used in the model do not provide a driving force that would create an impact on this area. The wind patterns, except for one, were either directed parallel to or away from the eastern coastal area north of Anchor Point. Winds from the northwest could create an impact if a spill site was located above Anchor Point.

Hayes et al., 1977

This study did not include risk ratings for the entire coastline that is described in OCSEAP's Kalgin Island Area. OCSEAP's Kalgin Area extends north to the Forelands whereas Hayes studies extend north to Kalifonsky on the eastern side of the Inlet and north to Harriet Point on the western side of the Inlet. Most of the shoreline in the area described by Hayes et al. has a risk rating of 2-[illegible] although all of Tuxedni Bay has a risk rating of 8-10 (Figure 65 and Table 47). Areas with risk ratings of 8-10, especially salt marsh areas, are subject to long term oil spill damage.

ADF&G, 1978b

Bottle trajectory studies off of Anchor Point showed a much greater northward transport than had been previously observed, indicating that spills in southeastern Lower Cook Inlet would be a significant threat to fish and wildlife resources in northeastern areas of Lower Cook Inlet, particularly the Kenai/Nikiski and Kalgin Island areas.

Chart VII. Shelikof Strait

CIRCULATION

NOAA, 1979

The Alaska Stream divides northeast of Kodiak. Water is transported northwest into the Amatuli Trough while the main part of the stream continues along the Kodiak Shelf break. Much of the water flowing into the Amatuli Trough flows directly into Shelikof Strait while the rest turns northward and enters Lower Cook Inlet. The offshore flow of water is dominated by the Alaska Stream, whereas the flow in onshore regions is dominated by tidal currents. The shelf break is considered the dividing line between the two systems.

ADF&G, 1978a

Circulation in Shelikof Strait is less well known than in Lower Cook Inlet. Figure 80 shows that the major portion of Alaska Current waters which enter Kennedy and Stevenson Entrances are primarily diverted directly into Shelikof Strait, where net transport is in a southwestward direction. The turbid and relatively low salinity water flowing out of western Cook Inlet around Cape Douglas is apparent throughout Shelikof Strait on the Alaska Peninsula side. The boundary between this turbid water and the clear seawater on the Kodiak side is a continuation of the same frontal zone which characterizes the Mid-channel Rip in Lower Cook Inlet. As this turbid water moves southwestward through the Strait, it experiences eastward dispersion or transport to the Kodiak Island side.

There is evidence for the existence of a clockwise (anticyclonic) gyre in the Strait near Katmai Bay, and a counterclockwise (cyclonic) circulation southwest of Kodiak Island. Complex and variable eddies may be found in the western Strait near Wide Bay.

A large proportion of the waters leaving Shelikof Strait continues westward along the southern Alaska Peninsula, probably at least as far west as Unimak Pass.

CURRENTS

NOAA, 1979

Current velocity data shows that there is a general southwestward flow of surface waters at a speed of approximately 0.3 to 0.8 knots (15 to 40 cm/sec) in central and eastern Shelikof Strait. Flow in western Shelikof Strait appears to be somewhat less than in the eastern strait and the flow direction may be reversed with gyres or eddies.

ADF&G, 1978a

Current velocity data for Shelikof Strait is limited. U.S. Coast Pilot 9 indicates tidal currents of 1 knot (50 cm/sec) have been recorded on the Alaska Peninsula side, whereas tidal current velocities appear to be less along the west coast of Afognak Island. NOAA current meter measurements a few miles east of Cape Douglas showed a mean southward current velocity of approximately 1 knot (50 cm/sec). Preliminary circulation modeling by NOAA indicates a general southwestward surface flow of roughly 0.3 - 0.8 kts (15-40 cm/sec) in central and eastern Shelikof Strait. Flow in the western Strait is somewhat less than in the eastern Strait, and the flow direction may be reversed within eddies or gyres.

SUSPENDED SEDIMENTS

ADF&G, 1978a

The major portion of Alaska Current waters which enter Kennedy and Stevenson Entrances are diverted rather directly into Shelikof Strait, where net transport is in a southwestward direction. The turbid and relatively low salinity water flowing out of western Cook Inlet around Cape Douglas is apparent throughout Shelikof Strait on the Alaska Peninsula side. The boundary between the turbid water and the clear seawater on the Kodiak side is a continuation of the same frontal zone which characterizes the Mid-channel Rip in Lower Cook Inlet. As this turbid water moves southwestward through the Strait, it experiences eastward dispersion or transport to the Kodiak Island side.

There is evidence for the existence of a clockwise (anticyclonic) gyre in the Strait near Katmai Bay, and a counterclockwise (cyclonic) circulation southwest of Kodiak Island. Complex and variable eddies may be found in the western Strait near Wide Bay: circulation in this area is indicated by broken arrows in Figure 80 .

A large proportion of the waters leaving Shelikof Strait continues westward along the southern Alaska Peninsula, probably at least as far west as Unimak Pass.

ERTS satellite imagery (Burbank, 1974) shows a distinct widening of the surface suspended sediment plume (originating in Cook Inlet) as the Cook Inlet water is carried southwestward through Shelikof Strait. In Figure 81 , which is a schematic rendition of an original ERTS image, the surface suspended sediment plume has dispersed completely across the Strait at the southwestern entrance to the Strait. After passing out of Shelikof Strait, the suspended sediments rapidly diffuse and settle out. Shelikof Strait provides a channel to the sea for all sediments discharged from Cook Inlet.

Other ERTS imagery shows characteristic bulges along the eastern boundary of the plume. These may be the result of eddy circulation, strong local winds such as williwaws, or transient reversals in the southwestward flow caused by the flood tides. U.S. Coast Pilot 9 indicates the flood tide sets into the Strait from both ends.

Feeley & Cline, 1977

The distribution patterns of particulate material in Lower Cook Inlet and Shelikof Strait show a direct relationship to water circulation. The inflowing relatively nonturbid Gulf of Alaska water moves along the eastern coastline until it reaches Kalgin Island where it mixes with the highly turbid brackish water from Upper Cook Inlet. Under the influence of tidal currents and coriolis forces the turbid water moves southwest along the western coast into Shelikof Strait where the particulate matter disperses and settles to the bottom. This counterclockwise circulation pattern gives rise to extremely large horizontal grandients in suspended matter. However, tidal mixing is extensive and rapid; and, therefore, no vertical suspended matter gradients are observed during the winter months in the central regions of Lower Cook Inlet.

BATHYMETRY

Muench et al., 1978

Water depths in Stevenson Entrance reach 100 fathoms. Depths increase southward reaching approximately 150 fathoms near the southern entrance of Shelikor Strait (Figure 64).

BOTTOM TYPE

Burbank, 1974

The bottom sediments in Shelikof Strait are generally characterized by mud, grading from sandy mud with pebbles near the Cook Inlet end to sandy gray mud near the center, and finally to very soft gray mud at the southwest end of the strait. Mud also fills the channel which incises the shelf from Shelikof Strait south to the continental shelf break.

WINDS

ADF&G, 1978a

Wind has a profound effect on the circulation, particularly the near-surface circulation, and greatly compounds the variability of the cirulation regime. Winds in Shelikof Strait generally blow either up (Southwest to northeast) or down the Strait. Gales are a frequent occurrence in the Strait, and usually continue without intermission for 1 to 3 days. Southwest and westerly winds are noted for their great force, where as northwest gales in the spring are associated with freezing weather and icing. Gale force westerly winds are frequently encountered during the fall and winter, and blow directly into major bays such as Uyak and Uganik Bays. Although no exact figures are available, the large number of fishing days lost to foul weather, especially during fall and winter, attests to the high frequency of adverse weather and seas in Shelikof Strait.

Weather conditions in the Strait can vary widely from one location to another at any one time. Data on the frequency of the wind direction and speed in Shelikof Strait is not yet available and, as in Lower Cook Inlet, there is inadequate information to comprehensively predict the effects of winds on the surface circulation.

VULNERABILITY OF SHELIKOF STRAIT TO OIL SPILLS

Dames & Moore, 1979

The model from this study shows that Shugak Island, at the northern end of Afognak Island, in the Shelikof Strait area is an area where the impacts of oil spills, both in terms of time to impact (1 day) and probability of exposure (primarily 3 to 6%), is a critical area. Spills from sites 7 and 8A (see Figures 71-72) suggest the possibility of exposure of Kodiak Island to oil spills.

ADF&G, 1978b

Recoveries of drift cards and bottle samples from the Kodiak Archipelago verify that the western shores of Shuyak, Afognak and Kodiak Islands are highly susceptible to pollution. Of particular note are the many recoveries well inside of the various inlets, coves and passages.

NOAA, 1979

Oil and other contaminants entering Kodiak waters are likely to be trapped and concentrated in the numerous bays and estuaries along the coast and offshore islands.

Hayes & Ruby, 1979

The only studies in Shelikof Strait have been done on Kodiak, Afognak and the Trinity Islands.

In general, the area is quite high risk. More than 78.9% of the shoreline falls in classes 6 - 10 (77.1% in classes 6 - 8) (See Table 50). These classes will have a spill longevity of a year or two to more than 10 years. Oil Spill vulnerablity on a scale of 1-10 is based primarily on the expected longevity of oil in the sediments of each environment if no clean-up procedures are initiated. The remaining 21% of the shorelines fall into classes 1 and 2 which are considerably lower risk areas where spilled oil would generally be expected to be cleaned by natural processes within a few weeks. Unfortunately, the Kodiak shoreline is very complex and the higher risk areas do not lend themselves well to being protected during a spill. In many instances, a low risk area lies just seaward of a large embayment with high risk pure gravel beaches. The indented (fjord) character of the islands will act as "oil traps" for floating oil. Oil will tend to be moved deeper into the fjords rather than to be flushed out. Additionally, long periods of relatively low wind and wave energy, especially during the summer, could prove particularly devastating since many of the areas classed 1 and 2 would become 7 and 8.

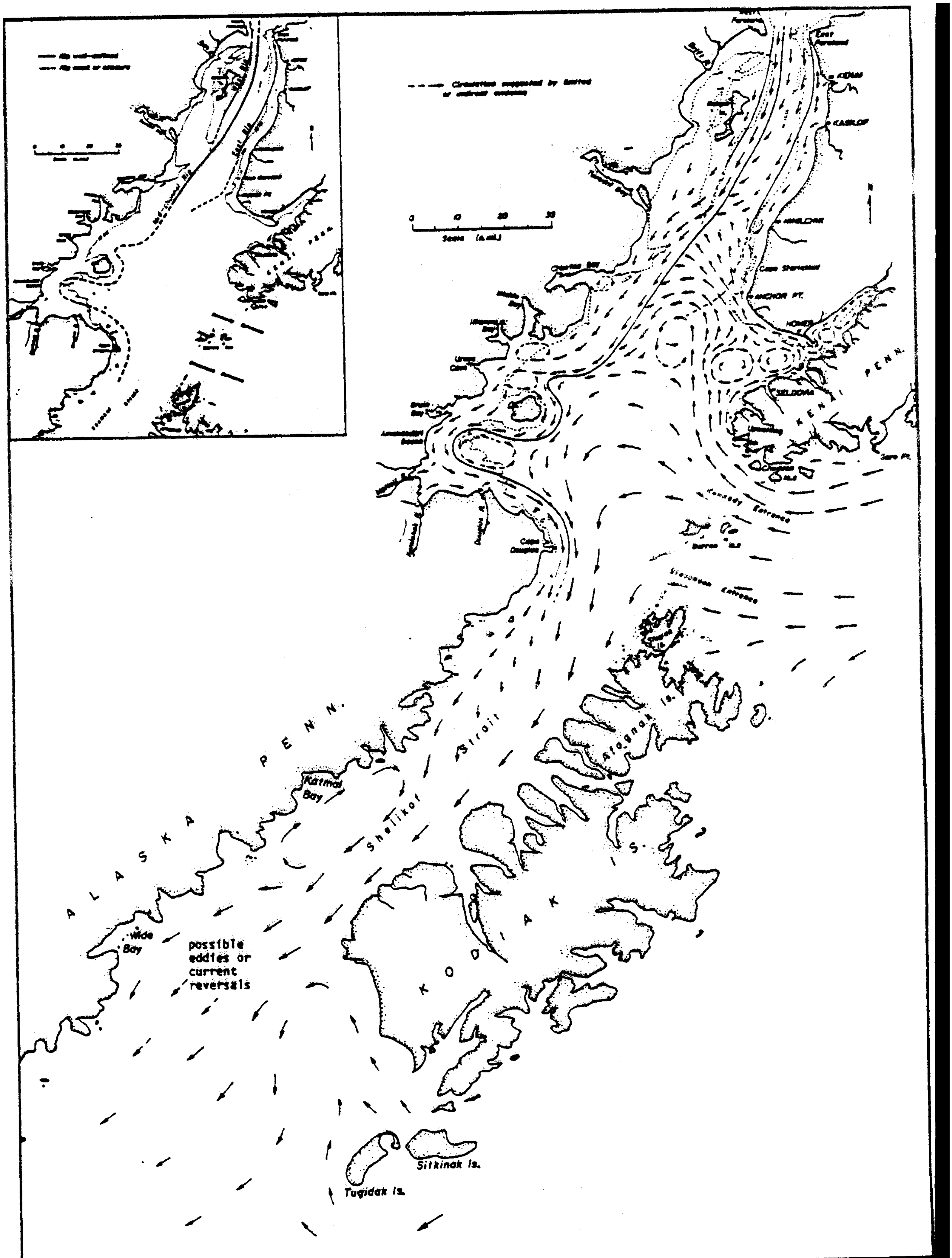


Figure 80. Surface circulation in Lower Cook Inlet and Shelikof Strait, based primarily on data collected during the spring, summer, and early fall seasons. (Burbank, 1977)

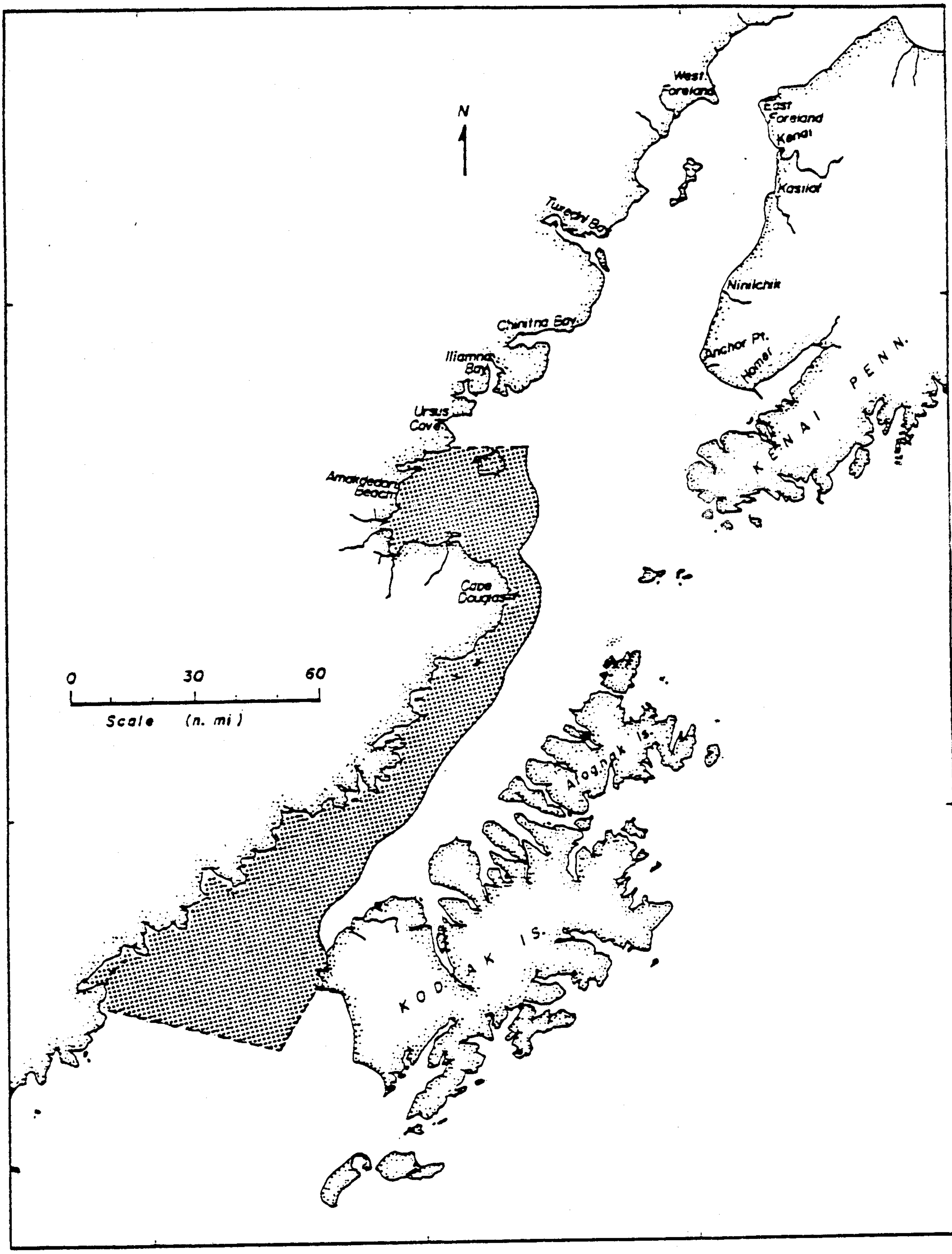


Figure 81. Turbid water outflow from Cook Inlet on 30 October 1973, based on ERTS-1 image I.D.'s 1464-20554-4 and 1464-20560-4 (after Burbank, 1974).

Table 50. Scale of environmental susceptibility to oil spill impact duration from Hayes et al. (1977).

Oil Spill Vulnerablity Scale	Discussion	Longevity of Spilled Oil
1	Straight rocky headlands: Most areas of this type are exposed to maximum wave energy. Waves reflect off of the rocky scarps with great force, readily dispersing the oil. In fact, waves reflecting off the scarps at high tide tend to generate a surficial return flow that keeps the oil off the rocks. Even if oiled, natural cleaning will only require a few days or weeks. No human intervention is necessary. There may be some problems in areas of gravel accumulation and in tidal pools. Pocket beaches may be particularly hard hit. Approximately 10% of eastern coastline of Shelikof Strait is of this type.	Oil that goes ashore could be expected to be dispersed within a few weeks.
2	Eroding wave-cut platforms: These areas are also swept clean by wave action. The rate of removal of the oil is a function of wave climate and the irregularity of the platform, but is generally under a year. Some problems in areas of gravel accumulation and in tidal pools. Pocket beaches may be particularly hard hit. In general, no clean-up measures are needed for this type of coast. However, there are large biologic populations in these areas. Most of these areas, 10.7% of the eastern coastline of Shelikof Strait, occur in highly exposed areas.	These areas would probably be free of oil within 6 months.
3	Flat, fine-grained sandy beaches: Beaches of this type are generally flat and hard packed. Oil that is emplaced on such beaches will not penetrate more than a few centimeters at most. Usually the oil will be deposited on the surface of the sand where it can be removed by elevated scrapers or other road grading machinery. Furthermore, these types of beaches change slowly, so sand deposition and resultant burial of oil will take place at a slow rate. There are no beaches of this type along the eastern shoreline of Shelikof Strait.	Same as above.
4	Steeper, medium to coarse-grained sandy beaches: On these beaches, the depth of penetration would be greater than for the fine-grained beaches (though still only a few centimeters), but rates of burial of the oil would be greatly increased (as much as 50-100 cm within a period of a few days on beaches of this class). In this situation, removal of the oil becomes a serious problem, since removal of the oiled sediments will often result in large scale erosion, as the beach changes into a new equilibrium state. Additionally, burial of the oil preserves it for release at a later date when the beach erodes as part of the natural beach	Possible pollution of up to one year.

	cycle, thus causing longer term pollution of the environment. There are no beaches of this type along the eastern coastline of Shelikof Strait.	
5	Impermeable exposed tidal flats: Penetration of the oil on these beaches is prevented by the extremely fine sediment size, saturated with water. Therefore, if an oiled tidal flat is subject to winds and currents, the oil will tend to be removed, although not at the rapid rate encountered on exposed beaches. These are often areas of high biologic importance. There are no beaches of this type along the eastern shoreline of Shelikof Strait.	Same as above.
6	Mixed sand and gravel beaches: Sand and gravel beaches represent a large percent, (17.7) of the shoreline tend to be relatively high risk beaches. They occur where till or glacial deposits are being reworked by marine processes and as pocket beaches between headlands. These beaches permit rather deep burial of oil and can retain oil for about 2 years, especially if it is emplaced high on the beach face (as during a spring tide). Mechanized clean up can be very difficult due to low bearing strength of the sediments. Removal of sediments may accelerate erosion. Natural cleaning may require many years.	Oil could remain in place for several years.
7	Gravel beaches: Pure gravel beaches will permit immediate deep burial of oil. Retention periods, espcially in a lower wave energy area can be many years. Mechanized clean up will be impossible without removal of sediment and increased erosion. Natural cleaning will be quite slow for this type of beach; the exact time required will depend on the intensity of the marine processes. Pure gravel beaches are quite common along the eastern shoreline of Shelikof Strait and represent 17.2% of the shoreline. They occur mostly as pocket beaches and fronting rock scarps. In some cases they can be quite long.	Same as above.
8	Sheltered rocky headlands: Sheltered rock headlands and their accociated gravel pocket beaches will be highly damaged in the event of a spill. In the absence of abrasion by wave action, oil could remain on such areas for years, with only chemical and biological processes left to degrade it. These beaches occur primarily in fjords on Kodiak Island and on Afognak Island. These beaches represent the largest single type of beach (42.2%) of the coastline of eastern Shelikof Strait. These areas should receive first protection priority in the event of a spill. All possible means should be used	Long-term pollution of 10 years or longer can be expected in these areas.

	to prevent oil from entering these areas (booms, skimmers, etc). Once these beaches are oiled, expect severe biological damage, deep penetration, difficult clean up and longevity up to 8 years.	
9	Protected estuarine tidal flats: If oil reaches a quiet, protected estuarine tidal flat, it will remain there for long periods because natural cleaning progresses at an extremely slow rate. Because of the low intensity of marine process parameters, removal of the oil will have to be accomplished by natural chemical and biogenic processes. This will take many years, dependent on the amount of oil deposited. Because of their high biologic populations, these environments are very sensitive to the toxic effects of oil. These areas are rare (1.1%) along the eastern coastline of Shelikof Strait occuring only at fjord heads and at river mouth estuaries.	Same as above.
10	Protected estuarine salt marshes: In sheltered estuaries, oil from a spill may have long-term deleterious effects. These areas are extremely important biologically, supporting large communities of organisms and are generally associated with the protected tidal flats (#9). They are also rare, representing only 0.7% of the eastern coastline of Shelikof Strait.	Same as above.

Table 51 Acute/toxic, physiological and behavioral effects of petroleum hydrocarbons on fish resources.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
CRAB					
Acute/Toxic Effects					
Tanner Crab (*Chionoecetes bairdi*) juveniles	Karinen and Rice, 1974	Bioassay 48 hr TLM	Prudhoe Bay crude oil	.056-1.00 mg oil/liter of seawater	Median tolerance limits for 48 hr. TLM for both premolt and postmolt tanner crabs was estimated to be .56 mg oil/liter. Molting success of premolt crabs after exposure to .32 ml oil/liter was significantly lower than the molting success of control crabs. Failure to molt usually resulted in death.
King Crab (*Paralithodes camtschatica*) larvae	Mecklenburg et al., 1976	Bioassay 96-120 hr LC50	Cook Inlet crude water soluble fraction	.93-4.75 ppm total hydrocarbons	Molting success in King crab larvae was reduced to almost zero by exposure to 1.2 ppm WSF for 48 hours. Failure to molt usually results in death. 50 percent of the larvae tested died within 96 and 120 hrs after being exposed to 1.37 ppm and .93 ppm of Cook Inlet crude respectively.
Dungeness Crab (*Cancer magister*)	Caldwell et al., 1976	Bioassay	Cook Inlet crude water soluble fraction and seawater solutions of benzene or naphthalene		Toxic effects were observed at levels as low as .0049 mg/l (as naphthalene) for the crude oil, and .13 mg/l and 1.1 mg/l for the benzene and naphthalene, respectively.
Adult and larvae King Crab (*Paralithodes camtschatica*) and Dungeness Crab (*Cancer magister*)	Rice et al., 1976b	Bioassays	Cook Inlet crude oil No. 2 fuel oil, Prudhoe Bay crude oil	water soluble fractions of oils measured as ppm of oil by IR method	96 hr TLM's for adult King Crab were 2.35 ppm and 4.21 ppm for Prudhoe Bay and Cook Inlet crude oil respectively. 96 hr TLM for No. 2 fuel oil was 5.10 ppm. Tanner Crab larvae were killed by 8 ppm of oil after 96 hrs of exposure. Exposure to WSF of Cook Inlet crude oil at low levels (.9 ppm - 3 ppm) caused moribundity in Tanner and Dungeness Crab larvae. Moribundity would usually last for several days before animal would die. Toxicity of hydrocarbons is greater during molting. Crab larvae molt more frequently than adults and are, therefore, more sensitive to hydrocarbon pollution.

ppm = parts per million
ppb = parts per billion
LC50 = concentration required to kill 50% of the test animals
TLM = median tolerance limit - the concentration required to kill 50% of the test animals within certain time limits

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
PHYSIOLOGICAL EFFECTS					
Tanner Crab (Chionoecetes bairdi)	Karinen and Rice, 1974	Bioassay 48 hr TLM	Prudhoe Bay crude	.32-.56 ml oil/ liter of seawater	Postmolt crabs lost a substantial number of legs due to exposure to oil levels as low as .32 ml oil/liter. Some larvae failed to molt but survived. Brief exposure of premolt tanner crab 1 to 4 weeks before molting probably has a detrimental effect on molting.
King Crab (Paralithodes camtschatica)	Smith and Bonnett, 1976	Bioassay	Cook Inlet crude	low concentration of the WSF of Cook Inlet crude oil	Crab gills after 6 day exposure to the water soluble fraction of Cook Inlet crude oil showed: (1) extensive vacuoloation, (2) nucleus change, (3) cytoplasm modifications, (4) fewer mitochondria and blebbing, (5) swollen rough endoplasmic reticulum cisternae and (6) distorted interdigitations along later and basal cell surfaces. Vacuolation was also present in blood cell cytoplasm, and the perinuclear space was enlarged. Some of these changes indicate morphologic damage related to the altered metabolic response to sublethal crude oil exposure.
King Crab (Paralithodes camtschatica) and Tanner Crab (Chionoecetes bairdi)	Rice et al., 1976b	Bioassay	Cook Inlet crude	less than 4.21 ppm WSF	Exposure of juvenile and adult King Crab to the water soluble fractions of Cook Inlet crude resulted in significant decrease in their respiration rate. Specimens recovered after removal to clean water. When placed in water containing the WSF of Cook Inlet crude oil, King Crab larvae accumulated significant quantities of aromatic hydrocarbons. Biomagnification of some compounds up to 1,260 times ambient levels occurred. Crabs depurated within 96 hrs after removal to clean water.
King Crab (Paralithodes camtschatica) and Tanner Crab (Chionoecetes bairdi)	Rice and Karinen, 1976	Bioassay	Cook Inlet crude oil	water soluble fractions	Spawning female King and Tanner Crab were exposed to the water soluble fractions of Cook Inlet crude oil. Preliminary findings indicate that the oil had little effect on the water hardening of the eggs or the attachment of the eggs to the pleopodal setae; however, development may be affected.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Behavioral Effects					
Dungeness Crab (*Cancer magister*)	Rice et al., 1976	Bioassay	Cook Inlet crude oil	oil slick	Dungeness crab larvae do not appear to avoid oil slicks and would repeatedly swim up into it. Observations of larvae strongly suggest that larvae are oblivious to the presence of oil until affected physiologically by toxic concentrations, i.e., unable to swim.
SHRIMP					
Acute/toxic Effects					
Coonstripe Shrimp (*Pandalus hypsinotus*) Humpback Shrimp (*Pandalus goniurus*) and Pink Shrimp (*Pandalus borealis*)	Rice et al., 1976b	Bioassay	Prudhoe Bay crude, Cook Inlet crude and No. 2 fuel oil	water soluble fraction	96 hr TLM's of 3 species of shrimp to the WSF's of Cook Inlet crude and No. 2 fuel oil (ppm of oil). Species — Cook Inlet Crude — No. 2 Fuel Oil Humpback Shrimp — 1.98 — 1.69 Coonstripe Shrimp — 2.72 — - Pink Shrimp — 2.43 — - The 96 hr TLM for humpback shrimp exposed to the WSF's of Prudhoe Bay crude oil was 1.26 ppm. 2.4-1.87 ppm of the WSF of crude oil would induce moribundity in Coonstripe Shrimp larvae. Moribund larvae showed some motion but were unable to move and were destined for death. Shrimp larvae are more sensitive to the WSF of hydrocarbons than adults. This may be due to the frequency of molting.
Coonstripe Shrimp (*Pandalus hypsinotus*)	Vanderhorst et al., 1976	Flow through bioassay	No. 2 fuel oil	water soluble fraction	Shrimp LC50 were .8 mg/liter as compared to values from 1.5 to 50 mg/liter reported for static bioassays.
Coonstripe shrimp (*Pandalus hypsinotus*)	Mecklenberg et al., 1976	Bioassay 6-144 hr	WSF Cook Inlet crude oil	0.25-7.94 ppm	Molting coonstripe shrimp larvae were 4 to 8 times more sensitive to the WSF of Cook Inlet crude than intermolt stage I and II. 1.15 and 1.37 ppm of total hydrocarbon severely inhibited molting (10% molting success) in exposures of 24 hr or longer. Concentrations of 0.25 ppm for 96 hrs produced little or no effect on molting but many larvae died within 48 hrs after removal to clean water. The 96 hr LC50 (conc. producing 50% mortality) for coonstripe shrimp molting larvae was 0.96 ppm but dropped to 0.24 ppm 48 hrs after removal to uncontaminated water, suggesting that the standard 96 hr bioassay is not long enough to determine the sensitivities of shrimp larvae to oils.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Physiological Effects					
Pink Shrimp (Pandalus borealis)	Rice et al., 1976b	Bioassays	Cook Inlet crude oil	water soluble fraction of Cook Inlet crude oil	Pink shrimp accumulate naphthalenes from the water soluble fraction in the seawater. Accumulations in tissue are up to 260 times background levels. Depuration in shrimp after return to clean water is slow and may take several weeks.
SALMONIDS					
Acute/Toxic Effects					
Pink Salmon fry (Onchorhynchus gorbuscha)	Rice, 1973	bioassay-acute toxicity effects	Prudhoe Bay crude oil - water soluble fraction	.75 mg-497 mg oil/liter of seawater	Observed 96 hr TLM levels for Pink Salmon fry were 213 mg oil/liter in June, and 110 mg/liter in August. Fish showed dramatic seasonal differences in sensitivity to oil pollution. Older fry were more susceptible to oil toxicity than younger fry and were more sensitive in their detection and avoidance of oil. Older fry in seawater avoided oil conc. as low as 1.6 mg of oil/liter of water.
Juvenile Coho (Onchorhynchus kisutch) and Sockeye Salmon (Onchorhynchus nerka)	Morrow, 1973	96 hr bioassay	Prudhoe Bay crude oil - water soluble fraction	500 ppm - 3500 ppm in seawater	500 ppm - 3500 ppm produced up to 100% mortalities in juvenile Coho and Sockeye Salmon. Stress behavior began within 45 minutes of formation of oil slick. Mortality rates were directly related to oil concentration and inversely related to temperature.
Eggs, Alevins, and fry of Pink Salmon (Onchorhynchus gorbuscha)	Rice et al., 1975a	96 hr bioassay	Prudhoe Bay crude oil (mechanical mixtures of oil and water)	.075 ml - 4 ml oil/liter of fresh and seawater	Standard 96 hr bioassays with "total" oil solutions in freshwater and seawater determined differences in developing life stages of Pink Salmon (Onchorhynchus gorbuscha). Eggs were the most resistant and emergent fry (yolk sac absorbed) the most sensitive to acute 4-day exposures. In fresh water, the 96 hr TLM of fry was 12 ppm. In seawater it was 6 ppm.
Pink Salmon fry (Onchorhynchus gorbuscha)	Rice et al., 1976b	96 hr bioassay	Cook Inlet crude, No. 2 fuel, and Prudhoe Bay crude (oil-water dispersions, and water soluble fraction)		Acute toxicity of the water soluble fractions of Prudhoe Bay and Cook Inlet crude oil to Pink Salmon fry was 1.41 ppm and 2.92 ppm respectively. The 96 hr TLM for No. 2 fuel oil was 0.81 ppm.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Dolly Varden smolt (Salvelinus malma)	Rice et al., 1976a	static bioassay	Cook Inlet crude and and No. 2 Fuel Oil	water soluble fractions of oils measures as ppm by IR method	96 hr TLM's for Dolly Varden were 2.28 and 2.93 ppm for Cook Inlet crude and No. 2 Fuel oil respectively.
Physiological Effects					
Rainbow Trout (Salmo gairdnerii)	Hawkes, 1976	bioassay	Prudhoe Bay crude oil	sublethal concentrations in ppm range	Rainbow trout which were exposed to water soluble fractions of Prudhoe Bay crude oil showed the following effects: (a) skin mucous release and erosion of upper dermal layers, (b) gill mucous release, lesions, cellular and subcellular damage, (c) liver damage, (d) increase in lens thickness causing mycopia. These debilitating factors increase the chances for infection, predation and disease and decrease the fishes' chance for survival.
Coho Salmon (Onchorhynchus kisutch)	Roubal et al., 1976	bioassay	water soluble fractions of aromatic hydrocarbons		Significant levels of metabolites were found in the brain, kidney, muscle and gall bladder of Coho Salmon which had been exposed to benzene, naphthalene and antracene. Indicates areas of detoxification, and possible sources of secondary infections, contaminants, etc.
Alevins and fry of Pink Salmon (Onchorhynchus gorbuscha)	Rice et al., 1975a	96 hr bioassay	Prudhoe Bay crude oil (mechanical mixture of oil and water	.075 ml - 4 ml oil/liter of fresh and seawater	Three life stages of alevins were exposed to 10 day sublethal exposures of the water soluble fraction of Prudhoe Bay crude oil. Growth was most severely affected in alevins exposed during later developmental stages. Decreased growth was observed in fry after 10-day exposures at the lowest dose tested (.075 ml oil/liter). Reduction in size from exposure could have a detrimental effect on the survival of wild fry.
Pink Salmon fry (Onchorhynchus gorbuscha)	Rice et al., 1976b	bioassay - uptake and depuration	Cook Inlet crude oil - water soluble		Pink Salmon fry which were exposed to the water soluble fractions of Cook Inlet oil accumulated naphthalenes in the gill, gut and muscle tissue. Investigators feel gill tissue is probable route of entry. Pink salmon are able to concentrate naphthalenes up to 480 times background levels. Pink Salmon fry are able to actively depurate naphthalenes.
King Salmon fry (Onchorhynchus tshanytsha)	Brockson and Bailey, 1973	bioassay - respiratory effects	benzene fraction	5-10 ppm benzene	Respiratory rate was increased during the early (24-48 hr) period of exposure to both 4 and 10 ppm of benzene. After longer periods, respiration decreases back to near control levels.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Pink Salmon fry (Onchorhynchus gorbuscha)	Rice and Karinen, 1976	bioassay	Cook Inlet crude oil		Respiratory rates in Pink Salmon fry increased significantly during exposures to water soluble fractions of Cook Inlet crude oil as low as 30 percent of 96 hr TLM value.
Pink Salmon fry (Onchorynchus kisutch)	Thomas and Rice, 1975	toxicity - respiratory effects	Prudhoe Bay crude	2.83 and 3.46 ppm	Opercular rates increased significantly for as long as 9 to 12 hrs after exposure to sub-lethal concentrations of the water-soluble fractions of Prudhoe Bay crude oil. Observed changes occurred at aproximately 20% of the 96 hr LC50.
Pink Salmon Fry	Rice et al., 1977	toxicity effects	WSF Cook Inlet and Prudhoe Bay crude and No. 2 fuel oil	sublethal	Breathing and coughing rates increased in proportion to oil concentrations. Significant responses were detected at about 30% of the 96 hr TLM. Breathing and coughing rates remained above normal during exposure for 72 hrs. Increased oxygen consumption was observed in fish exposed to oil concentrations that were 50% of a 96 hr TLM.
Coho Salmon (Onchorhynchus kisutch)	Malins et al., 1977	spill	diesel fuel	unknown	Spill of diesel fuel blinded Coho Salmon located in rearing pens adjacent to spill. Changes in the eyes included hydration and cloudiness.
Rainbow Trout (Salmo gairdnerii)	Krishnaswami & Kupchanko	static bioassay and field observation	petroleum refinery effluent	sublethal	Rainbow Trout exposed 24 hrs to refinery waste dilutions with threshhold odor number of .25 acquired an oily taste. Fish (trout) kept in cages in the river 15 mi (24 km) below refinery wastewater discharge point acquired an oily taste with river water odor levels of at least 1.0.
Coho Salmon (Onchoryncus kisutch) Starry Flounder (Platichthys stellatus)	Roubal et al., 1978	flow through bioassay	WSF Prudhoe Bay Crude	0.9 $\pm$ 0.1 ppm WSF Prudhoe Bay Crude	Coho salmon and starry flounder exposed to 0.9 ppm of a WSF of Prudhoe Bay crude oil, bioconcentrated low molecular weight aromatic hydrocarbons up to 1700 times the concentration in the water. Generally, starry flounder accumulated the greatest amounts. Alkylated aromatic hydrocarbons accumulated in tissues to a greater degree than unsubstituted derivatives, and accumulations of substituted benzenes and naphthalenes in muscles increased in relation to the degree of alkylation. Complex mixtures of aromatic hydrocarbons were found in gills and liver of starry flounder. Accumulated hydrocarbons were retained in starry flounder muscle for a longer period than in coho salmon tissue after removal to clean water than in coho salmon muscle.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Behavioral Effects					
Pink Salmon (*Onchorhynchus gorbuscha*)	Rice, 1973	bioassay avoidance tests	Prudhoe Bay crude oil - water soluble fraction	.75 mg - 16.0 mg oil/liter. Used water soluble fraction only	Pink Salmon fry showed clear avoidance responses to oil concentration of 16.0 and 1.6 mg oil/liter in June and August respectively. Avoidance in Atlantic salmon is well documented. Avoidance could have an adverse impact on salmon populations by changing migration during critical periods such as fry outmigration or return of adults to spawning streams.
Juvenile Coho (*Onchorhynchus kisutch*) and Sockeye Salmon (*Onchorhynchus nerka*)	Morrow, 1973	96 hr bioassay	Prudhoe Bay crude (surface oil slick in aerated tank)		Change was observed in behavior of salmon under oil film. Within 2 to 4 hrs, the fry took up a position at the water oil interface, with their dorsal and caudal fins touching the oil. After 12 to 24 hrs exposure the less resistant individuals lost equilibrium and began swimming vertically. Most animals died shortly after becoming vertical. Animals exposed to crude oil showed abnormal values for blood pH, K+, and Cl-. In conjunction with observed behavioral abnormalities, this suggests very strongly that the chemical CO_2 and H_2CO_3- balance had been upset.
Rainbow Trout (*Salmo gairdnerii*) Atlantic Salmon (*Salmo salar*)	Sprague and Drury, 1969	bioassay	phenol	.001 ppm - 10 ppm	Avoidance reactions were inconsistent event at lethal levels. Fish showed no signs of detection even though the phenol was lethal to them.
Atlantic Salmon (*Salmo salar*)	Rice, 1973	avoidance	copper and zinc pollution	sublethal	Although highly motivated by their instinct to migrate upstream when Atlantic salmon reached a sublethal conc. of copper and zinc pollution in the Miramichi River, they aborted their upstream migration and returned downstream.
OTHER FISH					
Acute/Toxic Effects					
Cod (*Gadus* sp.)	Kuhnhold, 1972	bioassay	Venezuelan and Libyan crude oil	.5 gm oil/liter of water	100% mortality of eggs in 3 and 6 days with Venezuelan and Libyan crude respectively. Controls developed normally. Larvae which hatch from eggs which have been exposed to oil are usually deformed.
Herring Larvae (*Clupea harengus pallasi*)	Rice et al., 1976	bioassay (96 hr TLM)	Cook Inlet crude	water soluble fraction	3 ppm of the water soluble fraction of Cook Inlet crude oil was sufficient to kill herring larvae within 96 hrs.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Herring (Clupea harengus) Lemon sole (Microstomus kitt)	Wilson, 1976	100 hr bioassay	oil dispersants, Atlas, Basol AD6, BP1002, Corexit 7664, D-tar, Finasol ESK, Houghtoslov, Penetone 861, Slix	.5 ppm - 400 ppm	The LC50 values of 8 dispersants ranged from 4 to 35 ppm. The value for Corexit 7664 was 400 ppm. The difference in toxicity was associated with the composition of the dispersants and the level of aromatic hydrocarbons.
Herring (Clupea harengus)	Zitko and Tibbo, 1971	spill in Nova Scotia	"intermediate oil" with large concentrations of aromatic hydrocarbons		Spill caused extensive kill of herring in 1969.
Selected Alaskan Marine Fishes and invertebrates	Rice et al., 1976a	static bioassay	Cook Inlet crude and No. 2 Fuel Oil	water soluble fractions of oils measured as ppm by IR method	Fish were consistently among the more sensitive species with 96 hr TLM's from 0.81 to 2.94 ppm. Sensitivity of some invertebrates, primarily subtidal organisms, equaled that of fishes while intertidal invertebrates were consistently among the most resistant species.
Saffron Cod (Eleginus gracillis)	Rice et al., 1976a	static bioassay	Cook Inlet crude and No. 2 Fuel Oil	water soluble fractions of oils measured as ppm by IR method	96 hr TLM's for Saffron Cod were 2.28 and 2.93 ppm for Cook Inlet crude and No. 2 Fuel Oil respectively.
Cod and pollock (Gadus morhua and Pollachius virens)	Longwell, 1977	spill	80% #6 fuel oil 20% #2 fuel oil	unknown	Over ½ of the cod and pollock eggs collected near the Argo Merchant spill were contaminated by adhering tar and oil droplets. A significant number of the eggs collected were either dead (up to 46%) or grossly malformed embryos (18%). Spawning had just occurred.
Sand launce	Longwell, 1977	spill	80% #6 fuel oil 20% #2 fuel oil	unknown	Larvae of sand launce were sampled in area of Argo Merchant spill. The abundance of larvae decreased sharply at the two stations within the area of the thick slick.
Physiological Effects					
Herring and Sole eggs and larvae	Wilson, 1976	bioassay	oil dispersant	5-10 ppm	Oil dispersants at levels from 5-10 ppm caused abnormalities in developing herring, sole and plaice eggs and larvae.
Herring (Clupea harengus) eggs and larvae	Struhsaker et al., 1974	bioassay 48-120 hr	benzene fraction	water soluble fraction	Considerable physiological stress was noted. Influence on the total metabolic rate (higher conc. = delay of metabolic rate) was also observed. Although eggs are relatively resistant and requite a greater amount of exposure before mortality, that exposure usually induces abnormalities whose effects are permanent and irreversible, eventually causing death. On the other hand, exposed larvae may sometimes partially recover.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
English Sole (*Parophrys vetulus*)	Malins et al., 1977	bioassay	Prudhoe Bay crude	water soluble fraction	English sole held on contaminated sediments for over 4 months had a higher frequency of liver abnormalities and weight loss than did control fish on uncontaminated sediment.
English Sole	McCain, 1978	toxicity effects	Alaskan crude	0.2% oil/sediment	English sole exposed to oil contaminated sediments for 4 months gained weight slower, had a higher frequency of liver abnormalities, a higher incidence of parasitic infestation of the gills, and were less active than control fish.
Fishery	Spears, 1971	field observation	petroleum wastes	unknown	Lower yields of fishery species were found in small tidal creeks receiving petroleum wastes than in similar creeks not receiving such additions.
Behavioral Effects					
Herring Larvae (*Clupea harengus pallasi*)	Rice et al., 1976	bioassay (96 hr TLM)	Cook Inlet crude	oil slick on surface	Herring larvae did not avoid an oil slick but would repeatedly swim up to the surface and touch it. Did not appear to be able to detect the slick. Larvae were eventually overcome by the oil and settled to the bottom.
Herring larvae (*Clupea harengus*)	Kuhnhold, 1972	bioassay	Venezuelan and Libyan	water soluble fraction	Larvae were unable to avoid contaminated water, especially when oil was present as a dispersion. Author believed chemoreceptors were blocked or destroyed. Larvae would have little chance of survival if they remained in oil dispersion.
CLAMS, MUSSELS AND SCALLOPS					
Acute/Toxic Effects					
Pink Scallop (*Chlamys rubida*)	Rice et al., 1976	bioassay (96 hr TLM)	Prudhoe Bay crude, Cook Inlet crude, and No. 2 fuel oil	water soluble fraction .80-3.15 ppm	96 hr TLM for scallops was 2.07 ppm and 3.15 ppm for Prudhoe Bay and Cook Inlet crude oil respectively. 96 hr TLM for No. 2 fuel oil was .80 ppm. Scallops continued to die up to 4 weeks after exposure to the WSF of crude oil.
Cockles (*Clinocardium* sp.)	Lechner, 1970	oil spill observation	JP5		Thousands of dead and extremely weak cockles were found throughout spill area. Area was declared a health hazard and residents were advised not to eat the clams.
Razor Clams (*Siliqua* sp.)	Tegelberg, 1964	oil spill	fuel oil		300,000 razor clams were killed in less than a week by a fuel oil spill.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Mussel (*Mytilus californianus*)	Kanter, 1974	bioassay	crude oil	$1x10^3$ppm - $1x10^5$ppm	Mytilus succumbed faster and in higher numbers at oil concentrations of $1x10^5$ ppm than $1x10^3$ ppm and $1x10^4$ppm. Larger experimental animals exhibited significantly higher mortalities than their smaller counterparts. Mortality varied by season.
Soft-shell clam (*Mya arenaria*)	Thomas, 1976	observation of spill	Bunker C oil	unknown	Mortalities of the soft-shell clam (*Mya arenaria*) from the 1970 Chedabucto Bay spill ranged from 19% to 73% in the areas sampled. Many clams left their burrows as these filled with oil. The clams either died on the surface or were eaten by predators. Soon after, clams started to die within their burrows. Dead clams were visibly contaminated with oil and mortalities were proportional to surface oil cover. In areas where the substrate become contaminated with oil, chronic mortalities in the clam population continued up to 5 years.
Physiological Effects					
Soft Shell Clam (*Mya arenaria*)	Stainken, 1976b	flow-through bioassay	No. 2 fuel oil	10, 50 and 100 ppm	Subacute oil exposure resulted in a depletion of glycogen and general leukocytosis particularly evident in the blood sinuses of the pallium and mantle membrane. There was also an increase in vacuolation of the diverticula, stomach and intestines. The increased vacuolation of oil-exposed clams may also represent inclusion and intracellular compartmentalization of hydrocarbons.
Mussel (*Mytilus edulis*)	Fossato and Canzonier, 1976	flow-through bioassay	diesel fuel	200-400 ug/liter	Mussels were exposed for as long as 41 days to diesel fuel adsorbed on Kaolin particles. Hydrocarbons were accumulated in the tissues in excess of 1,000 times the exposure levels. After removal, mussels began to depurate but still retained significant fractions after 32 days.
Scallops and other shellfish	Blumer et al., 1970	observations of Falmouth, Mass. oil spill	No. 2 fuel oil		Hydrocarbons ingested by shellfish became part of their lipid pool. Oil was incorporated in the adductor muscle of scallops.
Pink Scallops (*Chlamys rubida*)	Rice and Karinen, 1976	bioassay	Cook Inlet crude oil		Found that the growth rate of pink scallops may be reduced as the result of oil exposure.
Mussel (*Mytilus edulis*)	Blumer et al., 1971	No. 2 fuel oil, west Falmouth spill field observation	No. 2 fuel oil		Gonads of mussels failed to develop in affected areas.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Mussel (Mytilus californianus)	Kanter et al., 1971	bioassay	crude oil		Coal oil point mussels were more resistant than mussels from other areas, suggesting that chronic exposures lead to selection for tolerant forms. Alternative that inherent physiological variability between populations may account for differences in oil tolerance is not eliminated and is suggested by the 10-100 fold difference in tolerance of mussels from 2 nonseep area samples.
Pink Scallops (Chlamysrubida)	Rice et al., 1976	bioassay (96 hr TLM)	Prudhoe Bay crude, Cook Inlet crude, and No. 2 fuel oil	.80 - 3.15 ppm	Scallops accumulated significant paraffin concentrations. Scallops rapidly accumulated naphthalenes. Depuration was slow but steady. After 120 hrs certain fractions were still detectable.
Clams (Saxidomus giganteus and Mya arenaria) and Mussel (Mytilus edulis)	Mix et al., 1976	Analysis of background hydrocarbon levels	carcinogenic, polycyclic aromatic hydrocarbons (benzo-a-pyrene)		Detectable levels of carcinogenic benzoa-pyrenes were found in bivalves from 43 of 44 sampling sites. High levels were present in mussels collected from industrial dock areas. Significant levels were present in Mya arenaria collected near industrial docks.
Scallops (Pecten opercularis) Cockles (Cardium edule) Mussels (Mytilus edulis)	Swedmark, Granmo & Killberg, 1973	toxicity effects	oil pollution	sublethal	Scallops and mussels are considerably less tolerant to oil pollution than mussels. At sublethal concentrations the ability of the bivalves to close their shells was greatly impaired. Exposure to diesel oil illicited the most severe effects.
Oysters	NAS 1975	observation reports	chronic pollution brines and spills	500 ppm in sediments	Tainting of oysters in Louisiana oil fields is frequently reported and is generally associated with sediments containing high levels of petroleum hydrocarbons (500 ppm). Tainted oysters must be removed to unpolluted areas for several months to make them marketable.
Oysters	Ehrhardt, 1972 Anderson, R, 1975	field observation	chronic pollution (ship channel)		Oysters collected at the mouth of Houston Ship Channel showed much higher concentrations of hydrocarbons than those collected across the bay, 237 and 2 ug/g respectively.
Behavioral Effects					
Softshell Clam (Mya arenaria)	Stainken, 1976a	bioassay 96 hr	No. 2 fuel oil and Louisiana crude	oil water emulsion (sublethal)	With increased concentration of oil, clams increased mucus secretion and decreased tactile responses. General behavioral sequence: successively impaired activity; immobilization and death. Increased metabolic

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
					demands for mucus production and excretion and the disruption of normal physiological and biochemical processes occurred at much lower concentrations than the LC50 value indicates. LC50 values: Phenol 565 ppm; and #2 fuel oil 475 ppm.
Clam (*Macoma baltica*)	Taylor and Karinen, 1976	bioassay in situ experiment	Prudhoe Bay crude oil	0.234 and 0.367 ppm naphthalene equivalents	Water soluble fraction of oil and oil-treated sediment inhibited burrowing and caused clams to move to sediment surface where they would be vulnerable to predation or die from exposure.

Drilling Cuttings and Drilling Muds

Potential for long residence time of contaminant. During the exploration and development phases of oil development, exploratory wells are drilled to determine if oil and/or gas are present. If hydrocarbons are discovered in commercial quantities, platforms are erected and many development wells are drilled to extract these hydrocarbons from the oil bearing formation. During drilling, adverse impacts to the marine environment may result from the discharge of drilling muds and cuttings into marine waters. In 1976, the U. S. Department of Interior estimated that approximately 84 exploratory wells and 520 production wells could be drilled in the Lower Cook Inlet oil and gas lease sale area during the life of the field. They predicted that as a result of drilling a total of 210,000 cubic yards of cuttings and approximately 172,000 barrels of drilling muds could be discharged into the marine enviornment. The discharged muds and cuttings produce a surface plume of muddy water that can be distinguished for a few hundred feet down-current and then as an accumulation of cuttings on the bottom (Sheen Technical Subcommittee, 1976).

Drilling muds. Drilling muds are special mixtures of clay, water (or oil) and chemicals which are circulated into the drilling hole to cool and lubricate the drill bit, to remove formation cuttings from the hole, and to prevent blowouts by holding back formation pressures exerted by oil and gas accumulations (McDermott & Co., undated). Throughout drilling the muds are recirculated after cuttings and other debris are removed. Large volumes of mud are discharged into the marine environment usually after surface casings of wells have been set or the wells are drilled (Sheen Technical Subcommittee, 1976). In some cases, the muds are stored for future drilling activities at the end of drilling (USFWS, 1978b).

Drilling fluids and their chemical components have been shown to be acutely toxic to fish (including coho salmon) and marine invertebrates (Daugherty, 1951; Falk & lawrence, 1973; B. C. Research, 1975).

Beside the effects of toxicity, another potential adverse impact of drilling muds results from the accumulation of muds on the bottom. Muds settling on the bottom may result in the smothering of benthic (bottomdwelling) organisms which are incapable of moving out of the disturbed area (Dames & Moore, 1978). Diesel oil or other chemicals added to muds to facilitate the drilling of deep wells can adhere to mud particles and settle to the bottom causing pollution of the substrate. Filter feeding animals such as clams filter out the oil from the sediments and concentrate it causing them to develop an unpalatable, oily taste.

Hamilton, et al., 1979

Drilling Muds - The effects of drilling muds on the marine environment is related to: 1) the composition of the mud, 2) the quantity and rate of mud discharged, and 3) the receiving waters. Simple drilling muds without additives can be classified as low to moderately toxic compounds. Adverse effects will result primarily from discharging muds into shallow waters, into water bodies with limited circulation or mixing, or into waters containing high concentrations of eggs, larvae or sensitive juvenile adult organisms. Drilling muds which contain highly toxic additives to deal with specific drilling problems are toxic under any circumstances, however, the biological effects of these muds will be most severe in areas where little dilution or mixing occurs.

The discharge of large quantities of drilling muds over a long period of time such as from a development platform, will debilitate and possibly kill organisms which may survive one time discharges of muds from a single exploratory well. Long term mud discharges are more likely to result in lethal accumulations of toxic muds in sediments and smothering. The sudden discharge of a quantity of mud is potentially more destructive than the continuous discharge of a similar amount over a long period of time because less dilution will occur and the area of acute toxicity will be several times larger.

The discharge of drilling muds into productive aquatic environments with large numbers of non-mobile benthic or planktonic organisms is potentially more damaging than discharging drilling muds into sterile environments or areas supporting mobile organisms which could leave the area. In deep well-mixed marine waters, where muds are rapidly dispersed, the biological effects of mud discharges are limited to a small area surrounding the point of discharge. However, in shallow waters with weak currents little dilution will occur and drilling muds are likely to be sufficient to adversely affect marine organisms. Without dispersal drilling muds may settle directly to the bottom and may build up to toxic levels in marine sediments. Suspended solids from the discharge may also reduce light penetration and primary productivity in the area.

Drill Cuttings - Clean drill cuttings are non-toxic and their primary effect on the aquatic environment will be smothering of non-mobile benthic organisms such as clams, anemones and marine plants. The magnitude of this effect will depend upon the volume of cuttings discharged, the benthic community in the receiving waters, and the sediment transport processes in the area. The volume of cuttings discharged from a platform will depend upon the depth of a well and the number of wells drilled. A shallow well will produce less cuttings than a deep well, and a single exploratory well will produce considerably less cuttings than a producing platform where as many as 20-30 wells may be drilled during the life of the field. Using 2 million pounds of cuttings as an average per well, 40-60 million pounds of cuttings may be discharged from a production platform. If sediment transport processes are weak these cuttings will be deposited in a small area surrounding the discharge pipe, but if currents are strong these cuttings may be thinly distributed over a several square mile area. If sediment transport processes are weak and the platform happens to be located in a unique area, such as a larval king crab settling area, and the cuttings pile covered it, the effect could be significant. However, with the strong currents and the limited number of known critical habitats in the marine waters of Cook Inlet, it is unlikely that the discharge of clean drill cuttings will be a significant problem. Drill cuttings, however, may be contaminated with drill muds, chemicals, and hydrocarbons from the producing formation. The toxicity of these cuttings and their effect on the marine environment will generally be the same as the contaminating compound, and their disposal should be handled similarly.

Dames & Moore, 1978

Dames & Moore conducted a study to assess the effects of discharging drilling muds and cuttings during the drilling of a C.O.S.T. well 35 nautical miles west of Homer in Lower Cook Inlet. This well was located within the Lower Central Zone area. The study concluded that strong tidal currents in addition to a turbulent wake created by the semisubmersible exploratory drilling rig caused discharged drilling muds to be rapidly diluted (10,000:1) within 100 m of the vessel. The amount of total suspended solids discharged within 100 m of the drilling vessel was measured at 8.1 mg/l compared to a typical background level in Lower Cook Inlet of 2 to 20 mg/l. Drill cuttings were separated from the drilling muds upon discharge into the receiving waters. The drilled cuttings fell to the sea floor whereas the finer drilling muds remained near the surface. In some cases, the drilling muds adhered to the cuttings. Cuttings did not accumulate in a site on the sea floor but were mixed into the bottom to a depth of approximately 8 to 9 cm below the surface. Cuttings accumulation rates were 5.5×10^{-3} g/hr/m^2 85 m north of the drilling site, 1.25 g/hr/m^2 100 m north of the drilling site, 4.26×10^{-1} g/hr/m^2 200 m north of the drilling site, and 3.20×10^{-2} g/hr/m^2 400 m north of the drilling site.

BLM, 1978

Due to the lack of scientifically generated information with regard to the fate and effects of drilling fluids disposed of into the marine ecosystem, several field studies have been conducted in an effort to determine the effects of such discharges *in situ*.

Mobil Oil Corporation funded a monitoring study of their drilling operations near the East Flower Garden Bank offshore Texas. Sediment and sea water were analyzed for barium, chromium, iron, lead and hydrocarbons, before, during and after drilling operations; and observations of the coral reef were made. There was a marked elevation of barium, iron and lead in sediments at the drill site during and after drilling. Barium increased from 22 to 425 parts per million, iron increased for 8.5 to 13,000 ppm, and lead increased from 4.6 to 12.7 ppm. Hydrocarbon levels in sediments did not indicate any effect from drilling operations. The drilling fluids outfall was located near the bottom and the chemical analyses indicate that this served to concentrate them near the drill site and prevented them from reaching the coral reef.

Union Oil Company funded a monitoring study of their drilling activites near the West Flower Garden Bank, offshore Texas to assess the deleterious effect, if any, of their operations on this coral reef. The drilling fluid outfall was placed near the sea floor as a precautionary measure to protect the coral reef. On the basis of repetitive observations involving quadrat counts of benthonic organism, quantitative assessment of fish populations, quantitative and qualitative assessments of coral behavior and stress reactions and determinations of "health" and patholocical conditions among hermatypic corals and other epibenthic organisms, the investigation found no discernible effect on the reefal communitites.

Post drilling barium analyses indicated major amounts to the north and east-southeast of the drill site within 300 meters of the site. Transmissivity measurements during drilling indicated a turbid water plume that extended over 1,000 meters to the south of the drill site toward the reef.

Continental Oil Company funded a study of their drilling operations near Baker Bank, offshore Texas. In this case, the drilling fluids were disposed of at the sea surface. On the basis of sediment barium levels before and after drilling, a major increase in barium was found at the drill site. Pre-drilling barium levels ranged from 344 to 419 parts per million. Post-drilling levels were as high as 1618 parts per million at a distance of 500 meters from the drill site but decreased to a maximum of 678 ppm at a distance of 1,000 meters.

Burmah Oil and Gas Company funded an investigation of their drilling operations near Stetson Bank, offshore Texas. The drilling fluids outfall was located near the seafloor to protect the bank. Significant increases in sediment barium concenteations were limited to within 300 meters of the well site and no increase was noted on the bank itself.

In a BLM funded study offshore Texas, sediment barium levels were found to increase during drilling throughout the 1,000 meter sampling radius. Post-drilling samples taken three months after the termination of drilling showed somewhat decreased barium levels with the high levels remaining at the drill site. Presumably, the barium sulfate deposited during the drilling operation had been redistributed and diluted prior to the post drilling analysis.

In another BLM funded study offshore Texas, sediment concentrations of zinc, barium and cadmium increased markedly at the drill site compared to pre-drilling levels.

In a recently published EPA funded study, an enrichment of barium, lead, zinc and strontium was found in sediments near production platforms. The higher barium content can be attributed to drilling fluids; however, the overall variations were subtle and hardly indicative of major contamination.

Drilling fluids are one of the necessary materials for drilling wells in the search for oil and gas resources on the Outer Continental Shelf. Except for those which contain oil, these fluids have historically been disposed of into the marine ecosystem. Acute toxicity bioassays indicate that most drilling fluid components are relatively non-toxic; however, certain minor constituents, such as the chlorinated hydrocarbon bactericides, are toxic and persistent. Field studies indicate that the initial dilution and subsequent dispersion of drilling fluids results in minor changes in the chemical composition of the surrounding sediments. When drilling fluids are disposed of at or near the sea surface, then the radius of the impact zone is at least 1 km; however, if the outfall is located near the sea bottom, the radius of the zone of impact is generally less than 300 m. This latter disposal method has been found to be useful when drilling near biotic communities which are sensitive to turbidity.

<u>OCSEAP, 1979</u>

Field studies around existing platforms have been conducted to determine dilution rates for mud discharges and to assess whether the platforms do in fact, "affect" the environment, particularly the benthic assemblages surrounding them. Plume models have also been developed to predict the dilution and dispersion of the effluent. In general, the mathematical models tend to predict much smaller dilution than actually occurs, primarily because they do not take into account the interactions of the drilling ships and ocean currents. Dames and Moore predicted dilutions of 100:1 within 100 meters of a outfall, but a dye dispersion study demonstrated that the actual dilution was 10,000:1. Nalco, in its study for Union Oil in Lower Cook Inlet, also found dilution on the order of 10,000:1 near the drillship.

Ecomar measured the dilution rates around a semi-submersible off California, as part of its study of shell's Tanner Bank drilling operation. At discharges of 10 barrels per hour, dilutions of 50,000 to 100,000:1 occurred at distances of 100 meters from the discharge; with discharges of 750 barrels per hour, similar dilutions occurred at distances of 500 to 800 meters.

Field "effects studies" (in reality, "rig monitoring") have been performed in the Gulf of Mexico, near the Tanner Banks of Southern California, and in Cook Inlet, Alaska. A number of these have documented increases in metal concentrations in the sediments surrounding the platforms. Union Oil's study of its operations near the West Flower Garden Bank, off Texas, demonstrated increases in barium concentrations from 50 to 1300 ppm (predrilling) to 4.6 to 7800 ppm (postdrilling). Mobil's study of the East Flower Garden Bank demonstrated increases in barium (from 22 to 425 ppm), iron (from 8.5 to 13,000 ppm), and lead (from 4.6 to 12.7 ppm). Other studies (Continental Oil near the Baker Bank, Texas, Burmah Oil and Gas near Stetson Bank, Texas, and two BLM studies off Texas) showed similar increases. Generally, the increased metal concentrations were confined to within 200 to 500 meters of the drilling sites.

"Effects" of drilling platforms have been difficult to document. The Union Oil Study of the West Flower Garden Bank found "no discernible effect from the drilling operations on the reefal communities." Ocean Production Company performed a monitoring study of their drilling activities on the Georges Bank, and found no effect of drilling muds on pH, suspended solids, turbidity (except within 100 yards of the outfall), soluble barium and chromium in sea water. Shell was not able to document any accumulation of drilling muds or effects on the reefal communities associated with its activities on the Tanner Bank. Oil company reports tend to emphasize the "positive reef effect" of platforms and use this as evidence of the lack of adverse effects of drilling mud discharges.

The possibility of adverse effects has been suggested in at least two instances. An EPA flow-through infaunal community development study revealed that exposure to drilling mud reduced the number of settling macrobenthic infaunal individuals by 72%; the number of sea anemones (close relatives of corals) was 93% lower than controls.

The Dames and Moore study to Arco showed decreased abundances of the "most important" species in the immediate vicinity of the platform than at a control site, although there "may have been" fewer organisms there prior to drilling.

Didiuk & Wright, 1975 - A study conducted to assess the effects of the deposition of thin layers of drilling wastes on the survival of a benthic organism in Northern Canada showed that if the suspended solids in 1.6 x 196 1 of drilling mud settled out uniformly they could blanket an area of up to 95 hectares to a depth of 1 mm. The same volume could cover a 32 hectare and 14 hectare area to depths of 3 and 7 mm respectively. A thin layer of drilling effluents could adversely affect benthic organisms.

Drill cuttings. Drill cuttings, composed of bottom sediments and pieces of pulverized rocks from underlying sedimentary geologic formations, are produced during well drilling. These materials along with some drilling muds are discharged into the surrounding waters. Approximately 2 million pounds of drill cuttings may be discharged in the course of drilling a single well and as many as 20 wells may be drilled from a single platform. Because of their coarseness, most of the cuttings will rapidly settle out from the discharged material and collect on the bottom near the point of discharge. To what extent they accumulate and form piles depends largely on the speed of currents in the drilling area, although wave energy may be important in some areas. In shallow marine waters where currents are low (less then 0.25 knot) discharged cuttings have been reported to accumulate as mounds approximately 46 m (150 ft.) in diameter (Zingula, 1976) and up to 6 m (20 ft.) in height (Carlisle et al., 1964). If there is an accumulation of materials, the less mobile species of animals living on the bottom may be smothered.

Relative sensitivities of key species. The relative sensitivities of key species are presented in table 52.

Chronic Contamination from Formation Waters

Potential for long residence time of contaminant. The discharge of formation waters from offshore drilling platforms or onshore treatment facilities may adversely impact aquatic organisms. Crude oil as it comes from the ground is generally made up of natural gas, petroleum and water. The water, called formation or produced water, is contaminated with hydrocarbons and may be contaminated with heavy metals and hydrogen sulfide all of which may pollute marine and freshwater environments (USFWS, 1978d). Before the crude oil is delivered to a refinery, the water must be separated from the oil and gas. This process takes place either on the offshore production platform or the crude oil is transported ashore by pipeline and the oil, water and gas are separated at onshore treatment facilities. Once the formation water is separated from the oil and gas, it is generally treated by heat or chemicals and discharged back into marine waters, sometime in the same location for several years (USFWS, 1978d; Mackin, 1973). Formation waters may also be injected into disposal wells or pumped back into reinjection wells to maintain pressure (USDI, 1976). The amount, and therefore the effect, of the discharged formation waters on biological communities in the receiving waters is determined by the size of the treatment facility and ability of the receiving waters to accommodate the wastes. Because onshore treatment facilities may collect oil from several offshore platforms, the amount of formation waters discharged will be considerably greater than that discharged from treatment facilities on individual platforms. It may also be assumed that the biological effects from a single onshore treatment facility discharging formation waters into shallow nearshore waters might be significantly greater than the collective effects of formation waters discharged from several offshore platforms.

Table 52 Acute/toxic, physiological and behavioral effects of drilling muds and cuttings on fish resources.

Species	Reference	Type of Experiment	Product	Concentration	Effect and Evaluation
SALMONIDS					
Acute/Toxic Effects					
Pink Salmon Fry (Onchorhynchus gorbuscha)	Dames & Moore, 1978	Static bioassay	Drilling fluids	0.1-0.7% by volume	96 hr LC50's ranged from 0.3 to 2.9% by volume. Well stirred mixtures produced a much lower (0.3%) LC50 value than the same mud sample did with minimal stirring (2.9%). Pink salmon fry were the most sensitive species tested. Total suspended solids at the lowest LC50 equalled 1,100 mg/l.
Juvenile Rainbow Trout (Salmo gairdneri) Coho Salmon (O. kisutch), Chum Salmon (O. keta), Pink Salmon (O. gorbuska)	Environment Canada, 1975	Seawater bioassay	Drilling fluid wastes	0.56%-18%	96 hr LC50 values for rainbow trout and coho salmon juveniles ranged from 1.6% to 19.0%. Most were confined to the 1.6% to 3.9%. There appeared to be a general trend for sample-specific toxicity. All 4 species showed similar tolerances when tested with a single sample (2.4-2.9%) although pink salmon were slightly more tolerant (4.1%).
Rainbow Trout (S. gairdneri)	Beak Consultants Limited, 1974a	Static bioassay	Drilling muds	5-25% by weight	The 96 hr LC50's for rainbow trout ranged from 5.0% to 25.0% by weight. Filtrates of the drilling fluids were consistently less toxic than the whole mud systems. Source of toxicity was attributed to drilling components (muds) rather than drilled solids (cuttings). Toxicity was related to suspended solids and metal ions contained in barites and lignosulphonates.
Rainbow trout (S. gairdneri)	Beak Consultants Limited, 1974b	Static bioassay	Drilling fluids	9-27% by weight	96 hr LC50's varied from 9.0% to 27% by weight. Increased toxicity (LC50's of 9% and 11%) was attributed to the addition of KCL and increased barite and lignosulphonate concentrations.
Rainbow trout (S. gairdneri)	Herbert & Wakeford, 1962	Bioassay	Calcium sulphate (gypsum)	3163-6820 ppm	Four weeks of exposure at pH values of 8.1 produced 50% mortality at 6,820 ppm gypsum (4,250 ppm in suspension). 3,163 ppm (553 ppm in suspension was not acutely toxic.
Rainbow trout (S. gairdneri)	Logan et al., 1973	Bioassay	Bentonite clay	10,000	Bentonite clay was not acutely toxic to rainbow trout at 10,000 ppm after 96 hrs.
Rainbow trout (S. gairdneri)	Herbert & Merkens, 1961	Toxicity effects	Mineral solid suspensions of kaolin and diatamaceous earth	30-810 ppm	Concentrations of 270 and 810 ppm of mineral solid suspensions of kaolin and deatamaceous earth produced high trout mortality after several month exposure. Gill damage (thickening and fusion of lamellae) was noted.

ppm = parts per million
ppb = parts per billion
LC50 = concentration required to kill 50% of the test animals
TLM = median tolerance limit - the concentration required to

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Rainbow trout (*S. gairdneri*)	Herbert & Richards, 1963	Bioassay	Spruce fibre	50-200 ppm	Rainbow trout held in 200 ppm spruce fibre had mortalities of 50% after 16 weeks and 80% after 40 weeks. No deaths occurred at 50 ppm and 100 ppm.
Rainbow trout (*S. gairdneri*)	Logan et al., 1973	Bioassay	Sodium acid pyrophosphate (SAPP)	870 ppm	96 hr LC50 for rainbow trout was 870 ppm at a pH of 6.25-6.5.
Rainbow trout (*S. gairdneri*)	Logan et al., 1973	Bioassay	Lubricants and detergents	14-2,270 ppm	96 hr LC50 values for four water soluble surface active agents of unknown chemical composition (Scot-Free, B-Free, Swift's Rig Wash, and Dominion Rig Wash) were 52, 19, 22 and 14 ppm respectively. Tricron and Torq-Trim (surface wetting agents) had LC50's of 63 ppm and 2,270 ppm respectively.
Rainbow trout (*S. gairdneri*)	Lawrence & Scherer, 1974	Acute toxicity Bioassay	Mud from Imperial Oil's Immerk B-48 Beaufort Sea (Canada)	1-10,000 ul/l	The 96 hr LC50 values were determined to 75,000 ul/l.
Rainbow trout (*S. gairdneri*)	Moore, Beckett & Weir, 1975	Acute toxicity	Drilling fluids eight northern (Canada) drilling sites		Overall toxicity was a result of components in use at a particular time and the formation being drilled. Surface hole muds were most toxic (primarily from use of KCL to penetrate permafrost). Samples from greater depths exhibited multifactor toxicity (metals, solids and other compounds) compounded by high viscosity and extremely high solids content.
Rainbow trout (*S. gairdneri*)	Weir, Lake Thackeray 1974	Static bioassay	Samples from drilling sumps in Canadian arctic	8.6%-100%by volume	The 96 hr LC50 ranged from 8.6% to 100% effluent concentration. Acute toxicity appeared directly related to concentrations of drilling compounds (Barytes and Peltex). Greatest toxicity appeared due to high concentrations of sodium, potassium chloride, chromium, aluminum. There was evidence of gill chamber clogging and hemorrhaging of gill chambers and eye area.
Physiological Effects					
Juvenile king salmon (*O. tshawytscha*)	Olson, 1958		Hexavalent chromium (CrO_4--, Cr_2O_7---)	0.2 ppm	Juvenile king salmon exposed to 0.2 mg/l of hexavalent chromium for 12 weeks showed reduced growth and increased mortality.
Pink salmon fry (*O. gorbuscha*)	Nalco, 1976	96 hr Static bioassay	Whole drilling muds, whole mud plus paraformaldehyde (0.25 lb/barrel mud)	$\leq$10% mud	Dissolved oxygen concentrations in unareated aquaria containing pink salmon fry decreased with overtime. Greatest decreases were observed at the higher concentrations of toxicants. No acute toxicity was observed at this concentration.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Brown trout (Salmo trutta)	Herbert et al., 1961	Field observations	Suspended mineral solids	1,000 ppm	River fisheries of brown trout were severely reduced by 1,000 ppm china-clay wastes (containing mica, clay and sand in various proportions). Population reduction was due to cessation of reproduction, reduction of the aquatic invertebrate population and gill damage.
Rainbow trout (S. gairderni)	Herbert & Richards 1963	Toxicity effects	Spruce fibre Bioassay	50-200 ppm	Rainbow trout had a 20-40% reduction in growth growth after 40 weeks exposure to 50 and 100 ppm spruce pulpwood.
Behavioral Effects					
Rainbow trout (S. gairderni)	Lawrence & Scherer, 1974	Behavioral	Mud from Imperial Oil's Immerk B-48 Beaufort Sea and supernatent fraction	Sublethal	Response to mud suspensions and the supernatent fraction was neutral at 100 ml/l shifting to preference at 1000 ml/l. Avoidance was observed at 10,000 ml/l of supernatent.
OTHER FISH					
Acute/Toxic Effects					
White fish (Coregonus clupeaformis)	Lawrence & Scherer, 1974	Acute toxicity bioassay	Mud from Imperial Oil's Immark B-48 Beaufort Sea	25,000 ul/l	The 96 hr LC50 for whitefish was 25,000 ul/l.
Staghorn sculpin (Leptocottus armatus)	Dames & Moore, 1978	Static bioassay	Drilling fluids	5-20% by volume	Based on a small sample and limited number of organisms, the 48 hr LC50 value for staghorn sulpin was 10-20% by volume.
Bluegill (Lepomis macrochirus)	Pruitt et al., 1977	Bioassay and tissue accumulation	Pentachlorophenol (PCP)	LC50 and sublethal	The 96 hr median lethal concentration (LC50) was 0.3 mg PCP/l for bluegill. Fish exposed to sublethal concentrations (0.1 mg/l) accumulated PCP in various tissues from 10 to 350 times the ambient concentration. The liver had the greatest concentration followed by the digestive tract, gills and muscle. Upon removal from PCP-contaminated water the fish rapidly eliminated PCP. Residues ranging from 0.03 to 0.6 ppm were still detectable, however, 16 days after fish were placed into a clean environment.
Physiological Effects					
Starry flounder (Platichtys stellatus) Coho salmon (O. kisutch)	Varanasi, 1978	Bioassay partial flow through	Cadmium and lead	150 ppb	Starry flounder and coho salmon exposed to 150 ppb cadmium and lead in seawater at 10° and 4°C accumulated concentrations of these metals in the skin, mucus, brain, posterior

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
					kidney, and liver. Greatest accumulations occurred at 10°C, however depuration in starry flounder was slower at 4°C. Coho salmon tissues still retained >50% of the accumulated metals 37 days after removal to clean water. Lead was retained by both species in higher concentrations than cadmium.
Behavioral Effects					
Whitefish (*Coregonus clupeaformis*)	Lawrence & Scherer, 1974	Behavioral	Mud from Imperial Oil's Immerk B-48 Beaufort Sea and supernatent fraction	Sublethal 1 to 17,600 ml/l	Whitefish showed increasing attraction to mud suspensions with increasing concentrations (1-1000 ml/l). An increase in swimming speed was also observed. Response to supernatent was neutral at 55 ml/l, preference at 1000 ml/l, neutral at 10,000 and a tendency toward avoidance at a higher concentrations (17,600 ml/l).
SHRIMP					
Pandalid shrimp	Dames & Moore, 1978	Static bioassay toxicity effects	Drilling fluids	8.6-20% by volume	Mortalities of pandalid shrimp at 20% conc. (LC50-8.6%) occurred rapidly and all shrimp were dead within 3 hrs. At 15% all the shrimp were dead at 24 hrs. At concentrations greater than 15% the shrimp showed irritation when placed in the test solution and would jump completely out of the tank.
Kachemak Bay Pandalid shrimp	Dames & Moore, 1978	Static bioassay	Drilling fluids	.025-20% by volume	96 hr LC50's values for pandalid shrimp ranged from 3.2 to 15% by volume. Total suspended solids at lowest LC50 equalled 14,000 mg/l.
White shrimp (*Panaeus setiferus*)	Chesser & McKenzie, 1975	Bioassay	Drilling fluid additives	265-2100 ppm	The 96 hr TLM's for white shrimp were 265 ppm, 465 ppm, 2100 ppm for a modified Hemlock bark extract (tarrun), a chrome treated lignosulfonate and an iron lignosulfonate, respectively. The chrome was present as trivalent chromium.
CLAMS, MUSSELS, SCALLOPS					
Physiological Effects					
Mussel (*Modiolus modiolus*)	Dames & Moore, 1978	Toxicity effects	Drilling fluids	Sublethal 1-3% by volume	Fourteen days' exposure at 3% mud resulted in a reduction of feeding time, respiration, delayed bysus thread formation and possible abnormal uptake levels of heavy metals.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
OTHER INVERTEBRATES					
Acute/Toxic Effects					
Mysids	Dames & Moore, 1978	Static bioassay	Drilling fluids	1-20% by volume	96 hr LC50's were 1% to 5% by volume for well mixed solutions and 10 to 15% in mixtures with no continuous mixing.
Copepod/mysid	Nalco, 1976	24 hr and 48 hr static bioassay	Whole mud and whole mud + paraformaldehyde (1.0 lb/barrel)		The mud and paraformaldehyde mixture (4-10x expected field concentrations for paraformaldehyde) resulted in complete mortality at all concentrations. Significant mortalities also occurred in concentrations of mud supernatent $\geq$5.7% for mysids and 10% for copepods.
Physiological Effects					
Chironomid (*Chironomus tentans*)	Didiuk & Wright, 1975	Physiological	Waste drilling fluids	1, 3, 7 m layers on sediment surface	Populations of Chronomid larvae treated with 1 m, 3 m, and 7 m layers of drilling waste achieved only 65%, 47% and 12% emergence respectively, with peak emergence occurring 22, 23 and 25 days respectively after mud addition. Controls achieved 84% emergence with peak emergence occurring on the 16th day. Organisms from contaminated substrates were smaller in size. Muds appeared to interfere with the feeding mechanism.

Hamilton et al., 1979 - Formation waters appear to be more harmful if discharged into shallow waters than into deeper waters because deeper waters as well as larger bodies of water with tidal action, waves and strong currents tend to rapidly dilute the formation waters. Because of their ability to avoid the contaminated waters, fish and free swimming organisms do not seem to be affected by the discharge of formation waters. The effects on free floating plankton seem to be similar and localized. However, in shallow waters where dilution by seawater may not take place, benthic organisms living near the point of discharge may be totally destroyed. The oil in formation waters may adhere to sediment particles in the water column and settle to the bottom causing contamination of the bottom substrate. When accumulations reach a sufficient level, destruction of bottom communities occurs. This information suggests that although the concentration of oil in water may be low, oil may be accumulating in bottom sediments over a long period of time. In order to avoid destruction of bottom communities, these sediments should be carefully monitored.

Discharges of high salinity waters into freshwater lakes or streams, or low salinity waters into highly productive marine environments such as clam beds could be very destructive.

Armstrong et al., 1979 - A study by Armstrong, et al. (1979) showed that although the concentration of aromatic hydrocarbons in receiving waters some distance from oil separator platforms in Trinity Bay, Texas, was very low, the concentration of several alkyl-substituted naphthalene compounds in the sediments near the separator platforms were four orders of magnitude higher than in the overlying water. Naphthalenes accumulated in greater concentrations in sediments than in water and remained in the sediments for long periods of time.

Because of the presence of naphthalenes in the sediments the bottom was almost completely devoid of benthic organisms within 15 m of the outfall from the oil separator platform. The presence of fauna within a radius of approximately 150 m around the platform was severely depressed. Apparently low (approximately 2 ppm) concentrations of nephthalene are capable of restricting many species.

High, persistent levels of naphthalenes in the sediments surrounding the separator platform were probably due to the turbidity of Trinity Bay water and the slow rate of degradation of oil in sediments. Suspended particles in turbid waters readily adsorb hydrocarbons which then sink to the bottom.

From an ecological viewpoint, chronic oil pollution such as that caused by the discharge of formation waters is potentially more serious than catastrophic oil spills. Continuous introduction of even low levels of oil into the environment could result in an accumulation of hydrocarbons in sediments which may persist for a long period of time. Few studies have been conducted in the natural environment on the effects of chronic oil pollution.

Mackin, 1971 and 1973 - The effects of formation waters seem to decline farther from the point of discharge because of dilution by marine waters. Mackn studied the effect of produced waters on the marine plankton, benthic (bottom), and pelagic communities of six oil fields located in Texas estuaries. Bottom communities within 50 feet of heavy discharges were almost completely destroyed, whereas organisms from 150 to 200 feet appeared to receive noticeable but less impact. At 300 feet no short term impact was observed.

Mackin & Hopkins, 1962 - In a study by Mackin and Hopkins (1962) in Louisiana, trays of oysters placed within 25 feet of the formation water discharge site suffered very heavy mortalities near the bottom and slightly less at the top of the water column. Some mortality was observed out to 75 feet and between 75 and 150 feet there was evidence of stunted growth. Beyond 150 feet the report did not discuss any evidence of adverse effects from formation water discharges.

Formation waters are highly toxic and their disposal into the marine environment can be detrimental (NERBC, 1976). Formation waters contain up to 50 ppm of oil as small droplets and up to 35 ppm of dissolved hydrocarbons, primarily aromatic fractions. Levels of total dissolved aromatic hydrocarbons as low as 1 ppm have been found to acutely toxic to larval crustaceans found in Lower Cook Inlet (Rice, et al., 1977). Formation water may also contain toxic quantities of heavy metals, such as vanadium and mercury, and hydrogen sulfide, a poisonous gas. All formation waters are anoxic, and the concentrations of dissolved salts may vary greatly from receiving waters.

Polluted formation waters may affect both individual organisms and entire populations by causing short term (acute or lethal) biological effects such as death or long term (chronic or sublethal) effects including abandonment of a habitat and interference with the growth and reproduction. Once discharged, the formation waters are diluted with marine waters. The oil immediately undergoes a number of changes, such as dilution, evaporation, spreading, and biological degradation, which lowers the actual measured concentrations of hydrocarbons (Koons, et al., 1977). Other contaminants, such as hydrogen sulfide and heavy metals, undergo similar changes.

Relative sensitivities of key species. The relative sensitivities of key species are presented in table 53.

Interference with Fishing Activities

Conflicts between drilling platforms and the commercial fishing industry can be classified into one of the following categories: physical loss of fishing areas; interference with fishing gear and vessels; direct effects of oil pollution on commercial species; and tainting of commercial species by oil pollution.

Fishing areas may be lost if numberous offshore structures take up space in prime fishing grounds (St. Amant, 1971). Semisubmersible drilling platforms, with their large anchor network, may occupy up to four square miles. In areas with strong currents, the navigation problems associated with avoiding such structures remove even larger tracts of fishing grounds. The disposal of drill cuttings may remove small amounts of fishing grounds from production.

Interference with fishing gear by support vessels and vessels involved in the moving of drilling rigs is a major impact of oil development. Vessels operating in areas with fixed fishing gear (crab gear and halibut lines) often cut bouy and mooring lines. The gear thus becomes impossible to locate and recover. Tow ropes and nets can also be cut and fouled by the operation of vessels through congested fishing areas. Increases in the number of vessels and drilling platforms in an area increases the time spent in navigation and decreases the time available for fishing.

Table 53 Acute/toxic, physiological and behavioral effects of formation waters on fish resources.

Species	Reference	Type of Experiment	Product	Concentration	Effect and Evaluation
SALMONIDS					
Acute/Toxicity Effects					
Steelhead (*Salmo gairdneri*) Coho salmon *Onchorynchus kisutch*	Chapman & Stevens, 1978	Accute toxicity, bioassay	Heavy metals (cadmium, zinc and copper)	5.2 to 1,755 ug/l	The 96 hr LC50 values for adult male coho salmon and steelhead respectively were 46 and 57 ug/l for copper and 905 and 1,755 ug/l for zinc. Mortality induced by cadmium was slow in onset but 50% mortality occurred after more than a week at 3.7 ug/l for coho salmon and 5.2 ug/l for steelhead. Water hardness and alkalinity affected the toxicity levels.
Juvenile king salmon (*O. tshaisytscha*) Steelhead (*Salmo gairdneri*)	Chapman, 1978	continuous flow toxicity tests	Heavy metals (cadmium, zinc and copper)	ppm	The 96 hr LC50 values for four juvenile life stages of king salmon and steelhead ranged from 1.0 to > 27 ug Cd/l, 17 to 38 ug Cu/l and 93 to 815 ug Zn/l. The 200 hr LC50 ranged from 0.7 to > 27 ug Cd/l, 7 to 30 ug Cu/l and 54 to 555 ug Zn/l. Newly hatched alvenins of both species were more resistant to cadmium and zinc. Later juvenile stages were most sensitive. Copper sentivities showed little relationship to life history stage. Steelhead were consistently more sensitive to these metals than were king salmon.
Salmon (*Onchorynchus*)	McKee & Wolf, 1963	Literature review	Hydrogen sulfide H_2S	0.3 to 1.0 mg/l	0.3 and 0.7 mg H_2S/l were survived by king salmon and silver salmon respectively, while 1.0 and 1.2 mg H_2S/l were toxic.
Coho salmon (*O. kisutch*)	Chapman, unpublished (cited)	Bioassay	Heavy metals (lead)	6.8 mg/l	50% of four week old coho salmon were killed by a four day exposure to lead concentrations of 0.8 mg/l.
Coho salmon (*O. kisutch*)	Katz and Pierro, 1967	Toxicity effects	Ammonia		Toxicity of ammonia to coho salmon increases with increasing salinity.
Juvenile Atlantic salmon (*Salmo salar*)	Herbert & Shurben, 1965	Toxicity effects	Ammonia	0.2 mg/l	Concentrations of ammonia higher than 0.2 mg/l are toxic to Atlantic salmon smolts.
Rainbow trout (*Salmo gairdneri*)	Brown, 1968	Bioassay	Heavy metals (lead)	1 mg/l	96 hr LC50 for rainbow trout was 1 mg Pb/l.
Brook trout *Salvelinus frontinalis*	Benoit et al., 1976	Bioassay	Heavy metals (cadmium)	.06 ug/l.	Exposure to 3.4 ug/l Cd resulted in the death of a significant number of first and second generation brown trout males during spawning. This concentration also significantly retarded growth of juvenile second and third generation offspring. Bioaccumulation of cadmium occurred in gill liver and kidney tissue and was directly related to exposure concentrations. Depuration was rapid from gills but no loss was detectable from liver or kidney tissue.

ppm = parts per million
ppb = parts per billion

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Juvenile Rainbow Trout (*S. gairdneri*)	Wobeser, 1973	Bioassay	Heavy metals (mercury)	24-42 ug/l	50% of newly hatched fry and fingerling rainbow trout were killed by mercury concentrations of 24 and 42 ug/l.
Physiological Effects					
Juvenile Coho Salmon (*O. kisutch*)	Burrows, 1964	Toxicity effects	Ammonia	0.002 mg/l	Progressive gill hyperplasia is produced in fingerling chinook salmon at concentrations of 0.002 mg/l of ammonia.
OTHER FISH					
Acute/Toxic Effects					
Channel catfish (*Ictalurus punctatus*)	Bonn & Follis, 1967	Bioassay	Hydrogen sulfide H_2S	1.5 to 10.9 ppm undissolved sulfides (0.4 to 0.9 ppm unionized H_2S)	3 hr TLM's of unionized hydrogen sulfide for channel catfish fry ranged from 0.8 ppm at pH of 6.8 to 0.53 at pH of 7.8. Most deaths occurred within 10 minutes at the TLM values. Fingerling catfish were more sensitive than adults.
Fathead minnow	Pickerins & Henderson, 1966	Bioassay	Heavy metals (lead)	5.6 to 7.3 mg/l	96 hr LC50 for fathead minnows was 5.6 to 7.3 mg Pb/l.
Physiological Effects					
Flagfish (*Tordanella floridae*)	Spehar et al., 1978	Toxicity effects	Heavy metals (zinc and cadmium)	4.3 to 8.5 ug Cd/l 73.4-139 ug Zn/l	Effects of survival on flagfish exposed to cadmium and zinc as individual metals and as mixtures showed that the toxicity of the mixtures was little if any greater than the toxicity of zinc alone. Cadmium and zinc did not act additively when combined at sublethal concentrations, however, joint action was indicated. Tissue uptake of one metal was not influenced by the presence of the other metal. A significant decrease was observed in the survival of larvae exposed as empryos to individual zinc and cadmium concentrations. However, similar effects on survival were not observed with progeny of earlier chronic tests.
Bluegill (*Lepomis macrochirus*)	Atchison et al., 1977	Observation of contaminated lakes	Heavy metals (zinc, lead, cadmium)	1.1 to 270 ug/l suspended in water and 4.4 to 12,800 ug/g dry weight in sediment	The relative levels of contamination in bluegills from two metal contaminated lakes closely resembled the relative concentrations of metals in the water and sediment at each site. Up to 3.4 ug Cd/g dry weight of tissue, 220 ug Zn/g dry weight tissues and 6.1 ug Pb/g dry weight tissue were found in bluegills from the contaminated lakes. These levels were significantly above levels found in fish from uncontaminated lakes.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Fathead Minnows	Mount, 1974	Toxicity effects	Heavy metals (mercury)	0.07 to 0.12 ug/l	Fathead minnows did not spawn and males did not develop sexually when exposed to mercury concentrations of 0.12 ug/l. No toxic effects were noted at 0.07 ug/l.
Fathead Minnows	Pickering, 1974	Bioassay toxicity effects	Heavy metals (mercury)	380 ug/l	Survival, growth and reproduction of fathead minnow was unaffected at and below a nickel concentration of 380 ug/l.
Fish	McKim, 1974	Toxicity effects	Heavy metals (mercury)		Concentrations of mercury in excess of 10,000 times those present in surrounding water have been found in fish.
Behavioral Effects					
Channel Catfish (*Ictalurus punctatus*)	Bonn & Follis, 1967	Bioassay	Hydrogen sulfide H_2S	sublethal	When catfish of varying ages were exposed to sublethal concentrations of unionized hydrogen sulfide (0.2 ppm of TLM for given pH) they exhibited nervousness and excessive movement.
SHRIMP					
Acute/Toxic Effects					
Shrimp (*Penaous duorarum* and *Palaemonetes vulgaris*)	Nimmo et al., 1977	Flow through bioassay and toxicity tests	Heavy metals (cadmium)	.079 mg/l to 1.285 mg/l	The 96 hr and 30 day LC50's for pink shrimp (*P. duorarum*) were 3.5 mg Cd/l and 0.718 m Cd/l respectively. The 96 hr and 29 day LC50's for grass shrimp (*P. vulgaris*) were 0.76 mg Cd/l and 0.12 mg Cd/l respectively. Shrimp bioaccumulated cadmium up to 57 times surrounding water concentrations. Bioaccumulation occurred at concentrations as low as 2 ug/l. Exposure of shrimp to cadmium concentrations close to LC50's resulted in blackened gills, which were sloughed off by surviving shrimp after return to clean water. Cadmium was also accumulated from contaminated food but at a much lower rate.
CLAMS, OYSTERS, MUSSELS					
Acute/Toxic Effects					
Oysters	Oliveira, 1924	Toxicity effects	Hydrogen Sulfide H_2S		Hydrogen sulfide generated by a deposit on the bottom of a bay was an important factor in causing the death of young oysters.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Oysters	Menzel & Hopkins, 1951 and 1953	Toxicity effects	Formation water	Discharge of 6000 barrels/day	Trays of oysters within 25 ft of the effluent suffered heavy mortalities. Mortalities were noted out to 75 ft with evidence of stunted growth to about 150 ft. There was suspicion of stimulated growth from 150 ft. to about 500 ft.
American oyster (*Crassosterea virginica*)	Calabrese et al., 1973	Bioassay	Heavy metals (nickel)	1.180 m/l	One-half the embryos of American oyster were killed after a two day exposure to nickel concentrations of 1.180 mg/l.
American oyster (*Crassostrea virginica*)	Calabrese et al., 1973	Bioassay	Heavy metals (lead)	1.730 mg/l	One-half of a test population of oyster eggs were killed by a two day exposure to 1.730 mg/l.
Physiological Effects					
American Oyster (*Crassostrea virginica*)	Pringle, 1968	Bioassay	Heavy metals (lead)	100-200 ug/l	Long-term exposure to lead concentrations of 100-200 ug/l causes considerable atrophy and diffusion of the gonadal tissue, edema and less distinction of hepatopancreas and mantle edge of the American oyster.
Oysters, diatoms, and algae	Mackin, 1950	Aquaria	Formation water	2.5 ppt	Over a 4 month period, heavy growth of the plants occurred and the oysters stored significantly more glycogen and had lower mortality than controls.
Behavioral Effects					
Bivalves (*Mylilis edulis* and *Mya arenaria*)	Capuzzo and Sasner, 1977	Toxicity effects	Heavy metals (chromium)	0.01 mg Cr/g clay to 1.2 mg Cr/g clay and 1 mg Cr/l sea water	Reduction of filtration rates and disturbed ciliary activity were observed in response to uptake of dissolved chromium by *Mya arenaria* and uptake of dissolved and particulate bound chromium by *Mytilus edulis*. Inefficient retention of food particles (due to slower erratic movement of the cilia) and a reduction in oxygen consumption were also observed.
Oysters	Lunz, 1950	Toxicity effects	Louisiana formation water	10,000-100,000 ppm	A significant decrease in pumping rates of oysters occurred at 100,000 ppm. Pumping returned to normal after oysters were returned to clean water. No changes in pumping rate were noted at 10,000 and 50,000 ppm.
OTHER AQUATIC SPECIES					
Acute/Toxic Effects					
Daphnia magna	Biesinger & Christensen, 1972	Bioassay	Heavy metals (nickel)	130 ug/l	A three week exposure to a concentration of 130 ug/l nickel killed one-half the population of *Daphnia magna*.

Species	Reference	Type of Experiment	Petroleum Product	Concentration	Effect and Evaluation
Copopod (*Arctia tonsa*)	Gentile, 1975	Bioassay	Heavy metals (nickel)	625 ug/l	A four day exposure to nickel concentrations of 625 ug/l killed one-half of the population of the marine copepod, *Arctia tonsa*.
Benthic organisms	Armstrong et al., 1979	Observation of outflow	Formation water	Undiluted effluent 15 ppm total oil, 1.62 ppm total naphthalenes	Sediments 15 m from brine outflow in a shallow bay had hydrocarbon concentrations 4 times as great as concentrations in the effluent while bottom water 15 m from outfall had 3 orders of magnitude less. The bottom was devoid of organisms within 15 m of outfall and benthic faunas were severely depressed at 150 m. Use of a second temporary outfall resulted in rapid buildup of naphthalenes in the surrounding sediments which persisted for at least 6 months following shutdown. Benthic fauna was also severely depressed near this outfall.
Bottom and Pelagic Communities	Mackin, 1971	Toxicity effects	Formation water		Studies of formation water discharge in 6 oilfields in Texas estuaries showed bottom communities almost totally destroyed within 50 feet of heavy discharges with lessening of effect out to 300 ft. A zone of stimulated growth was observed from 400 ft to several thousand feet out.
Fish and invert.	Shaw, 1976	Literature review water quality	H_2S & mercaptans (RSH)	<1 ppm	Hydrogen sulfide and chemically similar mercaptans (RSH) are poisonous to most fish and most invertebrates at levels up to 1 ppm H_2S.
Physiological Effects					
Daphnia major	Biesinger & Christensen, 1972	Toxicity effects	Heavy metals (lead)	0.3 ug/l	Daphnia major (a small zooplankton organism) showed 16% reproduction impairment when exposed to a lead concentration of 0.3 ug/l.
Daphnia magna	Biesinger & Christensen, 1972	bioassay	Heavy metals (nickel)	sublethal	A 16% reproduction impairment was observed in *Daphnia magna* exposed to nickel concentrations of 30 ug/l.
Daphnia sp.	Anderson, 1944	toxicity effects	Heavy metals (arsenic)	4.3 to 7.5 mg/l	Toxic effects and symptoms of immobility in *Daphnia* sp. occur at concentrations of 4.3 to 7.5 mg As/l.
Aquatic species (freshwater)	Gilderhaus, 1966	Toxicity effects	Heavy metals (arsenic)	2.3 mg	Reduced growth of fish, bottom fauna and plankton occurred at concentrations of arsenic of 2.3 mg/l.

Oil pollution also reduces the numbers of fish and shellfish which are available to the fishery. The reproductive and early development stages of fish and crustaceans life history are the most vulnerable. Many fish species, such as Pacific salmon and herring, seasonally concentrate in small areas along the coastline and contamination of these important or critical habitats and the loss of these populations could have serious consequences on commercial fishing (Michael, 1976). Also of importance is the avoidance of oil polluted areas by target fish and the reluctance of fishermen to use their boats and gear in oil contaminated waters. Fish in the area of a spill are often tainted with an oily or chemical taste making them unpalatable and therefore undesirable for human consumption (Nelson-Smith, 1973). Even if no tainting has actually occurred, the public is often reluctant to buy fisheries products from areas where there has been an oil spill or which are known to be polluted. The majority of oil spills in Lower Cook Inlet are related to drilling platform activities although the largest (volume) spills are caused by tanker accidents and submarine oil pipeline ruptures (FERC, 1978).

Table 54 and Figure 82 show the locations of major fishing areas and proposed exploratory drilling platforms in Lower Cook Inlet and Shelikof Strait.

Potential Shore-based Facilities-Tanker Terminals

Impacts on the marine ecosystem by shore-based facilities arise from habitat destruction (site preparation or alteration), siltation of adjacent waters, the use of cooling waters, oil pollution, and interference with commercial fishing.

Habitat destruction and alteration occur during the clearing, grading, filling, and paving required to construct buildings, build access roads, and establish utility right of ways. The amount of habitat altered by construction activities will depend on the availability of existing onshore facilities such as construction docks, refineries, and tanker terminals.

As a result of site preparation processes, habitats of local fish and wildlife populations are often altered or destroyed. Species that are sensitive to disturbance will abandon the area (USFWS, 1978d). If site preparation alters a small part of a species habitat and if the surrounding area is not at peak carrying capacity, the displaced species may successfully relocate nearby. However, if the disturbed area is large in relation to the total available habitat or if a species has specific habitat requirements and the area destroyed provided the only suitable habitat, the species may be eliminated from the area. It is also possible that site preparation could create new habitat which will be colonized by different species from the surrounding area (NERBC, 1976).

Table 54

LOCATIONS OF MAJOR FISHING AREAS NEAR PROPOSED EXPLORATORY DRILLING PLATFORMS IN LOWER COOK INLET AND SHELIKOF STRAIT

	SALMON SET NET	SALMON DRIFT GILL NET	SALMON PURSE SEINE	HERRING	SHRIMP	CRAB	GROUNDFISH	HALIBUT	PROPOSED EXPLORATORY DRILLING RIGS
KALGIN ISLAND AREA	√	√		√					
KACHEMAK BAY	√		√	√	√	√			
KAMISHAK BAY			√	√		√			
LOWER CENTRAL ZONE	√	√	√	√		√			√
KENNEDY ENTRANCE			√		√	√			
SHELIKOF STRAIT	√		√	√	√	√	√		

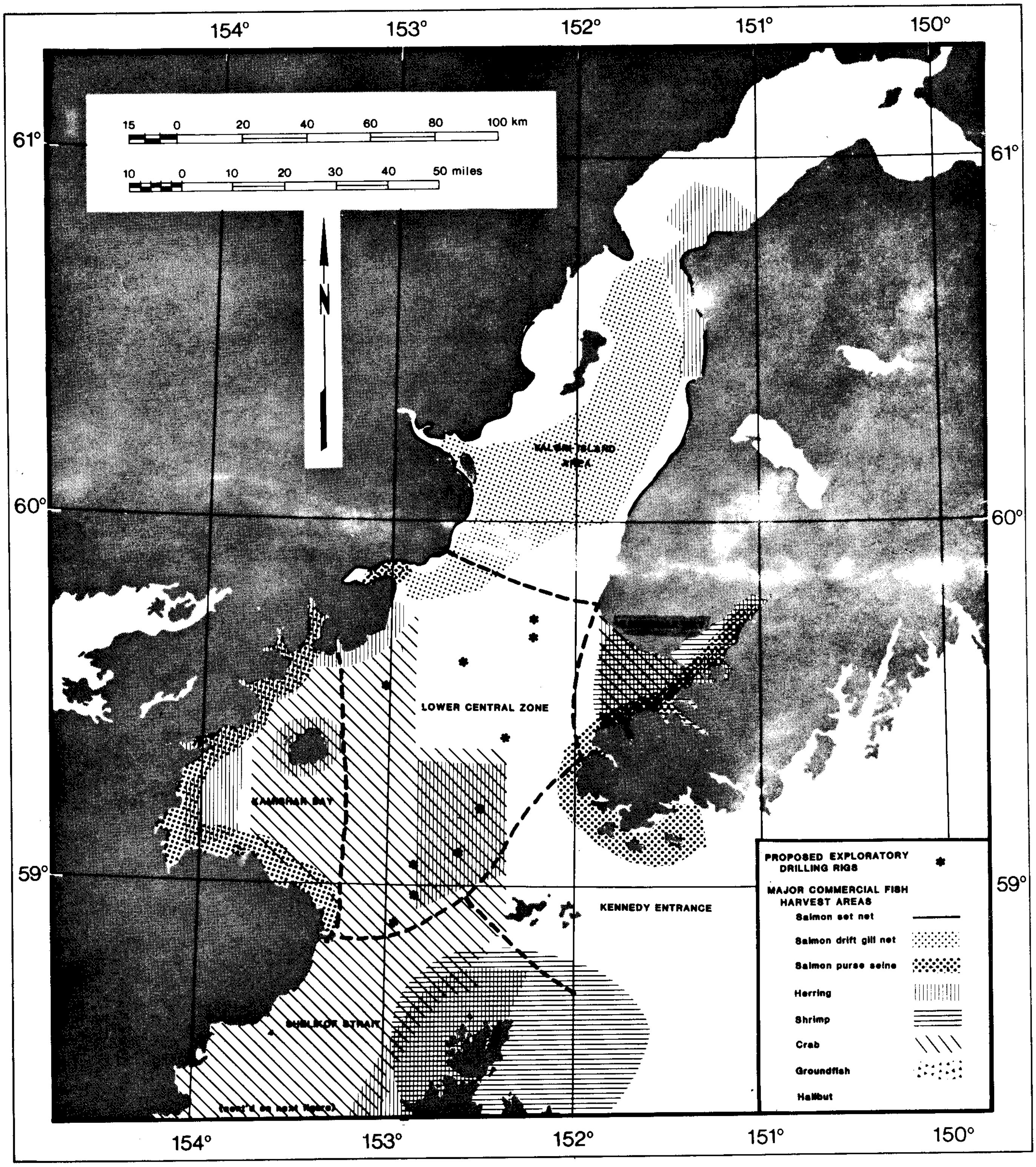


Figure 82. Locations of major fishing areas and proposed exploratory drilling platforms in Lower Cook Inlet and Shelikof Strait.

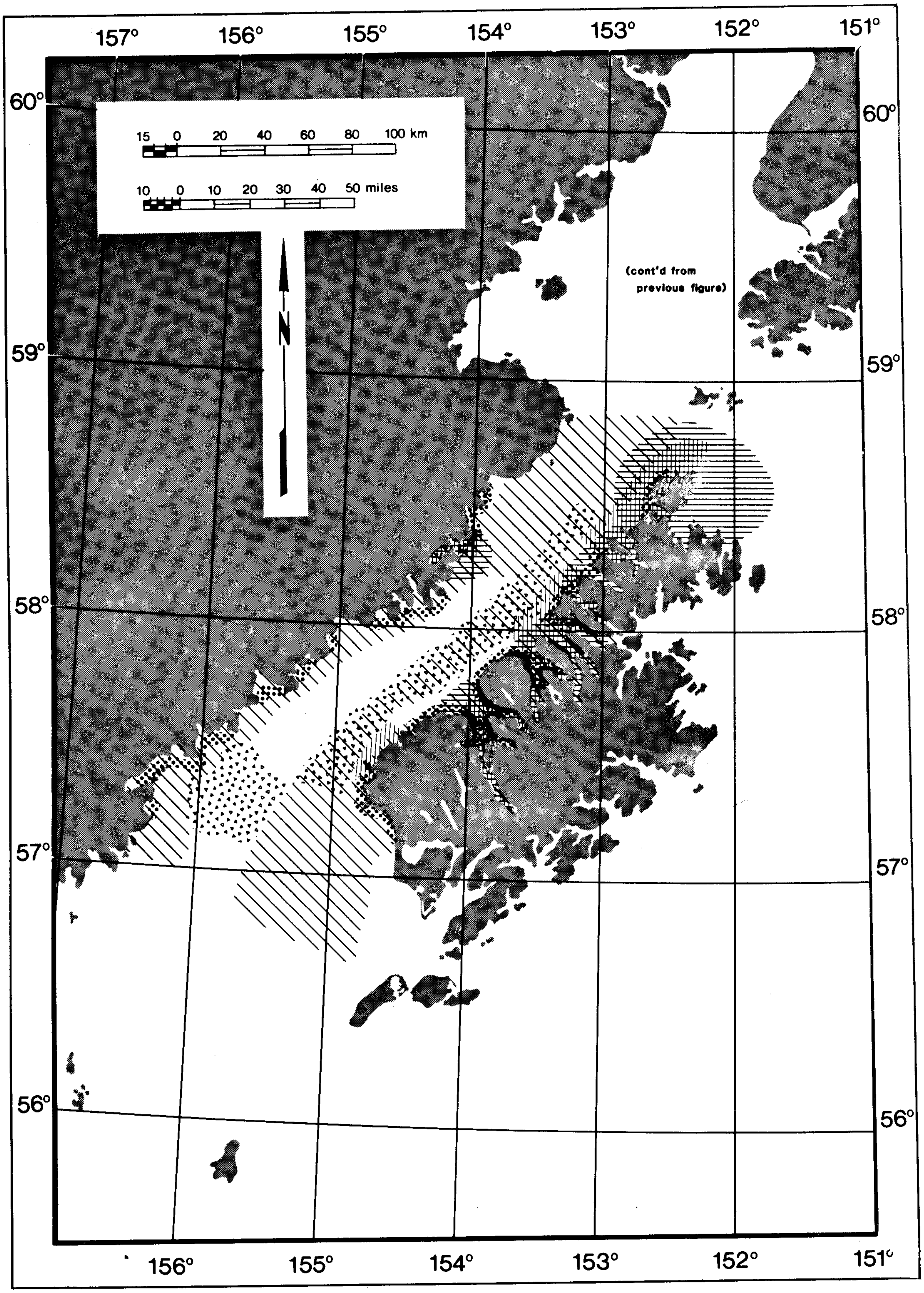


Figure 82. Locations of major fishing areas .... cont'd.

Site preparation in wetlands can alter the water and drainage patterns. The resulting vegetation changes may in turn change the composition of fish and wildlife species using the area (NPRA, 1978).

Siltation of marine and fresh waters occurs during construction as natural ground vegetation is removed and soils are exposed to the erosional processes of wind and water. Siltation of adjacent shoreline habitats can also occur if the shoreline is altered, therefore changing current patterns and altering longshore sediment transport. Siltation blocks light penetration to aquatic organisms and can eventually change an aquatic habitat to a terrestrial habitat. In addition to sediments, runoff from construction sites often contain contaminants, including metals from welding, riveting and paint spills; oil and chemicals; bacteria and other undesirable matter, all of which may pollute coastal waters. Freshwater storm runoff flowing into nearshore waters changes the salinity and increases the stress on coastal marine resources (USFWS, 1978c).

Shore-based facilities requiring cooling waters withdraw these waters from nearby lakes, estuaries, rivers, and wells. The aquatic life in these natural waters is threatened by passage through plant cooling systems (entrainment), by entrapment on the protective screens of water-intake structures (impingement), by the discharge of heated water into the aquatic environment (thermal pollution) and by the addition of chemicals to kill built up algae, bacteria and plankton growth (chemical pollution) (USFWS, 1978d; Murarka, 1977). The quantity of water required by closed (recycled) cooling systems is much less than that required by open (once through) systems, therefore the impacts, although the same, are on a smaller scale.

Although development drilling, production, transportation of oil, and oil processing have been chiefly responsible for most of the world's major and minor spills, shore-based support activities and facilities, such as fuel storage areas, refueling stations, and support bases, are also regular sources of spilled oil. Table 55 gives a breakdown of marine oil spills (by activity) in addition to other sources of oil in the marine environment. Oil spills attract considerable public attention because of their catastropic impacts but the long-range impacts from chronic oil contamination may be a more serious ecological problem because of the slow, steady degradation of the ecosystem (Michael, 1976). Onshore sources of chronic oil pollution include effluent from refinery and petrochemical plants, and discharges from vessels, tankers and ballast water treatment facilities. The impacts of oil pollution on marine life are discussed under section I. A. e.

Shore-based facilities can compete with commercial fishermen for dock space, fueling, repair and other facilities increasing the costs and time spent on these activities. Nearshore fishing areas such as clam beds and set net sites may be eliminated by the filling of intertidal areas and the construction of onshore facilities and docks. Piers, causeways, and docks may also change nearshore fish movement patterns, diverting them from once productive fishing areas.

Table 55. BUDGET OF PETROLEUM HYDROCARBONS INTRODUCED INTO THE OCEANS (BLM, 1976)

Source	Input Rate (million metric tons) Best Estimate	Probable Range	Reference
Natural seeps	0.6	0.2-1.0	Wilson et al. (1973)
Offshore Production	0.08	0.08-0.15	
Transportation			
Lot* Tankers	0.31	0.15-1.0	
Non-Lot* Tankers	0.77	0.65-1.0	
Dry docking	0.25	0.2-0.3	
Terminal Operations	0.003	0.0015-0.005	
Bilges Bunkering	0.5	0.4-0.7	
Tanker Accidents	0.2	0.12-0.25	
Non Tanker Accidents	0.1	0.02-0.15	
Coastal Refineries	0.2	0.02-0.3	Brummage (1973)
Atmosphere	0.6	0.4-0.8	Feuerstein (1973)
Coastal Municipal Wastes	0.3	-	Storrs (1973)
Coastal Non Refining			
Industrial Wastes	0.3	-	Storrs (1973)
Urban Runoff	0.3	0.1-0.5	Storrs (1973), Hallhagen (1973)
River Runoff	1.6	-	" "
TOTAL	6.113		

*Lot: Load to top.

In Kachemak Bay, the rocky, relatively shallow (less than 30m.; 90 ft. depth) nearshore areas are of prime importance as rearing areas for post-larval king crab. The Anchor Point to Bluff Point area, in particular, is considered critical to the maintenance of king crab stocks within the Bay. Any disturbance, such as dredging during construction activities could result in a major impact to the king crab resources of Kachemak Bay and Lower Cook Inlet (Trasky et al., 1977).

The majority of the diatoms and some of the macrophytes found in the stomachs of commercially important shrimp (pink, coonstripe and sidestripe) in Kachemak Bay are species common in the marsh/mud flat areas along the south side of the Bay. Disturbance of these marsh areas could have an adverse impact on shrimp resources of Kachemak Bay by destroying potential food organisms or the productive capability of the marshes themselves (Trasky et al., 1977).

Table 56 shows the disturbances caused by the various proposed shore-based facilities in Lower Cook Inlet and Shelikof Strait.

Pipelines

Laying Operations

Dredging during pipeline laying affects fish resources in the coastal environment by 1) the physical destruction of benthic habitat, 2) altering water quality through the suspension of sediments which may contain toxic chemicals and have a high biological oxygen demand, 3) smothering benthic organisms when suspended silt and over burden are deposited on adjacent areas, 4) modifying water circulation patterns through the alteration of natural bottom contours and features, 5) modifying salinity concentrations in estuaries by changes and disruption of freshwater inflow, and 6) direct mortality when marine life is swept into dredging equipment. The effects of dredging may be short or long-term, depending upon the area dredged, the amount of material removed and the extent to which bottom contours and natural features are altered.

Submerged bottoms, coastal wetlands and tidelands may be destroyed, drained or drastically altered by dredging (St. Amant, 1971). Fish spawning areas may be destroyed by filling in or disruption of the sub-strata (Morton, 1977). Alteration of circulation patterns within bays or estuaries may displace plankton and food species to a different environment. The resuspension of bottom sediments causes the water to become turbid limiting the amount of light entering the water column. When light penetration is reduced, the growth rates of phytoplankton are reduced limiting the amount of food available to marine food webs and lowering oxygen levels in the water column. Heavy loads of suspended sediments on filter feeding aquatic organisms (i.e. razor clams) cause abrasion of gill filaments, clogging of gills, impaired respiration, impaired feeding and excretory functions, and reduced growth and survival of larvae. If dredging occurs in locations where industrial effluents

Table: 56 DISTURBANCES CAUSED BY PROPOSED SHORE-BASED FACILITIES

	Kachemak Bay				Lower Central Zone	Kamishak Bay	Kennedy Entrance			Kalgin Island				Shelikof Strait
	SUPPORT AND SUPPLY BASES	CRUDE OIL TERMINALS	LIQUID NATURAL GAS (LNG) PLANTS	PRODUCTION TREATMENT PLANTS	NO PROPOSED FACILITIES AT THIS TIME	NO PROPOSED FACILITIES AT THIS TIME	CRUDE OIL TERMINALS	LIQUID NATURAL GAS (LNG) PLANTS	PRODUCTION TREATMENT	CRUDE OIL TERMINALS	LIQUID NATURAL GAS (LNG) PLANTS	PRODUCTION TREATMENT PLANTS	ONSHORE PIPELINE CORRIDORS	NO PROPOSED FACILITIES AT THIS TIME
HABITAT DESTRUCTION (SITE PREPARATION AND ALTERATION)	X	X	X	X	?	?	X	X	X	X	X	X	X	?
SILTATION	X	X	X	X	?	?	X	X	X	X	X	X	X	?
COOLING WATERS			X	X	?	?		X	X		X	X		?
OIL POLLUTION	X	X	X	X	?	?	X	X	X	X	X	X	X	?
INTERFERENCE WITH COMMERCIAL FISHING	X	X			?	?	X			X				?

have previously been discharged into marine waters, toxic and oxygen demanding chemicals may be released into the water column (Cardwell et. al., 1976).

High pressure water jets are used to bury pipelines by blowing away the sediment underneath the line. The pipeline then settles into the trench where the sediment was displaced and is covered over by backfilling or by natural sediment transport processes. This dredging technique disturbs the bottom habitat and causes suspension of solid particles in the water column resulting in turbidity and the displacement or burial of benthic organisms. The impacts of turbidity on benthic organisms have been reported to occur 200 or more feet (60 meters) from the pipeline construction site (USFWS, 1978b). When pipeline corridors are selected along bedrock, underwater blasting may be used causing marine organisms in the vicinity to be killed (NERBC, 1976). Long term damage from habitat disruption is more likely to occur in nearshore and onshore areas because of evnironmentally sensitive habitats such as estuaries and wetlands. Positioning of the pipeline landfall is extremely important. Special construction procedures must be followed to protect the integrity of dunes, barrier islands, wetlands, estuaries, intertidal areas and other sensitive areas at the marine-land interface (NERBC,1976).

The primary impact of onshore pipeline construction is the destruction of vegetation and the associated change in habitat (NPRA 1978). Pipelines crossing streams can impact fish habitat by disturbing the benthos and producing temporary or permanent blockage to fish and nutrient movements (USDI, 1972 and USDI, 1976 in NPRA, 1978). Sediments suspended by construction activities can cause adverse impacts on fish and their food sources. Turbid waters block light transmission reducing the visual feeding range of fish and decreasing primary productivity thereby limiting food sources for fish (Lynch et at., 1977). The direct effects of turbidity on adult fish may be less harmful than the effect of turbid waters on primary productivity and food organisms upon which fish depend for survival (Hesser et al., 1975). In addition, fine sediments affect juvenile fish by causing inflamation of the gill membranes and eventual death. Reports show that fry and fingerling trout reared in turbid water are more prone to bacterial infection of their gills (Lynch et al., 1977).

Increased siltation in streams affects the quality of fish habitat by covering it with a uniform substrate, eliminating protective hiding places for fish and by filling in pools where fish may overwinter. Fish spawning areas may be greatly impacted. The deposition of sediments reduces the flow of oxygen containing water through the interstitial spaces in the gravel, suffocating eggs, embryos or alevins (Lynch et al., 1977).

In Kachemak Bay the rocky, relatively shallow (less than 30 m. 90 ft. depth) nearshore areas are of prime importance as rearing areas for post-larval king crab. The Anchorage Point to Bluff Point area, in particular, is considered critical to the maintenance of king crab stocks within the bay. Any disturbance, such as dredging during pipeline laying, could result in a major impact to the king crab resources of Kachemak Bay and Lower Cook Inlet.

The majority of the diatoms and some of the macrophytes found in the stomachs of commercialy important shrimp (pink, coonstripe and side-stripe) in Kachemak Bay are species common in the marsh/mud flat areas along the south side of Kachemak Bay. Disturbance of these marsh areas could have an adverse impact on shrimp resources of Kachemak Bay by destroying potential food organisms or the productive capability of the marshes themselves (Trasky et al., 1977).

Figure 83 and Table 57 shows proposed pipeline corridors in the geographical areas of Lower Cook Inlet.

Pipeline Breaks & Chronic Leaks

The annual anticipated oil spillage from pipeline breaks in Lower Cook Inlet during peak production resulting from Cook Inlet Sale No. C1 is presented on Table 58. Long-term studies of several major oil spills indicate that oil has the following effects on marine life: 1) direct kill of organisms through coating and asphyxiation, 2) direct kill through contact poisoning, 3) direct kill through exposure to water soluble toxic components of oil at some distance in space and time from the spill, 4) destruction of the sensitive juvenile forms, 5) destruction of the food sources of higher organisms, 6) incorporation of sublethal amounts of oil and oil products into organisms, resulting in failure to reproduce, reduced resistance to infection, or physiological stress, 7) contraction of diseases due to exposure to carcinogenic components of oil, 8) chronic low level effects that may interrupt any of the numerous biochemical or behavioral events necessary for the feeding, migration, or spawning of many species of marine life and 9) changes in biological habitats (Blumer et al., 1970). Oil polluted marine waters affect humans by reduing recreational opportunities, tainting the flesh of commercial species of marine fish and crustaceans (e.g. halibut, clams, crabs, and salmon) and reducing commercial fisheries production (Blumer et al., 1970).

The effects of marine oil spills on marine ecosystems vary based on the 1) type of oil spilled, 2) amount of oil spilled, 3) physiography of the spill area, 4) weather conditions at the time of the spill, 5) biota in the area, 6) season of the year, 7) previous exposure of the area to oil, 8) exposure to other pollutants, and 9) method of treatment of the spill (USFWS, 1978b). The effects of oil pollution on key species in Lower Cook Inlet are discussed in Section 1.A.

Figure 83 and Table 57 show locations of proposed pipelines in Lower Cook Inlet and Shelikof Strait. Table 51 discusses the relative sensitivities of key species to oil pollution.

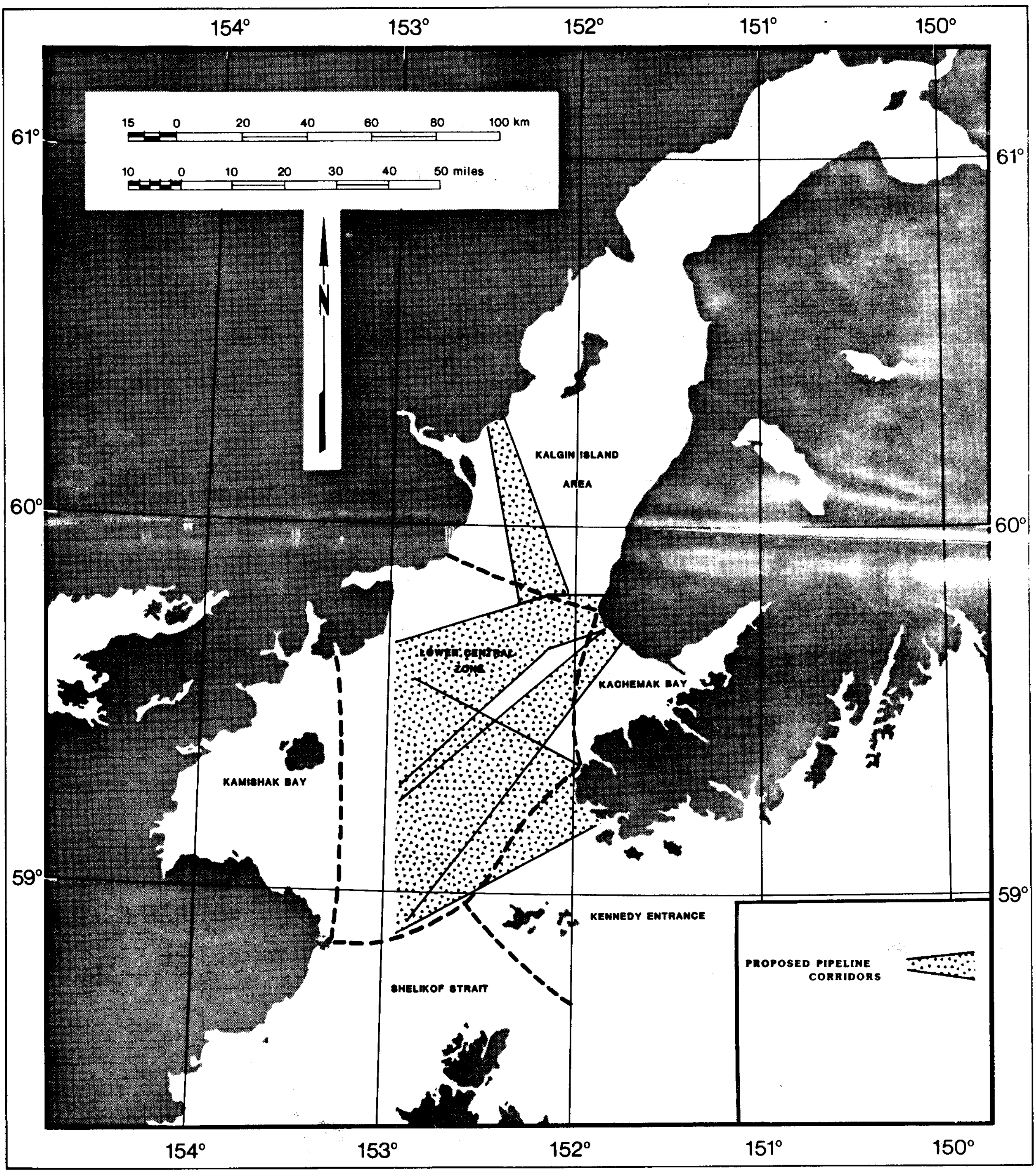


Figure 83. Proposed pipeline corridors in Lower Cook Inlet and Shelikof Strait.

Table 57
PROPOSED PIPELINES IN GEOGRAPHICAL
AREAS OF LOWER COOK INLET

Area	Proposed Pipeline?
Kalgin Island	Yes
Kachemak Bay	Yes
Kamishak Bay	No
Lower Central Zone	Yes
Shelikof Strait	No
Kennedy Entrance	Yes

TABLE 58 ANTICIPATED ANNUAL OIL INTRODUCTION TO THE MARINE ENVIRONMENT DURING PEAK PRODUCTION RESULTING FROM THE PROPOSED COOK INLET SALE NO. CI (BLM, 1976)

Location	Source	Maximum Annual Spillage Barrels	Cumulative 25 Year Total Barrels
Lower Cook Inlet	Pipeline Accidents	5,800	48,000
	Formation Water	780	19,500
	Spills from Platform Fires	9,900	82,000
	Overflow, Malfunction or Rupture	185	1,500
	Minor Spills (less than 50 bbls)	550	13,750
	Subtotal	17,215	164,750
Transportation Route	Tankers	54,400	450,000
	TOTAL	71,615	614,750

Tanker Routes

Tanker Spills Along Routes

This was discussed above under Drilling Platforms, Acute Oil Spills.

Interference with Fishing Activitites

Potential conflicts between oil tankers and fishing activities are similar to those discussed under drilling platforms and include loss of fishing habitat from over crowding and increased navigational problems, interference with and destruction of gear, competition for space and services, and oil contamination and tainting from spills and ballast waste water disposal. Although the majority of oil spills in Lower Cook Inlet are related to drilling platform activities, the largest volume spills are caused by submarine oil pipeline ruptures and tanker accidents (FERC, 1978). The annual anticipated oil tanker spillage during peak production resulting from Lower Cook Inlet Sale No. C1 is estimated to be 54,400 barrels (Table 58). The effects of oil spills (chronic and acute) on commercial fish species are discussed in sections I.A.e.

Table 59 and Figure 84 show locations of major fishing areas within proposed marine transportation corridors in Lower Cook Inlet and Shelikof Strait.

Table 59

LOCATIONS OF MAJOR FISHING AREAS WITHIN PROPOSED MARINE TRANSPORTATION CORRIDORS IN LOWER COOK INLET AND SHELIKOF STRAIT

	SALMON SET NET	SALMON DRIFT GILL NET	SALMON PURSE SEINE	HERRING	SHRIMP	CRAB	GROUNDFISH	HALIBUT	PROPOSED MARINE TRANSPORTATION CORRIDORS
KALGIN ISLAND AREA	√	√		√					√
KACHEMAK BAY			√	√	√	√			√
KAMISHAK BAY									
LOWER CENTRAL ZONE			√	√		√			√
KENNEDY ENTRANCE			√						√
SHELIKOF STRAIT				√		√			√

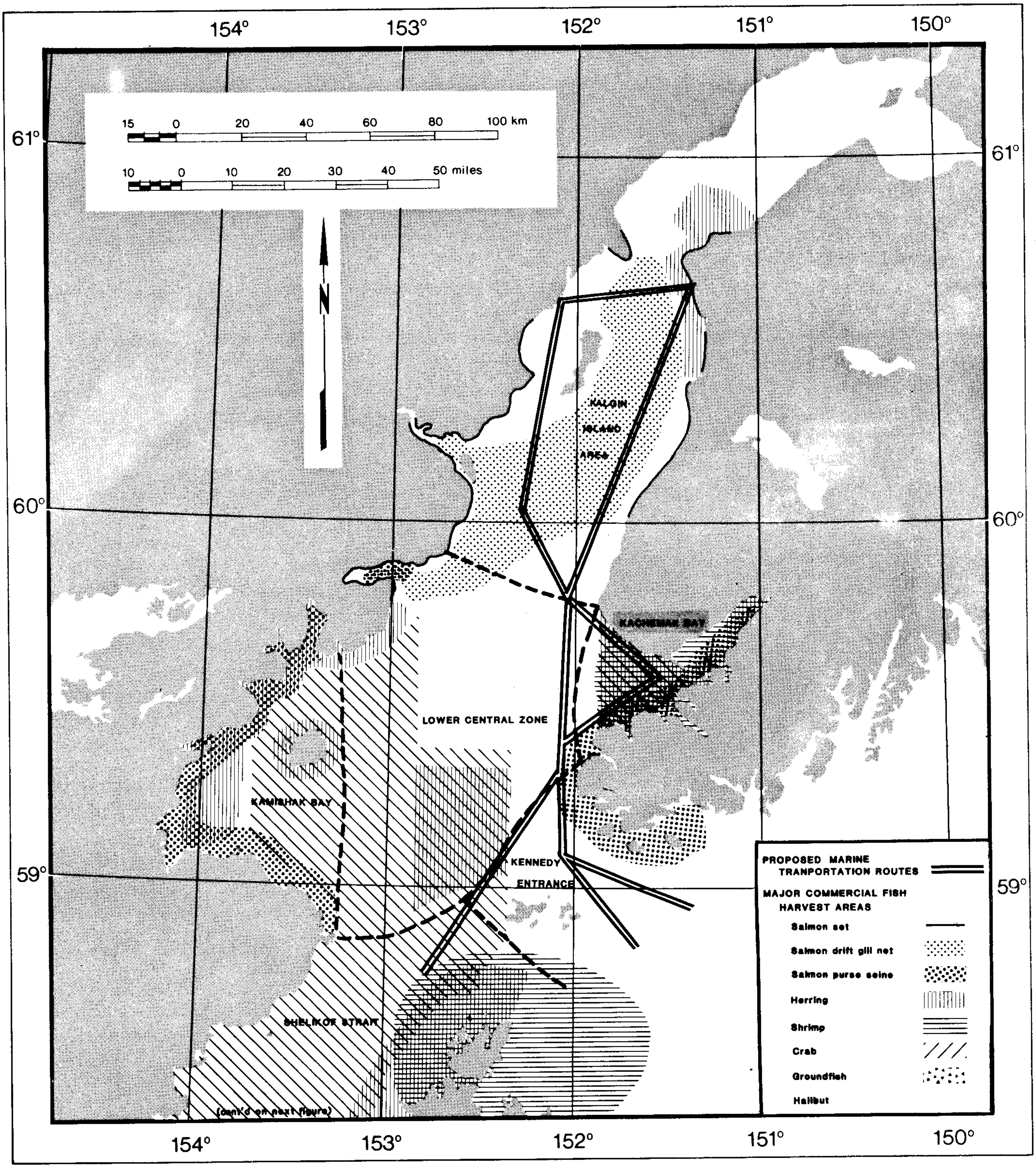


Figure 84. Locations of major fishing areas and proposed Marine Transportation Routes in Lower Cook Inlet and Shelikof Strait.

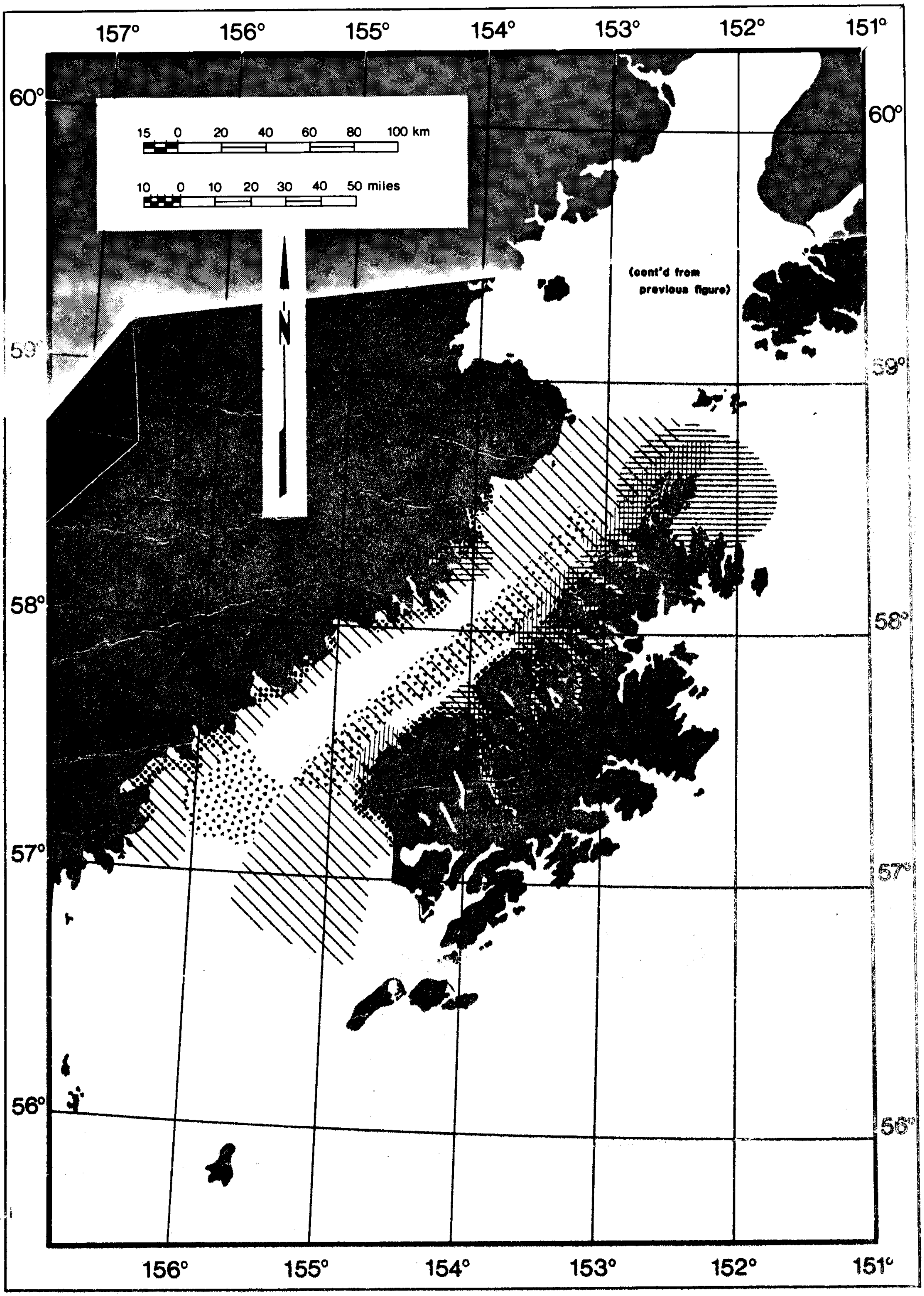


Figure 84. Locations of major fishing areas .... cont'd.

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APPENDIX I

Appendix Table 1. Herring food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Polychaetes			1 ± 0		t	7 ± 6	2 ± 2			t	t	
Gastropod veligers					t	8 ± 4	16 ± 6	14 ± 14	4 ± 2	t	t	
Bivalve larvae			2 ± 1									
Mites			t									
Unidentified crustacean larvae			t		1 ± 0		2 ± 2				t	
Cladocerans			t		t					t	t	
Copepods-calanoid			12 ± 6		64 ± 9	18 ± 6	17 ± 6		20 ± 8	14 ± 4	23 ± 9	75
Copepods-other			109 ± 18	1 ± 1	2 ± 1	5 ± 2	t	t			9 ± 1	19
Cirripede nauplii			2 ± 1		16 ± 5	93 ± 26	3 ± 2		t	2 ± 2	t	
Cirripede cyprids			6 ± 2		6 ± 2	5 ± 3	4 ± 2	t	t	t		
Mysids							20 ± 14		28 ± 28	t		
Cumaceans			2 ± 1		t	t	t					
Gammarid amphipods			2 ± 2	327 ± 327	t	2 ± 2	1 ± 1		t	2 ± 2	10 ± 10	1
Unidentified decapods			t									
Shrimp larvae					t	t						
Unidentified anomuran zoeae			t		t		t					
Pagurid zoeae			t		t							
Paralithodes camtschatica zoeae							t					
Unidentified cancrids							t					
Insect adults			t									
Chaetognaths												25
Larvaceans										1 ± 0	t	
Fish eggs					t							
Unidentified fish larvae				30 ± 30	t	13 ± 8	17 ± 11	105 ± 105				
Herring larvae						1 ± 1						
Number of fish examined			24	3	25	25	20	2	4	15	15	1
Number of empty stomachs			1	1	1	2	4				1	

Appendix Table 2. Sand sole food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Mysids			956									
Gammarid amphipods			324									
Number of fish examined			1									

Appendix Table 3. Juvenile pink salmon food item mean weight ± standard error in milligrams from fish collected in Cook Inlet in 1978.

	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31	MEAN
Polychaetes				t	1 ± 1		1 ± 1	t					
Gastropod veligers	t				t		3 ± 2	12 ± 11					
Bivalve veligers	t												
Mites	t							t					
Crustaceans-unidentified nauplii	2 ± 1												
Crustaceans-unidentified larvae					t								
Crustaceans-unidentified adults							t						
Cladocerans					t		t						
Copepods-nauplii	t												
Copepods-calanoids	2 ± 0			t	3 ± 1	4	69 ± 15	50 ± 17	106 ± 11				
Copepods-others	9 ± 1			63 ± 24	13 ± 6	2	7 ± 5	t	t				
Cirripede nauplii	t				t	t	t						
Cirripede cyprids	t			t	t		t	t					
Cirripede casts								t	2 ± 2				
Cumaceans					1 ± 1	10	1 ± 1	10 ± 7					
Isopods					t								
Gammarid amphipods	1 ± 1				1 ± 1		t	11 ± 7		239			
Shrimp larvae	1 ± 0				3 ± 2								
Pagurid zoeae					t								
Pagurid glaucothoe					1 ± 1		t	7 ± 7		2			
Insect parts					t								
Insect larvae	1 ± 0						t	t					
Insect adults	t				t	4	2 ± 1	53 ± 21	25 ± 11	119			
Chaetognaths					4 ± 2								
Fish larvae unidentified							t						
Herring larvae					4 ± 3								
Number of fish examined	35			3	15	1	15	9	5	1			

Appendix Table 4. Juvenile chum salmon food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Diatoms			t									
Polychaetes		t	t		1 ± 0	3 ± 2	t					
Gastropod veligers		t			t	1 ± 0	5 ± 2	37 ± 29	7 ± 4	t		
Spiders				t								
Mites			t	t								
Unidentified crustaceans		t	t		1 ± 1	2 ± 2	t		2 ± 2			
Cladocerans		t			t							
Copepod nauplii									t			
Copepods-calanoid		t	7 ± 4	t	1 ± 0	15 ± 8	13 ± 5	43 ± 22	5 ± 3	3 ± 3		
Copepods-other		17 ± 3	8 ± 2	18 ± 4	21 ± 9	26 ± 7	4 ± 3	2 ± 1		t		
Cirripede nauplii		t	t		4 ± 4	2 ± 2			t			
Cirripede cyprids		t	t	t	3 ± 2	2 ± 1	t		t			
Cirripede casts		t	t			1 ± 0		t	t	1 ± 1		
Mysids			t						20 ± 20	78 ± 46		
Cumaceans		1 ± 0	t	3 ± 0	2 ± 1	14 ± 5	1 ± 1	27 ± 18	3 ± 3	3 ± 3		
Isopods		t										
Gammarid amphipods		1 ± 0	2 ± 1	t	5 ± 2	27 ± 12	24 ± 9	13 ± 7	107 ± 54	300± 68		
Caprellid amphipods						t	t					
Unidentified decapods		t	t		t	t	t	t				
Shrimp larvae		t	t		1 ± 0	3 ± 2						
Pagurid glaucothoe							12 ± 7	6 ± 3	2 ± 1	2 ± 2		
Insect parts		1 ± 0		t	10 ± 6							
Insect larvae		t	t	4 ± 4	t	1 ± 0	t	t	t	35 ± 30		
Insect adults			1 ± 0	12 ± 4	2 ± 2	26 ± 6	20 ± 8	67 ± 29	129 ± 55	23 ± 4		
Chaetognaths					1 ± 1				14 ± 9			
Larvaceans										1 ± 1		
Unidentified invertebrates							t		2 ± 2			
Fish eggs				1 ± 1								
Unidentified fish larvae			t		22 ± 16	4 ± 4	48 ± 20	111 ± 84	14 ± 14	12 ± 9		
Capelin larvae									37 ± 37			
Herring larvae					8 ± 8	3 ± 2	40 ± 20	5 ± 5	37 ± 37			
Herring juveniles						25 ± 15						
Sculpin larvae					t							
Stichaeid larvae					1 ± 1							
Flounder larvae					t							
Number of fish examined		25	25	17	25	26	26	10	10	15		

Appendix Table 5. Juvenile coho salmon food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Unidentified crustacean larvae					3	6 ± 6						
Copepods - calanoid					8							7
Copepods - other						1 ± 1						
Cumaceans					210	1 ± 1						
Gammarid amphipods					8	28 ± 22	7 ± 7					
Euphausiids												373
Shrimp larvae							7 ± 7					
Pagurid glaucothoe							339±339					
Unidentified majid zoeae							213±213					
Unidentified majid megalops							36 ± 36					
Insect larvae						42 ± 42						
Insect adults						219 ± 219	6 ± 4					
Chaetognaths												871
Unidentified fish larvae					81		211±141					249
Snake prickleback larvae												871
Sand lance larvae							569±329					
Number of fish examined					1	2	4					1

Appendix Table 6. Juvenile sockeye salmon food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Algae						t						
Polychaetes					t	t						
Gastropod veligers						5 ± 3						
Unidentified crustacean larvae					3 ± 2							
Cladocerans					t							
Copepods-calanoid					12 ± 5	7 ± 2						
Copepods-other				76	1 ± 1							
Cirripede nauplii					1 ± 1	13 ± 6						
Cirripede cyprids					7 ± 3	1 ± 0						
Cirripede casts					t							
Cumaceans				7	25 ± 13							
Isopods					t							
Gammarid amphipods				7	1 ± 1							
Caprellid amphipods					t							
Unidentified decapod larvae				t								
Shrimp larvae						53 ± 23						
Unidentified anomuran zoeae					t	1 ± 0						
Paralithodes _camtschatica_ zoeae					t							
Unidentified cancrid megalops					7 ± 5							
Telmessus _cheiragonus_ megalops					16 ± 10							
Insect parts					4 ± 2							
Insect larvae						7 ± 4						
Insect adults				7	13 ± 9	44 ± 11						
Fish eggs					109 ± 40							
Unidentified fish larvae					16 ± 16	19 ± 9						
Herring larvae						14 ± 9						
Sand lance larvae						13 ± 13						
Number of fish examined				1	15	16						

Appendix Table 7. Juvenile chinook salmon food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Unidentified crustacean larvae						t	20 ± 9	5 ± 3	2 ± 1			
Cirripede casts								9 ± 9				
Mysids									16 ± 16			
Gammarid amphipods						1 ± 1				8		
Pagurid zoeae							11 ± 11	3 ± 2				
Pagurid glaucothose									120 ± 64	2		
Unidentified majids									6 ± 6			
Insect larvae						17 ± 9						
Insect adults						6 ± 4	10 ± 4	95 ± 37	80 ± 42	415		
Unidentified fish larvae						24 ± 20	133 ± 16	52 ± 29	128 ± 45	24		
Unidentified fish juveniles								68 ± 68				
Herring larvae						136 ± 39	104 ± 24					
Stichaeid larvae						3 ± 3						
Number of fish examined						11	14	8	10	1		

Appendix Table 8. Juvenile dolly varden food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Algae				4 ± 4		t						
Polychaetes			t	t	57 ± 57			5 ± 5				2 ± 2
Gastropod veligers					t	t	4 ± 4			3 ± 3		t
Gastropod adults							9 ± 9					
Bivalve larvae				t	t	t	t					
Pseudoscorpionid												t
Spiders			t									
Mites			t									
Unidentified crustacean larvae					1 ± 1	2 ± 1	1 ± 1					
Unidentified crustacean adults							t					
Copepods-calanoid				t	t	5 ± 5	t					
Copepods-other			13 ± 5	76 ± 32	t	3 ± 3	7 ± 5					
Cirripede cyprids			10 ± 10	1 ± 0	t	t	t					
Cirripede casts			t	1 ± 1	2 ± 2	t						
Mysids			27 ± 20	9 ± 9	23 ± 23	14 ± 14	2 ± 2	4 ± 3	37 ± 37	711 ± 445	331 ± 262	
Cumaceans			7 ± 6	25 ± 10	142 ± 73	75 ± 31	18 ± 16	261 ± 178				
Isopods			9 ± 5	3 ± 2	8 ± 7		t					
Gammarid amphipods			116 ± 45	269 ± 87	326 ± 86	1342 ± 324	465 ±118	953 ± 372	1111±333	575 ± 314	17 ± 293	663 ± 342
Euphausiids									35 ± 35			
Unidentified decapods			4 ± 4	12 ± 12								
Shrimp larvae				t	1 ± 1	6 ± 5		12 ± 9				
Shrimp adults					1 ± 1			1 ± 1	10 ± 10		23 ± 23	t
Unidentified anomurans				t								
Pagurid zoeae				t								
Paralithodes camtschatica zoeae				t								
Unidentified brachyurans				t								
Chionoecetes bairdi megalops			1 ± 1									
Unidentified cancrid larvae				8 ± 8						2 ± 2		
Telmessus cheiragonus magalops				114 ± 60	184 ± 116							
Cancer magister megalops				116 ± 51								
Insect parts					43 ± 20							
Insect larvae			t	6 ± 3	7 ± 7	26 ± 22	287 ± 125		8 ± 8	t	12 ± 12	
Insect adults			5 ± 2	48 ± 28	42 ± 18	51 ± 34	186 ± 84	25 ± 21	137 ± 105	14 ± 13	60 ± 57	2 ± 2
Unidentified invertebrates			38 ± 38	t	t		13 ± 12					2 ± 2
Fish eggs				t								
Unidentified fish larvae			2 ± 2		64 ± 44	18 ± 15	122 ± 86	161 ± 161	193 ± 103	288 ± 149	56 ± 42	47 ± 39
Herring larvae							4 ± 4	69 ± 69	213 ± 213	431 ± 241	445±445	
Herring juveniles										154 ± 154		
Salmon fry			18 ± 18		85 ± 85							1578 ± 844
Chum salmon fry			20 ± 20									
Longfin smelt larvae			20 ± 20									
Greenling juveniles					23 ± 23							
Sculpin larvae					4 ± 4							
Irish lord larvae				161±112								
Staghorm sculpin larvae												2 ± 2
Snake prickleback larvae						124 ± 124	t					
Sand lance juveniles			50 + 50							180 ± 177		710 ± 710
Number of fish examined		1	20	22	25	25	25	10	10	15	15	10
Number of empty stomachs		1	1							1	1	

Appendix Table 9. Adult dolly varden food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Polychaetes			8370±8370									
Telmessus cheiragonus megalops				65±65								
Sand lance juveniles			13,392±3531	3705±3705								
Herring juveniles				27,138±9082								
Pink salmon juveniles				208±208								
Capelin larvae			1430±1430									
Walleye pollock juveniles				4120±4120								
Irish lord larvae				365±365								
Unidentified fish parts				t								
Number of fish examined			4	4								

Appendix Table 10. Capelin food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Cirripede nauplii			2 ± 2									
Cirripede cyprids			t									
Gammarid amphipods			t									
Number of fish examined			10									
Number of empty stomachs			9									

Appendix Table 11. Longfin smelt food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Polychaetes			1 ± 1	t								
Bivalve larvae				3 ± 3								
Unidentified crustacean adults			t									
Copepods-calanoid			5 ± 3	t								
Copepods-other			2 ± 1	5 ± 2								
Cirripede nauplii			t	t								
Cirripede cyprids			1 ± 0	1 ± 0								
Mysids				6 ± 6								
Cumaceans			1 ± 1	6 ± 5								
Isopods			17 ± 9	8 ± 4								
Gammarid amphipods			91 ± 25	28 ± 26								
Shrimp larvae			29 ± 11	23 ± 12								
Unidentified anomuran zoeae			3 ± 2	t								
Pagurid zoeae			1 ± 1									
Chionoecetes bairdi megalops			32 ± 17									
Telmessus cheiragonus zoeae				t								
Larvaceans				t								
Fish eggs			2 ± 2	t								
Unidentified fish juveniles				t								
Number of fish examined			15	10								
Number of empty stomachs			1									

Appendix Table 12. Surf smelt food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Copepods			71									
Cirripede cyprids			4									
Isopods			39									
Shrimp larvae			116									
Number of fish examined			1									

Appendix Table 13. Saffron cod food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Gammarid amphipods			2380									
Isopods			2530									
Number of fish examined			1									

Appendix Table 14. Walleye pollock food item mean weights ± standard error in milligrams from fish collect in Cook Inlet in 1978.

ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Polychaetes		2 ± 2										
Copepods-calanoid		1 ± 1										
Copepods-other		1 ± 1										
Cirripede nauplii		1 + 1										
Cirripede cyprids		1 ± 1										
Mysids		8 ± 8										
Cumaceans		2 ± 2										
Gammarid amphipods		31 ± 13										
Unidentified decapods		20 ± 13										
Shrimp larvae		13 ± 10										
Chionoecetes bairdi megalops		156 ± 48										
Unidentified fish larvae		t										
Number of fish examined		10										

Appendix Table 15. Juvenile whitespotted greenling food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Polychaetes					1 ± 0							
Ostracods				t								
Copepods-calanoid	1 ± 1		9 ± 4	t	1 ± 1							
Copepods-other	4 ± 2		5 ± 2	16 ± 6	t							
Cirripede nauplii					t							
Cirripede cyprids	t		t	t	1 ± 1							
Cumaceans				1 ± 1	1 ± 0							
Gammarid amphipods			1 ± 1		20 ± 11							
Unidentified decapods				t								
Shrimp larvae					3 ± 2							
Telmessus cheiragonus megalops					1 ± 1							
Insect adults				t								
Fish eggs				1 ± 0								
Unidentified fish larvae				2 ± 2								
Number of fish examined	4		3	13	11							

Appendix Table 16. Adult whitespotted greenling food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Cirripede cyprids			t									
Mysids			15 ± 15									
Gammarid amphipods			76 ± 52									
Unidentified invertebrates			185 + 155									
Fish eggs			1 + 1									
Number of fish examined			2									

Appendix Table 17. Staghorn sculpin food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Polychaetes			100 + 100									
Unidentified crustacean		57 ± 57										
Mysids			152 ± 152									
Isopods			236 ± 145									
Gammarid amphipods		t										
Unidentified invertebrates		333 ± 333										
Herring larvae			468 ± 468									
Chum salmon fry			270 ± 270									
Sculpin parts			40 ± 40									
Sand lance larvae			2104 ± 2104									
Number of fish examined		3	5									
Number of empty stomachs		2										

Appendix Table 18. Juvenile great sculpin food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Unidentified crustacean adults			26 + 26									
Copepods	? + 2	t	t									
Mysids	11 + 11			1 + 1								
Cumaceans		4 + 3										
Gammaried amphipods	182 + 60	240±81	397 ± 71	261±70								
Euphausiids	2 + 2											
Unidentified decapods		t										
Shrimp larvae				1 ± 1								
Insect larvae				3 ± 3								
Unidentified invertebrates		76 + 76										
Pink salmon fry	40 ± 40											
Number of fish examined	5	8	20	8								

Appendix Table 19. Sand lance food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Diatoms		t	2 ± 1									
Polychaetes		t	t	t	1 ± 1	t	t			t	1 ± 0	
Gastropod veligers	t		t		t	t	1 ± 0	t	1 ± 0	t	1 ± 0	
Bivalve veligers			t	t								
Unidentified crustaceans	1 ± 0			1 ± 1			t	1 ± 1	t			t
Cladocerans		t	t			t						t
Copepods-calanoid		65 ± 24	48 ± 12	90 ± 15	27 ± 8	114 ± 15	64 ± 9	93 ± 28	12 ± 4	28 ± 10	22 ± 6	15 ± 5
Copepods-other	24 ± 9	8 ± 4	24 ± 8		t	1 ± 1					t	t
Cirripede nauplii	1 ± 1	t	17 ± 4	37 ± 7	2 ± 1	1 ± 1			4 ± 2	1 ± 1	t	t
Cirripede cyprids	t	1 ± 0	6 ± 2	9 ± 3	1 ± 0	4 ± 2	t			t	t	t
Cumaceans			t									
Gammarid amphipods		t	1 ± 1	t							t	t
Unidentified decapod larvae		t	4 ± 1	1 ± 1			t					
Shrimp larvae	7 ± 2	28 ± 28		68 ± 18				11 ± 11				1 ± 1
Unidentified anomuran larvae			t	1 ± 1								
Pagurid larvae		t	t	1 ± 0			t					
Paralithodes camtschatica zoeae			t	t								
Unidentified majid larvae			t	3 ± 2								
Unidentified cancrid larvae				t								
Telmessus cheiragonus zoeae				t								
Insect adults			t									
Chaetognaths						t				t		4 ± 4
Larvaceans									t	20 ± 11	1 ± 0	1 ± 1
Fish eggs			t	6 ± 2								
Unidentified fish larvae	13 ± 6		t			1 ± 1		1 ± 1				
Herring larvae			t			t						
Number of fish examined	5	4	25	25	16	25	25	10	11	15	15	15
Number of empty stomachs	1				2		1		4	2	1	4

Appendix Table 20. Rock sole food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Algae			1483 ± 927									
Polychaetes			468 ± 378									
Gastropods			1 ± 1									
Limpets			191 ± 191									
Chitons			197 ± 131									
Bivalves			61 ± 32									
Copepods-calanoid		1	t									
Copepods-other		3	t									
Cirripede adults			20 ± 20									
Mysids			20 ± 20									
Cumaceans			13 ± 13									
Gammarid amphipods			328 ± 191									
Shrimp			t									
Unidentified brachyurans			t									
Unidentified invertebrates			272 ± 147									
Number of fish examined		1	9									

Appendix Table 21. Butter sole food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Polychaetes			90									
Bivalves			40									
Gammarid amphipods			30									
Number of fish examined			1									

Appendix Table 22. Yellowfin sole food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Algae			106±106	119±79								
Polychaetes				8±5								
Gastropods				13±13								
Bivalves			7±4	48±27								
Unidentified crustaceans				25±25								
Ostracods				t								
Copepods				t								
Cirripede adults				17±17								
Gammarid amphipods			208±208	8±8								
Unidentified decapods				4±4								
Unidentified brachyurans			3±3									
Unidentified invertebrates			3±3	218±152								
Unidentified fish juveniles			6±6									
Capelin juveniles			592±592									
Number of fish examined			9	10								
Number of empty stomachs			4									

Appendix Table 23. Starry flounder food item mean weights ± standard error in milligrams from fish collected in Cook Inlet in 1978.

FOOD ITEM	APRIL 11-30	MAY 1-15	MAY 16-31	JUNE 1-15	JUNE 16-30	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	SEPTEMBER 1-15	SEPTEMBER 16-30	OCTOBER 1-31
Algae			41±41									
Bivalves			122±105									
Mysids			14±14									
Isopods			666±330									
Gammarid amphipods			5241±1354									
Shrimp			22±22									
Insect larvae			4±4									
Number of fish examined			11									

Appendix Table 24. Names and general locations of salmon spawning streams that averaged 10,000 or more spawners of any species, as listed in Figures 3, 4 and 5. Streams are listed in the sequence they appear on the shoreline from north to south.

Figure 3. Cook Inlet.

West Side		East Side	
Name	Location	Name	Location
Crescent River	Tuxedni Bay	Kenai River	Town of Kenai
Fitz Creek	Chinitna Bay	Kasilof River	Town of Kasilof
Iniskin River	Iniskin Bay	Humpie Creek	Kachemak Bay - E. of Halibut Cove
Cottonwood Creek	Cottonwood Bay	Barabara Creek	E. of Seldovia
Browns Peak	North side - Ursus Cove	Seldovia River	Seldovia Bay
Unnamed	Ursus Cove Lagoon	Port Graham River	Port Graham
Sunday Creek	Rocky Cove	Unnamed	Windy Bay
Unnamed	Bruin Bay		
Amakdedori Creek	Amakdedori Beach		
McNeil River	McNeil Cove		
Mikfik Creek	McNeil Cove		
Little Kamishak River	Akumwarvik Bay		
Kamishak River	Akumwarvik Bay		
Douglas River	Kamishak Bay - extreme south		

Figure 4. Alaska Peninsula.

Big River	Between Swikshak and Cape Chiniak
Village Creek	At Kaguyak, north of Cape Chiniak
Kinak	On Kinak Bay
Dakavak Creek	On Dakavak Bay
Long Kashvik	On Kashvik Bay
Big Creek	North side of Wide Bay

Figure 5. Afognak and Kodiak Islands.

Long Lagoon Creek	Paramanof Bay
Malina Creek	Raspberry Strait, south west Afognak
Terror River	Terror Bay
East Uganik	East Arm, Uganik Bay
Little River Lake	2 miles south of Cape Ugat
Spiridon	Head of Spiridon Bay
South East Zachar	Head of Zachar Bay
Brown's Lagoon	Uyak Bay, opposite Amook Island
East Uyak	Near head of Uyak Bay
Dora's Creek	Larsen Bay
Karluk River	Village of Karluk
South Sturgeon River	2 miles south of Cape Karluk
East Sturgeon River	2 miles south of Cape Karluk
Grant Lagoon Creek	8 miles south of Cape Karluk
Halibut Beach	Halibut Bay
Red River	8 miles south east of Cape Ikolik

APPENDIX II

A PRELIMINARY ASSESSMENT OF COMPOSITION AND FOOD WEBS FOR DEMERSAL FISH ASSEMBLAGES IN SEVERAL SHALLOW SUBTIDAL HABITATS IN LOWER COOK INLET, ALASKA

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1.0 INTRODUCTION

The success of the marine fishes in adapting themselves to the various habitats along the Alaskan sea coast is well shown by their distribution in Lower Cook Inlet. Salt water fishes have been found from the upper reaches of the numerous estuaries and embayments of Cook Inlet to the deep water central arm. The sea floor is typically composed of soft or unconsolidated sediment, while the shoreline on the east side is rocky and irregular. The shallow sublittoral zone contains numerous species of fish which regularly are taken for sport, commercial and subsistence purposes. However, most of this activity is highly seasonal, and has been directed at only a few dominant species. The target fish have traditionally been salmon, herring and halibut. Currently, the shrimp fishery harvests an incidental catch of bottom fish, and some commercial test fishing for bottom species has been conducted. However, the future of the newly emerging bottom fishery is still uncertain in this geographical region.

Despite the intensity of the fishing effort, and the emotional feelings surrounding the extraction of aquatic resources from the Cook Inlet region, management is still hampered by the lack of basic knowledge of the marine ecosystem. In order to determine the effects of a man-induced perturbation, such as results from an oil spill, or to develop a resource management plan for an area, certain background information on the biology of the fish fauna is needed. In addition, since many of the fish occupy a portion of the water column that is less than 30 meters deep or live and feed in the near proximity of the shoreline, they inadvertently become vulnerable to OCS exploration and development.

This study has been directed at an assemblage of fishes that characteristically inhabit the nearshore waters in Lower Cook Inlet. Since most conventional sampling gear, i.e., trawls, grabs, nets, etc., either does not sample adequately under conditions of extreme water motion, or fails to collect representative samples in rocky, shallow habitats, we employed diver observations for data acquisition. To this end, diver-biologists were the primary sample tool. This has the secondary advantage of providing the investigators with direct observations of not only the fishes but also their habitats and associated assemblages of marine organisms.

Our efforts were directed at: (1) upgrading the inventory or check list of inshore fish, (2) collecting data on key habitats not easily surveyed by traditional methods, and (3) estimating the relative abundance of the dominant species. Temporal variation or seasonal differences in the shallow water fish populations was also examined. Additional information on trophic interaction, food habits and spawning or reproductive behavior of the conspicuous species was also recorded. The majority of the field time was devoted to working in shallow water habitats, dominated by solid substrate, and overlain with a moderate to heavy coverage of marine vegetation.

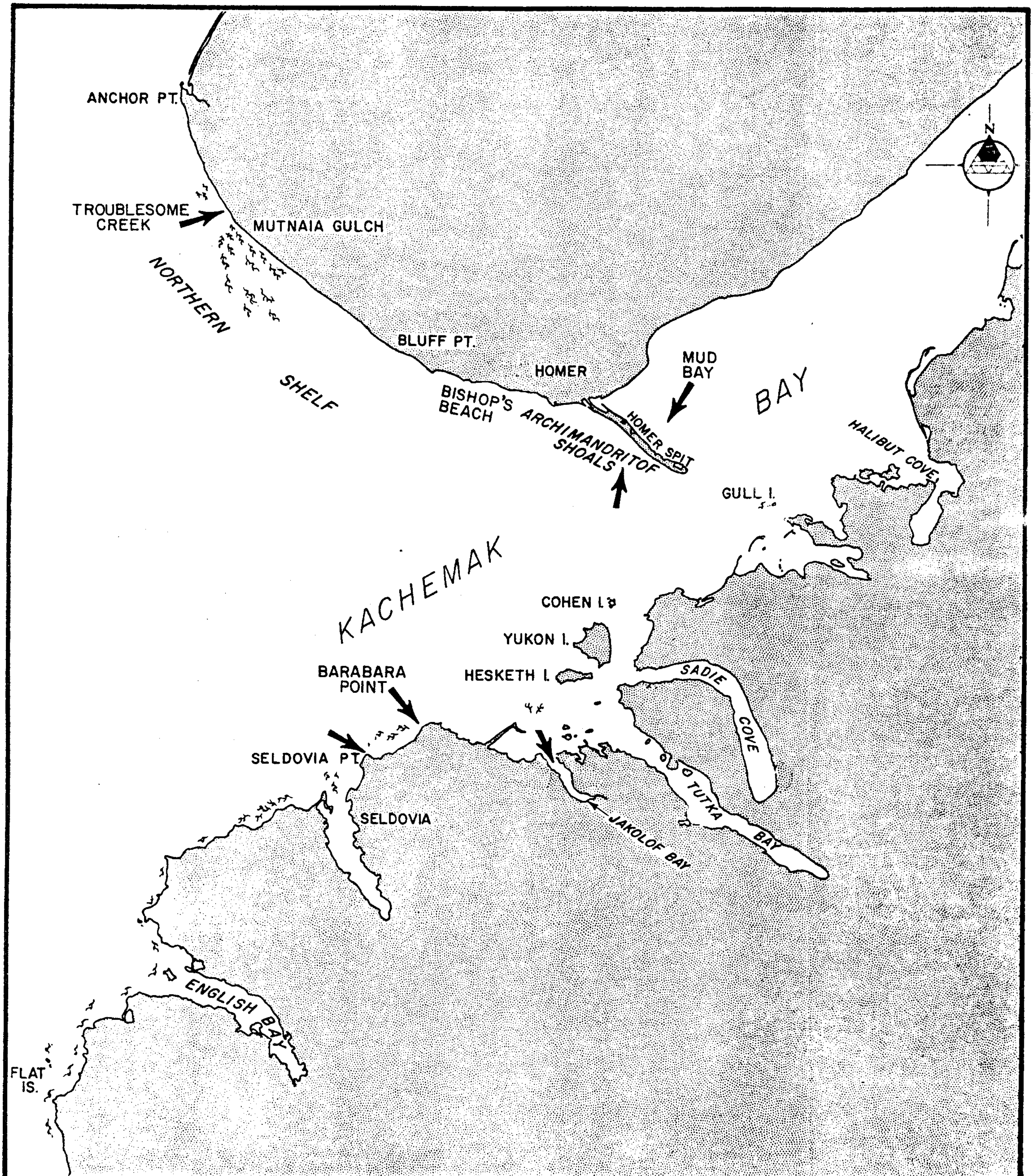
2.0 DESCRIPTION OF THE MAJOR STUDY AREAS

2.1 Kachemak Bay

Most of the systematic field work on the east side of Lower Cook Inlet was conducted in three key locations in Kachemak Bay; namely, (1) the entrance to Jakolof Bay, (2) the kelp bed off Seldovia Pt. and (3) the Northern Shelf from Archimandritof Shoals to Mutnaia Gulch (Figure 1). A number of other sites have been examined in the shallow subtidal zone since 1974 (Rosenthal & Lees 1976; Lees et al 1977, etc.). However the areas that were selected for more intense study were known to be areas of considerable fish activity and/or represented different habitat types. Additionally, several other sites were examined cursorily during the course of this survey.

2.1.1 Jakolof Bay

Jakolof Bay, less than 0.25 miles wide and only about 1.75 miles long, is located on the south side of Kachemak Bay. The entrance is narrow and less than 12 meters deep. Most of the observations and data collection effort was confined to the shallow reef that projects off the rocky headland on the northwest side of the Bay. A prominent feature of this location was the kelp bed and associated floating canopy which was highly visible on slack tides. The substrate underlying the vegetative canopy is composed of pavement rock, cobbles and small boulders. The slope is moderate and the edge of the entrance channel is terraced with boulders and overhanging ledges. Coarse sands and calcareous shell debris are common around the base of the reef. Rock outcrops which were covered by sea anemones, and other suspension feeding forms were prominent biological landmarks. During spring and summer the shallow areas were overlain with a heavy growth of kelp *Alaria fistulosa*. The algal understory beneath the *Alaria* canopy was also thick, and composed of numerous species of brown, red and green algae. Strong tidal currents are typical of this location, and on either a flood or ebb stage of the tide the floating portion of the kelp bed is usually pulled beneath the sea surface.



ARROWS INDICATE LOCATIONS OF STUDY AREAS

FISH STUDY SITES IN KACHEMAK BAY, 1978

FIGURE 1

DAMES & MOORE

2.1.2 Seldovia Point

The largest and most conspicuous kelp bed in Kachemak Bay was found off Seldovia Point. Most of the investigation of the near-shore zone was conducted from the intertidal-subtidal fringe out to the 12 fathom contour, approximately one mile offshore. The shallow subtidal zone is heterogeneous in relief. The bottom substratum consists primarily of coal pavement, overlain by boulders, cobbles and outcrops. Vertical relief is gradual and then drops off sharply beyond the shelf. Silt was prominent on most of the solid substrate and associated marine vegetation. Beyond the shelf is an expanse of sand interspersed with patch reefs of coal and rock.

Inshore currents are typically strong, especially during periods of extreme low and high tide. Seldovia Point is strategically located in terms of exposure to the surface waters of Lower Cook Inlet. Wave activity usually amounts to only a slight onshore break. The fringing kelp bed probably dampens some of the surface water movement in the vicinity of the Point.

2.1.3 Barabara Point

The kelp bed at Barabara Point is continuous with that at Seldovia Point, but is more strongly dominated by bull kelp, *Nereocystis luetkeana.* The depth of the area surveyed was about 10 m. Tidal currents are considerably dampened by the effects of the large, floating kelp bed. The bottom substrate and algal undergrowth are more silt-laden than at Seldovia Point. The boulder-bedrock substrate, with numerous crevices and ledges, offers considerable bottom relief. Many of the outcrops appear to be low-grade coal well overgrown with encrusting coralline algae and epifaunal invertebrates.

2.1.4 Northern Shelf

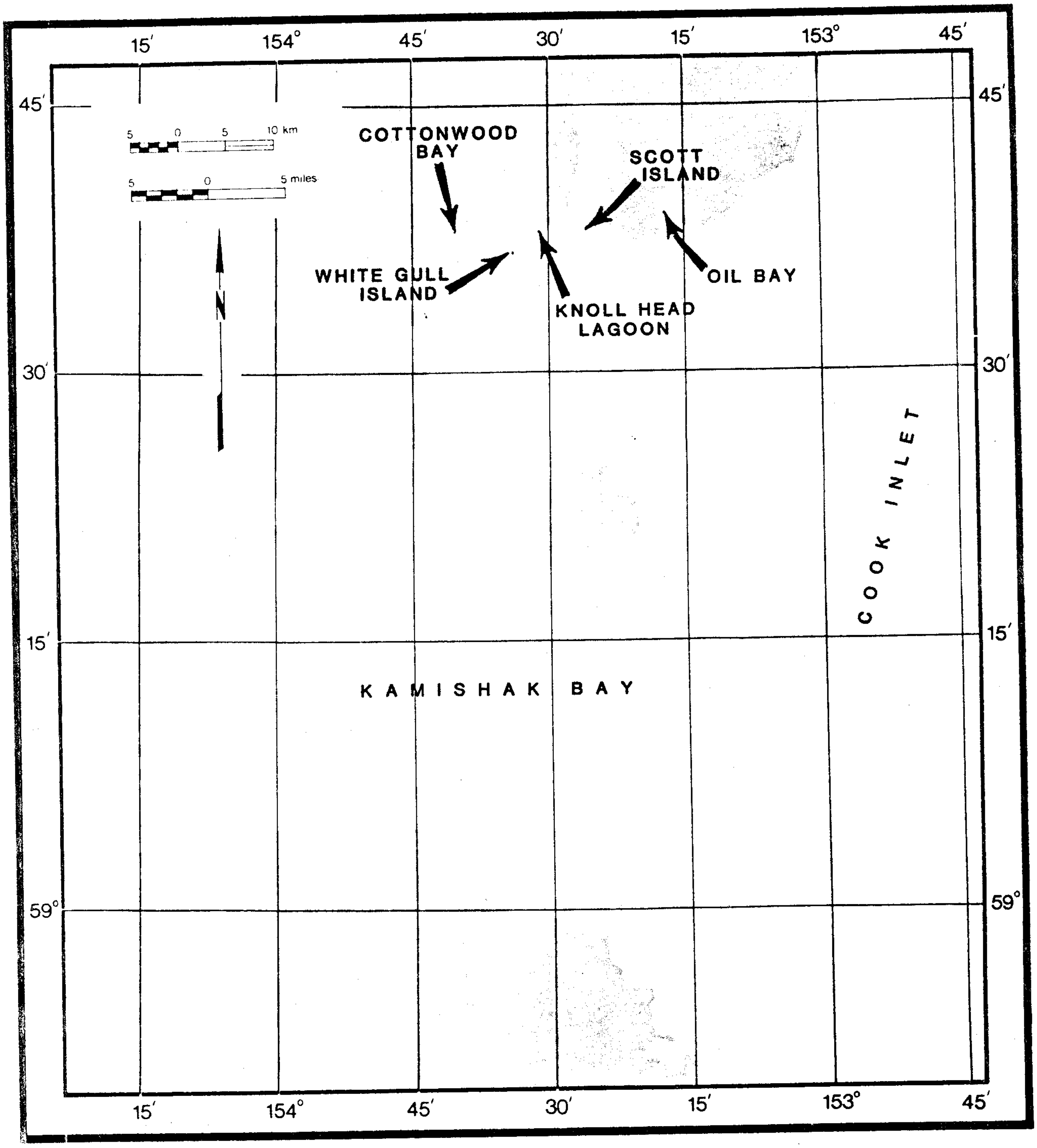
On the north side of Kachemak Bay, west of Homer Spit is a broad, rocky shelf. This relatively flat bench extends from Archimandritof Shoals, off the west side of the Spit, northwest to its widest point off Mutnaia Gulch. The substrate of the shelf is flat and characterized by rock, which predominated at every site. Cobble and boulder fields were the principal type of structure observed, and patches of shell debris were also common. In several areas, the boulders and associated outcrops were composed of coal. Evidence of silt deposition varied locally. Generally algal cover was substantially lower on the shelf than in the other study areas. The physical and chemical characteristics of the sea water that envelops the study area becomes more oceanic when proceeding from Archimandritof Shoals to Mutnaia Gulch.

2.1.5 Mud Bay

The intertidal-shallow subtidal area lying just east of Homer Spit, generally called Mud Bay, has a flat mud bottom. The only surface relief is provided by shell debris and scattered small boulders deposited by rafting ice. Currents and wave action are generally mild and the water is frequently rather turbid. The fauna is dominated by deposit feeding polychaetes and clams, but motile epifaunal crustaceans and snails are common.

2.2 Kamishak Bay

We initially planned to conduct studies in Kamishak Bay similar to those conducted at the major survey sites in Kachemak Bay, but unsuitable water conditions made this undertaking unfeasible. The problems revolved around suitable weather, water clarity and schedules. Field work was initially scheduled for April/May, August and September, 1978. Stormy conditions and turbid water forced a delay of the first field work until early June, and even then, activities were curtailed because of poor visibility. In August, working conditions were marginal because of water clarity, and estimates of fish density were of questionable accuracy. In several areas, the highly irregular slopes of large boulders combined with turbidity to foil attempts to work transects effectively. In September, planned field activities were aborted because of weather conditions and turbidity.



FISH STUDY SITES IN KAMISHAK BAY

FIGURE 2

A further complication arose from the general narrowness of the rock shelf. In rocky areas the rock ends at depths between about 8 and 12 m, and the substrate changes to gently sloping gravel or muddy sand.

2.2.1 Knoll Head Lagoon Area

At the Knoll Head Lagoon site (Figure 2), smooth bedrock and boulders extended gently from the mid-intertidal zone out to a depth of about 3 to 7 m. Rock was replaced by gently sloping gravel. Surface relief on the rock substrate was moderate, but crevices, caves and ledges were relatively uncommon. Kelps became sparse or absent below a depth of 3 m. Based on exposure to Kamishak Bay and surrounding reefs, it seems probable that this location is exposed to heavy wave action during winter and spring storms, but tidal currents are not extreme.

2.2.2 White Gull Island

Reconnaissance dives were made on the east, south and west sides of White Gull Island, in the passage into Cottonwood and Iliamna Bays (Figure 2). On the exposed east side of the island, a bedrock shelf extends across the intertidal zone to a depth of about 1.5 m, where a vertical face extends to a depth of about 5 m. At the bottom of this face, a steep, highly irregular talus slope of medium to large boulders extends down to a depth of about 12 m. Surface relief on this slope is considerable, with crevices, small caves and ledges common. Kelps do not extend over the edge of the vertical face. This side of the island is exposed directly to fairly long period storm waves from the east or southeast but is fairly well exposed to strong incoming tidal currents that sweep the north and south sides of the island in the channels connecting Cottonwood and Iliamna Bays to Kamishak Bay.

The west side of the island is bordered intertidally by moderately sloping gravel beaches and sheer rock faces or outcrops.

Subtidally, these substrates are replaced by a gently sloping, gravelly cobble with boulders, and finally silty sand flats in the southern channel. This side of the island is exposed to small wind waves from the Cottonwood-Iliamna Bay complex but protected from long period storm waves. Surface relief is limited to scattered small boulders and, in the channel, hummocks of a sabellid polychaete. The west side of the island is somewhat exposed to strong outgoing tidal currents leaving the bay complex to the west.

3.0 SAMPLING METHODS

Direct observations were made while SCUBA diving at depths from 3-23 m below MLLW (mean lower low water). All of the diving was done during daylight hours between 0800 and 1900 hours. The underwater surveys were designed to gather both quantitative and qualitative information about the fish fauna of Lower Cook Inlet. Estimates of fish density (number of fish/square meter) in each of the study areas was determined by counting fish along either fixed or randomly placed transect lines. In some areas polypropylene line (0.60 cm in diameter) was positioned on the bottom, and held in place with galvanized boat spikes (20 cm). The other technique employed the use of a diver to unwind a sinking plastic tape that was attached to a reel. One end of the transect was secured to a fixed point, and as the diver-biologist ran a compass course, the metric tape was unraveled. The transect band, usually 0.5 to 2 m wide and 5-50 m in length, was determined by the working depth, amount of bottom time and the number of fish present in each area. In most instances the transect followed a specific isobath or depth contour. Occasionally the transect tapes were left on the bottom between dives. This was done in order to check the consistency of the count, and to compare fish density and species composition after an elapsed time interval of 1 or 2 hours.

Species lists and density estimates obtained by diving techniques are subject to several limitations. Variations in water conditions, especially water clarity, effect the efficiency of the observer. This problem definitely limited effectiveness in Kamishak Bay. Since these transect methods were biased against smaller or more cryptic species, another technique was employed to estimate the relative abundance of the smaller fish. Replicated 1/4 m^2 quadrats were placed in a random manner, or stratified in such a way that a particular habitat or micro-habitat was sampled in the subtidal zone. All fish that occurred within the quadrat frame were subsequently recorded.

Samples from these fish populations were collected with the aid of hand spears and mesh bags. All specimens were measured (standard length) to the nearest millimeter, and the sex was determined when possible. If a species identification was in doubt, or a confirmation of a range extension was needed, the specimen was usually sent to Dr. Robert Lavenberg, Curator of Ichthyology, Los Angeles County Museum of Natural History.

When the fish was collected for stomach analysis, the specimen was dissected, and the stomach was removed. The contents (if any) were examined fresh under a dissecting microscope. Occasionally the stomach contents were preserved in 10% formalin for examination at a later date. The degree of stomach fullness was recorded, the contents were sorted, and the organisms were identified to the nearest taxon.

In conjunction with infaunal studies on the sand beach at Homer Spit, a small beach seine effort was mounted. The net used was a beach seine 32-m long by 2.1-m deep, with 15-m long, 2.5-cm stretch mesh wings. The money bag was 2.1-m wide with a 0.6-cm web. For each haul, the net was extended perpendicularly from the beach to its full length offshore, then both ends of the net were pulled 30 m along the beach. At this point the offshore end was swung in an arc back to the beach, and the net was pulled up onto the shore. The area covered was approximately 1000 m^2. The contents were then picked from the net, and fish and invertebrates were placed in a 10% formaldehyde-seawater solution. Fish stomachs were slit immediately to facilitate preservation of stomach contents for diet evaluation. Three replicate hauls were made consecutively about 100 m apart in each sample set.

4.0 RESULTS

The shallow water fish assemblages of Kachemak and Kamishak Bay include at least 56 species which are typically found in the near-shore zone (Table 1). Fourteen percent (8/56) of the fish identified to date were previously unreported in these waters. Some of the range extensions were significant (as great as a few thousand miles) while others were less than a hundred miles.

4.1 Inshore Fish Assemblages in Kachemak Bay

A total of 358 fish were counted in the transect sampling from May to November 1978. Of the censused fish, 211 were seen in the transects off Seldovia Point, 138 fish at Jakolof Bay, 6 along the Northern Shelf, and 11 in Mud Bay. The disparity in number is largely due to differences in sampling effort.

4.1.1 Exposed Offshore Kelp Bed - Seldovia Point

Twenty-eight species of fish have been seen in the shallow subtidal waters off Seldovia Point. More species are no doubt still to be found here as the current inventory includes only the more conspicuous species, which are presumed to be either the numerical or functional dominants in the nearshore system. The greatest number of individual fish and highest species diversity were usually sighted along the edges of the kelp forest. This was particularly true of the coal outcroppings and rock piles just seaward of the floating kelp canopy (Figure 3).

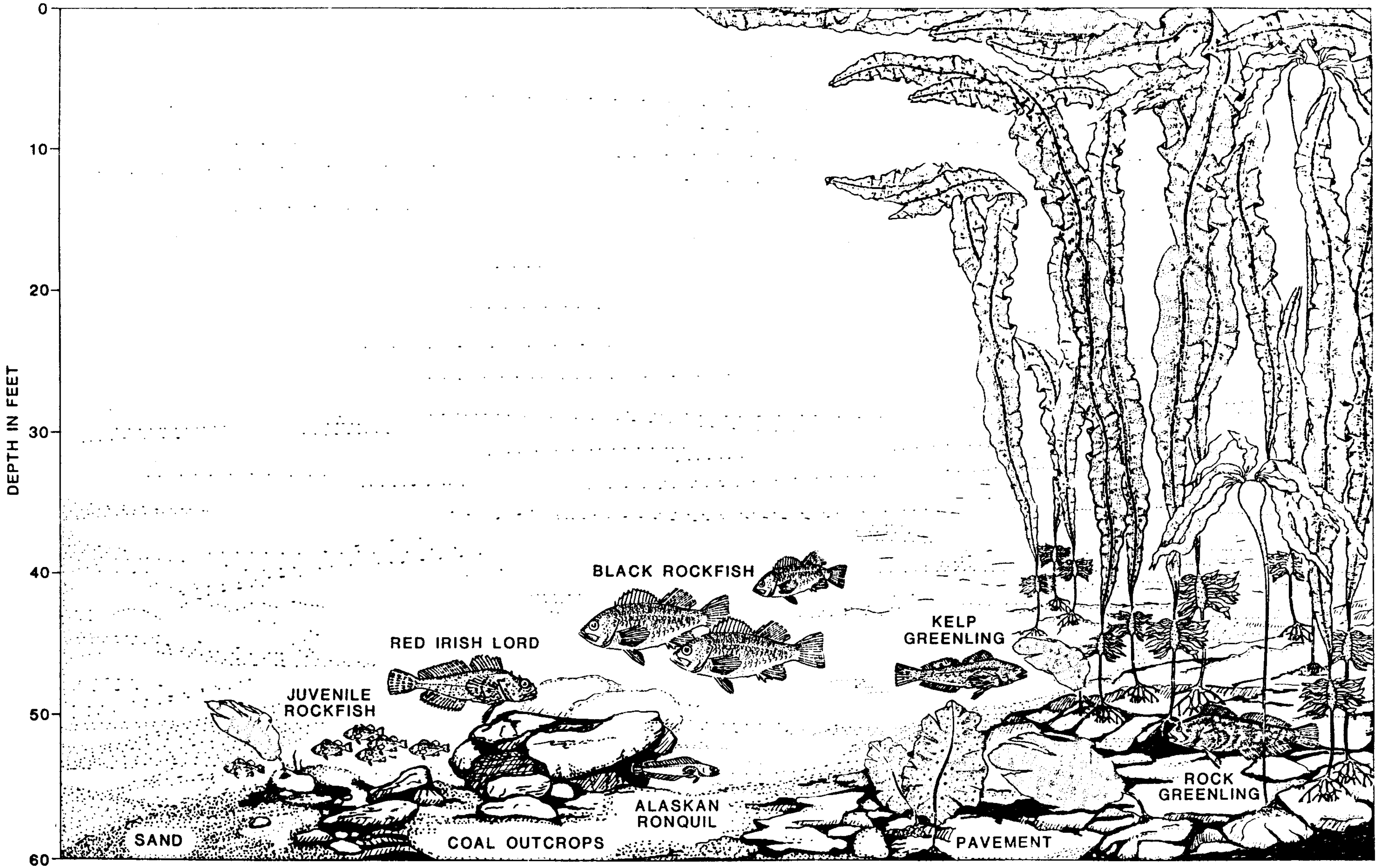
Within the confines of the kelp stand were solitary bottom dwellers such as kelp, rock, and whitespotted greenlings. Red Irish lord (*Hemilepidotus hemilepidotus*) and great sculpin were also common in this location. A number of other fish were also encountered in the algal understory. Usually these species were more cryptic or difficult to detect because of their small size or drab coloration which matched the surrounding habitat. For instance, the arctic shanny (*Stichaeus*

TABLE 1

LIST OF FISHES FROM THE SHALLOW SUBLITTORAL ZONE, LOWER COOK INLET

Taxon	Jakolof Bay	Seldovia Point	Northern Shelf	Kamishak Bay
Clupea harengus pallasi. Pacific herring	X			
Oncorhynchus gorbuscha. pink salmon	X			
O. kisutch. coho salmon		X		
Salvelinus malma. Dolly Varden	X			X
Hypomesus pretiosus. surf smelt			X	
Mallotus villosus. capelin			X	
Microgadus proximus. Pacific tomcod	X	X		
Aulorhynchus flavidus. tube-snout*			X	
Gasterosteus aculeatus. threespine stickleback	X			
Bathymaster caeruleofasciatus. Alaskan ronquil	X	X	X	
B. leurolepis. smallmouth ronquil			X	
B. signatus. searcher			X	
Ronquilus jordani. northern ronquil		X	X	X
Anoplarchus purpurescens. high cockscomb		X		
Lumpenus sagitta. snake prickleback			X	X
Stichaeus punctatus. Arctic shanny*	X	X		
Pholis laeta. crescent gunnel	X			X
Anarrhichthys ocellatus. wolf-eel	X	X		
Delolepis gigantea. giant wrymouth		X		
Ammodytes hexapterus. Pacific sand lance	X			
Sebastes caurinus. copper rockfish*	X	?		
S. ciliata. dusky rockfish*	X	X		
S. melanops. black rockfish	X	X	X	
Hexagrammos decagrammus. kelp greenling	X	X	X	
H. lagocephalus. rock greenling	X	X	X	
H. octogrammus. masked greenling	X	X		X
H. stelleri. whitespotted greenling	X	X	X	X
Artedius ?fenestralis. padded sculpin				X
A. harringtoni. scalyhead sculpin*		X	X	X
A. lateralis. smoothhead sculpin*	X			
A. notospilotus. bonyhead sculpin*	X			
Blepsias cirrhosus. silverspotted sculpin		X		X
Clinocottus acuticeps. sharpnose sculpin		X		
Enophrys diceraus. antlered sculpin	X	X		
Gymnocanthus galeatus. armorhead sculpin			X	
Hemilepidotus hemilepidotus. red Irish lord	X	X	X	
H. jordani. yellow Irish lord		X	X	
H. spinosus. brown Irish lord*		X		
Leptocottus armatus. Pacific staghorn sculpin			X	X
Myoxocephalus polyacanthocephalus. great sculpin	X	X	X	
Myoxocephalus sp.	X			X
Oligocottus maculosus. tidepool sculpin	X			
Rhamphocottus richardsoni. grunt sculpin			X	
Triglops pingeli. ribbed sculpin	X		X	
Podothecus acipenserinus. sturgeon poacher	X	X	X	
Anoplagonus inermis. smooth alligatorfish	X			
Pallasina barbata. tubenose poacher			X	
Liparis callyodon. spotted snailfish		X		
L. cyclopus. ribbon snailfish		X		
Hippoglossoides elassodon. flathead sole			X	
Hippoglossus stenolepis. Pacific halibut		X		
Isopsetta isolepis. butter sole			X	
Lepidopsetta bilineata. rock sole	X	X	X	X
Limanda aspera. yellowfin sole	X			
Parophrys vetulus. English sole			X	
Platichthys stellatus. starry flounder	X	X		X
Psettichthys melanostictus. sand sole			X	

* denotes range extension



FISH DISTRIBUTION ALONG THE OUTER EDGE OF THE KELP BED
SELDOVIA POINT

FIGURE 3

punctatus), was previously unreported in Cook Inlet, however it was common in the seaweed and rock-dominated portions of the sea floor off Seldovia Point. Small cottids of the genus Artedius, northern ronquil (Ronquilus jordani) and silver-spotted sculpin (Blepsias cirrhosus) were also repeatedly sighted in the central portion of the kelp bed. Further offshore, around the lower limit of the Alaria/Nereocystis stand the bottom relief was more irregular, and the dominant species in terms of frequency of occurrence was Alaskan ronquil, Bathymaster caeruleofasciatus. Mixed schools of black rockfish and dusky rockfish were also sighted. Some of the schools contained hundreds of individuals, and usually the adults were segregated from the juveniles. Juvenile rockfish hovered above outcrops and rock piles or schooled beneath over-hanging ledges. Around these same patch reefs were more demersal species such as red Irish lord, rock greenling and kelp greenling.

The density of fish at Seldovia Point ranged from 0.020 to 0.433 fish/m^2 (Table 2). The average density was 0.176 fish/m^2 or 1760 fish per hectare. Most of the fish were solitary bottom species. Alaskan ronquil was the most abundant bottom species; density estimates ranged from 0-0.194 fish/m^2. Hexagrammidae was the most frequently encountered family of fish at Seldovia Point, and kelp greenling was the most common species. Juvenile rockfish (unidentified), black rockfish and dusky rockfish were the dominant schooling species in this location. Typically, the aggregations comprised less than 20 individuals; however, on the September survey a large school of black rockfish was encountered at a depth of 17-18 m above a low profile reef. The aggregation was made up of both juvenile and adult black rockfish, and estimates of the size of the school ranged from 300-400 fish. Black rockfish densities during the five survey periods ranged from 0-0.164 fish/m^2. Other conspicuous species sighted in the transect bands were the red Irish lord, rock greenling, whitespotted greenling, northern ronquil, arctic shanny, Pacific halibut and scalyhead sculpin.

The kelp bed 2 km west of Barabara Point, a more protected

TABLE 2

DENSITY ESTIMATES (FISH/M^2) OF SOME CONSPICUOUS FISH
AT SELDOVIA POINT, KACHEMAK BAY 1978

Taxon	29June	11-12July		30July		29Sept	8Nov	24Nov
Wolf-eel	0	0	0.033	0	0	0	0	0
Alaskan ronquil	0	0	0	0.045	0.194	0.036	0.021	0.027
Northern ronquil	0	0	0	0	0.006	0	0.007	0
Scalyhead sculpin	0	0	0	0	0	0	0.014	0
Ribber sculpin	0	0	0.033	0	0	0	0	0
Sculpin, unid.	0	0.053	0	0	0	0	0	0
Red Irish lord	0	0	0	0.005	0	0	0	0
Yellow Irish lord	0	0	0.033	0	0.006	0	0	0
Kelp greenling	0.020	0.080	0.133	0.025	0.031	0.044	0	0.030
Rock greenling	0	0.027	0.100	0.015	0	0.014	0.014	0
?Rock greenling, juv.	0	0.027	0	0	0	0	0	0
Whitespotted greenling	0	0	0	0	0	0.008	0	0
Pacific halibut	0	0	0	0	0	0	0.007	0
Black rockfish/Dusky rockfish	0	0	0.100	0.010	0.019	0.164	0	0
Rockfish, juv.	0	0	0	0	0	0.014	0	0
Arctic shanny	0	0	0	0	0	0	0.007	0.003
Total number of fish:	1	7	13	20	41	101	10	18
Area examined (m^2):	50	37.5	30	200	160	360	140	300
Density (fish/hectare)*:	200	1867	4333	1000	2563	2806	714	600
Corrected depth (m):	9.2	6.1	12.2	12.2	16.5	16-16.5	16-16.5	16-16.5

Overall density ($\bar{x} \pm s$) = 1760 ± 1405 fish/hectare

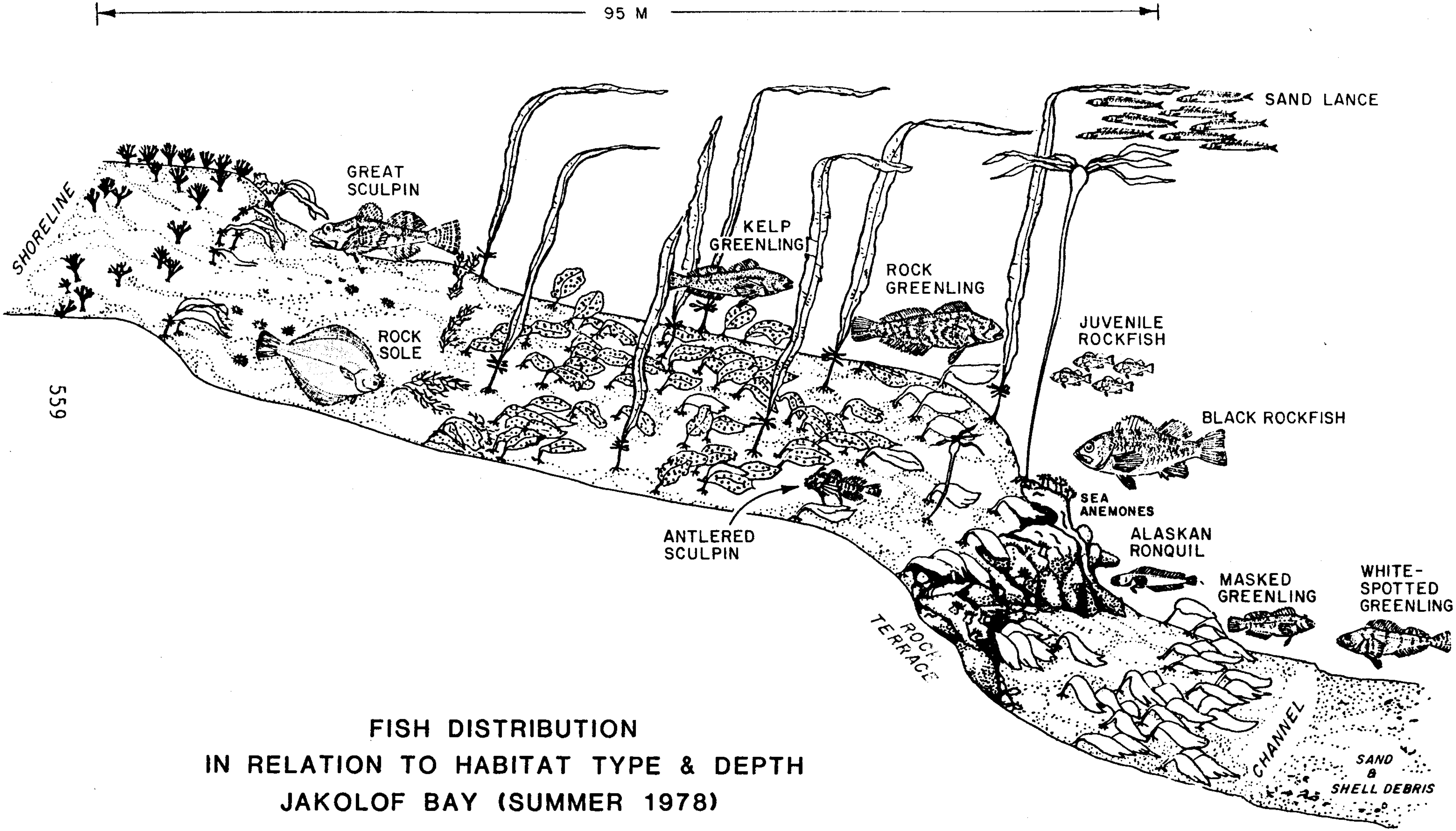
*Fish/hectare = fish/m^2 x 10^4

offshore habitat dominated by bull kelp, was surveyed one time. Composition of the ichthyofauna was rather similar (Table 3) to that reported for Seldovia Point (Table 2). Kelp greenling were the dominant fish species, and juvenile black and/or dusky rockfish were common. The density was probably somewhat lower than at Seldovia Point, even if accurate counts per rockfish had been obtained.

4.1.2 Semi-Protected Embayment - Jakolof Bay

Of the major study sites, Jakolof Bay had the greatest number of identifiable species of fish. A total of 29 species of fish was sighted in this location. However, species richness may not be any greater here than it is at Seldovia Point. Since more time has been spent at Jakolof Bay, the chances to see and collect more species is certainly increased. The high species richness might be related to the pronounced bottom relief. Unlike other protected embayments in Lower Cook Inlet, where the predominent substratum is usually relatively flat, mud and gravel, the entrance channel into Jakolof is rocky and swept by strong tidal currents. Rapid circulation is one reason for the apparent high productivity of the reef. Suspension feeders such as mussels, clams, sponges and barnacles would certainly benefit from the water flow, which in turn would provide more food for the fish population of the reef.

Proceeding from the middle of the entrance channel and moving up slope, the habitat changes from shell debris, cobbles and low statured kelps to a rocky terrace overlain by suspension feeders and seaweeds (Figure 4). Growing on this portion of the reef was a small, moderately dense stand of _Alaria fistulosa_ and bull kelp (_Nereocystis luetkeana_). Beneath the floating canopy were patches of the sabellid worm (_Potamila reniformis_) and horse mussels (_Modiolus modiolus_), nestling clams (_Entodesma saxicola_), balanoid barnacles and an erect red sponge (?_Esperiopsis rigida_). Along the upper edge of the kelp bed were dense aggregations of green sea urchin (_Strongylocentrotus droebachiensis_). This zone was relatively devoid of fleshy macroalgae; cobbles and rocks were the predominent features of the sea floor. Near the intertidal-



FISH DISTRIBUTION
IN RELATION TO HABITAT TYPE & DEPTH
JAKOLOF BAY (SUMMER 1978)

FIGURE 4

DAMES & MOORE

subtidal fringe was a narrow band of Alaria ?crispa. Rockweed (Fucus distichus) grew from the upper limit of the Alaria to well above MLLW.

Fish were distributed from MLLW down to the deepest part of the entrance channel, but the key part of the reef complex in terms of species diversity and relative abundance was the rock terrace near the lower end of the Alaria fistulosa stand. For example, black rockfish and dusky rockfish frequently hovered around the overhanging ledges, or swam in quiet schools beneath the floating kelp canopy (Figure 4). Within this same rock terrace were more solitary species of fish such as the Alaskan ronquil (Bathymaster caeruleofasciatus), wolf-eel (Anarrhichthys ocellatus) and small cottids of the genus Artedius. Kelp and rock greenling (Hexagrammos decagrammus and H. lagocephalus) and great sculpin (Myoxocephalus polyacanthocephalus) were also commonly seen on this part of the reef. Just below the rock terrace were masked and whitespotted greenling (H. octogrammus and H. stelleri). During summer months Pacific sand lance (Ammodytes hexapterus) were seen in dense schools around the outer edges of the kelp bed. Occasionally there were small schools of juvenile pink salmon (Oncorhynchus gorbuscha) and Pacific herring (Clupea harengus pallasi) in the shallow portions of the water column. The occurrence of these pelagic species was highly seasonal, and they usually appeared during summer and early fall.

Within the confines of the kelp forest were masked, kelp, rock and whitespotted greenling, antlered sculpin (Enophrys diceraus), rock sole (Lepidopsetta bilineata), crescent gunnel (Pholis laeta) and great sculpin. On the shallower parts of the reef, where the solid substratum was almost devoid of fleshy macroalgae, occurred right-eye flounders (Pleuronectidae), sculpins (Cottidae) and pricklebacks (Stichaeidae).

Fish densities at Jakolof Bay ranged from 0.017-0.210 fish/m^2 (Table 4). The average density during the four survey periods was 0.104fish/m^2, or 1,036 fish per hectare. Although non-schooling species were dominant in this location, juvenile or immature black rockfish,

TABLE 3

OCCURRENCE OR DENSITY (FISH/M^2) OF SOME CONSPICUOUS FISH AT MISCELLANEOUS LOCATIONS IN KACHEMAK BAY, 1978

Taxon	Barabara Bluffs 13Jul78	Archimandritof Shoals 28Jun78	Archimandritof Shoals 28Jun78	Archimandritof Shoals 28Jun78	Archimandritof Shoals 10Jul78	Mud Bay 10Jul78
Wolf-eel	P[a]	0	0	0	0	0
Alaskan ronquil	0.007	0	0	0	0	0
unid. juv. sculpin	0	0	0.030	0	P	0.030
Kelp greenling	0.033	0	0	0	0	0
Rock greenling	0.007	0	0	0	0	0
Rock sole	0	P	0.030	P	P	0.060
unid. great sculpin	0	0	0	0	P	0
unid. juv. flatfish	0	0	0	0	0	0.070
Copper rockfish, juv.	P	0	0	0	0	0
Black rockfish, juv.	C[b]	0	0	0	0	0
unid. juv. rockfish	P	0	0	0	0	0
Total number of fish:	7	-	2	-	-	11
Area surveyed (m^2):	150	-	30	-	50	70
Density (fish/hectare)[c]:	>470	-	60	-	-	160
Corrected depth (m):	10	5	7	9	15	11
Substrate:	Boulder & Bedrock, _Nereocystis_ & _Laminaria_	Cobble & scattered Boulders w/ _Agarum_ & _Modiolus_	Cobble & Shell w/ _Modiolus_ & _Agarum_	Cobble & Shell w/ _Modiolus_	Cobble & Shell w/ _Modiolus_	Mud w/ Scattered Boulders

[a] P = Present [b] C = Common [c] Fish/hectare = fish/m^2 x 10^4

TABLE 4

DENSITY ESTIMATES (FISH/M^2) OF SOME CONSPICUOUS FISH AT JAKOLOF BAY, KACHEMAK BAY

Taxon	12May78	02Aug78	25Sept78	28Nov78
Alaskan ronquil	0	0.005	0.007	0.002
Antlered sculpin	0.006	0	0	0.004
Black rockfish/Dusky rockfish	0	0.030	0.030	0
Crescent gunnel	0	0.007	0	0
Great sculpin	0.013	0.005	0	0
Kelp greenling	0.013	0.030	0.013	0.002
Masked greenling	0	0.100	0.030	0.006
Rock greenling	0.006	0.005	0.013	0.002
Rock sole	0.013	0.005	0	0
Whitespotted greenling	0.019	0.007	0.020	0
Total number of fish:	11	84	35	8
Area examined (m^2):	155	400	300	480
Density (fish/hectare)*:	710	2100	1167	167

Overall mean density ($\bar{x} \pm s$) = 1036 ± 819 fish/hectare

*Fish/hectare = fish/m^2 x 10^4

copper rockfish (Sebastes caurinus) and dusky rockfish were observed around the rocky terrace, and beneath the kelp canopy. Black and dusky rockfish densities ranged from 0-0.03 fish/m^2.

The greenlings were the most frequently encountered and abundant family in the shallow subtidal zone. Masked greenling was the most common, with density estimates within the transects ranging from 0-0.10 fish/m^2. The others, in order of their relative abundance, were kelp, white-spotted, and rock greenlings (Table 4). Usually greenlings were solitary in distribution, although occasionally they were observed swimming in small groups. Activity patterns changed markedly during the calendar year. During the spawning and reproductive period (May-October) the fish were highly visible and aggressive. However, with the onset of oceanic winter, most became cryptic or inactive, and dramatic changes in the body coloration of the males was noted. Other non-schooling species common in this site were Alaskan ronquil, antlered sculpin, crescent gunnel, great sculpin and rock sole.

4.1.3 Exposed Cobble - Boulder Habitat - Northern Shelf

Twenty-one species were sighted in the northern shelf area (Table 1). Species richness was lower than at Jakolof Bay or Seldovia Point, despite the fact that the shelf constitutes a greater area, and a larger variety of habitats was examined. Examinations of the ichthyofauna were made at seven different locations. Most of the fish were either solitary or bottom dwelling species. The ronquil family was represented by four of the species known to be present in these waters (Quast and Hall, 1972). Thirty-three percent of the species were sculpins, and most of the others were either highly cryptic, drab in coloration or relatively inconspicuous on the sea floor. In areas dominated by cobbles, flat pavement, shell debris and small rocks were scalyhead sculpin (Artedius harringtoni), northern ronquil and ribbed sculpin (Triglops pingeli).

Although algal cover was usually light to sparse off Bishop's Beach and Bluff Point, the inshore area west of there supported a

TABLE 5

DENSITY ESTIMATES (FISH/M^2) OF SOME CONSPICUOUS FISHES ON THE NORTHERN SHELF, KACHEMAK BAY

Taxon	31Jul78	01Aug78	26Sept78	25Nov78
Scalyhead sculpin	0	0.017	0.032	0
Alaskan ronquil	0.020	0.017	0.009	0
Ribbed sculpin	0.020	0	0	0
Northern ronquil	0	0	0.077	0
Whitespotted greenling	0	0.033	0.009	0
Total number of fish:	2	4	28	0
Area Examined (m^2):	50	60	220	120
Density (fish/hectare)*:	400	670	1270	0
Depth (m):	17-18	12-13	14-15	14-15
Location:	Bluff Point	Mutnaia Gulch	Bishops Beach	Bishops Beach

* Fish/hectare = fish/m^2 x 10^4

moderate coverage of perennial brown algae. Coal and rock outcrops were important micro-habitats of Alaskan ronquil, which frequently perched in front of, or hid beneath larger rocks. Another member of this family, the smallmouth ronquil (Bathymaster leurolepis) was also collected in these same habitats. Northern ronquils were the most commonly observed member of this family; they were particularly common on areas of flat relief that were dominated by cobbles, shell debris and beds of horse mussel. Searchers (Bathymaster signatus) occurred in these same habitats.

West of Bluff Point, inside the 10 fathom contour, were numerous patch reefs and outcroppings of coal overlain by a thin veneer of crustose coralline algae. Here the fish assemblage was more diverse, and certainly more visible. Greenlings, red Irish lord, yellow Irish lord (Hemilepidotus jordani) and Alaskan ronquil were commonly seen in these patch reef habitats. There seemed to be a positive correlation between the degree of bottom relief and the abundance and diversity of fishes along the shelf.

Fish density along the northern shelf was significantly lower than it was in the other two study areas. Overall densities ranged from 0 to 0.127 fish/m^2 (Tables 3 and 5). Ronquils were the most conspicuous group of fish. Although searcher, smallmouth ronquil, Alaskan Ronquil, and northern ronquil were all seen off Bluff Point, only the latter two were included in the transect counts. Density estimates for Alaskan ronquil ranged from 0-0.020 fish/m^2. Other species observed in the transect surveys were ribbed sculpin, scalyhead sculpin and juvenile whitespotted greenling. However, because of their small size and cryptic nature, estimates of relative abundance and frequency of occurrence were also determined from 1/4 m^2 quadrat counts. For example sculpins (Artedius spp.) occurred in 6/70 quadrats cast; their densities ranged from 0-4.0 fish/m^2. Alaskan ronquil was only encountered in 2 of 70 quadrats, with densities of between 0-4.0 fish/m^2. Ribbed sculpin was more uncommon as it only occurred in 1 of 70 quadrats.

Composition of the ichthyofauna of Archimandritof Shoals, a cobble-boulder habitat, appeared to differ considerably from the rest of the northern shelf. The main fish observed were small cottids and rock sole; the latter were observed at all sites (Table 3). Fish densities were quite low. Sturgeon poacher (Podothecus acipenserinus) have also been observed on the shoals.

4.1.4 Semi-Exposed Sand Beach - Homer Spit

The purpose of the field work at Homer Spit was to (1) examine composition of the inshore fish assemblage, (2) assess changes in species composition in shallow water between high and low tide and between summer and winter, and (3) to examine the diet of these species for utilization of the sand beach infaunal organisms.

Eighteen species of fish and 3,602 specimens from ten families were collected in the nine beach seine hauls made in July and December. The low tide hauls in December were so unproductive that the plans for high tide hauls were aborted. Many of the fish apparently occurred in schools or aggregations and hence catches were quite variable.

In the summer low tide sample sets, totals of seventeen species and 3,514 specimens from ten families were collected (Table 6). Sand lance dominated in terms of abundance and biomass. Other important species included Pacific staghorn sculpin (Leptocottus armatus), English sole (Parophrys vetulus), sturgeon poacher, rock sole and Dolly Varden (Salvelinus malma) (Table 6).

Dolly Varden, English sole, snake prickleback and an unidentified sculpin were collected in all three hauls. Immature specimens dominated the catch for all species except sand lance, capelin (Mallotus villosus), surf smelt (Hypomesus pretiosus), threespine sticklebacks, Dolly Varden, tubenose poachers (Pallasina barbata), and Pacific staghorn sculpin.

In the summer high tide sample set, totals of eight species

TABLE 6

CATCHES OF FISHES IN BEACH SEINE HAULS
ON THE WEST SIDE OF HOMER SPIT, 1978

Taxon	Average Number (±s) of Fish per Seine Haul 25Jul78 Low Tide	26Jul78 High Tide	19Dec78 Low Tide
Salmonidae			
Pink salmon	0.3 ± 0.6(1)*	10.0 ± 13.9(3)	0
Dolly Varden	4.7 ± 1.5(3)	5.6 ± 6.0(2)	0
Pleuronectidae			
Rock sole	6.3 ± 6.5(2)	0	0
Yellowfin sole	1.3 ± 1.5(2)	0	0
English sole	19.3 ± 16.3(3)	0	0
Starry flounder	0.3 ± 0.6(1)	0	0
Sand sole	1.0 ± 1.0(2)	0	0
Cottidae			
Pacific staghorn sculpin	64.7 ± 104.3(2)	0.3 ± 0.6(1)	1.0 ± 1.7(1)
unid. sculpin	1.0 ± 0.0(3)	0.3 ± 0.6(1)	0
Agonidae			
Sturgeon poacher	13.3 ± 22.2(2)	0	0
Tubenose poacher	1.0 ± 1.7(1)	0.3 ± 0.6(1)	0
Forage spp.			
Pacific sand lance	1049.0 ± 1810.9(2)	0	1.3 ± 1.5(2)
Capelin	0.3 ± 0.6(1)	0.7 ± 0.6(2)	0
Surf smelt	0	7.0 ± 12.2(1)	0.3 ± 0.6(1)
Miscellaneous			
Snake prickleback	1.0 ± 0.0(3)	0	0
Greenling sp (juv.)	0.7 ± 0.6(2)	0	0
Rockfish sp (juv.)	0.3 ± 0.6(1)	0	0
Threespine stickleback	2.0 ± 3.5(1)	2.3 ± 2.1(2)	0
Average No. of Individuals:	1171.3 ± 1781.8	26.7 ± 31.8	2.0 ± 1.2
Number of Species:	17	8	3
Total No. of Individuals:	3514	80	8

* Numbers in parentheses indicate number of hauls in which species occurred.

and 80 specimens from five families were collected (Table 6). Juvenile pink salmon dominated in terms of abundance but Dolly Varden in terms of biomass. Other important species included surf smelt and threespine stickleback (Gasterosteus aculeatus) (Table 6). Juvenile pink salmon were caught in all three hauls. Again, immature specimens dominated the populations caught.

In the winter low tide sample set, totals of three species and eight specimens from three families were collected. Sand lance were most common (Table 6). The other two species collected were Pacific staghorn sculpin and surf smelt (Table 6). The surf smelt, at 11 cm standard length, was the largest fish caught. All specimens were immature.

Comparisons of species composition, richness and abundance with a Kruskal-Wallis one-way analysis of variance suggest some differences between different tide stages and seasons (Table 6). In July, significantly more species of fish were collected at low tide than at high tide (P=0.05). Moreover, despite large variations in catches, fish were considerably more abundant at the low tide level than at that of high tide (P=0.10). The most notable differences in composition were 1) the absence of flatfish and sand lance, 2) the paucity of Pacific staghorn sculpin, 3) the appearance of surf smelt and 4) the increase in abundance of pink salmon at the high tide level (Table 6).

The contrasts between species composition, richness and abundance of fish in the hauls at the low tide level in July and December are quite dramatic. The differences in species richness and abundance is significant (P=0.05) when tested with the Kruskal-Wallis analysis of variance. The number of families declined from ten in July to three in December. Most notable absences were salmonids, flatfish and poachers. Abundance of forage species also declined substantially.

4.1.5 Protected Mud Substrate - Mud Bay

A limited survey effort was expended to examine the ichthyofauna on the muddy substrate in Mud Bay. Only a limited number of demersal fish was observed, but water clarity may have hampered survey efforts to a degree. Flatfish appeared to be the dominant fish; both rock sole and unidentified juvenile flatfish were observed (Table 3). Small unidentified sculpins were the only other species observed. Notable by their apparent absence were Pacific staghorn sculpin and starry flounder, both of which have been collected in large numbers in beach seine hauls along the shoreline of Mud Bay (personal observation).

4.2 Inshore Fish Assemblages in Kamishak Bay

A total of eleven fish species was observed in diving surveys in shallow subtidal habitats in Kamishak Bay. Whitespotted greenling was the most abundant and commonly observed species (Table 7). The only other species occurring frequently were rock sole and masked greenling. Fish densities were low in comparison to most areas on the east side of Cook Inlet.

4.2.1 Exposed Rocky Habitat

The exposed east face of White Gull Island appeared to offer the greatest refuge for solitary bottom fish, especially species preferring crevices and holes. Nevertheless, whitespotted greenling was the only commonly observed species (Table 7), and only two other species were sighted. Densities were not quantified because of the difficulties resulting from poor visibility and the irregularity of the talus slope.

Similar habitat was observed at Black Reef, approximately one-fourth the distance from White Gull Island to Iniskin Bay. The rock outcrop forming the reef extends vertically to a depth of about 5 m, and then a slope of large boulders continues down to silty-sand substrate at 12 m. Fish were quite scarce, and only a few whitespotted greenling and an unidentified small sculpin were observed (Table 7). In all, only four species were observed in about six man-hours of diving on this type of habitat.

TABLE 7

OCCURRENCE OR DENSITY (FISH/M^2) OF CONSPICUOUS FISH AT SEVERAL LOCATIONS IN KAMISHAK BAY, 1978

	LOCATION									
	Knoll Head Lagoon				White Gull Island		Black Reef	Scott Island	Oil Bay	Cotton-wood Bay
Taxon / Survey date:	11Jun78	2Aug78	2Aug78	2Aug78	12Jun78	3Aug78	12Jun78	4Aug78	4Aug78	3Jun78
Padded sculpin	0	0	0	0	S[a]	0	0	0	0	0
Silverspotted sculpin	0	0	0	P[b]	0	0	0	0	0	0
unid. sculpin	0	0	0	0	0	0	S	0	0	0
Masked greenling	0	0.016	0.050	0	0	0	0	P[c]	0	0
Whitespotted greenling	P	0.016	0.100	0.051	S	C[d]	S	0.067	0	P
Butter sole	0	0	0	0	0	0	0	0	P	0
Rock sole	P	0	0	0	S	0	0	0	P	P
Snake prickleback	0	0	0	0	0	0	0	0	C	0
Great sculpin species	0	0	0	0	0	S	0	0	0	0
unid. juv. flatfish	0	0	0	0	0	0	0	0	0.030	P
Northern ronquil?	0	0	0	0	0	S	0	0	0	0
Total number of fish:	-	2	6	6	-	-	-	1	1	-
Area surveyed (m^2):	-	60	40	117.5	-	-	-	15	30	150
Density (fish/hectare)[e]:	-	300	1500	510	-	-	-	667	333	-
Corrected Depth (m):	3-6	0.5	1.8	4.0	5-8	5-15	3-10	3	1-3	2
Substrate:	Boulders interspersed w/ gravel	Bedrock and boulders with gravel patches, *Alaria* bed			Silty gravel	Boulder slope & bedrock	Boulder slope & bedrock	Sand w/ sparse boulders	Silty sand	Sandy silt

[a] S = Scarce [b] P = Present [c] Guarding egg clutch [d] C = Common [e] Fish/hectare = fish/m^2 x 10^4

4.2.2 Semi-Protected Rock Habitat - Knoll Head Lagoon

The Knoll Head Lagoon area is somewhat protected from wave exposure and tidal currents by an offshore reef. The rock slopes gently, and surface relief is somewhat less than at White Gull Island and Black Reef. As a consequence, attempts to obtain estimates of fish densities were relatively successful. Nevertheless, only four species of fish were encountered (Table 7). Whitespotted greenling was most common, followed by masked greenling. Overall density in August was 643 fish/ hectare.

4.2.3 Soft Substrates

Silty sand habitats with scattered boulders were examined on the west side of White Gull Island and south of Scott Island. Only four species of fish were encountered in this habitat; as above, the most common fish were whitespotted greenling (Table 7). Masked greenling were observed around a boulder supporting *Laminaria*. Fish density was quite low.

An exposed sand bottom was examined in Oil Bay. The dominant large infaunal species was the razor clam (*Siliqua patula*). Most important of the four fish species encountered were juvenile flatfish and snake pricklebacks (Table 7). Adults of two species of flatfish were observed, and density was quite low.

A protected sandy silt substrate was examined in Cottonwood Bay. The dominant large infaunal species were the basket cockle (*Clinocardium nuttallii*) and the eastern soft shell clam (*Mya arenaria*). Only three species of fish were observed, but density was quite low (Table 7); probably flatfish were most common.

4.3 Seasonal Patterns

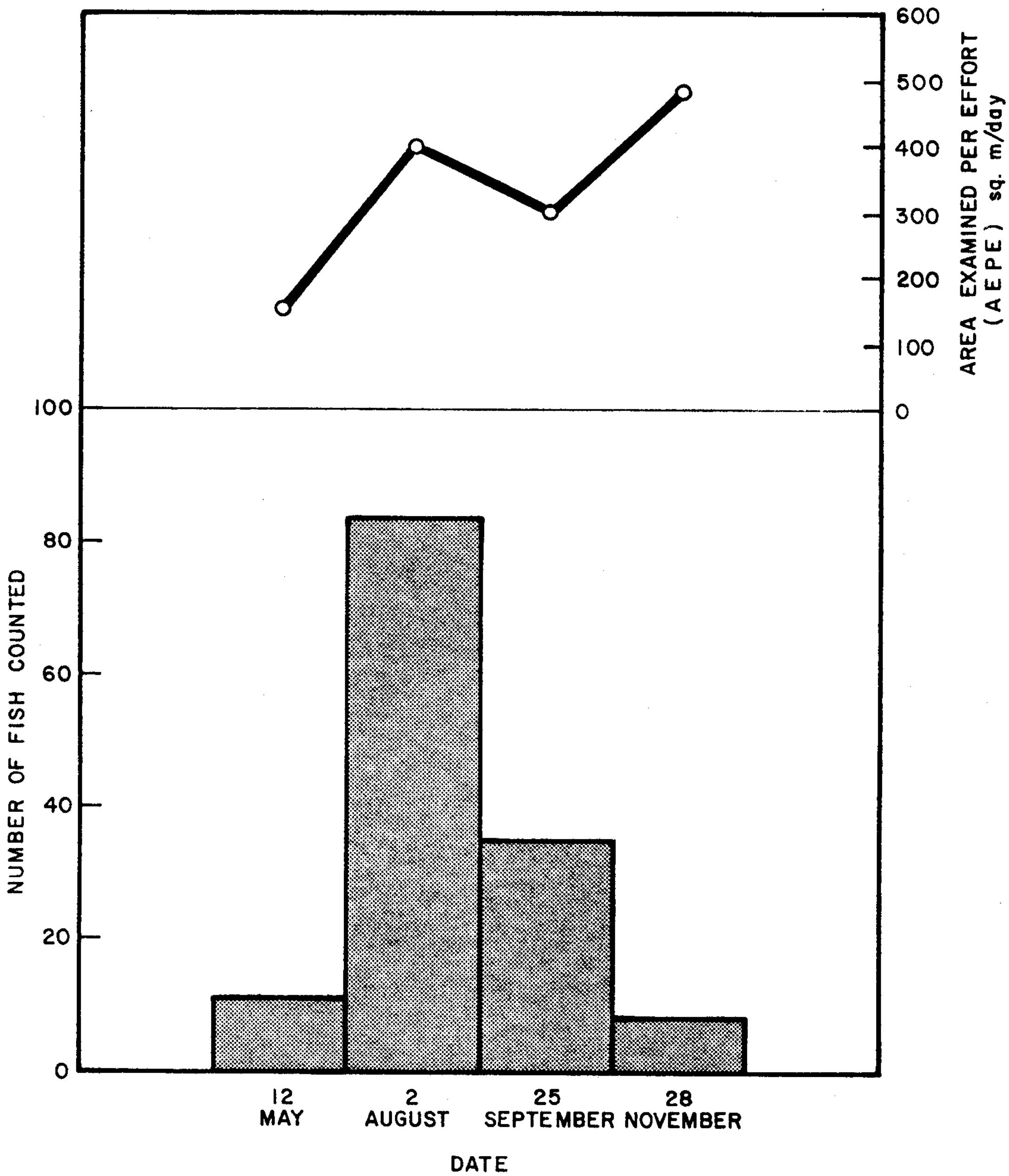
Density and composition of the fish populations in Kachemak Bay exhibited marked seasonal flucuations. Maximum densities were recorded during summer and early fall in the three detailed study areas.

During summer months, these areas were dominated by non-schooling species, as well as more pelagic fish such as salmon, herring and sand lance. However by late fall most of these same species had either disappeared from the nearshore, or become more secretive in behavior. For example, on May 12, 1978 fish density was 710 fish/hectare in the transect bands at Jakolof Bay (Table 4). With the progression of summer the density of fish increased dramatically. In the August survey, fish density was 2100 fish/hectare; approximately half of these were nest-guarding male greenlings. Densities slowly declined during fall, and by November 28, 1978 the overall density was 167 fish/hectare. These low numbers cannot be attributed to seaweed canopies concealing the fish from view because, at this time of year, vegetative cover is generally light. In addition, the area examined per effort (AEPE) was even greater than in previous surveys, yet still the counts remained low (Figure 5).

4.4 Food Habits and Dietary Trends

Samples from the shallow water fish populations in Lower Cook Inlet have been taken for the purpose of describing their food habits, thus leading to a better understanding of trophic interaction in the nearshore zone. The stomach contents of 258 specimens, comprised of 31 species have been examined for food items. Usually only adult fish were examined, as juvenile stages of fish are sometimes known to exploit different resources than the adult members of the same species. Feeding has also been shown to be related to predator body size, and any dietary trends established from this survey are mostly directed towards the adult fish.

Most of the solitary bottom dwelling fish in the shallow water zone are generalists or opportunistic predators. Some appear to scrutinize the sea floor prior to feeding, while others were observed to bite indiscriminately at the substrate, rejecting or filtering out the undesirable material during the feeding process. However, a few of the fish were specialists, and as such restricted their mode of feeding to specific types of prey.



COUNTS AND AEPE DATA FOR FISHES ALONG RANDOMLY PLACED TRANSECT LINES IN JAKOLOF BAY, 1978

FIGURE 5

The data presented herein should not be construed as a definitive study on fish food habits, it is however a start on understanding trophic relationships, and establishing dietary trends for some of the common species in the shallow waters of Cook Inlet and Kachemak Bay.

4.4.1 Bathymaster caeruleofasciatus (Gilbert & Burke) - Alaskan ronquil

The Alaskan ronquil, which can attain a standard length of 268 mm, is probably one of the more common fish in the rocky sublittoral zone. During daylight hours it was usually sheltered among the rocks, particularly along the more exposed or seaward edge of a kelp forest. It has been observed to pluck or give chase to food items a few meters off the bottom, but most of the feeding was directed at the benthos. Its diet was highly variable; twenty-five different categories or taxa of prey are listed in Table 8. Based on our observations, Alaskan ronquils are generalists, but since very little detritus or undigestible fragments were contained in the stomachs of 23 specimens, the fish must scrutinize the substrate before feeding. Gammaridean amphipods were the most important prey, followed by caridean shrimp and a brittle star (Ophiopholis aculeata). Other important prey were crabs, small fish and gastropod snails.

4.4.2 Lepidopsetta bilineata (Ayres) - rock sole

One of the most conspicuous flounders in the nearshore zone is the rock sole. Nine specimens ranging in size from 270-338 mm SL, were collected in Kachemak Bay. The food items obtained were principally epifaunal. For example, limpets (Notoacmaea spp.) comprised 58.7 percent (N=115) of the total prey (Table 9). Although the small isopod Gnorimosphaeroma oregonensis was found in only one stomach, this one specimen had ingested 38 isopods. Other important food included brittle stars, polychaete worms, clam siphons and chitons (Table 9). The rock sole is a versatile predator that dines on a variety of prey. Most of the feeding observed over the past few years has occurred in shallow water, and the target species and feeding zone are associated with the benthos.

TABLE 8

FOOD OF ALASKAN RONQUIL (*Bathymaster caeruleofasciatus*)
FROM KACHEMAK BAY (N=23)

Food Items	Frequency of Occurrence	Number	Percentage of Total
gammaridean amphipods	11/23	76	41.7
caprellid amphipods	1/23	3	1.6
caridean shrimps	14/23	22	12.1
brachyuran juveniles	2/23	4	2.2
Ophiopholis aculeata (brittle star)	7/23	11	6.0
Paralithodes kamtschatica (juvenile king crab)	3/23	3	1.6
Oregonia gracilis (decorator crab)	2/23	2	1.1
Musculus vernicosus (mussel)	4/23	5	2.7
Lacuna variegata (snail)	2/23	4	2.2
Pagurus spp. (hermit crab)	4/23	4	2.2
fish larvae	1/23	2	1.1
megalops crab larvae	1/23	10	5.5
mysids	2/23	5	2.7
fishes	6/23	6	3.3
Cancer oregonensis (crab)	2/23	3	1.6
Cucumaria sp. (sea cucumber)	1/23	1	0.5
Mitrella sp. (snail)	1/23	1	0.5
Fusitriton oregonesis (oregon triton)	1/23	1	0.5
aeolid nudibranch	1/23	1	0.5
chiton	2/23	2	1.1
Rhodophyta (red algae)	8/23	8	4.4
gastropod operculum	3/23	3	1.6
serpulid operculum	1/23	1	0.5
shell fragments	1/23	2	1.1
tanaid	2/23	2	1.1

TABLE 9

FOOD OF THE ROCK SOLE (*Lepidopsetta bilineata*)
FROM KACHEMAK BAY (N=9)

Food Items	Frequency of Occurrence	Number	Percentage of Total
Notoacmaea spp. (limpet)	4/9	115	58.7
polychaetes	5/9	7	3.6
chitons	1/9	4	2.0
clam siphons	2/9	4	2.0
Ophiopholis aculeata (brittle star)	1/9	22	11.2
gammaridean amphipods	1/9	2	1.0
Eubonellia vallidus (echiuroid worm)	1/9	1	0.5
Gnorimosphaeroma oregonensis (isopod)	1/9	38	19.4
Monostroma sp. (green algae)	2/9	2	1.0
Rhodophyta (red algae)	1/9	1	0.5

4.4.3 Myoxocephalus spp. - great sculpin

The taxonomy of the genus Myoxocephalus is apparently in need of revision. There are reports of a least 2 species: M. polyacanthocephalus and M. scorpius from the northern Gulf of Alaska (Quast and Hall, 1972). Because of these taxonomic problems our observations on food habits are directed at the genus Myoxocephalus.

Myoxocephalus is more of a specialist than some of the other predatory bottom fish in this area. Seventeen specimens ranging from 270-571 mm SL were captured in the Bay. Of these, 14 contained food items; stomach fullness ranged from 0-90 percent. Crustaceans, particularly brachyuran crabs, caridean shrimps and hermit crabs, made up over 85 percent of the total prey (Table 10). A small rock crab, Cancer oregonensis, two decorator crabs, and the helmet crab were common food items. In addition, hermit crabs occurred in 4/14 captured great sculpin. Fish were also contained in the diet. One great sculpin had a 371 mm M. polyacanthocephalus in it's stomach. Along with the fish the sculpin had also eaten a large helmet crab.

Most of the food material was swallowed whole. Great sculpin seem to be an ambush predator that lies in wait for its prey. The somewhat lethargic behavior and cryptic coloration makes it ideal for this kind of predation.

4.4.4 Enophrys diceraus (Pallas) - antlered sculpin

Antlered sculpin were common around the kelp forests at Seldovia Point and Jakolof Bay. These fish ranged in length from 50-270 mm. Nine specimens were collected for food habits information; of the eight with food material in stomachs, fullness ranged from 40-90 percent. This is another relatively sluggish cottid; a good indication of its sedentary behavior is the fact that most antlered sculpin examined had marine leeches and parasitic copepods attached to their bodies. All identifiable food material contained in the stomachs of these sculpins was of benthic origin. The major prey item was the green sea urchin Strongylocentrotus droebachiensis ranging in size (test diameter) from

TABLE 10

FOOD OF GREAT SCULPIN (*Myoxocephalus* spp.)
FROM KACHEMAK BAY (N=14)

Food Items	Frequency of Occurrence	Number	Percentage of Total
Oregonia gracilis (decorator crab)	3/14	4	11.8
Telmessus cheiragonus (helmet crab)	2/14	2	5.9
Pugettia gracilis (spider crab)	3/14	4	11.8
Cancer oregonensis (crab)	5/14	8	23.5
caridean shrimps	5/14	5	14.7
Pagurus ochotensis (hermit crab)	3/14	3	8.8
Myoxocephalus polyacanthocephalus (great sculpin)	1/14	1	2.9
gammaridean amphipods	1/14	2	5.9
Elassochirus gilli (hermit crab)	1/14	1	2.9
Rhodophyta (red algae)	2/14	2	5.9

14-22 mm (Table 11). Typically, E. diceraus swallows its prey whole. One antlered sculpin (270 mm) taken from Jakolof Bay had eaten 14 S. droebachiensis ranging from fresh ones lodged in the mouth and esophagus to well digested ones in the intestinal tract. The dissected sculpin resembled an assembly line processing sea urchins from the mouth to the lower end of the alimentary canal. Other food items were limpets, brittle stars, snails, crabs and gammarid amphipods.

4.4.5 Hemilepidotus hemilepidotus (Tilesius) red Irish lord

Red Irish lord also dines on benthic macroinvertebrates. Five of the eight specimens collected during summer 1978 contained identifiable food items. The fish ranged in size from 195 to 362 mm. Brittle stars (Ophiopholis aculeata) were found in 40% of the stomachs and accounted for 44.8 percent of the total number of food organisms (Table 12). A small cancroid crab was found in 60% and comprised around 15.9 percent of the total prey. Other prevalent food items were a decorator crab, caridean shrimps, hermit crabs and red algae.

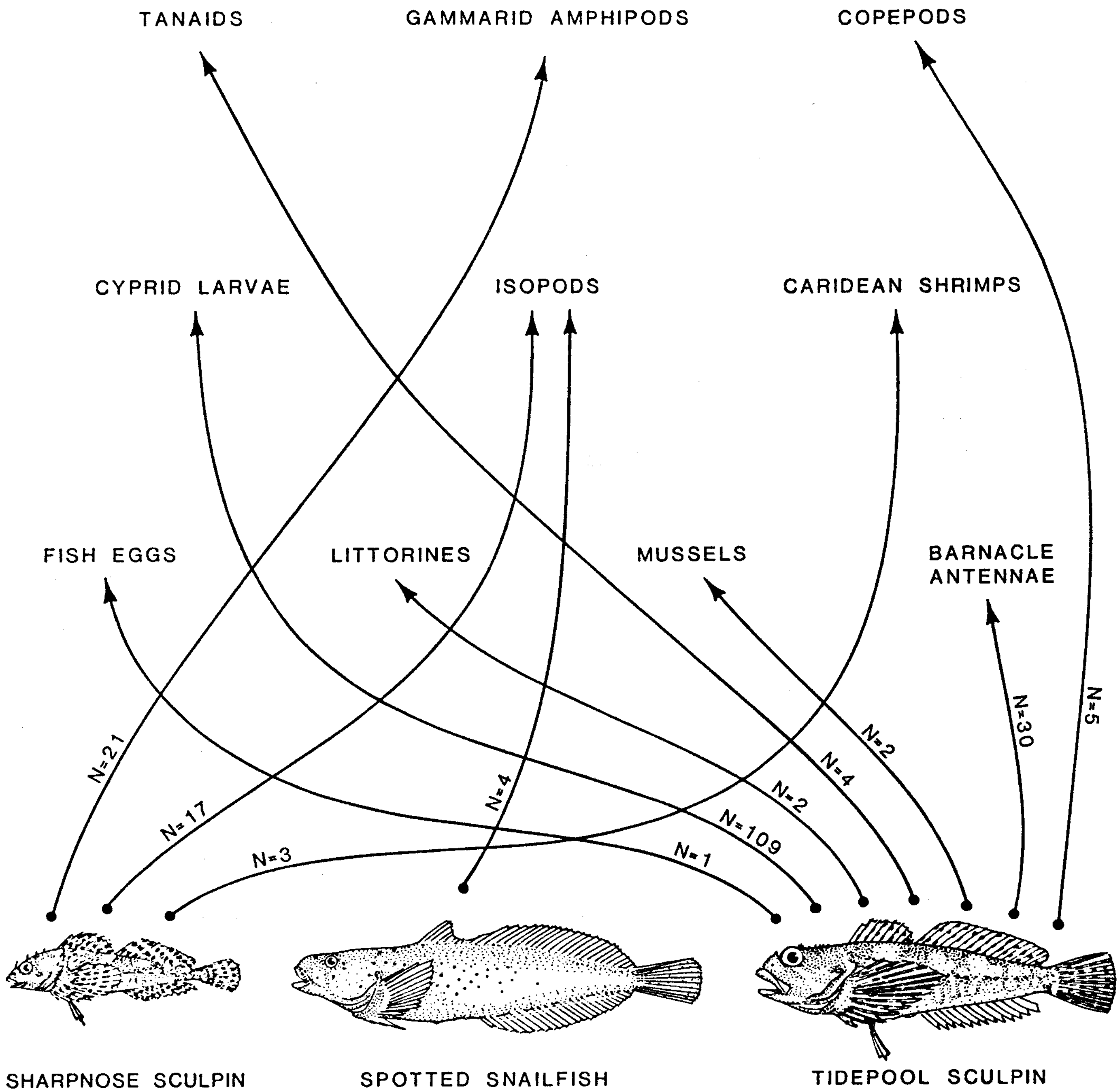
4.4.6 Tidepool Species

Sufficient evidence of trophic interaction between tidepool fishes was collected to permit constructing a qualitative food web (Figure 6). Three of the more common species from the intertidal zone are tidepool sculpin (Oligocottus maculosus), sharpnose sculpin (Clinocottus acuticeps), and spotted snailfish (Liparis callyodon). These specimens were collected in Kachemak Bay during 1977-78, and most were taken in the proximity of the shallow subtidal stations.

4.4.7 Hexagrammos decagrammus (Pallas) - kelp greenling

Kelp greenling were one of the most widely distributed bottom-dwelling fish in Kachemak Bay. In the daytime, it was frequently seen resting on the seafloor or swimming slowly through kelp forests. Rarely was it more than a few meters above the bottom.

Diet was quite varied in the 13 specimens that contained food



TROPHIC INTERACTION BETWEEN TIDEPOOL FISHES IN KACHEMAK BAY

FIGURE 6

TABLE 11

FOOD OF ANTLERED SCULPIN (Enophrys diceraus)
FROM KACHEMAK BAY (N=8)

Food Items	Frequency of Occurrence	Number	Percentage of Total
Strongylocentrotus droebachiensis (sea urchin)	7/8	27	79.4
Collisella = (Acmaea) pelta (limpet)	1/8	1	2.9
Ophiopholis aculeata (brittle star)	1/8	1	2.9
Acmaea mitra (limpet)	1/8	1	2.9
Cancer sp. (crab)	1/8	1	2.9
Calliostoma ligatum (top-shell)	1/8	1	2.9
gammaridean amphipods	1/8	1	2.9
Volutharpa ampullacea (snail)	1/8	1	2.9

TABLE 12

FOOD OF THE RED IRISH LORD (Hemilepidotus hemilepidotus) FROM KACHEMAK BAY (N=5)

Food Items	Frequency of Occurrence	Number	Percentage of Total
caridean shrimps	2/5	2	5.3
Ophiopholis aculeata (brittle star)	2/5	17	44.8
Pugettia gracilis (crab)	2/5	2	5.3
Cancer oregonensis (crab)	3/5	6	15.9
chitons	1/5	1	2.6
Elassochirus gilli (hermit crab)	1/5	1	2.6
Fusitriton oregonensis (snail)	1/5	1	2.6
polychaetes	1/5	1	2.6
Sertularella sp. (hydroid)	1/5	1	2.6
Cryptochiton stelleri (chiton)	1/5	1	2.6
sea star arm	1/5	1	2.6
Phaeophyta (brown algae)	1/5	1	2.6
Rhodophyta (red algae)	3/5	3	7.9

items (Table 13). At times, feeding must be indiscriminate, based on the amount of detritus, gravel and undigestable material found in the gut. However, on other occasions, foraging is probably more specific. Principle foods were gammaridean amphipods, caridean shrimps, snails of the genus Lacuna, and a small cancroid crab. Usually the prey were associated with the attached vegetation. One female (429 mm) was found to have eaten the operculum and foot of eight Oregon tritons. Another highly specific food item was the operculum and stalk of the serpulid worm Crucigera zygophora.

4.4.8 Hexagrammos lagocephalus (Pallas) - rock greenling

One of the most exquisitely colored fish in the inshore zone is the male rock greenling. During summer, mature males range from reddish-brown to blood-red in body coloration, mottled with green and turquoise blue. Rock greenling, which can exceed a total length of 400 mm, were quite numerous in the shallow portions of the subtidal zone.

All eight rock greenling collected in Kachemak Bay, ranging in size from 90-438 mm SL had food material in their stomachs. Stomach fullness averaged 74 percent. Degree of stomach fullness, condition of the prey and our in situ observations suggest that most feeding takes place during daylight hours. Sixteen different categories of food material were consumed by these fish (Table 14). Gammaridean amphipods accounted for 47.4 percent of the total. Crustaceans, gastropod snails and fish eggs were important constituents of the diet during summer. Siphons of the butter clam, were found in 25% of the stomachs, and comprised 11.4 percent of the food items. Lacuna, a small snail typically associated with benthic vegetation, made up another 12.4 percent. Both juveniles and adult stages of brachyuran crabs accounted for another 7.0 percent. Fish eggs, particularly those of other hexagrammids, were common in the stomachs of the captured specimens. Eggs were present in 5 of 8 fish, and in some of the H. lagocephalus, eggs made up 70 percent of the ingested biomass. Rock greenling are omnivorous carnivores that ingest macroalgae incidental to the uptake of

TABLE 13

FOOD OF KELP GREENLING (*Hexagrammos decagrammus*)
FROM KACHEMAK BAY (N=13)

Food Items	Frequency of Occurrence	Number	Percentage of Total
gammaridean amphipods	3/13	73	42.2
caridean shrimps	7/13	14	8.1
brachyuran juveniles	1/13	2	1.2
tanaids	1/13	1	0.6
Pugettia gracilis (crab)	1/13	2	1.2
Cancer oregonensis (crab)	7/13	10	5.8
Lacuna spp. (snail)	4/13	22	12.7
Velutina sp. (snail)	1/13	1	0.6
clam siphons	2/13	3	1.7
polychaetes	1/13	1	0.6
fishes	3/13	3	1.7
fish eggs	1/13	1	0.6
serpulid operculum	2/13	14	8.1
Elassochirus gilli (hermit crab)	2/13	3	1.7
chitons	2/13	2	1.2
Pagurus spp. (hermit crab)	2/13	2	1.2
Notoacmaea sp. (limpet)	1/13	1	0.6
Fusitriton oregonensis (snail)	1/13	8	4.6
sipunculid worm	2/13	2	1.2
Sertularella spp. (hydroid)	1/13	1	0.6
Balanus sp. (barnacle)	1/13	1	0.6
Rhodophyta (red algae)	5/13	5	2.9
Phaeophyta (brown algae)	1/13	1	0.6

TABLE 14

FOOD OF ROCK GREENLING (*Hexagrammos lagocephalus*)
FROM KACHEMAK BAY (N=8)

Food Items	Frequency of Occurrence	Number	Percentage of Total
gammaridean amphipods	3/8	54	47.4
caprellid amphipods	1/8	2	1.7
brachyuran juveniles	1/8	1	1.0
caridean shrimps	1/8	1	1.0
clam siphons	2/8	13	11.4
fishes	1/8	1	1.0
fish eggs	5/8	5	4.4
Oregonia gracilis (decorator crab)	1/8	1	1.0
Lacuna spp. (snail)	1/8	14	12.3
Cancer oregonensis (crab)	4/8	7	6.1
Elassochirus gilli (hermit crab)	1/8	1	1.0
Fusitriton oregonenis (snail-operculum & foot)	2/8	4	3.5
Abietinaria sp. (hydroid)	2/8	2	1.7
Rhodophyta (red algae)	4/8	4	3.5
Phaeophyta (brown algae)	2/8	2	1.7
detritus	2/8	2	1.7

animal material.

4.4.9 Hexagrammos stelleri (Tilesius) - whitespotted greenling

Whitespotted greenling are characteristically found in more protected habitats of Kachemak Bay and Lower Cook Inlet, but individuals are also observed in more exposed areas. The foraging behavior and activity pattern of this fish seems to be similar to H. decagrammus, with active feeding on the bottom during the day. Nine of eleven specimens taken for food habits information in Kachemak Bay had identifiable material in their stomachs (Table 15). Another sixteen H. stelleri were collected at White Gull Island and Knoll Head Lagoon, Kamishak Bay, to compare diets between seemingly different habitats (Table 16). The data suggest that H. stelleri feeds heavily on crustaceans, gastropods and small fish. Gammaridean amphipods comprised 24.4 percent of the total from Kamishak Bay. Caridean shrimps were found in 7/9 specimens from Kachemak Bay and 7/16 of those taken in Kamishak Bay; the percentage of the total was 15.1 and 11.4 percent, respectively. Some differences in diet were noted. For example, Cancer oregonensis comprised 25.6 percent of the total food items in Kachemak Bay but were insignificant in Kamishak Bay.

Other important food items were hermit crabs, decorator crabs, the operculum and foot area from gastropod snails, and demersal fish eggs. The fish eggs were from other greenlings, and this pilfering of eggs from the nests of both conspecifics and congeners is apparently a common practice with the hexagrammids.

4.4.10 Hexagrammos octogrammus (Pallas) - masked greenling

Masked greenling ranging from 154 and 243 mm SL were collected in Kachemak Bay, and from Knoll Head Lagoon in Kamishak Bay, during summer 1978. Most were nest guarding males. From the specimens obtained at Jakolof Bay, fish eggs were a dominant food item in terms of frequency of occurrence and biomass (Table 17). The size and appearance of the eggs suggests that they were obtained from the nests of other greenlings. Brittle star arms occurred in 33% and accounted for 17.4 percent of the

TABLE 15

FOOD OF WHITESPOTTED GREENLING (*Hexagrammos* *stelleri*)
FROM KACHEMAK BAY (N=9)

Food Items	Frequency of Occurrence	Number	Percentage of Total
gammaridean amphipods	5/9	21	24.4
caridean shrimps	7/9	13	15.1
Pugettia *gracilis* (crab)	1/9	1	1.2
Sebastes sp. (rockfish)	2/9	2	2.3
Cancer *oregonensis* (crab)	5/9	22	25.6
Pagurus sp. (hermit crab)	2/9	2	2.3
Paralithodes *kamtschatica* (juvenile king crab)	1/9	1	1.2
Fusitriton *oregonensis* (snail)	2/9	2	2.3
Pagurus *ochotensis* (hermit crab)	1/9	1	1.2
Cancer sp. (crab)	2/9	4	4.7
Oregonia *gracilis* (decorator crab)	3/9	5	5.8
fish eggs	2/9	2	2.3
nemertean	1/9	1	1.2
Abietinaria sp. (hydroid)	2/9	2	2.3
Elassochirus *gilli* (hermit crab)	1/9	1	1.2
polychaetes	1/9	2	2.3
detritus	2/9	2	2.3
Rhodophyta (red algae)	2/9	2	2.3

TABLE 16

FOOD OF WHITE SPOTTED GREENLING (Hexagrammos stelleri)
FROM THE WEST SIDE OF COOK INLET (N=16)

Food Items	Frequency of Occurrence	Number	Percentage of Total
gammaridean amphipods	6/16	17	16.2
caridean shrimps	7/16	12	11.4
Pugettia gracilis (crab)	2/16	5	4.8
megalops crab larvae	3/16	16	15.2
Musculus sp. (mussel)	2/16	2	1.9
Pagurus spp. (hermit crab)	8/16	12	11.4
Fusitriton oregonensis (snail)	4/16	7	6.7
Pagurus beringanus (hermit crab)	1/16	4	3.8
Elassochirus gilli (hermit crab)	2/16	2	1.9
Telmessus cheiragonus (helmit crab)	1/16	1	0.9
Oregonia gracilis (decorator crab)	1/16	1	0.9
fish eggs	3/16	3	2.9
Cancer oregonensis (crab)	1/16	1	0.9
gastropod operculum	3/16	6	5.7
Corella sp. (ascidian)	1/16	1	0.9
sabellid tubes	1/16	2	1.9
polychaetes	1/16	1	0.9
Sertularella	2/16	2	1.9
barnacle cirri	1/16	1	0.9
fishes, unid.	1/16	1	0.9
Sertularia sp.	2/16	2	1.9
eelgrass	1/16	1	0.9
Rhodophyta (red algae)	5/16	5	4.8

TABLE 17

FOOD OF MASKED GREENLING (*Hexagrammos octogrammus*)
FROM KACHEMAK BAY (N=6)

Food Items	Frequency of Occurrence	Number	Percentage of Total
caridean shrimps	1/6	1	4.4
caprellid amphipods	1/6	1	4.4
Cancer sp. (crab)	1/6	1	4.4
Ophiopholis aculeata (brittle star)	2/6	4	17.4
fish eggs (greenling)	5/6	5	21.7
Oregonia gracilis (decorator crab)	1/6	1	4.4
Abietinaria sp. (hydroid)	2/6	2	8.7
polychaetes	1/6	3	13.0
Elassochirus gilli (hermit crab)	1/6	1	4.4
Phaeophyta (brown algae)	2/6	2	8.7
Rhodophyta (red algae)	2/6	2	8.7

total number of identifiable food material. Polychaete worms were also prominent in the diets of the Jakolof Bay population. Mollusks were common in the stomachs of masked greenling from Knoll Head Lagoon (Table 18). For example, one fish (136 mm) had eaten 62 *Margarites helicinus* prior to capture. A chiton (*Tonicella*) and a snail (*Lacuna*) accounted for 17.4 percent and 5.7 percent of the total, respectively. Polychaetes and gammarid amphipods were also common. Based on these limited numbers, it appears that masked greenling are opportunistic predators that feed on a variety of epibenthic organisms.

4.4.11 *Sebastes melanops* (Girard) - black rockfish & *Sebastes ciliatus* (Tilesius) - dusky rockfish

Black rockfish and dusky rockfish were initially recorded as only one species - *Sebastes melanops*. This was due to our inability at first to recognize the two as distinct fish. However, after more intense study the two species were distinquished. Both aggregate in small to moderate size schools along the edges of the kelp forest at Seldovia Point. At times the schools were mixed. Both species have been observed to feed during the day, but the condition of some of the food material suggests that it was obtained during nocturnal hours.

Plankton is the most important component in the diet of the dusky rockfish. Calanoid copepods, ctenophores, megalops crab larvae, chaetognaths and tomopterid polychaetes were repeat food items. These same plankters were also found in the stomachs of black rockfish, however small fishes seem to play a key role in the diets of larger individuals. For example, one *S. melanops* had two righteye flounder in its stomach. In addition, juvenile rockfish and sandlance were consumed by black rockfish living off Seldovia Point.

4.4.12 Feeding Patterns in Fishes from Rocky Subtidal Habitats

The three main types of data collected regarding feeding by each predator species are 1) prey taxa consumed, 2) number of each prey item and 3) number of predators consuming each prey item. A comparison of the relative contribution to the total diet of each predator, in

TABLE 18

FOOD OF MASKED GREENLING (*Hexagrammos octogrammus*)
FROM THE WEST SIDE OF COOK INLET (N=4)

Food Items	Frequency of Occurrence	Number	Percentage of Total
gammaridean amphipods	2/4	10	8.7
caridean shrimps	2/4	4	3.5
Margarites helicinus (snail)	1/4	62	53.9
Lacuna sp (snail)	1/4	6	5.7
Tonicella spp. (chiton)	2/4	20	17.4
fish eggs (greenling)	1/4	1	0.8
Pagurus beringanus (hermit crab)	1/4	1	0.8
polychaetes	3/4	4	3.5
polychaete jaws	1/4	4	3.5
Rhodophyta (red algae)	2/4	2	1.7
gravel	1/4	1	0.8

terms of numbers, by each prey category is presented in Appendix I. However, because of the potential bias by a single anomalous feeding, especially with a small sample size, this comparison has limited value, A comparison of the relative proportions of each predator population consuming major prey items may provide a better indication of prey resource utilization and competitive interactions (Table 19). Major prey taxa are defined as those upon which over 20 percent of the sample population of at least one predator were observed to feed.

Nineteen prey items qualified as major foods. Only four of these were planktonic, and only dusky rockfish commonly consumed them. Among the remaining benthic prey, crustaceans dominated and epifaunal organisms were more important than infaunal. Eight (53%) of the benthic items were taken as prey by at least half of the predator species suggesting potentially strong competitive interactions. This pattern was particularly strong in crustaceans (e.g., Cancer oregonensis, caridean shrimp, gammarid amphipods and hermit crabs) among Alaskan ronquil, great sculpin, red Irish lord, and kelp, rock, whitespotted and masked greenling.

Probably the most intense competition occurs between the four greenling species. This is apparently not only for food but also for nest sites. Nest guarding behavior is necessarily quite aggressive as indicated by the high incidence of greenling eggs in the stomach contents of those species. Both inter- and intraspecific nest robbing occur seasonally.

Dusky rockfish and antlered sculpin had the most restricted diets. The diets of these species and rock sole differed most distinctly from the above mentioned group and from each other, with dusky rockfish specializing in planktonic forms, antlered sculpin in sea urchins and rock sole in worms, limpets and possibly isopods.

Snails were somewhat more important than indicated by Table 19, but the issue is partially hidden by the fact that eleven snail species

TABLE 19

PERCENTAGES OF FISHES FROM ROCKY HABITAT
FEEDING ON MAJOR PREY TAXA

Major Prey Taxa	Predator: Alaskan ronquil	Rock sole	Great sculpin	Antlered sculpin	Red Irish lord	Kelp greenling	Rock greenling	Whitespotted greenling	Masked greenling	Black rockfish	Dusky rockfish
PLANKTON											
Tomopterid polychaetes											40
Chaetognaths											40
Crab megalops								12			40
Calanoid copepods											20
BENTHIC INFAUNA											
Polychaetes		56*			20	8		8	40		
Clam siphons		22				15	25				
BENTHIC EPIFAUNA											
Lacuna sp	9					31	13		10		
Limpets		44		25		8					
Chitons	9	11			40	15			20		
Cancer oregonensis	9		36	13	60	54	50	32	10		
Caridean shrimp	61		36		40	54	13	56	30	25	
Gammaridea	48	11	7	13		23	38	47	20		
Hermit crabs	17		21		20	15	13	50	20		
Oregonia gracilis	9		21				13	16	10		
Pugettia gracilis			21		40	8		12			
Ophiopholis aculeata	30	11			40				20		
Strongylocentrotus droebachiensis				88							
Greenling eggs						8	63	20	60		
Fishes	26		7			23	13	12		75	
No. of Specimens Examined:	23	9	14	8	5	13	8	25	10	4	5

* The two most preferred prey species of each fish are underlined

were identified as fish food. Although apparently preferred by a large number of individual fish, frequently the number or biomass of snails consumed was high. Snails comprised 48.9, 18.5, 15.8 14.7 and 11.6% of the diets, respectively for masked, kelp, rock and whitespotted greenling and antlered sculpin. The large species *Fusitriton oregonensis* was taken by the most species (five predators), followed by *Lacuna* spp. (four predators).

4.4.13 Feeding Patterns in Fishes from Sand Beach

Stomach contents of 83 specimens from 15 species collected in beach seine hauls at Homer Spit were examined to assess feeding patterns. The raw data are presented in Appendix II. Forty-one food items were identified, comprising mainly worms, crustaceans, clams and fish. Forage species (sand lance, surf smelt, and capelin), salmon fry and sticklebacks concentrated on planktonic food items(Table 20). Most other species concentrated on benthic prey, especially gammarids and other crustaceans. Pacific staghorn sculpin and several species of flatfish also preyed on the major forage fish (sand lance and surf smelt). Rather surprisingly although eleven polychaete taxa were identified as food items, worms were not a major food item for any fish species. Prey items utilized by the largest number of species were gammarid amphipods, cumaceans, harpacticoid copepods, eggs, calanoid copepods and polychaetes (Appendix II).

TABLE 20

PERCENTAGE OF FISH FROM SAND BEACH IN WHICH PREY SPECIES WAS THE DOMINANT FOOD ITEM

		Dominant Prey Species									
Predator	(N)	Eggs	Calanoid copepods	*Lamprops* and other cumaceans	*Anisogammarus* and gammarids	Harpacticoid copepods	Shrimp, mysids and euphausiids	*Ammodytes hexapterus*	*Hypomesus pretiosus*	Unidentified fish	Number of prey species
Pacific sand lance	(19)		84								5
Surf smelt	(9)	78									3
Capelin	(2)	50	50								3
Dolly Varden	(9)			38	50						9
Pink salmon juv.	(6)	67									9
Threespine stickleback	(5)				80						7
Sturgeon poacher	(6)			60		40					4
Tubenose poacher	(3)						100				3
Greenling juv.	(1)				100						3
Snake prickleback	(1)					100					4
Pacific staghorn sculpin	(8)							25	37		6
Rock sole	(6)							67			21
English sole	(5)				80						9
Starry flounder	(1)				100						3
Sand sole	(1)									100	3
No. of Species Preferring:		3	2	2	5	2	1	2	1	1	

5.0 SUMMARY

1. The shallow water fish assemblages of Lower Cook Inlet include at least 56 species which are typically found in the nearshore zone. Fourteen percent of the fish were previously unreported in these waters. These are: tube-snout, copper rockfish, brown Irish lord, scalyhead sculpin, arctic shanny, smoothhead sculpin and bonyhead sculpin.

2. Surveys were conducted during 1978 at several general areas on the east side of Cook Inlet (especially Jakolof Bay, Seldovia Point and the northern shelf). Field work was also carried out on the west side of the Inlet around White Gull Island and in the vicinity of Knoll Head Lagoon. Direct observations and quantitative sampling was done while SCUBA diving from 3-23 m below MLLW.

3. The composition of the ichthyofauna was different at each location. Jakolof Bay and Seldovia Point were most similar in terms of species composition, while Jakolof Bay and the Northern Shelf were least similar. Non-schooling species dominated the nearshore fish fauna in all rocky locations. Sculpins (Cottidae), greenlings (Hexagrammidae), ronquils (Bathymasteridae), and rockfishes (Scorpaenidae) were the major families in the rocky subtidal zone. However, only greenling were common on rock habitats in Kamishak Bay.

4. Replicate samples indicated that fish populations varied substantially in space and time on both rock and sand substrates. Seldovia Point had the highest numerical density, followed by Jakolof Bay and the northern shelf. Overall mean density estimates ranged from 585 fish/hectare along the shelf to 1539 fish/hectare at Seldovia Point. Densities of demersal fish in inshore waters are highest in summer and lowest in winter.

5. Black rockfish and dusky rockfish were the most abundant schooling

fish in the rocky subtidal zone in Kachemak Bay, while Alaskan ronquil and kelp greenling were the dominant demersal species. Other common species in terms of frequency of occurrence were whitespotted greenling, rock greenling and northern ronquil.

6. In Kachemak Bay, the subtidal rocky reefs and outcroppings that occur along outside edge of the kelp forests usually supported the highest density of fish. Shallow areas with abundant vegetative cover were typically high in species richness, especially during summer months when there was an influx of fish into these habitats.

7. Whitespotted and masked greenling were the dominant demersal fishes on rock habitat in Kamishak Bay.

8. Demersal fish assemblages on subtidal soft substrates were generally characterized by flatfish in both Kachemak and Kamishak Bays.

9. Important species in the fish assemblage on a sand beach in summer included Pacific sand lance, Pacific staghorn sculpin, English sole, rock sole, sturgeon poacher and Dolly Varden. The catches were dominated by juveniles. Several forage species were common.

10. The only species observed on sand in winter were Pacific sand lance, Pacific staghorn sculpin and surf smelt. Densities were extremely low.

11. Beach seine catches varied significantly between high and low tide in the summer at Homer Spit.

12. The stomach contents of 258 specimens, comprised of 31 species, were examined for food material. Most of the non-schooling species encountered in shallow water were generalists or opportunistic predators. The most commonly consumed prey were gammaridean amphipods, brachyuran crabs, caridean shrimps, brittle stars, gastropods and hermit crabs.

13. The prey groups most frequently ingested by the fish populations from rocky habitats in lower Cook Inlet are epifaunal and strongly associated with the macrophyte (seaweed and seagrass) resource.

14. Both planktonic and benthic prey groups are utilized by fish assemblages on soft substrates. Generally, schooling species fed on planktonic items whereas non-schooling species fed on benthic items or fish.

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APPENDIX 1

PERCENTAGE (%) OF TOTAL NUMBER OF FOOD ITEMS CONSUMED BY CONSPICUOUS PREDATOR SPECIES FROM THE SHALLOW SUBTIDAL ZONE, KACHEMAK BAY

Food Items	Alaskan ronquil (121-268mm)	Rock sole (270-338mm)	Great sculpin (270-571mm)	Antlered sculpin (50-270mm)	Red Irish lord (195-362mm)	Rock greenling (90-438mm)	Kelp greenling (99-429mm)	Whitespotted greenling (222-322mm)	Masked greenling (154-237mm)	Black rockfish (158-460mm)
Mysids	3									
Gammarids	42	1		3		47	42	24		
Tanaids	1						1			
Isopods		19								
Caprellids	2								4	
Fishes	3		3			1	2	2		7
Fish larvae	1									
Calanoid copepods										29
Caridean shrimps	12		15		5	1	8	15	4	6
Brittle stars	6	11		3	45				17	
Hermit crabs	2		12		3	1	3	5	4	
Chitons	1	2			3		1			
Brachyuran megalops	6									16
Brachyuran crabs	4		59	3	21	8	8	37	9	
Polychaetes	1	4			3		9		13	
Chaetognaths										24
Sea urchins				79						
Sea cucumbers	1									
Gastropods	4			6		12	13			
Gastropod operculums	2				3	4	5	2		
Lithodid crabs	2							1		
Mussels	3									
Sipunculids							1			
Ctenophores										9
Hydroid fragments						2	1	2	9	
Limpets		59		6			1			
Clam siphons		2				11	2			
Nemerteans								1		
Tomopterids										9
Red algae	4	1	6		8	4	3	2	9	
Brown algae					3	2	6		9	
Green algae		1								
Detritus						2		2		

APPENDIX 2

FREQUENCY OF OCCURRENCE OF PREY ITEMS IN DIET OF PREDATOR SPECIES
FROM BEACH ON WEST SIDE OF HOMER SPIT, 1978

PREY ITEMS	PREDATOR SPECIES: *Ammodytes hexapterus* (19)	*Hypomesus pretiosus* (9)	Capelin (2)	*Salvelinus malma* (9)	*Onchorhynchus gorbuscha* juv. (6)	*Gasterosteus aculeata* (5)	*Hexagrammos* sp (1)	*Lumpenus sagitta* (1)	*Leptocottus armatus* (10)	*Lepidopsetta bilineata* (6)	*Parophrys vetulus* (5)	*Platichthys stellatus* (1)	*Psettichthys melanosticus* (1)	*Podothecus acipenserinus* (6)	Tubenose (3)	No. of utilizing Species
PLANKTERS																
Calanoid copepods*	16				1	3	1				1					5
Cladocerans	11															1
?Hyperiid amphipods						1										1
Euphausiids*					1	1					1				1	4
Cypris larvae (barnacles)	10															1
Veligers	10															1
Eggs*	8	7	1		4	1		1								6
BENTHOS																
WORMS																
Abarenicola ?pacifica										1						1
?*Echiurus echiurus*													1			1
Eteone nr *longa*											1					1
Eteone sp						1				1						2
Magelona sp								1		1						2
Nephtys sp									2							1
Nereis sp									1							1
Phyllodoce groenlandica										1	1					2
Scolelepis sp										2		1				2
Scoloplos armiger										1						1
Spionidae										3	1	1				3
CRUSTACEANS - Gammaridea																
Anisogammarus pugettensis				1			1		1	1						4
Anisogammarus sp									1	1						2
Atylus sp							1			2						2
Gammaridea, unid.			1	7	3	4			1	1	5	1		1	1	10
?Oedicerotidae										1						1
Paraphoxus sp					1											1
Synopiidae				1				1	1							3
Talitroidea				1												1
CRUSTACEANS - Miscellaneous																
?*Acanthomysis* sp										2					2	2
Archaeomysis sp									2	1			1			3
Caridea, unid.		1	1	1						1						4
Crangon sp									1	1						2
Cumaceans				3	1	1				1	1			1		6
Diptera					8											1
Harpacticoidea		1						1						5		7

APPENDIX 2 cont.

FREQUENCY OF OCCURRENCE OF PREY ITEMS IN DIET OF PREDATOR SPECIES
FROM BEACH ON WEST SIDE OF HOMER SPIT, 1978

PREY ITEMS	PREDATOR SPECIES: *Ammodytes hexapterus* (19)	*Hypomesus pretiosus* (9)	Capelin (2)	*Salvelinus malma* (9)	*Onchorhynchus gorbuscha* juv. (6)	*Gasterosteus aculeata* (5)	*Hexagrammos* sp (1)	*Lumpenus sagitta* (1)	*Leptocottus armatus* (10)	*Lepidopsetta bilineata* (6)	*Parophrys vetulus* (5)	*Platichthys stellatus* (1)	*Psettichthys melanosticus* (1)	*Podothecus acipenserinus* (6)	Tubenose (3)	No. of utilizing species
CRUSTACEANS - Misc. cont.																
Lamprops sp				1						2				5		3
?Mites				1												1
Pagurus sp					1											1
Tanaids					1											1
PELECYPODS																
?*Axinopsida sericata*											1					1
?*Clinocardium* sp juv.											1					1
?*Modiolus modiolus*										1						1
SEA SQUIRTS																
?Tunicates										1						1
FISH																
Ammodytes hexapterus				1					3	3						3
Hypomesus pretiosus									3							1
Pholididae													1			1
No. of Prey Species:	5	3	3	9	9	7	3	4	6	21	9	3	3	4	3	41

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EPIPELAGIC MEROPLANKTON, JUVENILE FISH, AND FORAGE FISH: DISTRIBUTION AND RELATIVE ABUNDANCE IN COASTAL WATERS NEAR YAKUTAT

by

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Interim Report

to

OCSEAP - Outer Continental Shelf Environmental Assessment Program

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Roy E. Nakatani
Acting for the Director

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INTRODUCTION

Alaska's Continental Shelf supports abundant and diverse fish and shellfish populations. At the same time, these areas contain or may contain natural gas and oil. Since the 1970's, the Outer Continental Shelf Environmental Assessment Program (OCSEAP) has been funding research over much of the Alaskan shelf. These studies collected biological, chemical, geological, and physical baseline data to be used in managing the natural resources of the shelf.

The shelf off Yakutat represents only a small portion of Alaska's Continental Shelf; however, it supports several fish and shellfish taxa of commercial and ecological importance (Table 1). While adult distributions and abundances for many taxa are known from commercial trawl catches, relatively little is known about epipelagic larval and egg stages of these taxa or about forage fish which also frequent the epipelagic zone.

This report constitutes Part I of a proposed two-part study of meroplankton (pelagic eggs and larvae of fish and shellfish), juvenile fish, and forage fish in the Yakutat Bay area, and is preliminary to field work to be conducted in spring, summer, and fall of 1981. The specific objectives of this report were to: 1) review and analyze information on the distribution and abundance of the selected taxa and on the basis of this information to assess their probable occurrences, geographic distributions, and relative abundances in the region off Yakutat; 2) present information on general spawning biology, history of the commercial fisheries, and adult catch statistics.

Part II of the study will include three field sampling periods (2- 3 weeks, each) and the objectives will be to: 1) determine seasonal occurrence, spatial distribution, and relative abundances of epipelagic life stages of selected species of commercially important fish, shellfish, and forage fish, 2) assess the potential vulnerability of those species to spilled hydrocarbons with respect to position in the water column, season, relative abundance in the study area, and known effects on epipelagic life stages of the organisms, and 3) identify information gaps and present an approach for future study in the region.

Table 1. Target species for Yakutat meroplankton and juvenile fish and forage fish survey, 1980-1981.

Taxa	Life stage Egg	Larvae	Juvenile	Adult
Forage Fish				
Pacific herring-*Clupea harengus pallasi*		x	x	x
Pacific sand lance-*Ammodytes hexapterus*		x	x	x
Capelin - *Mallotus villosus*		x	x	x
Salmon				
Pink salmon-*Oncorhynchus gorbuscha*			x	
Chum salmon-*O. keta*			x	
Coho salmon-*O. kisutch*			x	
Sockeye salmon-*O. nerka*			x	
Chinook salmon-*O. tshawytscha*			x	
Demersal fish and shellfish				
Pacific cod-*Gadus macrocephalus*		x	x	
Walleye pollock-*Theragra chalcogramma*	x	x	x	
Pacific ocean perch-*Sebastes alutus*		x	x	
Sablefish-*Anoplopoma fimbria*	x	x	x	
Arrowtooth flounder-*Atheresthes stomias*	x	x		
Pacific halibut-*Hippoglossus stenolepis*	x	x		
Starry flounder-*Platichthys stellatus*	x	x		
Butter sole-*Isopsetta isolepis*	x	x		
Dungeness crab-*Cancer magister*		x*		
Tanner crab-*Chionecetes bairdi*		x*		
Weathervane scallop-*Patinopecten caurinus*	x	x		
Razor clam-*Siliqua patula*	x	x		

*Further sorting and analysis to zoea and megalops stages.

STUDY AREA

The Yakutat region is located in the northeastern Gulf of Alaska about halfway between Prince William Sound and southeastern Alaska. It is largely open coast, with the exception of Yakutat Bay. Mountains rise from sea level rather abruptly and, in some areas, attain heights of 900 to 5,400 meters. From many of these emerge large alpine glaciers. The coastline is intersected by a large number of glacially fed rivers and streams and the shoreline is composed of wide sandy beaches. The Continental Shelf is about 60 to 90 km wide, except for incursions at Yakutat Bay and Dry Bay (Alsek Canyon). The waters over the shelf support commercial fisheries for salmon, halibut, groundfish, king crab, tanner crab, Dungeness crab, shrimp, and scallops.

The Alaska current is the prevailing current of the area and flows in a northwesterly direction at about 16 cm/sec (Arctic Environmental Information and Data Center and Institute of Social, Economic, Government Research, 1974). At Yakutat, the diurnal tide range is about 3.1 m. Because of the close proximity to the sea, there is a marine influence on the climate, resulting in cloudy skies, fog, heavy annual precipitation, and fairly mild temperatures. Rain occurs on an average of 63% of the days in a year, and the average annual precipitation totals over 335 cm (132 inches). The prevailing wind direction is westerly and the average wind speed is 7.7 knots. Sea ice is not generally found although pieces of ice do break off in sites of coastal glaciers (Brower et al. 1977).

Sampling is proposed for April-May, July-August, and October. Average air temperatures for these months are about 2°, 6°, 12°, 12°, and 4.5°C, respectively and the frequency of precipitation, based on hourly observations, ranges from 24.9% in April to 41.0% in October. The percent frequency of occurrence of obstructions to vision (fog) based on hourly observations is 9.0, 9.7, 19.7, 21.3, and 10.8 for the above months, respectively (Brower et al. 1977).

The proposed study area (Fig. 1) encompasses the waters of the Continental Shelf between Point Manby (on the north shore of Yakutat Bay) to Cape Fairweather. Yakutat Bay opens to the southwest, extending inland for about 63 km before it bends to the south ending in a diverticulate fjord; the longer arm (Russell Fjord) is an additional 58 km. Depth at mid-bay is about 60 fm. Hemlock-spruce forests are located around the main part of the bay with meadows and barren areas in the vicinity of the glaciers at the head of the fjords.

The coniferous forests extend southward from Yakutat Bay to Dry Bay but are interrupted by a strip of watersedge tundra in the low-lying areas near the coast. This area is considerably moist, containing many river drainages. The Continental Shelf in this vicinity is relatively wide. Dry Bay itself is very shallow and is fed by the Alsek River, the largest river in the area. From just south of Dry Bay to Cape

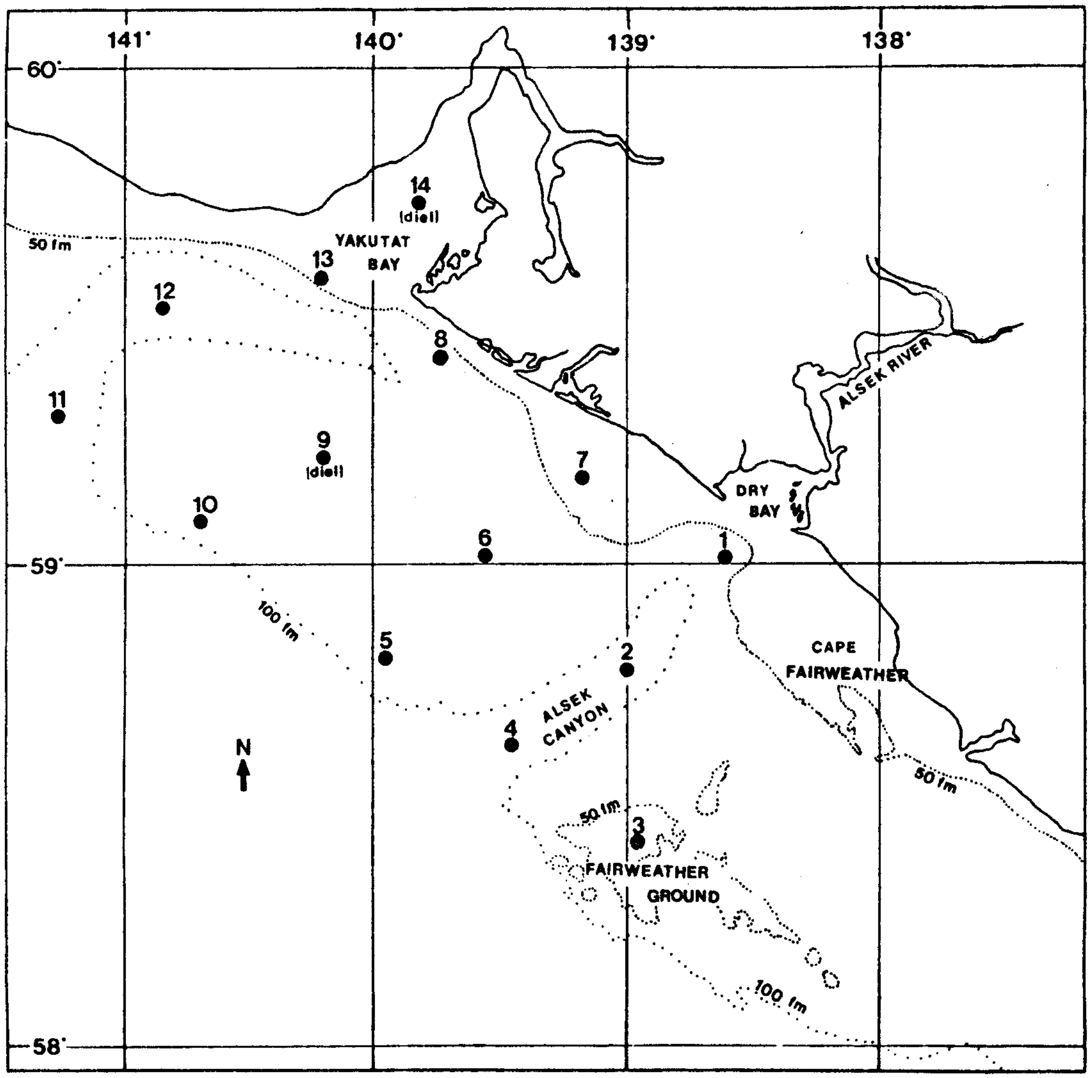

Fig. 1. Proposed station locations in the Yakutat study area, 1981.

Fairweather, the hemlock-spruce forest continues in a thin coastal strip. The local relief is much greater here and is comprised of alpine meadows, peaks above timberline, glaciers, and barren rock. The 4670-m tall Mt. Fairweather is here. The Continental Shelf is also relatively wide south of the Alsek Canyon and contains the Fairweather Ground, which has depths of only 30-40 fm.

DISCUSSION

Studies of distributions and abundances of fish eggs and larvae have been conducted in various parts of Alaska (Table 2). In some cases, studies have been located in important fishing areas such as the Bering Sea, Kodiak shelf, and Cook Inlet. Other surveys have been restricted to single larval species (Lisovenko 1964; Thompson and Van Cleve 1936) and in some, larval fish were secondary to trawl catches (Aron 1958) or zooplankton surveys (LeBrasseur 1970). Emphasis has generally been on sampling in the spring and summer when the ichthyoplankton fauna in the Northeast Pacific is more diverse and abundant.

Few studies have included stations adjacent to or near the proposed Yakutat study area. Lisovenko (1964) reports catches of rockfish larvae near Yakutat and Thompson and Van Cleve (1936) surveyed shelf waters for halibut eggs and larvae. During October, English (1976) included a three-station transect off Yakutat Bay during an ichthyoplankton survey of the Gulf of Alaska. Results of these studies and ichthyoplankton studies in other areas are included in sections for individual species.

Spawning times for the proposed taxa are known from other areas (Table 3) and can be used to predict the time of occurrence of eggs and larvae in the Yakutat area (Table 4). Winter spawners include Pacific sand lance, sablefish, Pacific halibut, Pacific cod, and arrowtooth flounder. The following are spring and/or summer spawners: Pacific herring, capelin, walleye pollock, Pacific ocean perch, butter sole, starry flounder, razor clams, weathervane scallops, tanner and Dungeness crabs. Spring and summer sampling in the Yakutat area should yield the most kinds and greatest abundances of fish and shellfish eggs and larvae as well as juvenile salmon and adult forage fish. However, juveniles of some species will most likely occur in fall.

General distributions of eggs and larvae in the Yakutat area can be estimated from knowledge of spawning behavior of adults. For example, some species--herring and capelin--spawn in bays or on beaches and their larvae are located near these inshore areas. However distributions of pelagic eggs and larvae are not static, but change over time as larvae and eggs are transported by currents and later, for larvae, by their own power. It would not be unusual to find herring and capelin at some shelf stations. Similarly, species which spawn in deep water--halibut, arrowtooth flounder, sablefish--are not expected to occur as larvae in the inshore areas, but perhaps at some shelf stations. The remainder of the fish species probably spawn throughout depths of the shelf and their eggs and larvae should be widely distributed.

Predicting abundances of eggs and larvae in the Yakutat area is more difficult for several reasons: 1) lack of past catch data in the Yakutat area; 2) lack of data on year to year variations in timing and abundance of eggs and larvae, and 3) limitations of using abundance data from other studies in other areas, due in part to different methods,

Table 2. Summary of studies which include data on fish eggs and larvae from the Northeast Pacific.

Location	Dates	Reference
Bering Sea	Jun-Sep 1958 Mar 1959	Musienko 1963
	Jun-Jul 1962	Kashkina 1970
	Apr-May 1977	Waldron and Vinter 1978
	May-Jun 1971	Dunn and Naplin 1973
Kodiak Shelf	Apr-May 1972	Dunn and Naplin 1974
	Oct-Nov 1977 Mar-Apr 1978 Jun-Jul 1978 Oct-Nov 1978 Feb-Mar 1979	Kendall et al. 1980
Kodiak Bays	Mar-Aug 1978 Nov 1978 Mar 1979	Rogers et al. 1979
Cook Inlet	Apr-May 1976 Jul-Aug 1976 Oct 1976 Feb 1977	English 1977, 1978
NE Pacific		
- Willapa Bay to Dixon Entrance	Oct-Nov 1971	Naplin et al. 1973
- Gulf of Alaska	Jul-Sep 1957	Aron 1958
- Gulf of Alaska	May-Sep 1956 Mar-Sep 1957 Mar-Aug 1958 Mar-Jul 1959	LeBrasseur 1970
- Northern Gulf of Alaska	Apr-Jul 1963	Lisovenko 1964*
- Northern Gulf of Alaska	Sep-Oct 1975	English 1976*
- Gulf of Alaska	Jan-Jun 1928-1934	Thompson and Van Cleve* (1936)

*Studies which included some stations near the proposed Yakutat meroplankton study area.

Table 3. Spawning times, by months and geographical areas, for proposed fish species in the Yakutat meroplankton and forage fish survey.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Area	References[1]
Pacific herring	X	X	X	X									California	Scattergood et al. 1959
	X	X	X	X									Oregon	Scattergood et al. 1959
		X	X	X	X	X							British Columbia	Outram and Humphreys 1974
			X	X	X	X							Southeast Alaska	Scattergood et al. 1959; Skud 1959
				X	X								Cook Inlet	Rounsefell 1930
				X	X								Prince William Sound	Rounsefell 1930
				X	X	X							Kodiak Island	Kasahara 1961
				X	X								Western Alaska	Scattergood et al. 1959
					X								Southeast Bering Sea	Rumyantsev and Darda 1970
					X	X							Northeast Bering Sea	Rumyantsev and Darda 1970
Capelin									X	X			Straits of Georgia	Hart and McHugh 1944
										X			Sitka	Marsh and Cobb 1908
					X	X							Kodiak	
					X	X							Bristol Bay	Blaxter 1965
						X	X	X					Bering Sea	Kashkina 1970
								X	X				Point Barrow	Andriyashev 1954
Pacific sand lance	X	X										X	Northeast Pacific	Trumble 1973
Pacific cod	X	X										X	British Columbia	Hart 1973
	X	X											Bering Sea	Musienko 1970
Walleye pollock			X	X									British Columbia	Hart 1973
			X	X	X								Western Gulf of Alaska	Hughes and Hirshhorn 1978
		X	X	X	X	X							Northeast Bering Sea	Serobaba 1968
				X	X	X							Kamchatka Peninsula	Kanamaru et al. 1979
Sablefish	X	X											British Columbia	Hart 1973
	X	X							X	X	X	X	Vancouver-Oregon	Kodolov 1968
	X	X							X	X	X	X	Bering Sea	Kodolov 1968
Pacific ocean perch	X								X	X	X	X	[2]Gulf of Alaska	Lisovenko 1972; Lyubimova 1965
				X	X	X	X						[3]Gulf of Alaska	Lisovenko 1964

Table 3. Spawning times, by months and geographical areas, for proposed fish species in the Yakutat meroplankton and forage fish survey - continued.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Area	References[1]
Butter sole	X	X	X	X	X								Oregon	Richardson et al. (In press)
		X	X	X									British Columbia	Hart 1973
		X	X										Skidgate Inlet, B.C.	Levings 1968
Starry flounder	X											X	California	Orcutt 1950
		X	X	X									Puget Sound	Hart 1973
		X	X	X									British Columbia	Hart 1973
					X	X							Bering Sea	Musienko 1963
Pacific halibut	X										X	X	British Columbia	Hart 1973
	X	X	X								X	X	Northeast Pacific	Bell and St. Pierre 1970
	X	X							X	X	X	X	Bering Sea	Pertseva-Ostroumova 1961
Arrowtooth flounder	X	X	X									X	North Pacific	Pertseva-Ostroumova 1960

[1]References for herring, capelin, and sand lance summarized from Macy et al. 1978.
[2]Time of mating.
[3]Time of release of larvae.

Table 4. Predicted time(s) of occurrence for egg, larval, juvenile, and/or adult stages of fish and invertebrate taxa in the Yakutat study area.

Species	Stage	Proposed sampling months: Apr-May	Jul-Aug	Oct	Remarks
Pacific herring	larvae	x	x		
	juveniles			x	
	adults	x			
Capelin	larvae		x		
	juveniles			x	
	adults	x			
Pacific cod	larvae	x	x		
	juveniles			x	
Walleye pollock	eggs	x	x		
	larvae	x	x		
	juveniles			x	
Sand lance	larvae	x	x		
	juveniles			x	
	adults	x			
Pink salmon	juveniles		x	x	
	adults		x		
Chum salmon	juveniles		x	x	
	adults		x	x	
Coho salmon	juveniles		x		
	adults		x		
Sockeye salmon	juveniles		x		
	adults		x		
Chinook salmon	juveniles		x		
	adults	x	x		
Rockfish (Sebastes spp.)	larvae	x	x	x	
	juveniles			x	
Sablefish	eggs				Occur in winter
	larvae	x	x		
	juveniles		x		
Arrowtooth flounder	eggs	x			Occur primarily in winter
	larvae	x	x		
Pacific halibut	eggs				Occur in winter
	larvae	x	x		
Starry flounder	eggs	x			
	larvae		x		
Butter sole	eggs	x			
	larvae		x		
Razor clams	eggs		x		Eggs approx. 90 μ
	larvae		x		Settle at approx. 325 μ
Scallops	eggs				Eggs are demersal
	larvae		x		larvae are 80-200 μ
Dungeness crab	larvae	x	x		
Tanner crab	larvae	x	x	x	

gears, and expressions of catch statistics. However, after sampling is underway, it should be possible to compare relative abundances of taxa between Yakutat and other areas in Alaska. In addition, thorough knowledge and duplication of methods used in Kodiak ichthyoplankton work (Rogers et al. 1979; Kendall et al. 1980) will allow comparisons between catches in the western Gulf of Alaska and in the eastern portion off Yakutat.

Forage Fish

Forage fish may be defined as those species that are present in sufficient quantities during their larval, juvenile, and adult stages to constitute a major part of the diet of larger predators including birds, marine mammals, and fish. Important forage fish species in the Yakutat area include Pacific herring, sand lance, and capelin.

Pacific Herring *(Clupea harengus pallasi)*

General Biology. In the eastern Pacific, herring are distributed from northern California through Canada and Alaska to the Beaufort Sea (Hart 1973).

Pacific herring are schooling fish and their local distribution is related to environmental and biological factors such as salinity, temperature, food sources, age, and spawning condition. In general, during fall or early winter, large schools of mature herring move inshore and remain there until spawning. After spawning, schools either move into deeper water offshore to feed or remain inshore. In the Gulf of Alaska, feeding schools during summer are not as dense as wintering schools and have been reported close to the surface in passages in Southeast Alaska and Prince William Sound (Macy et al. 1978).

The primary commercial concentrations of herring in the Gulf of Alaska have occurred historically in Southeast Alaska, Prince William Sound, and Kodiak Island. In the past, small-scale fisheries have occurred in Cook Inlet, Chignik, Shumigan Islands, and Yakutat. Herring are also important as prey items for many invertebrates, fish, birds, and marine mammals. Eggs, larvae, juveniles, and adults of Pacific herring are consumed, often in large quantities (Macy et al. 1978).

A comprehensive review of the biology and early life history of Pacific herring is given by Macy et al. (1978) and is summarized below.

Pacific herring are late-winter to late-spring spawners, depending on geographic location. In general, southern stocks spawn earlier than the more northern populations. In Alaskan waters, herring spawning occurs in March through June in Southeast Alaska, April and May in Cook Inlet and Prince William Sound, April through June in Kodiak and western Alaska, and May and June in the Bering Sea.

In Alaska, Pacific herring generally are mature at age 3 or 4 and at lengths of 15-20 cm. Fecundity is related primarily to body length and secondarily to age, hence large, old herring produce the most eggs. Females may produce between 10,000 and 134,000 eggs. Pacific herring in North America are generally smaller and produce fewer eggs than Asian stocks.

Large schools of mature fish move into sheltered bays, along steep or shelving rocky beaches, or along open sand beaches to spawn. Spawning takes place in shallow water at high tide and the water may become discolored with milt. Eggs are usually deposited on vegetation, but may also be attached to gravel, boulders, logs, and tree limbs. Eggs may be deposited in several layers, and two to four layers are considered optimal for larval production. Salinity and temperature during spawning are variable, and ranges of 8-28°/oo and 5-9°C are reported as conducive to the spawning of herring in North America.

Eggs hatch in 12-50 days, depending on water temperature. In Prince William Sound, average hatching time was 12 to 21 days. Normal development occurs at temperatures of 5-9.2°C and salinities of 6.7-25.8°/oo. Fraser (1922) describes egg development after fertilization. Newly hatched larvae are 4-8 mm long, and herring reach 90-100 mm by the end of their first year. Transformation from larval to juvenile fish begins at about 35-40 mm.

Food of first-feeding larvae consists of small, relatively immobile planktonic organisms such as invertebrate eggs, diatoms, and copepod nauplii. Postlarval (20-100 mm) herring feed primarily on copepods, followed by cirrepedes, molluscs, ova, and other zooplankters. Food items of juvenile herring include mysids, euphausids, and amphipods. Herring do not have a strong preference for particular foods, but consume organisms of a suitable size which predominate in the plankton. Hence food habits may differ among locations and seasons.

History of the Fishery. Yakutat Bay has supported a commercial herring fishery only twice in recent years. In 1970-1971 and 1972-1973, the catches were 44 and 158 short tons, respectively. These catches were insignificant compared to those in Southeast Alaska which were 4,093 and 5,837 short tons, respectively (Moberly 1973, 1974). The herring fishery at Yakutat supplied the local bait fish market, although generally fishermen rely on outside sources (Don Ingledue, Alaska Department of Fish and Game (ADF&G), personal communication). The current sentiment is that the herring populations should be preserved as a food source for king salmon in the area (Alex Brogall, ADF&G, personal communication).

Distribution and Abundance.

Adults. Spawning areas of Pacific herring in the Gulf of Alaska are shown in Fig. 2. Currently, an estimated 2,000-3,000 tons of herring spawn from April to early May along the east shore of Yakutat

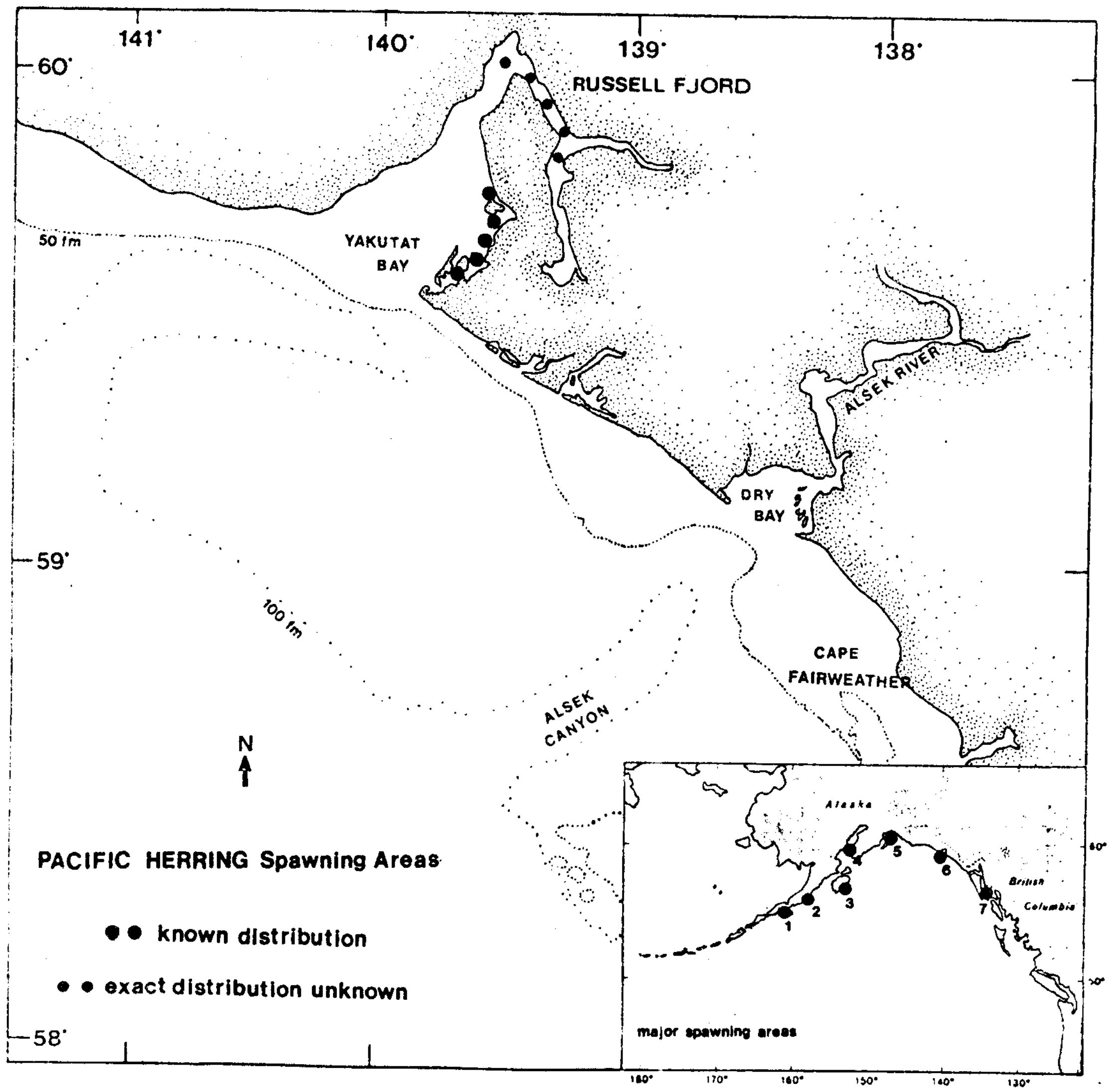

Fig. 2. Spawning areas of Pacific herring in the Yakutat area and Gulf of Alaska (1-Shumigan Islands, 2-Chignik, 3-Kodiak Island, 4-Kachemak Bay, 5-Prince William Sound, 6-Yakutat, 7-Southeast Alaska).

Sources: A. Brogall, personal communication; Macy et al. 1978.

Bay. A population estimated to be three times that size spawns in Russell Fjord; however, because of ice the area is inaccessible at the time of spawning, so the actual size of that population is unknown (A. Brogall, personal communication).

Larvae. Initially, we would expect to find herring larvae in greatest abundance close to the spawning grounds. Unfortunately, these areas are in shallow water and are often not accessible to plankton gear. We may catch small larvae which drift out into Yakutat Bay during late April and May, but the peak in larval abundance may occur later. By July and August, herring larvae will be actively schooling near the spawning grounds. These schools may reach deeper water by late summer, residing below the surface during the day and rising to the surface at dusk (Macy et al. 1978). These herring may be captured by plankton gear at night, but otherwise will probably avoid capture. Lampara net sets at dusk and beach seine hauls in Yakutat Bay during the summer may yield herring juveniles. At the end of summer, juvenile herring may either migrate to offshore waters or remain inshore. No one knows if they remain in Yakutat Bay through the winter.

Pacific Sand Lance *(Ammodytes hexapterus)*

General Biology. Pacific sand lance range from southern California to Alaska and the Bering Sea (Hart 1973) and are mainly in shallow water close to shore. Because they lack a swim bladder, sand lance exist by actively swimming, resting on the bottom (Trumble 1973), or burying in sand or fine gravel (Nikol'skii 1954 cited in Macy et al. 1978). They may form large pelagic feeding schools during the day and return to the bottom at night (Trumble 1973).

Sand lance adults and larvae are an important food item to many commercially important fish such as juvenile sockeye and coho salmon (Straty and Jaenicke 1971), cod, chinook salmon, halibut, ling cod (Bean 1889; Hart 1973), and hake (Outram and Haegele 1972). Sand lance are also consumed by fur seals and birds.

Spawning of Pacific sand lance in the Northeast Pacific probably occurs in winter (Trumble 1973). Sand lance up to 15 mm long were caught during early March near Kodiak Island, which also indicates that sand lance spawn during the winter (Rogers et al. 1979).

Fecundity of Japanese sand lance is about 1,000-8,000 eggs, and spawning takes place at depths of 25-100 m in areas of strong currents. Spawning fish may be 1-3 years old (Hamada 1966). Eggs are demersal, adhesive, and are deposited in clusters of three or four eggs on a sand bottom. Mature eggs are .72-.97 mm in USSR (Nikol'skii 1954 cited in Macy et al. 1978), .66 mm in Japan (Inoue et al. 1967), and .67-.91 mm in the Atlantic (Williams et al. 1964). Descriptions of sand lance eggs are given in Williams et al. (1964).

Larvae hatch at 3-4 mm and under natural conditions remain buried in the sand until the yolk sac is absorbed. At this point, larvae become planktonic and remain so until metamorphosis to the adult stage at 30-40 mm (Trumble 1973). Larval illustrations are given in Kobayashi (1961).

First-feeding larvae consume diatoms and dinoflagellates, but they switch to copepod nauplii and copepods as they grow (Trumble 1973).

Distribution, and Abundance

Adults. At present, there is no fishery in the Northeast Pacific on sand lance; however, they are commercially fished in Japanese waters. Their distribution and abundance off Yakutat is unknown.

Larvae. Sand lance larvae are relatively abundant in plankton hauls in the Bering Sea and Gulf of Alaska during spring. In the Kodiak area, small (5-15 mm) larvae were found within the bays as well as distributed over the shelf. In summer, the larvae (averaging 35-45 mm long) disappeared from the bays, but continued to be caught offshore. No larvae were caught during fall (Table 5).

In the Yakutat area, the largest catches of larval sand lance will probably occur during April and May. They may be caught anywhere from Yakutat Bay to the 100 fm contour, although they may be concentrated nearshore. Older larvae and juveniles may occur in the study area during summer and be distributed throughout the area. We expect that only juveniles and adults occur in October and in relatively low abundance compared to other months. Because the eggs are demersal, they will not be sampled by the plankton gear.

Capelin *(Mallotus villosus)*

General Biology. Capelin occur along the Northeast Pacific coast from the Strait of Juan de Fuca to Arctic Alaska. They are especially abundant in the Bering Sea and along the Aleutian Islands (Macy et al. 1978).

Capelin are an important forage food for fish and marine mammals, particularly during spawning migrations. Predators on capelin include salmon, cod, dogfish, Arctic char, seals, porpoise, and killer and baleen whales. They are also eaten by gulls and terns.

Reproduction and early life history information for capelin have been summarized by Trumble (1973), Jangaard (1974), and recently by Macy et al.(1978). In the Straits of Georgia and near Sitka (southeastern Alaska) spawning occurs in the fall. However, at Kodiak and in Bristol Bay, capelin spawn in late spring. Capelin in the Bering Sea spawn in summer, and far-northern (Pt. Barrow) populations spawn in late summer.

Table 5. Distribution and abundance of larval sand lance in the Northeast Pacific Ocean and Bering Sea.

Location	Time	Gear	Station depths, m	Larval length, mm	Abundance	Reference
Bering Sea	Apr-May 1977	bongo[1]	100-2000 (caught at stations <200m)	6.7-29	Third most abundant larvae; accounted for 3% of all larvae caught.	Waldron and Vinter 1978
Bering Sea	Jun-Jul 1962	CPN[2]	20-120	10.0-47.0	Average catch of 4 larvae per haul; ranged from 0-445 per haul.	Kashkina 1970
Bering Sea	Jun-Sep 1958 Mar 1959	CPN	35-2100	7.4-33.7 35.9-95.6	Caught in late July-early Sep. averaged about 8 larvae per haul.	Musienko 1963
Kodiak Shelf	Apr-May 1972	bongo		5-13	Second most abundant larvae caught; accounted for 11.3% of all larvae caught.	Dunn and Naplin 1974
Kodiak Bays	Mar-Aug 1978 Nov 1978 Mar 1979	bongo	31-171	5-34	Second most abundant overall; occurred primarily Mar-Jun.	Rogers et al. 1979
Kodiak Shelf	Oct-Nov 1977 Mar-Apr 1978 Jun-Jul 1978 Oct-Nov 1978 Feb-Mar 1979	bongo	40-1000	5.5-58	Most abundant larvae caught during Mar-Apr 1978.	Kendall et al. 1980
Cook Inlet	Apr-May 1976 Jul 1976 Aug 1976 Oct 1976	bongo	35-210		Most abundant during Apr-May; catches ranged from 0-344 per $10m^2$ or 0-1296 per 1000 m^3.	English 1977, 1978

[1] Bongo net, 60 cm opening, 505μ mesh.
[2] Conical plankton net, 80 cm opening, No. 140 mesh.

Mature capelin range in length from 89-146 mm. Fecundity varies among locations and ranges from 3,020-6,670 eggs per female in British Columbia to 15,000-57,000 eggs per female in the Sea of Japan. Larger fish may account for higher fecundities in some areas.

During most of the year, capelin reside in large schools in bottom waters, sometimes far from shore. However, in the spring these concentrations move toward shore and about one month before spawning, are located at about 50 m depths or less.

Capelin commonly spawn on beaches, avoiding rocky areas, and preferring sand grain sizes of 0.04-.2 mm. Deposition of eggs occurs at night or on overcast days, and spawning may be greatest just after high tide. One or two males accompany a female to the beach where fertilization takes place, and eggs are subsequently buried in the sand by wave action. Spent females return to deeper water and it is not known if females spawn more than one batch of eggs in a given season. Males may remain inshore to fertilize other females. Spawning in deep water may also occur in Alaskan waters. Postspawning mortality is assumed to be high and may be as high as 90% of the fish spawning for the first time.

Capelin eggs are 1.0-1.1 mm in diameter and stick to gravel or sand. Hatching occurs in 1-4 weeks, depending on water temperature. Descriptions of capelin larvae are given by Templeman (1948). Newly hatched larvae are swept out to sea and spend most of their early life in deep water.

Distribution and Abundance

Adults. Currently there is no large-scale commercial fishery on capelin stocks in the Northeast Pacific and only a limited recreational fishery. The abundance and distribution of adult capelin offshore from Yakutat are unknown.

Larvae. Larval capelin have been sampled from the Bering Sea, Kodiak Shelf, and Gulf of Alaska. In several studies, they were numerically important components of the ichthyoplankton (Table 6). Initially, capelin larvae are located nearshore in close proximity to the beaches where spawning occurred. This can lead to large concentrations of larvae during summer, and this occurred in Kodiak bays and lower Cook Inlet. After hatching, larvae are immediately susceptible to transport by local currents and thus are dispersed over the shelf. By fall and winter, the larvae have metamorphased into mobile juveniles and range from nearshore to the edge of the shelf.

Capelin spawning in the Yakutat study area takes place on beaches between Dry Bay and Yakutat Bay (Fig. 3) from July to mid-August. It is a relatively large population (A. Brogall, personal communication). We expect to catch larval capelin during July and August nearshore as well as out to the 100 fm contour. In the fall we will probably capture

Table 6. Distribution and abundance of larval capelin in the Northeast Pacific Ocean and Bering Sea.

Location	Time	Gear	Station depths, m	Larval length, mm	Abundance	Reference
Bering Sea	Apr-May 1977	bongo[1] neuston[2]	100-2000	31-65	Accounted for .2% of all larvae caught in the bongo and 8% (third in abundance) of larvae from neuston.	Waldron and Vinter 1978
Bering Sea	Jun-Sep 1958 Mar 1959	CPN[3]	25-375	5.5-27.3	Occurred in July and late August-early September; maximum concentration was 250 per m^2.	Musienko 1963
Kodiak Bays	Mar-Aug 1978 Nov 1978 Mar 1979	bongo neuston	31-171	3.0-40.0	Only identified as "Osmeridae;" accounted for >90% of all larvae in bongo tows. First in abundance over all cruises in both gear types.	Rogers et al. 1979
Kodiak Shelf	Nov 1977 Mar-Apr 1978 Jun-Jul 1978 Oct-Nov 1978 Feb-Mar 1979	bongo neuston	40-1000	12-55	Occurred in all seasons, although only identified as "Osmeridae" during summer. Osmerids ranked third in abundance in bongo tows in summer.	Kendall et al. 1980
Cook Inlet	Apr-May 1976 Jul 1976 Aug 1976 Oct 1976 Feb 1977	bongo	35-210		Peak catches in July-August. Catches range from 0-2505 per $10 m^2$ (or 0-2766 per $1000 m^3$)	English 1977, 1978
Gulf of Alaska	Sep-Oct 1975	bongo	30-2500	9-27	Third most abundant larval taxa collected.	English 1976

[1]Bongo net, 60 cm opening, 505µ mesh.
[2]Sameoto neuston sampler, .3m x .5m opening, 505µ mesh.
[3]Conical plankton net, 80cm opening, No. 140 mesh.

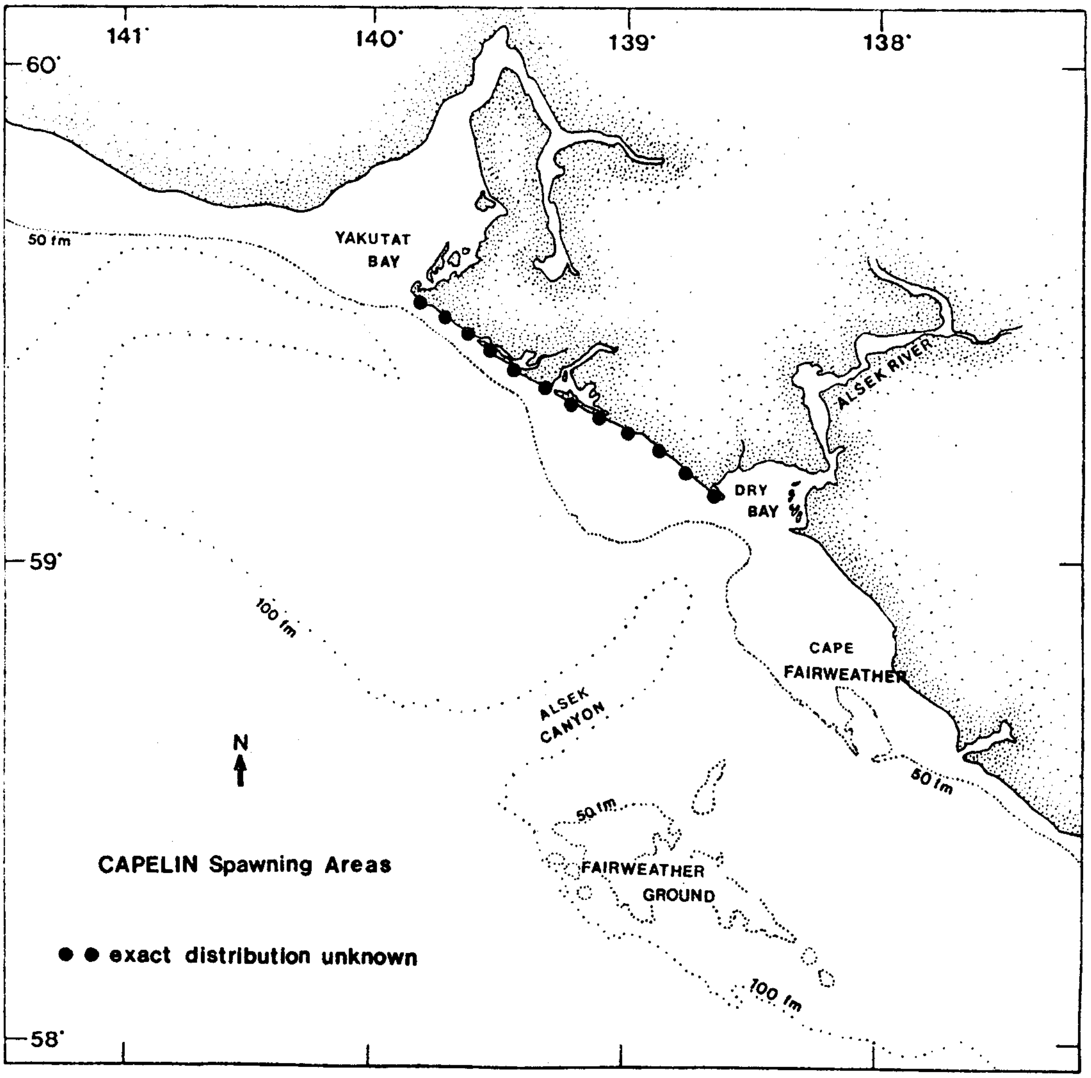

Fig. 3. Spawning areas of capelin in the Yakutat area.

Source: A. Brogall, personal communication.

juvenile capelin. Eggs will probably not occur in the plankton samples because of their demersal, adhesive quality.

Eulachon (*Thaleichthys pacificus*)

Eulachon were not targeted for this study; however, since they are a potentially important species to the ecology of the Yakutat area, we have included this section in the report.

Large numbers of adult eulachon spawn in the Yakutat study area during March to early June (A. Brogall, personal communication). Eulachon are anadromous, sometimes traveling tens of miles upstream to spawn. The eggs are spawned over gravel and sand and become attached to the sediment by an outer adhesive membrane. The larvae are carried out to sea as soon as they hatch and little is known about their marine life.

Eulachon are not presently exploited commercially in Alaska, although they are an important forage fish (Macy et al. 1978). We expect to see larval eulachon at nearshore stations during spring and/or summer. However, it will be difficult to distinguish among species of smelt when the larvae are small (i.e., prior to the development of fin rays).

Pacific Salmon

The Fishery

The first salmon cannery in Alaska which became operative in 1857, was located on Prince of Wales Island. Since that time, the salmon fishery has become the dominant fishery in Alaska. Salmon represented 39 to 63% of the value of the total commercial catch of fish and shellfish in Alaska between 1966 and 1977 (Terry et al. 1980).

Generally, the commercial catch of salmon in the Yakutat management area (Cape Suckling to Cape Fairweather--see Fig. 4) is small relative to the rest of Alaska; however, the salmon fishery is important to the local economy. Off Yakutat, this fishery is by set gillnets and trolling gear. Boats in the setnet fishery are small (<25 ft long), generally with a crew of one, and primarily based in Yakutat. Trollers are much larger (35-45 ft), with a crew of two to three, and most are based outside the area (Terry et al. 1980).

Most of the salmon from the Yakutat area are produced at the southeast edge of the bay and in coastal river systems to the southeast. Thus, setnet sites are located primarily in Yakutat Bay and to the southeast along the coast (McLean and Delaney 1978). In the Gulf of Alaska there is a small sport fishery on coho, chum, and chinook salmon, which is insignificant compared to the commercial catch.

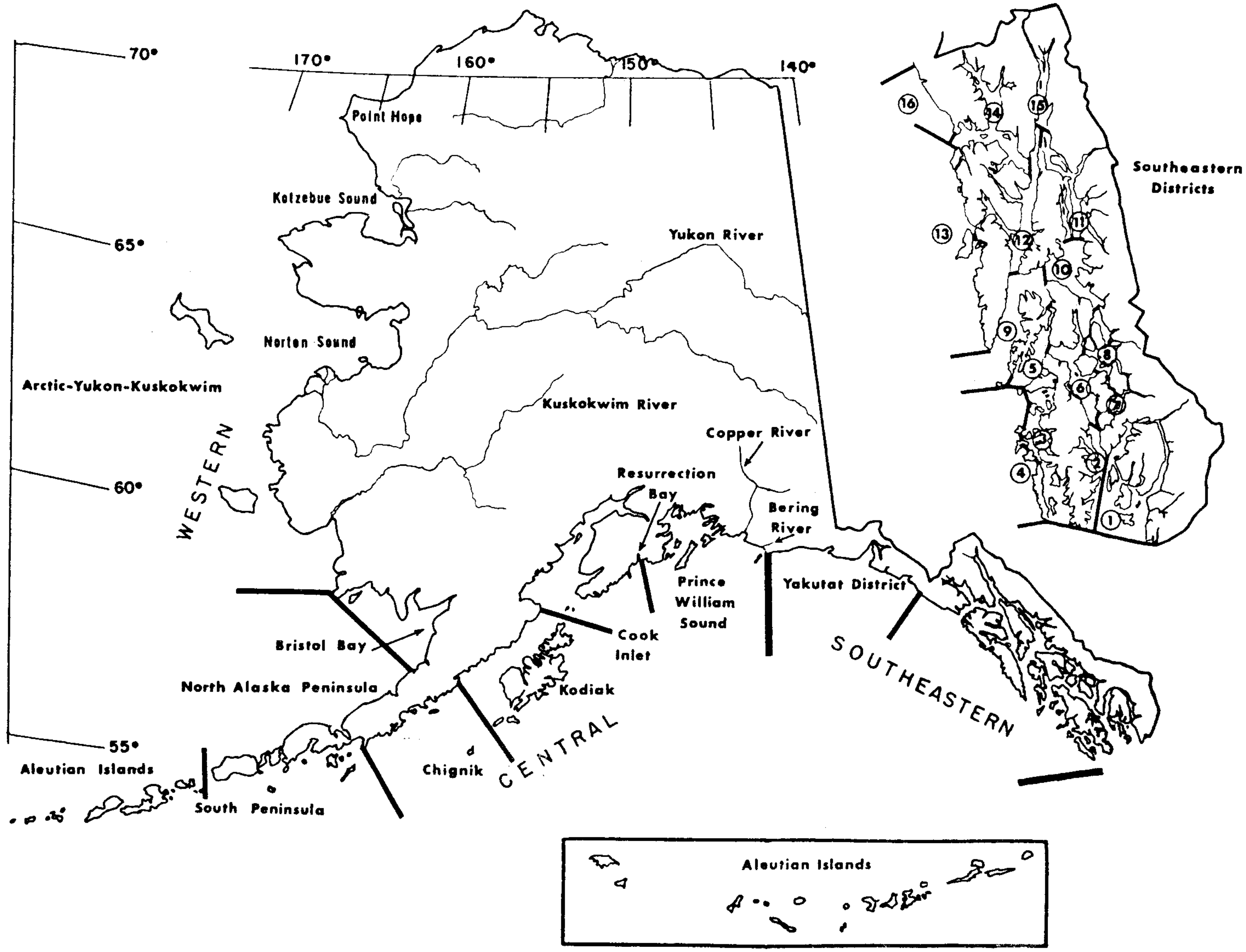

Fig. 4. Statistical divisions of the State of Alaska.

Source: International North Pacific Fisheries Commission 1979.

Stern et al. (1976) estimated that if the average catch in the Yakutat District was 30% of the run, then annual runs to the district average about .4 million salmon, with a potential of up to 1.3 million.

Migrations in the Northeast Gulf of Alaska

All five species of North American salmon are anadromous, although some pink salmon spawn intertidally. Adults spawn in the fall and fry emerge from the gravel the following spring. Chum, pink, and most chinook fry migrate directly to saltwater; however, sockeye fry generally reside in freshwater nursery lakes for 1-2 years. Coho and some chinook fry remain in freshwater for about 1 year, entering saltwater the following spring as smolts. If entering an estuary, most juveniles remain near the water surface and gradually, as the summer progresses, move offshore. Fry entering an unprotected coastline tend to move directly offshore over the Continental Shelf. By July-August, the catch-per-unit-effort (CPUE) of juvenile salmon is high over the shelf, indicating movement from estuaries and coastal rivers. Many chum and pink salmon remain over the shelf as late as October, but after October the abundance of all species is low because the juveniles have moved offshore over deeper waters.

While in waters over the Continental Shelf, the juveniles may migrate hundreds of miles, generally in a counterclockwise direction along the broad arc of the Gulf of Alaska. Juveniles from stocks as far south as California mix with those from Alaska in coastal waters off Yakutat.

Adult salmon bound for spawning grounds in the northeast Gulf also tend to migrate extensively along the coast. Adults tagged off Yakutat have returned to spawn in southeastern Alaska. (This section was derived from Stern et al. 1976.)

Pink Salmon *(Oncorhynchus gorbuscha)*

General Biology. Pink salmon occur along the west coast of North America from California to the Aleutian Islands and Arctic Ocean. They usually spawn after two summers at sea in the late summer or early fall. The average size at maturity is 1.4-2.3 kg, although they can attain a maximum size of 5.4 kg and 76 cm long. Fecundity is related to length, with usually 1,500-1,900 eggs per female. Spawning is in coastal streams and rivers or in the intertidal zone. Eggs develop in gravel during the winter and fry emerge the following spring. Fry emerging in freshwater migrate immediately to saltwater. During their first summer at sea, the fry remain close to shore, feeding primariy on zooplankton, insects, and epibenthic crustacea (Rogers et al. 1980). Pink salmon in the Gulf of Alaska prefer temperatures of 7-15°C. Thus, they are primarily surface dwellers, avoiding the thermocline (Stern et al. 1976). The maturing fish grow rapidly in their last spring and summer at sea, feeding extensively on euphausids, copepods, amphipods, fish and squid. (Most of the preceeding was modified from Hart 1973).

Distribution and Abundance. Experimental purse seine catches of juvenile pink salmon were low over the Continental Shelf near Yakutat in April-June, but high July-October, therefore migration from estuaries and coastal rivers probably begins in July (Stern et al. 1976). After October, they migrate offshore.

Spawning runs peak during August (Fig. 5), the adults returning to spawn in several streams, rivers, and along some beaches in Yakutat Bay. Two spawning sites are of major importance, one located near the town of Yakutat and the other in the Situk River to the southeast. Adult pink salmon have been observed in a few other rivers, but spawning sites have not been verified (McLean and Delaney 1978).

Pink salmon catches in the Yakutat District average only 0.1% of the catch in the entire state (Table 7). In the Yakutat area, pink salmon ranked third in the number of salmon landed, whereas they ranked first in the state of Alaska.

Chum Salmon *(Oncorhynchus keta)*

General Biology. Chum salmon range from northern California through the Aleutian Islands to the Arctic Ocean. Their maximum size at maturity is 102 cm and 15 kg. Most return to spawn after 3-5 years at sea, although the range is 2-7 years. This species tends to spawn later than the other four species of Pacific salmon--one stock in British Columbia spawns as late as April. In Asia, where there are both fall and spring runs, spring run females carry 2,000-3,000 eggs, while those spawning in the fall run carry 3,000-4,000 eggs. Spawning takes place in coastal rivers and streams. In the spring, after fry have emerged from gravel, they migrate directly to saltwater, generally between April and July. Juveniles consume zooplankton, insects, and small epibenthic crustacea such as amphipods, where they occupy the coastal strip (Rogers et al. 1980). Chum salmon can tolerate a wide range of temperatures, and perhaps for this reason they are not closely tied to the surface waters as are pink and sockeye salmon (Neave et al. 1976) (the preceding, with noted exceptions, was derived from Hart 1973).

Distribution and Abundance. In the Yakutat District, runs of returning spawners peak in September (Fig. 6), although the migration continues well into October. Only two watersheds contain documented spawning sites: the Italio River and East Alsek River drainages, although chum have also been observed in the Situk, Ahrnklin, Akwe, and Alsek River drainages. Since the runs are quite sparse, the average yearly catch (1959-1979) has been only 10,000 fish as opposed to 6,014,000 in Alaska (Table 8). Chum salmon rank fourth in the number of salmon caught in Yakutat and third in Alaska.

Near Yakutat, juveniles occupy the coastal strip between July and October (Stern et al. 1976) and are probably in the estuaries somewhat earlier.

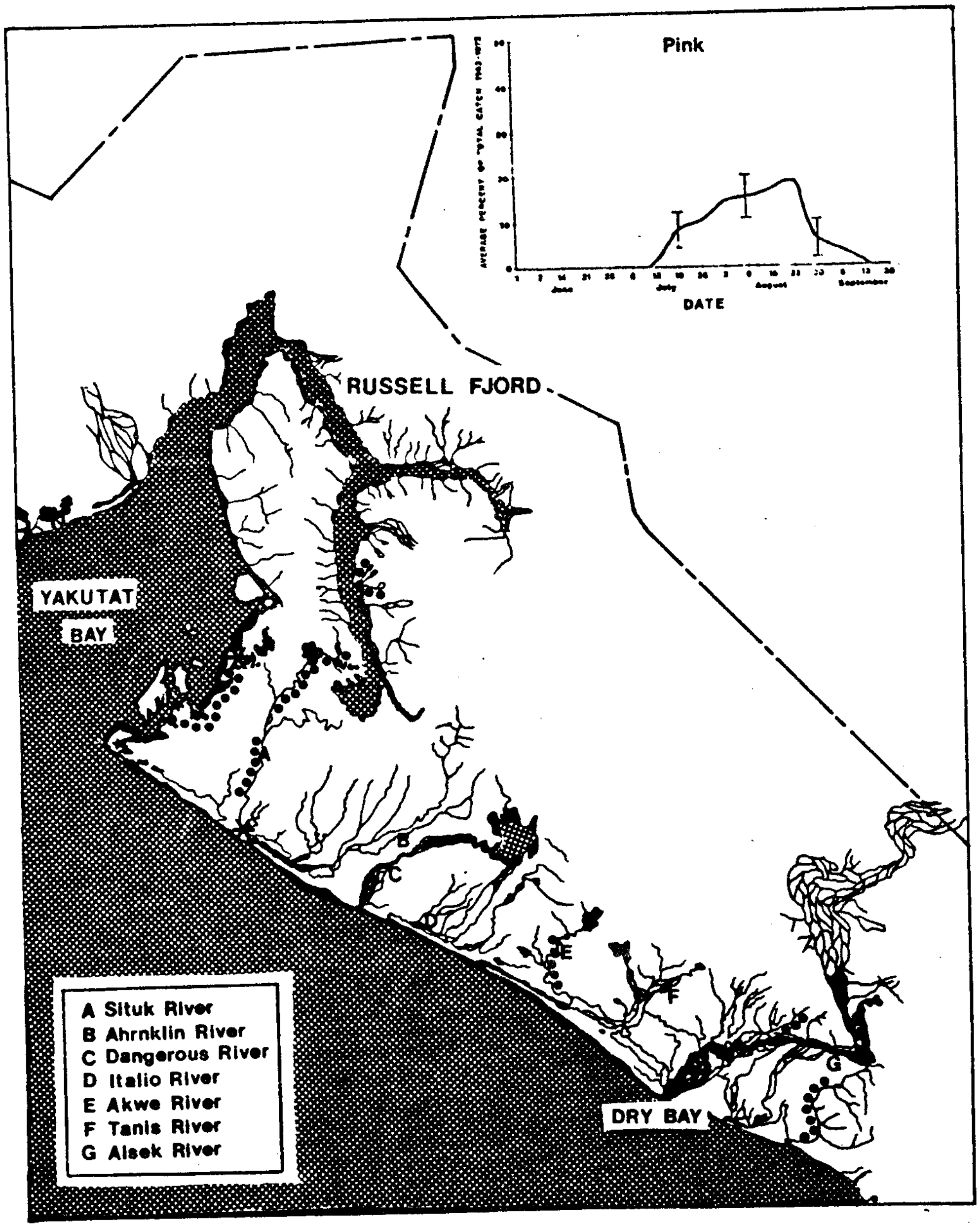

Fig. 5. Spawning sites of pink salmon in the Yakutat area (dots). The inset graph shows the average timing of pink salmon runs to the district with 95% confidence intervals on selected dates (determined from weekly catch statistics, 1963-1972).

Sources: Atkinson et al. 1967; McLean and Delaney 1978; and Stern et al. 1976.

Table 7 The commercial catch (numbers x 1000) of pink salmon in the Yakutat District, southeastern Alaska, and Alaska, 1959-1979.

Year	Yakutat	Southeastern Alaska	Alaska
1959	12	7,851	10,930
1960	14	2,985	16,079
1961	65	12,638	21,506
1962	28	11,585	43,864
1963	79	19,145	34,276
1964	40	18,581	45,291
1965	4	10,880	20,347
1966	1	20,438	40,051
1967	32	3,111	6,559
1968	2	25,085	44,727
1969	64	4,870	25,767
1970	4	10,657	31,147
1971	80	9,345	23,528
1972	3	12,400	15,920
1973	17	6,455	9,802
1974	4	4,889	9,859
1975	80	4,027	12,984
1976	29	5,330	24,751
1977	75	13,458	28,098
1978	30	19,988	52,668
1979	152	10,304	48,518
$\bar{X}$	40.8	11,701.1	28,333.7

Sources: International North Pacific Fisheries Commission 1979; Alaska Department of Fish and Game, preliminary data.

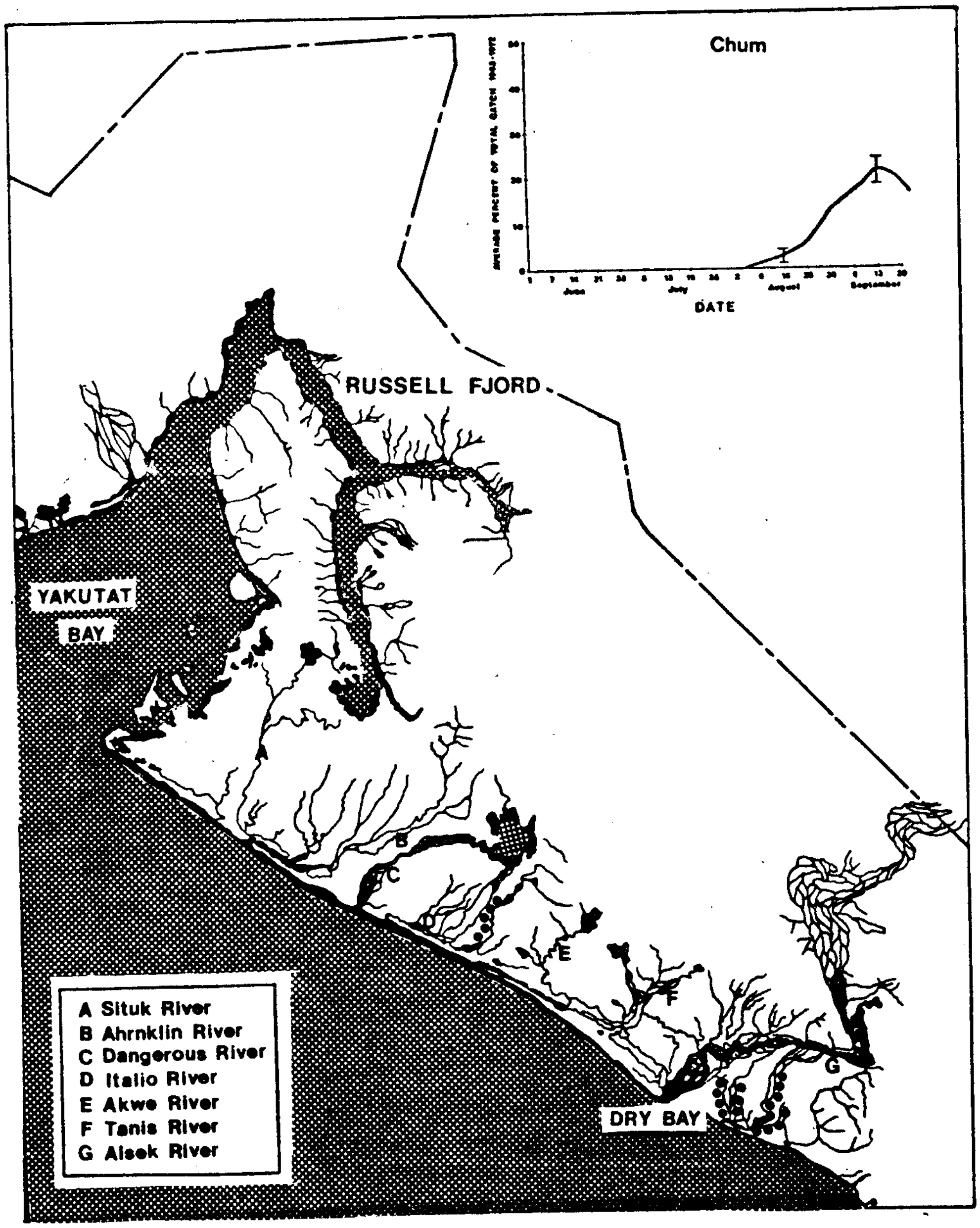

Fig. 6. Spawning sites of chum salmon in the Yakutat area (dots). The inset graph shows the average timing of chum salmon runs to the district with 95% confidence intervals on selected dates (determined from weekly catch statistics, 1963-1972).

Sources: Atkinson et al. 1967; McLean and Delaney 1978; and Stern et al. 1976.

Table 8. The commercial catch (numbers x 1000) of chum salmon in the Yakutat District, southeastern Alaska, and Alaska, 1959-1979.

Year	Yakutat	Southeastern Alaska	Alaska
1959	37	1,291	4,086
1960	12	1,019	6,625
1961	12	2,559	5,631
1962	18	1,996	7,149
1963	11	1,479	4,464
1964	6	1,936	7,271
1965	4	1,474	3,364
1966	3	3,273	6,456
1967	4	1,810	3,654
1968	14	2,644	6,082
1969	15	561	2,953
1970	7	2,446	7,500
1971	5	1,946	7,679
1972	8	2,942	7,065
1973	9	1,832	6,020
1974	4	1,683	4,730
1975	4	687	4,322
1976	8	1,031	5,925
1977	8	632	7,177
1978	6	597	6,368
1979	7	786	5,757
$\bar{X}$	10.1	1,731.2	6,013.9

Sources: International North Pacific Fisheries Commission 1979; Alaska Department of Fish and Game, preliminary data.

Coho Salmon *(Oncorhynchus kisutch)*

General Biology. This species is distributed along the west coast of North America from central California to the Aleutian Islands and Norton Sound, with a center of abundance between Oregon and southeastern Alaska. Coho range up to 98 cm long and 14 kg in weight. They spawn in the late fall in rivers and streams. Fecundity is related to the size of the female with 2,500 eggs per female 55 cm long to 5,000 eggs per female 70 cm long. Fry emerge in the early spring and remain in freshwater for about 1 year. Foods of juveniles that have reached saltwater include zooplankton, insects, small epibenthic crustacea such as gammarid amphipods, other benthic organisms, and fish (Rogers et al. 1980). After the coho migrate offshore, they feed on squid, amphipods, and shrimp. The maturing salmon feed and grow a great deal on their homeward migration. Their favored foods include herring and Pacific sand lance. (The preceding section is primarily derived from Hart 1973).

Experimental longlining and gillnetting in the Gulf of Alaska has revealed that coho salmon most frequently occur near the surface between 0-10 m and that they do not move below the thermocline (Godfrey et al. 1975).

Distribution and Abundance. The highest CPUE of juvenile coho salmon in coastal waters off Yakutat occurs during July and August, after which, most apparently move offshore. A large proportion, however, may reside in coastal water throughout their lives (Stern et al. 1976).

Spawning runs to the Yakutat District peak between late August and mid-September (Fig. 7). Coho occupy nearly every stream in the Yakutat area, and spawning populations have been observed in many of these. A large population spawns in the Situk/Ahrnklin River drainages.

Coho are the second most numerous salmon in commercial catches off Yakutat, but they only rank fourth in Alaska. Over 5% of the total catch of coho in Alaska orginated from the Yakutat District (Table 9).

Sockeye Salmon *(Oncorhynchus nerka)*

General Biology. In North America, sockeye salmon are distributed from northern California to the Aleutian Islands and the Canadian Arctic. They usually mature after 2-3 years at sea, with a maximum length at maturity of 84 cm long. Spawning occurs in rivers, streams, and on beaches of some lakes. Spawning grounds usually have access to lakes where the fry generally reside for 1-2 years. The number of eggs per female is related to size of the fish and ranges from 2,200-4,300. The length of incubation is temperature-dependent and ranges from 50-150 days. After hatching, the alevins remain in gravel for 3-5 weeks. Fry usually migrate into nursery lakes after emerging from the gravel. Migrations of smolts out of lakes begin in the spring when water

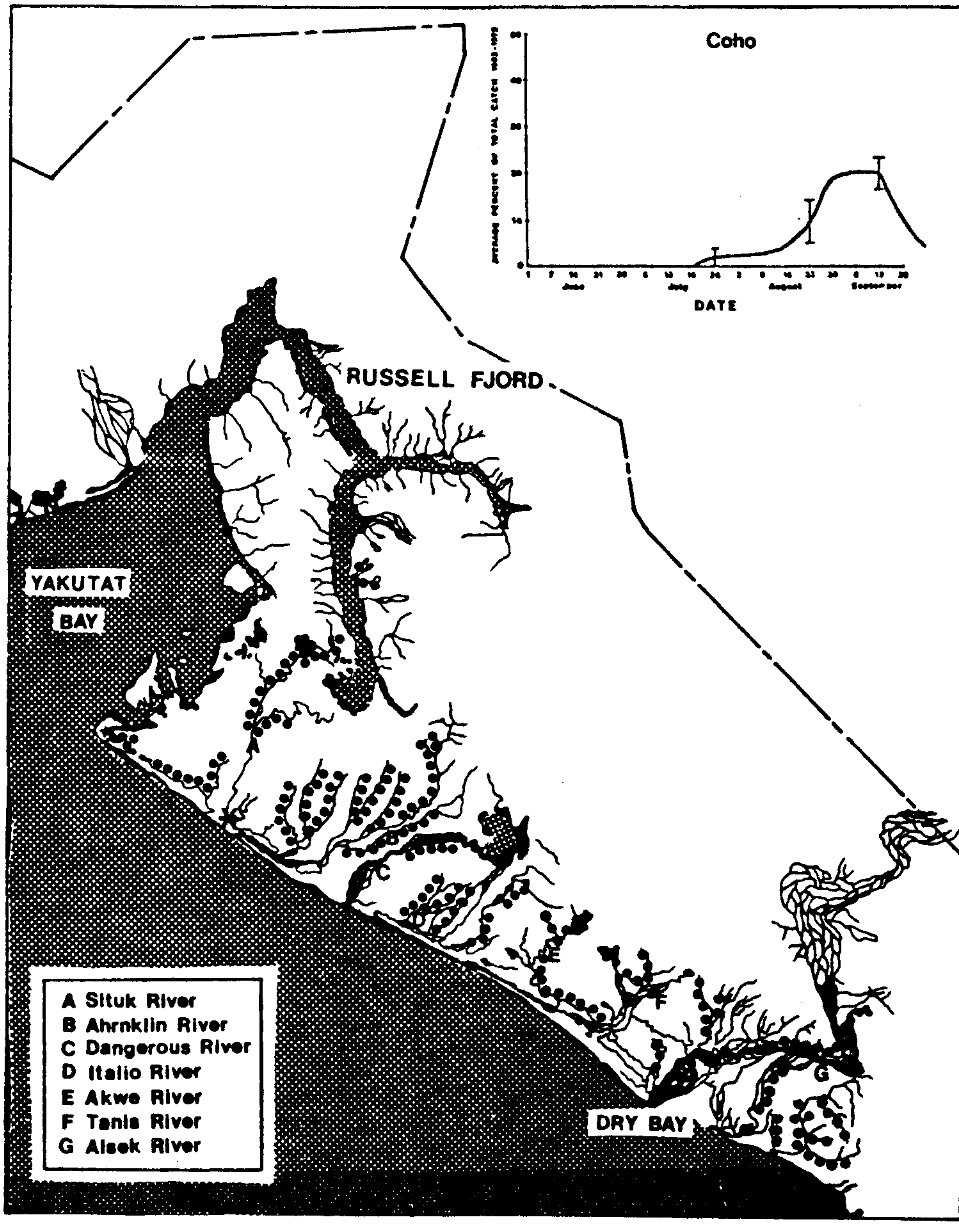

Fig. 7. Spawning sites of coho salmon in the Yakutat area (dots). The inset graph shows the average timing of coho salmon runs to the district with 95% confidence intervals on selected dates (determined from weekly catch statistics, 1963-1972).

Sources: Atkinson et al. 1967; McLean and Delaney 1978; and Stern et al. 1976.

Table 9. The commercial catch (numbers x 1000) of coho salmon in the Yakutat District, southeastern Alaska, and Alaska, 1959-1979.

Year	Yakutat	Southeastern Alaska	Alaska
1959	139	1,024	1,433
1960	121	721	1,404
1961	130	889	1,314
1962	190	1,223	2,039
1963	146	1,275	2,022
1964	170	1,588	2,558
1965	125	1,548	1,998
1966	67	1,227	1,921
1967	120	866	1,489
1968	122	1,543	2,751
1969	60	596	1,133
1970	39	759	1,527
1971	41	914	1,448
1972	56	1,509	1,831
1973	43	836	1,457
1974	79	1,278	1,855
1975	38	427	1,014
1976	52	824	1,432
1977	83	708	1,593
1978	130	1,573	2,614
1979	95	1,102	2,935
$\bar{X}$	102.3	1,121.5	1,888.4

Sources: International North Pacific Fisheries Commission 1979; Alaska Department of Fish and Game, preliminary data.

surface temperatures are 4-7°C. While in the coastal strip, the juveniles consume insects, zooplankton, small epibenthic crustaceans, and small fish (the preceding was modified from Hart 1973).

While in saltwater, sockeye stay in the upper 60 m between mid-May and early June. They continue to be in the upper 36 m in late June-July and are mostly shallower than 10 m during the summer. Sockeye salmon migrate toward the surface at night and probably always remain above the thermocline. During the winter, approximately 90% of the sockeye captured by test gillnets were within 15 m of the surface (Stern et al. 1976). According to Godfrey et al. (1975), sockeye tend to be in shallower water than the other four species of salmon.

Distribution and Abundance. Juvenile sockeye are in the coastal belt in July and August, after which they migrate offshore (Stern et al. 1976).

Mature sockeye spawn in several rivers in the Yakutat area (Fig. 8). More sockeye are caught commercially in the Yakutat area than any other species of salmon, but the catch in Yakutat is less than 1% of the total catch of sockeye in Alaska (Table 10). The peak of the run to Yakutat occurs in early July.

Chinook Salmon (*Oncorhynchus tshawytscha*)

General Biology. This species is distributed from central California to the Aleutian Islands and north to Norton Sound, and possibly Kotzebue Sound. The largest of the *Oncorhynchus* species, chinook salmon, mature at a maximum of 147 cm and 59 kg. Spawning runs occur throughout the year. Maturation is usually after the fourth or fifth year at sea and one female carries an average of 4,800 eggs. The fry generally migrate to sea soon after hatching, although some reside in freshwater for about one year. After reaching saltwater, the juveniles consume a variety of small fish, zooplankton, and small epibenthic crustaceans (from Hart 1973).

Chinook salmon occupy the greatest vertical range of all the Pacific salmon. They were frequently captured in herring trawls off the west coast of British Columbia and were common in water 20-110 m deep (Taylor 1969, cited in Major et al. 1978). Chinook salmon were captured in these trawls even during the summer when all the other species of salmon were in surface waters.

Distribution and Abundance. Like coho salmon, a large proportion of chinooks may reside in the coastal belt of the Northeast Pacific (Stern et al. 1976). The highest CPUE for juvenile chinook salmon is in July-August, after which, most apparently move offshore (Stern et al. 1976).

Chinook salmon spawn in only two rivers near Yakutat: the Situk and the Alsek (Fig. 9). Their spawning migration is earlier than the other

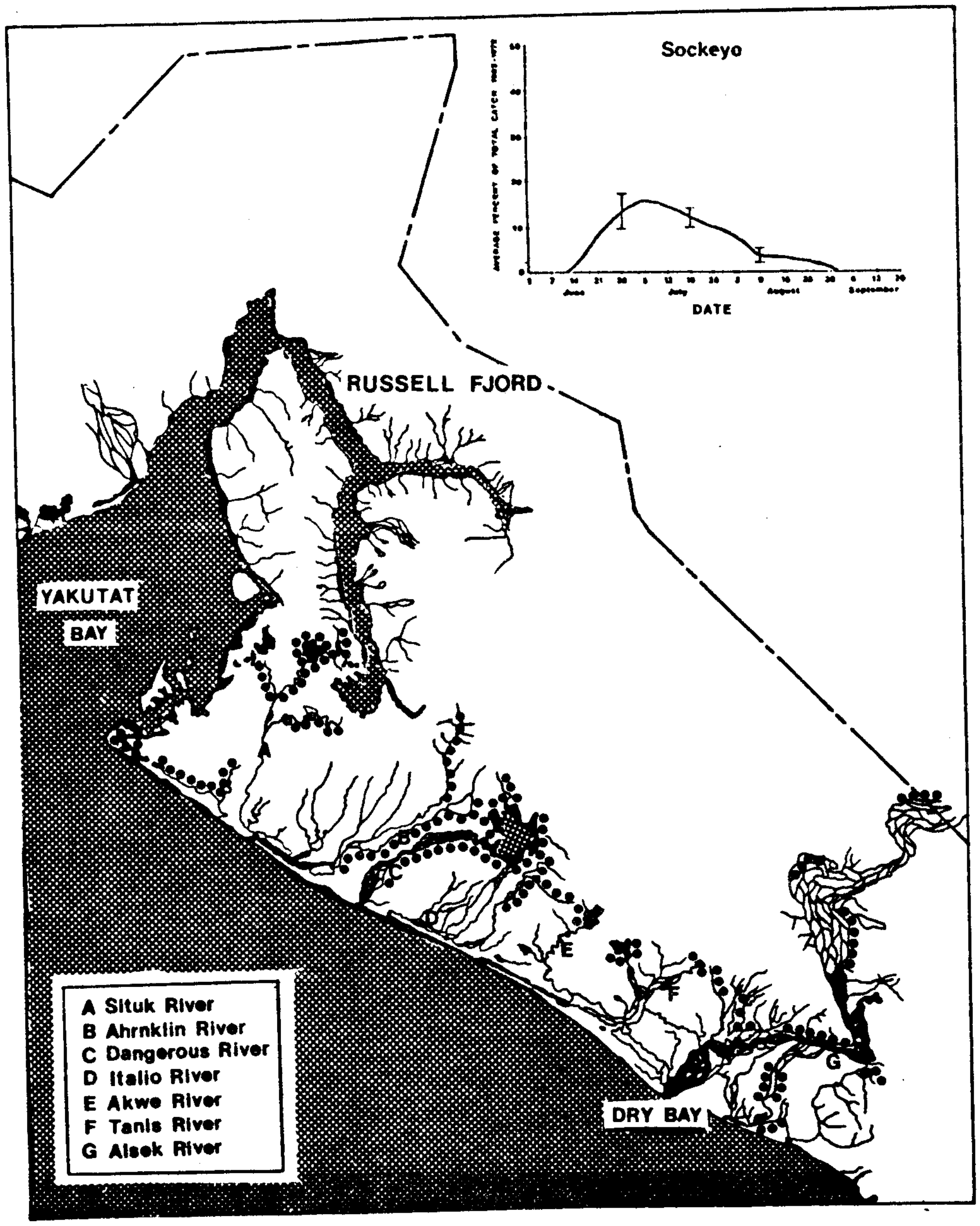

Fig. 8. Spawning sites of sockeye salmon in the Yakutat area (dots). The inset graph shows the average timing of sockeye salmon runs to the district with 95% confidence intervals on selected dates (determined from weekly catch statistics, 1963-1972).

Sources: Atkinson et al. 1967; McLean and Delaney 1978; and Stern et al. 1976.

Table 10. The commercial catch (numbers x 1000) of sockeye salmon in the Yakutat District, southeastern Alaska, and Alaska, 1959-1979.

Year	Yakutat	Southeastern Alaska	Alaska
1959	77	891	8,077
1960	48	588	17,834
1961	83	744	16,081
1962	81	772	9,297
1963	53	678	6,215
1964	92	924	9,966
1965	123	1,085	29,770
1966	185	1,054	15,073
1967	88	972	8,576
1968	81	831	8,130
1969	118	812	11,417
1970	112	668	27,634
1971	129	623	14,180
1972	131	917	6,590
1973	128	1,011	4,490
1974	83	687	4,869
1975	73	245	7,455
1976	130	595	11,783
1977	184	995	12,049
1978	128	692	17,787
1979	166	996	28,789
$\bar{X}$	114.6	839.0	13,803.1

Sources: International North Pacific Fisheries Commission 1979; Alaska Department of Fish and Game, preliminary data.

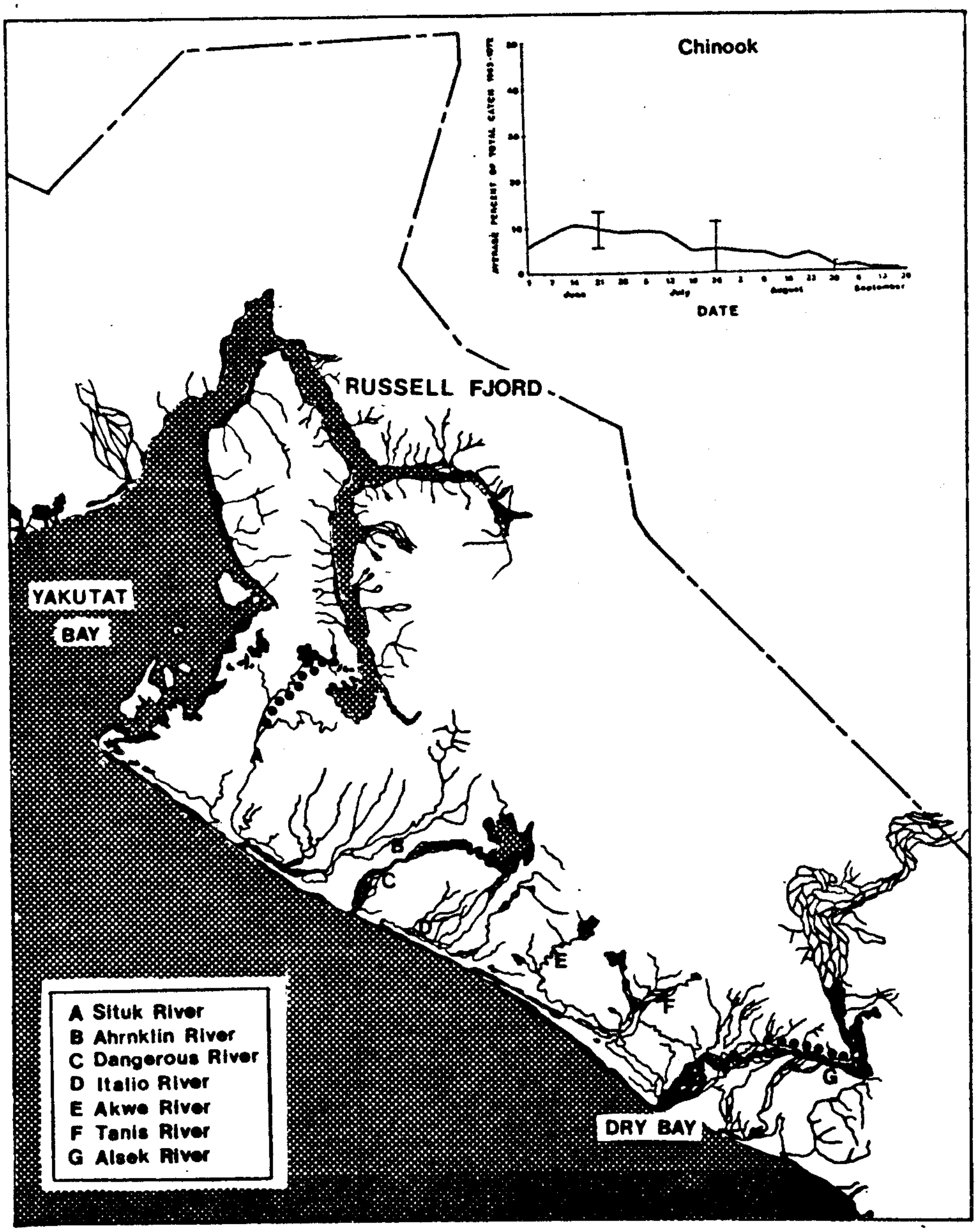

Fig. 9. Spawning sites of chinook salmon in the Yakutat area (dots). The inset graph shows the average timing of chinook salmon runs to the district with 95% confidence intervals on selected dates (determined from weekly catch statistics, 1963-1972).

Sources: Atkinson et al. 1967; McLean and Delaney 1978; and Stern et al. 1976.

salmon species, with the peak of the migration occurring in early June to mid-June. Annual catches have averaged only 4,200 fish. Chinook are thus the least abundant salmon in the Yakutat District and average less than 1% of the total catch of chinook salmon in Alaska (Table 11).

Demersal Fish and Shellfish

In recent years, there have been a number of exploratory studies on distribution, abundance, and species composition of ground fish species in the Northeast Pacific Ocean and the Gulf of Alaska. Hitz and Rathjen (1965) conducted a survey during the summer and fall of 1961 and the spring of 1962 in the northeastern Gulf of Alaska from Dixon Entrance to the Kenai Peninsula (Fig. 10). They trawled 617 stations to obtain an accurate account of the bottom topography to determine the extent of trawlable ground and the abundance and species composition of demersal fish and shellfish. A summary showing the ranking of species and species groups by depth (0-250 fm) is presented in Table 12.

Ronholt et al. (1978) reported on cruises that took place during June-August 1962, September-November 1962, and April-October 1973-1976 from Cape Spencer to Unimak Pass (Fig. 10). Alverson (1968) evaluated available information on exploited and unexploited fish and shellfish resources of the Northeast Pacific to document general distribution and stock magnitude. Maturgo (1972) compiled a report for the Shell Oil Company with figures on catch statistics gathered from about 2,500 exploratory drags by the National Marine Fisheries Service (NMFS) from 1950-1968 in the Gulf of Alaska.

Most catch statistics (foreign and domestic, where domestic includes both United States and Canadian catches) originate from the International North Pacific Fisheries Commission (INPFC). The INPFC's North Pacific region contains eleven areal divisions, and these are presented in Fig. 11. One of these is the Yakutat area, and it extends from 147°W longitude to 137°W longitude. Other catch statistics come from the Bureau of Land Management's (BLM) Yakutat Management area (Cape Suckling to Cape Fairweather) or the various regulatory areas, regions, and statistical areas (see Fig. 12) of the International Pacific Halibut Commission (IPHC).

Pacific Cod (*Gadus macrocephalus*)

General Biology. Along the shores of western North America, Pacific cod occur from Santa Monica, California, through Alaska to the Bering Sea (Hart 1973). The northern limit is reported as St. Lawrence Island (63°N) in the Bering Sea (Ketchen 1961). Pacific cod undergo seasonal vertical migrations, descending to depths of 300 fm in winter and entering shallower water in early summer. The extent of these migrations is influenced by seasonal temperature cycles (Ketchen 1961).

Table 11. The commercial catch (numbers x 1000) of chinook salmon in the Yakutat District, southeastern Alaska, and Alaska, 1959-1979.

Year	Yakutat	Southeastern Alaska	Alaska
1959	1	365	607
1960	1	310	547
1961	3	230	504
1962	3	206	461
1963	1	258	501
1964	2	357	639
1965	1	287	581
1966	2	308	540
1967	2	301	611
1968	4	332	611
1969	5	314	639
1970	10	322	646
1971	10	334	662
1972	6	287	553
1973	4	344	551
1974	8	347	556
1975	6	301	455
1976	6	242	533
1977	2	310	646
1978	3	389	794
1979	4	374	824
$\bar{X}$	4.2	325.9	623.0

Sources: International North Pacific Fisheries Commission 1979; Alaska Department of Fish and Game, preliminary data.

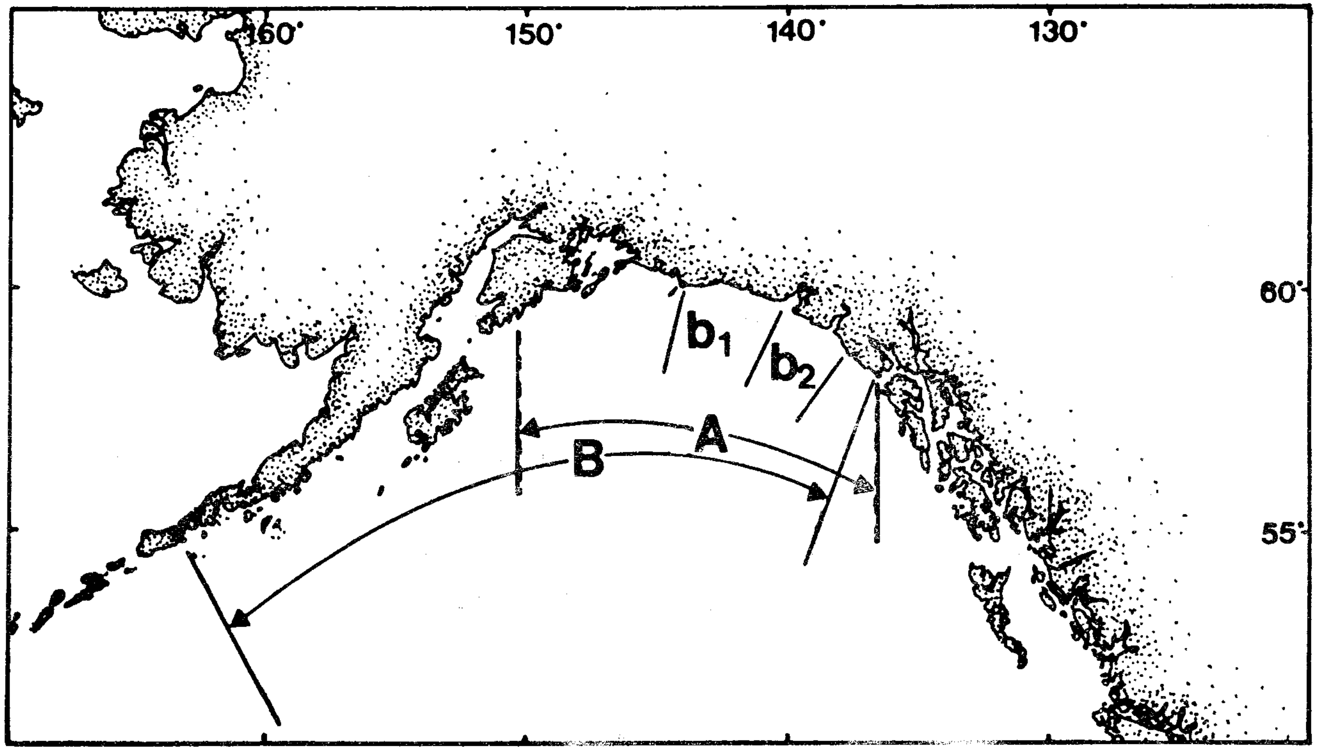

Fig. 10. Trawl surveys in the Gulf of Alaska:
A - Dixon Entrance to the Kenai Peninsula (Hitz and Rathjen 1965);
B - Cape Spencer to Unimak Pass;
b_1 - Yakutat region;
b_2 - Fairweather region (Ronholt et. al. 1978).

Table 12. Ranking of individual species or species groups by catch-per-unit-effort and depth for the Northeast Pacific. Figures in parentheses are pounds caught per hour trawled.

Depth (fm)					
1-50	51-100	101-150	151-200	201-250	All depths
PACIFIC COD (296)	ARROWTOOTH FLOUNDER (366)	ARROWTOOTH FLOUNDER (355)	Heart urchin (1,179)	Dover sole (499)	ARROWTOOTH FLOUNDER (330)
BUTTER SOLE (203)	Flathead sole (105)	Heart urchins (252)	ARROWTOOTH FLOUNDER (386)	SABLEFISH (428)	Heart urchins (171)
ARROWTOOTH FLOUNDER (129)	TANNER CRAB (84)	P.O.P. (204)	P.O.P. (158)	Other fish sp. (361)	P.O.P. (101)
STARRY FLOUNDER (125)	WALLEYE POLLOCK (84)	TANNER CRAB (106)	Dover sole (135)	Rougheye (336)	Flathead sole (82)
Starfish (81)	Starfish (78)	WALLEYE POLLOCK (91)	Flathead sole (72)	ARROWTOOTH FLOUNDER (218)	PACIFIC COD (76)
HALIBUT (61)	PACIFIC COD (74)	Flathead sole (78)	Rex sole (59)	Heart urchins (148)	TANNER CRAB (76)
DUNGENESS CRAB (38)	P.O.P. (58)	*Sebastolobus* (55)	HALIBUT (53)	Starfish (132)	WALLEYE POLLOCK (72)
English sole (37)	Heart urchins (58)	Starfish (49)	WALLEYE POLLOCK (30)	*Sebastolobus* (74)	Starfish (67)
Flathead sole (25)	HALIBUT (34)	SABLEFISH (42)	*Sebastolobus* (23)	Rex sole (24)	SABLEFISH (39)
SABLEFISH (13)	Skate (31)	Skate (36)	SABLEFISH (19)	Skate (20)	Dover sole (35)
Skate (13)	SABLEFISH (24)	Dover sole (35)	Skate (18)	Misc. invertebrate (19)	HALIBUT (32)
SCALLOP (10)	DUNGENESS CRAB (15)	Rex sole (31)	Starfish (9)	HALIBUT (8)	Skate (29)
Rex sole (10)	Misc. invertebrate (12)	Misc. invertebrate (18)	TANNER CRAB (5)	TANNER CRAB (8)	BUTTER SOLE (26)
WALLEYE POLLOCK (10)	Rex sole (11)	HALIBUT (18)	Other fish sp. (5)	Other rockfish (1)	*Sebastolobus* (22)
Rock sole (9)	Dogfish (9)	PACIFIC COD (12)	Shrimp (2)	PACIFIC COD (0.3)	Rex sole (20)
Dogfish (9)	Dover sole (7)	Rougheye (9)	Misc. invertebrate (1)	Dogfish (0)	STARRY FLOUNDER (16)

Source: Hitz and Rathjen (1965)

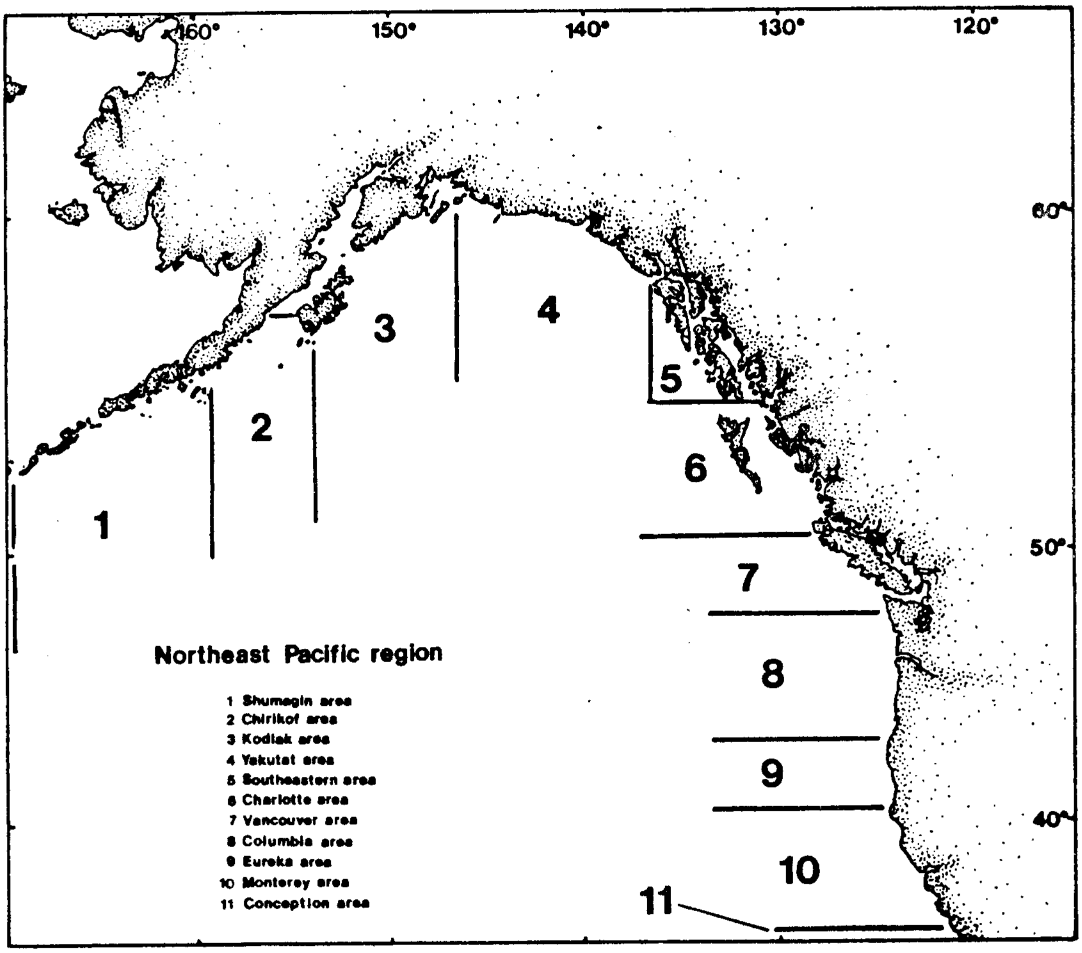

Fig. 11. Areal divisions of the Northeast Pacific region.

Source: Forrester et al. 1978.

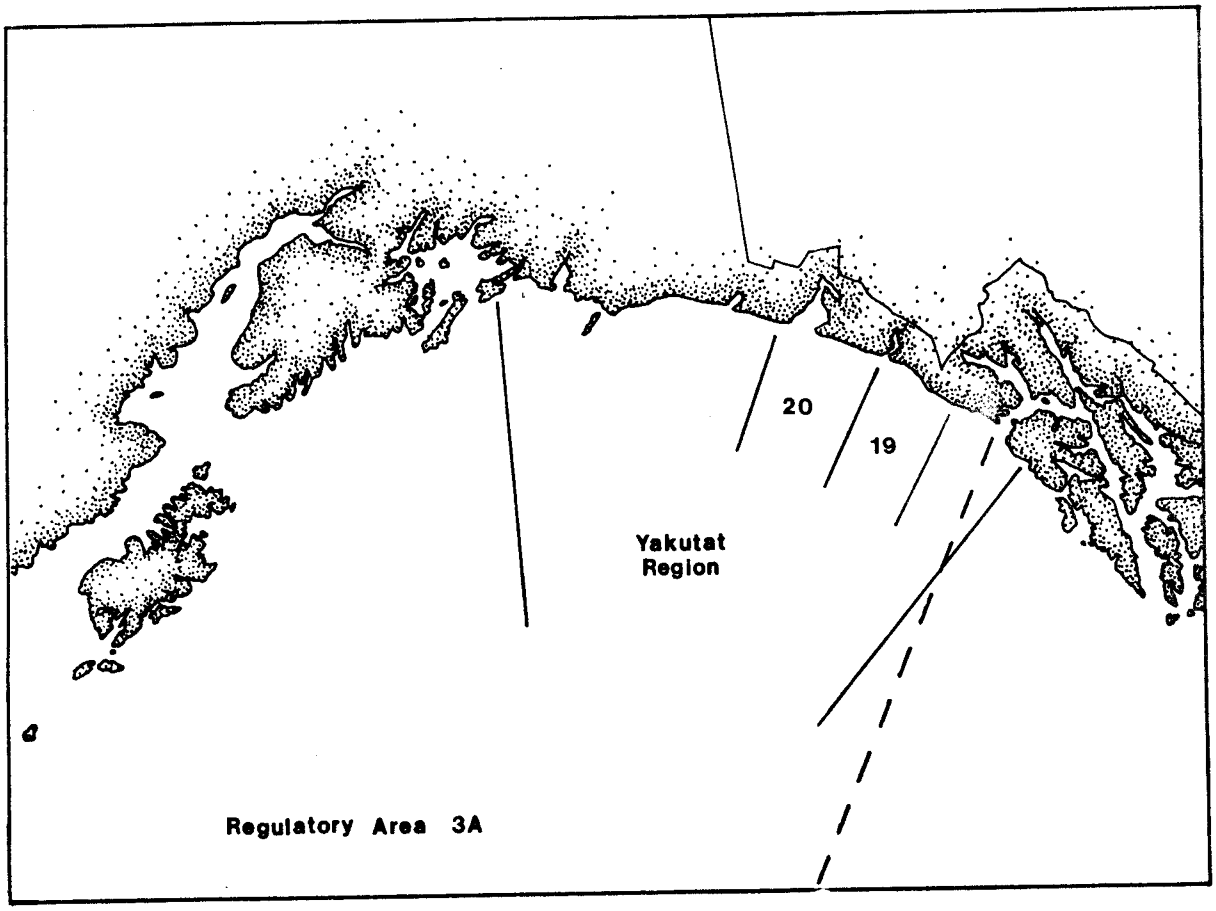

Fig. 12. The northeastern Gulf of Alaska showing a section of the International Pacific Halibut Commission's regulatory area 3A (Cape Spencer - dotted line - to Kupreanof Point), the Yakutat region, and statistical areas 19 and 20.

Source: Mayer et al. 1977.

Spawning of Pacific cod occurs in winter. Eggs are thought to be demersal (Thomson 1963; Forrester 1964) and range in diameter from .98-1.08 mm ($\bar{x}$ = 1.02 mm). Fecundity ranges from 1.5-3.0 million eggs for females 60-90 cm long (Thomson 1962). The size of fish at first maturity varies with area. In western Kamchatka, 50% of female Pacific cod were mature at about 70 cm (Moiseev 1953, cited in Hart 1973) while cod in British Columbia were mature at 55 cm for females and 50 cm for males (Thomson 1962). Age of first maturity is 2 or 3 years for both sexes (Ketchen 1961).

Hatching of eggs occurs in 1-4 weeks depending on water temperature: 8 days at 11°C, 17 days at 5°C, and 28 days at 2°C, and newly hatched larvae range from 3.5-4.0 mm (Forrester and Alderdice 1966; Forrester 1964). Larval illustrations are given by Gorbunova (1954). At one year, young cod from British Comunbia are 23-26 cm and at two years are 44-49 cm (Hart 1973).

Pacific cod tend to eat small epibenthic crustacea and zooplankton when they are small (Rogers et al. 1979), but as they grow, they rely less upon these organisms and more upon shrimp and fish. Several authors have named shrimp as the most important (and fish second) food item for Pacific cod (Hunter 1979; Feder 1977; Forrester 1969; Hart 1949; Karp and Miller 1977).

History of the Fishery. Unlike most demersal species, there has been a sizeable domestic fishery for cod for many years, the United States fishery beginning in the Okhotsk Sea in 1857. Until the turn of the century most fishing was in Asia and in the Bering Sea, but in 1907 processing stations were established in the Shumagin Islands and areas south of the Aleutian chain became more important. Cod line vessels were used during the early days of the fishery, but were discontinued in the early 1950's. Cod landings peaked during World War I at about 20,000 m.t. and in the 1960's have averaged about 10% of that (Table 13).

The Japanese catch most of their cod in the Bering Sea. In the Gulf of Alaska cod are taken in their stern trawl fishery, but between 1969 and 1971 less than 1% of this catch was Pacific cod. The Japanese stern trawl fishery has existed in the Gulf since 1963, but, except for one year, the Yakutat area has contributed very little to this catch. It has ranged from 0 to 7.2%, except for 1968 when it was 30.5% (Forrester et. al. 1978).

Distribution and Abundance

Adults. Pacific cod are relatively abundant and widely distributed in the Gulf of Alaska. In a trawl survey, Alverson (1968) reported that for the Northeast Pacific, cod ranked fourth by frequency of occurrence and fifth by abundance. Hitz and Rathjen (1965) reported that by catch-per-unit-effort (CPUE by weight), cod were the fourth most important fish species over all depths (1-250 fm) and that they were the

Table 13. Annual total catch (m.t.) of Pacific cod in the Northeast Pacific by the United States, Canada, and Japan.

Year	United States	Canada	Japan
1956	4,428	2,338	--
1957	5,364	3,858	--
1958	5,738	4,562	--
1959	6,033	4,167	--
1960	2,474	3,126	--
1961	1,390	2,063	--
1962	1,439	2,693	--
1963	2,887	4,047	180
1964	2,907	7,050	193
1965	4,597	11,098	584
1966	4,578	12,160	1,358
1967	3,986	6,601	2,156
1968	2,681	6,731	1,059
1969	1,730	4,394	1,345
1970	1,263	2,915	1,774

Source: Forrester et al. 1978.

most important species at depths of 1-50 fm (Table 12). Furthermore, Alverson et al. (1964) noted that cod occur in shallower waters than walleye pollock. Ronholt et. al. (1978) reported that cod were more abundant in waters to the north and west of Yakutat than in waters off Yakutat. For example, during the survey expeditions of April-October, 1973-1976, Pacific cod in the Fairweather region (Yakutat Bay to Cape Spencer) contributed only 1.1% to the total catch in the entire study area.

Larvae and Eggs. Pacific cod are reputed to spawn at depths of 100-250 m in the Bering Sea (Musienko 1970). In the Yakutat area, we can expect to find larvae distributed over the shelf. Larvae have been reported from the plankton in June and July in the Bering Sea (8.8-11.6 mm) (Musienko 1963), May and July in Cook Inlet (5.3-9.0 mm), April and May in Kodiak bays (Rogers et. al. 1979), and March-April, June-July on the Kodiak Shelf (Kendall et al. 1980). In every case catches of cod larvae were low relative to other larval fish taxa found at these times. In most cases, walleye pollock was the dominant gadid larvae collected.

Spawning occurs in winter and eggs are demersal, hence not accessible to plankton tows. We expect to find larvae in April-May and July-August in the Yakutat area.

Walleye Pollock (*Theragra chalcogramma*)

General Biology. Walleye pollock range from central California through the Bering Sea (Hart 1973). In Alaskan waters, some of the largest concentrations of pollock are in the northeastern shelf of the Bering Sea (Serobaba 1968) and in the western Gulf of Alaska (Hughes and Hirschhorn 1978). Walleye pollock are found from the surface to below 200 fm (366 m) although most catches are primarily between 50 and 300 m. It is possible that pollock are bathypelagic at depths greater than 200 m (Hart 1973).

Walleye pollock are late winter to spring spawners throughout their range. In British Columbia, larval pollock (4-22 mm) occur during April and May and in the western Gulf of Alaska, over 85% of adult pollock examined had spawned prior to their collection in May, implying that spawning occurred in March and April. Ripe males and females were obtained as late as August but were less than 0.1% of the fish sampled (Hughes and Hirschhorn 1978). Spawning in the Bering Sea begins in late February with fish in the southeastern Bering Sea spawning first. Most spawning occurs from late March to mid-June with the highest spawning rate in May (Serobaba 1968).

Sexual maturity is reached at age 3 for both sexes, although a small percentage of 2-year-old males were in a spawning condition near Kodiak. Lengths of first-mature fish from the Gulf of Alaska were 29-32 cm for males and 30-35 cm for females (Hughes and Hirschhorn 1978).

Spawning occurs at temperatures of 1-3°C in the Bering Sea (Serobaba 1968) and there is some evidence that pollock may spawn under sea ice (Kanamaru et al. 1979).

High densities of pollock occurred at 91-270 m during spring and summer in the western Gulf of Alaska (Hughes and Hirschhorn 1978). Spawning pollock in the Bering Sea occurred between 50 and 300 m and were rarely found over the continental slope (i.e., >300 m) (Serobaba 1968).

Eggs are pelagic (Kanoh 1954) and range from 1.35-1.45 mm in British Columbia (Hart 1973) to 1.46-1.65 mm in the Bering Sea (Serobaba 1968). Illustrations of developing eggs are given by Gorbunova (1954). During development, eggs remain pelagic and newly hatched larvae are 3.5-4.3 mm. Larvae have been described and illustrated by Gorbunova (1954). Most larvae are collected in upper layers (≥50 m) (Kanamaru et al. 1979) and larvae may undergo vertical migrations which are associated with growth (Kobayashi 1963).

Copepods, mysids, and euphausids are often the most important foods of juvenile pollock (Rogers et al. 1979; Simenstad et al. 1977; Nikol'skii 1954; Bailey and Dunn 1979; Smith et al. 1978) but as the fish grow, their reliance upon such prey becomes less, and prey such as fish and shrimp become more important (Bailey and Dunn 1979; Smith et al. 1978; Rogers et al. 1979).

History of the Fishery. Commercial exploitation of walleye pollock by domestic fishermen has been minor. In both the United States and Canada, this species has been utilized almost exclusively for animal food (Forrester et al. 1978) and in general, North American ground fish fleets have not expanded into the Gulf of Alaska beyond the Queen Charlotte Islands (Reeves 1972). Through the 1960's and 1970's, United States and Canadian landings have only averaged around 100 m.t. (220,500 lbs) each (Forrester et al. 1978).

Foreign fleets utilize pollock to a much greater extent, but fish more in the Bering Sea than in the Gulf of Alaska. The Japanese have fished for pollock in the northeastern Gulf, and their catches have ranged up to almost 18,000 m.t. (Table 14). The proportion of this to their total catch off Alaska is small because of the size of the Bering Sea fishery. In 1970, over 1 million m.t. of pollock was taken in the Bering Sea. The Yakutat region (Cape Suckling to Cape Spencer) is relatively unimportant to the Japanese fishery for pollock in the Gulf, and has ranged from 0 to only 12.3% of the total, except for 49% in 1968.

Distribution and Abundance

Adults. Walleye pollock are widely distributed in the Gulf of Alaska. Alverson (1968) reported that pollock ranked as the fifth most frequently caught fish, and as the fourth most abundant fish. In a

Table 14. Annual Japanese catches (m.t.) of walleye pollock in the Yakutat region and the Northeast Pacific, 1963-1970.

Year	Yakutat[1]	Northeast Pacific[2]
1963	--	1,141
1964	3	1,126
1965	--	2,746
1966	63	9,117
1967	805	6,526
1968	3,107	6,345
1969	1,878	17,993
1970	292	9,701

[1]Cape Suckling to Cape Spencer.
[2]Shumagin to Columbia regions.

Source: Forrester et al. 1978.

si ilar study Ronholt et al. (1978) reported that during April-October, 19/3-1976, pollock ranked highest in relative apparent abundance of any species captured. Hitz and Rathjen (1965) reported that pollock occurred over a wide depth range, but were most abundant in catches from between 51 and 200 fathoms (Table 12). In the Ronholt et al. (1978) study, catches in the Fairweather area were low during all cruises and comprised only 0.2% of the total catch during the latter cruise (April-October, 1973-1976).

Larvae and Eggs. Walleye pollock larvae and eggs are important components of the ichthyoplankton during early spring (April-May) in various parts of Alaska including areas in the southeastern Bering Sea, Kodiak shelf, and Cook Inlet. Eggs occur in the surface waters and are distributed throughout the water column. Larvae are caught more frequently and in higher abundances in subsurface waters than at the surface. During April and May larvae range from hatch size (3.5 mm) to 13 mm, and by summer, larvae are 16-38 mm (Table 15). We expect to find pollock eggs distributed throughout the Yakutat study area during April and May. In July, eggs may occur, but in lesser abundance than during spring sampling. Larvae are likely to be found during spring and summer and distributed over the shelf area. Pollock over 38 mm are not likely to be caught by plankton nets, but may be caught in other gears. These juvenile pollock may occur during October.

Pacific Ocean Perch (*Sebastes alutus*)

General Biology. Pacific ocean perch occur mainly offshore from southern California to the Bering Sea. In the Gulf of Alaska, Pacific ocean perch are at depths ranging from 50-450 m but usually are found near 180 m (Major and Shippen 1970). A well defined oxygen deficient layer may prevent movement into deeper water (Lyubimova 1965). Distribution may also be affected by food availability, state of maturity, and ecological factors (Major and Shippen 1970).

Rockfish mate before ovulation and sperm are stored in the ovary. Fertilized eggs are retained by the female (ovoviviparous) and larvae are extruded one to two months later (DeLacy et al. 1964). Descriptions of intraovarian larvae of some rockfish species, including Pacific ocean perch are given in Efremenko and Lisovenko (1972). Females contain between 2,000-69,000 eggs in the Gulf of Alaska (Lisovenko 1965) and 31,000-305,000 eggs off Oregon (Westrheim 1958). Lyubimova (1965) reported 10,000-270,000 larvae may be released and larvae are extruded at a size of 5-8 mm (Paraketsov 1963; Lisovenko 1964; Westrheim 1975). Separation of rockfish larvae by species is difficult from plankton samples and larvae will only be identified as *Sebastes* spp.

In the Gulf of Alaska, larvae were in upper layers over 200-250 m depths (Lisovenko 1964). In the Bering Sea, release of larvae was documented at 390-400 m depths and larvae ascended to 150 m off the bottom (Moiseev and Paraketsov 1961). Juvenile Pacific ocean perch remain

Table 15. Distribution and abundance of walleye pollock eggs and larvae in the Northeast Pacific Ocean and Bering Sea.

Stage	Location	Time	Gear	Station depths, m	Larval lengths, mm	Abundance	Reference
Larvae	Bering Sea	Apr-May 1977	bongo[1] neuston[2]	100-2000	3.1-11.8	Accounted for 84% of larvae caught in bongo tows; 34-108 larvae per haul or 194-695 per $10m^2$. Accounted for 6% of larvae caught in neuston net.	Waldron and Vinter 1978
Eggs	Bering Sea	Apr-May 1977	bongo[1] neuston[2]	100-2000		Accounted for 98% of eggs caught in the bongo; 32-154 per haul or 172-910 per $10m^2$. Comprised 97% of all eggs in the neuston hauls; 15-162 per haul or .6-6.7 per $10m^2$.	"
Larvae	Bering Sea	May-Jun 1971	bongo		5.4-8.0	Accounted for 1.5% of all larvae.	Dunn and Naplin 1973
Larvae	Bering Sea	Jun-Jul 1962	CPN[3]		16, 27	Only 2 larvae taken.	Kashkina 1970
Eggs	Bering Sea	Jun-Jul 1962	CPN			Only 16 stage I and II eggs.	"
Larvae	Bering Sea	Jun-Sep 1958 Mar 1959	CPN	135-3600[4]	5-13 21-38(fry)	Maximum concentration occurred in Mar and was 60 larvae per m^2.	Musienko 1963
Eggs	Bering Sea	Jun-Sep 1958 Mar 1959	CPN	77-3701[4]		Mass spawning in March, maximum concentration was 598 eggs per m^2.	"
Larvae	Kodiak Shelf	Apr-May 1972	bongo		3.5-5.2	Comprised 62% of all larvae; mean catch was 192 per $10m^2$; range was 0-12,118 larvae per $10m^2$.	Dunn and Naplin 1974
Eggs	Kodiak Shelf	Apr-May 1972	bongo			Accounted for 97% of all eggs; mean catch was 1792 per $10m^2$; range was 0-104,645 eggs per $10m^2$.	"

Table 15. Distribution and abundance of walleye pollock eggs and larvae in the Northeast Pacific Ocean and Bering Sea - continued.

Stage	Location	Time	Gear	Station depths, m	Larval lengths, mm	Abundance	Reference
Larvae	Kodiak Shelf	Nov 1977 Mar-Apr 1978 Jun-Jul 1978 Oct-Nov 1978 Feb-Mar 1979	bongo	40-1000		Second most abundant larvae during Mar-Apr.	Kendall et al. 1980
Eggs	Kodiak Shelf	Nov 1977 Mar-Apr 1978 Jun-Jul 1978 Oct-Nov 1978 Feb-Mar 1979	bongo neuston	40-1000		Most abundant egg species in each gear type during Mar-Apr.	"
Larvae	Kodiak Bays	Mar-Aug 1978 Nov 1978 Mar 1979	bongo neuston	39-171		In the bongo - eleventh most abundant larvae over all cruises and stations; average catch per bay was 0-102 larvae per $1000m^3$. Ranked 28th in neuston catches over all cruises and stations.	Rogers et al. 1979; Garrison and Rogers 1980
Eggs	Kodiak Bays	Mar-Aug 1978 Nov 1978 Mar 1979	bongo neuston			Second most abundant egg from bongo hauls over all cruises and stations; mean catch per bay ranged from 0-89 per $1000m^3$. Ranked third over all cruises and stations in neuston hauls; mean catch per bay ranged from 0-503 per $1000m^3$.	"
Larvae	Cook Inlet	Apr-May 1976 Jul-Aug 1976 Oct 1976 Feb 1976	bongo NIO[5]	35-210	3.6-9.4	Most abundant larvae in 6-13 Apr cruise; 32,083 larvae caught over 13 stations.	English 1977, 1978

[1]Bongo net, 60 cm diameter, 505μ mesh.
[2]Sameoto neuston sampler, .3m x .5m, 505μ mesh.
[3]Conical plankton net, No. 140 mesh.
[4]Depths of stations where larvae occurred.
[5]Nonclosing plankton net, 1m, 571μ mesh.

pelagic for 1-3 years before descending to a near bottom habitat (Lyubimova 1964; Carlson and Haight 1976). Juveniles make nocturnal vertical migrations to feed on planktonic crustaceans and the major food item of adults are euphausiids (Somerton 1978).

History of the Fishery. United States fishermen began to commercially exploit Pacific ocean perch in 1946 off the Oregon coast. Prior to 1946, other rockfish species were commercially fished in California and eventually the fishery moved northward. The Oregon-Washington areas became important fishing grounds and from 1961 to 1970, the bulk of the catch was from the Charlotte to Columbia areas. The fishing effort by United States fishermen for demersal species in the Northeast Gulf of Alaska has been low but there are plans to develop a groundfish fishery at Yakutat and four other Alaskan communities (Terry et al. 1980).

The bulk of the fishing has been carried out by foreign trawlers (Japanese, Soviets, South Koreans, Poles) and competition between them and domestic fishermen has been low in the Gulf of Alaska. By far, the Soviets and Japanese have carried on most of the fishing here. The Soviet fishery for Pacific ocean perch began in the Bering Sea in 1960 and briefly centered on the Gulf of Alaska before moving southward. Catches of over 225,000 m.t. were reported for the Gulf in 1964 and 1965 (Forrester et al. 1978). The Japanese, though, have largely concentrated on the eastern Gulf area. From 1966 to 1968, Yakutat (INPFC area) yielded the second highest catch of Pacific ocean perch (21% of all areas in the northeast Pacific region) in the Japanese stern trawl fishery. The Japanese catch of Pacific ocean perch at Yakutat from 1965-1974 is given in Table 16.

Distribution and Abundance

Adults. In the Gulf of Alaska, feeding schools of Pacific ocean perch occur in the Unimak, Shumagin, Kodiak and Yakutat regions during spring and summer (Lyubimova 1965). Both Pacific ocean perch and flatfish constitute a major portion of the standing stock of demersal fish in the Gulf. By 1972, catchable stocks of Pacific ocean perch were reduced to about 39% of their original levels in North America (Quast 1972). Even so, Pacific ocean perch are quite abundant. Alverson (1968) reported that Pacific ocean perch ranked second by abundance and sixth by frequency of occurrence. Hitz and Rathjen (1965) reported that (by CPUE) Pacific ocean perch were second in importance behind arrowtooth flounder and they became more important with depth (Table 12). Pacific ocean perch is abundant in the vicinity of Yakutat. Ronholt et al. (1978) reported that from 1973-1976, 17.6% of the total estimated Pacific ocean perch biomass (Cape Spencer to Unimak Pass, excluding the Shumagin region), occurred in the Yakutat and Fairweather areas. Pacific ocean perch seems to occur in large concentrations around submarine canyons (Reeves 1972) such as off Dry Bay (Hitz and Rathjen 1965). Comparisons of CPUE by decade (1962-1976) in both the Yakutat and Fair-

Table 16. Annual catch (m.t.) of Pacific ocean perch in the Yakutat region, the Fairweather area, and total catch for the Northeast Pacific.

Year	Yakutat[1]	Fairweather[2]	Total
1965	33	--	42,476[3]
1966	422	--	68,702[3]
1967	13,615	--	73,266[3]
1968	30,890	--	73,429[3]
1969	18,395	--	66,330[3]
1970	10,598	--	51,785[3]
1971	13,545	4,623	31,579[4]
1972	14,943	5,650	30,488[4]
1973	16,100	5,710	35,488[4]
1974	10,901	4,826	24,683[4]

[1]Cape Suckling to Cape Spencer.
[2]Yakutat Bay to Cape Spencer.
[3]Shumagin, Chirikof, Kodiak, Yakutat, and southeastern to Conception areas.
[4]Cape Spencer to Unimak Pass.

Sources: Forrester et al. 1978; Ronholt et al. 1978.

weather regions by Ronholt et al. (1978) seem to indicate a moderate decrease in Pacific ocean perch abundance. The largest decreases were in the upper slope area.

Larvae. Plankton studies from Alaskan waters report the distribution and abundance of rockfish larvae as *Sebastes* spp. due to the difficulty of separating species which may co-occur in plankton samples. *Sebastes* spp. have been reported from the majority of spring, summer, and fall cruises in Alaskan waters and significant concentrations of larvae have been reported from the Yakutat region during April and May (Lisovenko 1964).

Larvae may be distributed over the shelf, but more dense concentrations have been reported for areas over the slope (Lisovenko 1964; Kendall et al. 1980). They are also reported from bays in Kodiak Island (Rogers et al. 1979). Rockfish larvae have been caught in surface and subsurface tows and in greater abundance in tows during the night (Kendall et al. 1980). Rockfish up to lengths of 30 mm seem to be susceptible to capture in plankton nets (Table 17).

In the Yakutat study area, we expect to catch rockfish larvae in all seasons with relatively higher catches during spring. Larvae may be distributed over the shelf area and possibly at higher densities near the shelf edge.

Sablefish (*Anoplopoma fimbria*)

General Biology. Sablefish (or black cod) exist along the North American coast in the offshore waters from Cedrus Island, Baja California to Alaska and in the Bering Sea.

Sablefish spawn primarily from autumn through winter. From Vancouver Island to Oregon, spawning occurred from September to the end of February, and in the Bering Sea spawning peaked in fall and ended in early spring. However, some spawning continued into summer.

On the Pacific coast of North America, 50% of sablefish caught were sexually mature at ages 5-7 years and 60-70 cm in length. In the Bering Sea, 50% were sexually mature at 5-6 years and 60-62 cm in length (Kodolov 1968). Fecundity is high and increases with age for Bering Sea sablefish: 725 cm length - 438,000 eggs; 740 cm length - 468,000 eggs; and 825 cm length - 503,000 eggs (Kodolov 1968).

It is thought that sablefish spawn at considerable depth and probably beyond the continental slope. Eggs are pelagic, smooth, have a narrow perivitelline space, and range from 2.056-2.097 mm in diameter (Thompson 1941). Larvae have been illustrated by Kobayashi (1957) and post-larvae (21-35 mm) are described by Brock (1940).

Table 17. Distribution and abundance of *Sebastes* spp. larvae in the Northeast Pacific Ocean and Bering Sea.

Location	Time	Gear	Station depths, m	Larval length, mm	Abundance	Reference
Bering Sea	Apr-May 1977	bongo[1] neuston[2]	100-1000	5.0-8.3	Fourth in abundance in bongo hauls, comprising 3.7% of larvae caught. Accounted for .7% of all larvae from neuston tows.	Waldron and Vinter 1978
Bering Sea	May-Jun 1971	bongo		3.6-8.0	Accounted for 51% of larvae caught.	Dunn and Naplin 1973
Bering Sea	Jun-Jul 1962	CPN[3]		8.2-14.6	Total of 13 larvae caught.	Kashkina 1970
Bering Sea	Jun-Sep 1958 Mar 1959	CPN	58-3600	5.3-19.4	Caught in surface tows during July and August.	Musienko 1963
Kodiak Shelf	Apr-May 1972	bongo			Represented less than .1% of all larvae caught.	Dunn and Naplin 1974
Kodiak Shelf	Oct-Nov 1977 Mar-Apr 1978 Jun-Jul 1978 Oct-Nov 1978 Feb-Mar 1979	bongo neuston	40-1000		Occurred in bongo during summer and fall, second most abundant larvae during summer. Present in summer, fall, and winter in neuston catches.	Kendall et al. 1980
Kodiak Bays	Mar-Aug 1978 Nov 1978 Mar 1979	bongo neuston	31-171		Occurred June-August in relatively low abundances. Ranked 13th in bongo catches and 20th in neuston catches overall stations and cruises.	Rogers et al. 1979; Garrison and Rogers 1980.
Cook Inlet	Apr-May 1976 Jul 1976 Aug 1976 Oct 1976	bongo NIO[4]	35-210	3.0-18.0	Larvae caught during all cruises. Total numbers caught per cruise ranged from 3-57.	English 1977, 1978

Table 17. Distribution and abundance of *Sebastes* spp. larvae in the Northeast Pacific Ocean and Bering Sea - continued.

Location	Time	Gear	Station depths, m	Larval length, mm	Abundance	Reference
Gulf of Alaska	Sep-Oct 1975	bongo NIO		4-16	Most abundant larvae caught, 93 specimens.	English 1976
Gulf of Alaska	Apr-Jul 1963	CPN	90-3000		Highest concentrations: Yakutat - 100-200 per m^2; Kodiak - 40-50 per m^2; Shumagin - 20-30 per m^2; Unimak - 10-15 per m^2.	Lisovenko 1964
Gulf of Alaska	Summer 1957 Summer-Fall 1958	IKMT[5]			Reports catches of postlarvae and juveniles. Data not quantifiable.	Aron 1958
Northeast Pacific	May-Sep 1956 Mar-Sep 1957 Mar-Aug 1958 Mar-Jul 1959	NPN[6]			Most frequently occurring larvae during 1956-1959.	LeBrassuer 1970
Northeast Pacific	Oct-Nov 1971	bongo		10.6-30.6	Represented 2.3% of all larvae caught.	Naplin et al. 1973

[1]Bongo net, 60 cm diameter, 505μ mesh.
[2]Sameoto neuston sampler, .3m x .5m, 505μ mesh.
[3]Conical plankton net, No. 140 mesh.
[4]Nonclosing plankton net, 1m, 571μ mesh.
[5]Isaacs-Kidd midwater trawl, 3′ and 6′.
[6]Norpac net.

arvae and young in early stages lead a pelagic life and remain in upper layers at surface temperatures of 9-16°C. Brock (1940) observed larvae 21-35 mm long in surface waters 100-180 miles from the Oregon coast during May. In summer large numbers of young sablefish remain over the continental slope and shelf although juveniles measuring 7.6-26 cm are also in surface waters along the shores of the United States, Canada, and well heated bays in Alaska (Kodolov 1968) and schools of juveniles occasionally come inshore into harbors (Cox 1948, cited in Hart 1973). When fry are about 12 cm and 5-7 months old they approach the shelf or upper slope and massive descent of fry takes place in the fall at sizes of 30 cm. In winter, young are on the shelf or adjoining parts of the slope (Kodolov 1968).

Sablefish are chiefly piscivorous (Shubnikov, 1963; Grinols and Gill, 1968; Rogers et al. 1979) but also consume ophiuroids, shrimp and other invertebrates (Shubnikov, 1963). Shrimp ranked a high second in the diet of sablefish caught in the nearshore zone of Kodiak Island (Rogers et al. 1979).

The History of the Fishery. The fishery for sablefish dates back to before 1900 off Washington and British Columbia and it later expanded to California, Oregon, and Alaska. During both World Wars, black cod was in demand. However, recently it has not been important to the domestic fishery. United States landings in the Northeast Pacific from 1956 to 1970 averaged over 1,000 m.t., and ranged from 739 to 2,485 m.t. The bulk was caught by longline gear (Table 18). Most of the Canadian longline fishery is off the southern British Columbia coast and southeastern Alaska. Since 1957, yearly catches by the Canadians in the the Northeast Pacific have not exceeded 1,000 m.t.

Although the Soviets have no specific fishery for sablefish, the Japanese have been fishing for this species since 1958. Their original efforts were in the Bering Sea and by 1963, they were fishing in the Gulf of Alaska (Table 19); first with sunken gillnets, then trawlers, then longline gear. By 1968, the bulk of sablefish were taken by longline gear and in 1970, the total catch by the Japanese in the Gulf of Alaska was nearly 30,000 m.t. Yakutat and southeastern Alaska have become major fishing grounds for sablefish to the Japanese and in 1968 these areas contributed 79% to their total sablefish longline catch (Reeves 1972).

Distribution and Abundance

Adults. Sablefish are an important species of groundfish in the Gulf of Alaska. In a trawl survey of demersal species, Alverson (1968) reported that they ranked as the eight most abundant and frequently caught fish in the Northeast Pacific Ocean. They are relatively important at all depths, but are caught mainly in water deeper than 200 fm (Table 12). Sablefish were taken mainly from the deepest 50 fm interval trawled (1-250 fm), and off Yakutat the CPUE was highest in the

Table 18. Annual total catch (m.t.) of sablefish by the United States, Canada, and Japan in the Northeast Pacific.

Year	United States	Canada	Japan
1956	2,485	354	
1957	924	1,019	
1958	852	383	
1959	1,254	362	
1960	1,505	705	
1961	919	306	
1962	1,910	428	
1963	1,085	396	1,819
1964	940	637	1,047
1965	988	649	2,217
1966	1,084	970	3,952
1967	749	591	7,526
1968	739	577	17,570
1969	1,104	391	24,673
1970	1,444	327	29,811

Source: Forrester et al. 1978.

Table 19. Annual catch (m.t.) of sablefish in the Yakutat region by year and the total catch for the Northeast Pacific. Catch data for 1971-1974 for stern trawl only.

	Yakutat[1]				Total[2]			
Year	Long-line	Stern trawl	Other	Total	Long-line	Stern trawl	Other	Total
1963			229	229		261	1,558	1,819
1964						1,046	1	1,047
1965		4		4		2,140	77	2,217
1966		32		32		3,841	111	3,952
1967	213	1,418		1,631	569	6,893	64	7,526
1968	3,112	2,454		5,566	12,029	5,541		17,570
1969	5,121	1,666		6,787	19,639	5,034		24,673
1970	6,935	1,318		8,253	25,670	4,141		29,811
1971	--	1,290	--	--	--	3,182	--	--
1972	--	2,666	--	--	--	6,521	--	--
1973	--	1,687	--	--	--	5,393	--	--
1974	--	1,280	--	--	--	3,100	--	--

[1]Approximately Cape Suckling to Cape Spencer.

[2]Total catch for 1963-1970 includes Shumagin, Chirikof, Kodiak, Yakutat, and southeastern to Conception areas. Total catch for 1971-1974 includes Cape Spencer to Unimak Pass.

Source: Forrester et al. 1978; Ronholt et al. 1978.

canyon off Dry Bay (Hitz and Rathjen 1965). Furthermore, Terry et al. (1980) reported that commercial quantities of black cod adults are most abundant from 200 to 500 fm. According to Ronholt et al. (1978), there appears to have been a general decline in the density of sablefish in the eastern Gulf of Alaska from 1962 to 1976. The importance of the catch from the Fairweather area (Cape Spencer to Yakutat Bay) in relation to other areas (Fairweather through Kenai) varied by date. Fairweather area ranked second and first in the catch of sablefish, containing 28% and 69% of the total catch respectively. However, during April-October, 1973-1976, this area contained less than 2% of the total catch.

Larvae and Eggs. Sablefish larvae (11.5-43 mm) have been reported from plankton sampling during spring and summer in the Bering Sea (Waldren and Vinter 1978; Kashkina 1970; Kobayashi, cited in Kashkina 1970), and during the summer off the Kodiak Shelf (Kendall et al. 1980). In the Bering Sea, larvae were over depths of 105-115 m and in Kodiak they occurred at stations near the shelf break. Larvae have been caught in both surface (neuston) and subsurface (bongo) plankton tows, but usually in relatively low abundance.

It is unclear if sablefish in the eastern Gulf of Alaska spawn in fall or winter or throughout both seasons. However, since young remain pelagic through fall of the following year they may be in plankton samples during spring and summer. Since larvae are relatively well developed by summer, they may be able to avoid plankton gear except at night. Lampara sets at the surface may yield larger larvae and juveniles in late summer. Larvae are expected to occur over the shelf area and possibly be more abundant at deeper stations.

Arrowtooth Flounder (*Atherestes stomias*)

General Biology. Arrowtooth flounder range from central California to the eastern Bering Sea. They are generally caught at depths from 400 to 499 fm (730-900 m) and young have been caught at depths greater than 700 m (Hart 1973).

Little information is available on the early life history of arrowtooth flounder. Spawning is thought to occur in December-March, with peak activity in January and February, at depths greater than 150 m, and at temperatures of 2-3°C (Pertseva-Ostroumova 1960).

In the Asian arrowtooth flounder, *A. evermanni*, females reach sexual maturity at 9 or 10 years and males at 6 or 7 (Pertseva-Ostroumova 1961). Eggs are large, 2.5-3.5 mm and bathypelagic-developing in deep water. Larvae are distinct from other flatfish in that they have spines on the preoperculum and above the eyes. Descriptions and illustrations of larvae are given in Pertseva-Ostroumova (1961).

Arrowtooth flounder feed largely on crustaceans and fish. Smith et al. (1978) reported that the most frequently consumed food was euphausiids and that they increased in importance as the fish grew to 350 mm long. For larger arrowtooth flounder, fish became the most important food. Rogers et al. (1979) indicate that arrowtooth flounder feed primarily upon fish and secondarily upon shrimp. This specialized feeding is further echoed in the literature; Hart (1973) listed shrimp and herring, and Hunter (1979) stated that fish (mostly pollock) comprised comprised 98.6% to the weight of the diet of arrowtooth flounder sampled near Kodiak Island.

History of the Fishery. Arrowtooth flounder or turbot is one species of flatfish important to domestic commercial trawl fisheries. However, United States and Canadian efforts have largely been south of the Queen Charlotte region.

Japanese efforts for flatfish in the Gulf are small compared to their effort in the Bering Sea, but catches in the Gulf of Alaska from 1963 to 1970 averaged around 4,000 m.t. In 1969 and 1970, about 40% of this was arrowtooth flounder (Table 20). Japanese catches of arrowtooth flounder from 1969 to 1974 in the Gulf of Alaska averaged 2,371 m.t.

Distribution and Abundance

Adults. The arrowtooth flounder is a very common species in the northeastern Gulf of Alaska. According to Alverson (1968), it was the most frequently encountered and most abundant demersal species in the northeastern Pacific. In fact, in one study, it occurred in 90% of all trawl tows in the Gulf (Alverson et al. 1964). These large abundances and high frequency of occurrence are perhaps related to its wide geographic and/or bathymetric distribution. Hitz and Rathjen (1965) reported that it was the most important species (by CPUE in lbs) for all depths (1-250 fm) and that for each 50 fm interval it ranked in the top five (Table 12). Furthermore, Taylor (1967) stated that catches of arrowtooth flounders (using a midwater trawl) were highest near the surface at night. Within the northeastern Gulf area, arrowtooth flounder are very abundant (CPUE) off Yakutat Bay (Ronholt et al. 1978) and off Dry Bay (Hitz and Rathjen 1965) with the latter yielding up to 4,500 lbs per hour trawled. Comparisons between 1962 surveys and 1973-1976 surveys indicate an area-wide change. Ronholt et al. (1978) state that the CPUE for almost all species declined from one period to the next and that the CPUE ratio between "decades" showed a moderate decrease for arrowtooth flounder in the Fairweather region (Yakutat Bay to Cape Spencer) and a moderate increase for arrowtooths in the Yakutat region (Cape Suckling to Yakutat Bay). Both areas contributed a combined 27.5% to the total (Cape Spencer to Unimak Pass, except the Shumagin region), during April-October, 1973-1976.

Table 20. Annual Japanese trawl catches (m.t.) of arrowtooth flounder in the Fairweather and Yakutat regions, and in the Gulf of Alaska, 1969-1974.

Year	Fairweather[1]	Yakutat[2]	Gulf of Alaska[3]
1969	359	474	1,467[4]
1970	504	301	1,588[4]
1971	88	125	1,293
1972	166	202	1,612
1973	216	1,406	5,110
1974	50	356	3,157
$\bar{X}$	230.5	477.3	2,371.1

[1]Yakutat Bay to Cape Spencer.
[2]Yakutat Bay to Cape Suckling.
[3]Cape Spencer to Unimak Pass.
[4]This compares with a total Japanese catch (of all flatfish other than halibut) of 3,480 and 4,091 m.t. for 1969 and 1970, respectively.

Sources: Ronholt et al. 1978; Forrester et al. 1978.

Larvae and Eggs. Catches of arrowtooth flounder larvae and eggs are reported from the eastern Bering Sea, Kodiak Shelf and Gulf of Alaska in winter and spring. Larval catches were relatively low partly because of the time and location of plankton surveys. Generally, larvae are most often taken in waters beyond the shelf (>200 m) and over depths as deep as 3,000 m. Plankton-caught larvae range in length from 5-38 mm (Table 21).

In the proposed study area, eggs and larvae are expected to occur primarily at stations near the edge of the shelf during April-May, however they may drift landward into shallower stations. Larvae may transform at fairly large sizes (Musienko 1963) hence remaining susceptible to plankton nets through summer. By October, arrowtooth flounder juveniles will have assumed a demersal lifestyle and be out of reach of our gear.

Starry Flounder (*Platichthys stellatus*)

General Biology. Starry flounder occur off the coast of North America from southern California to the Bering Sea at depths of a few inches to approximately 150 fm (Hart 1973). Adults seem to prefer soft sand but may be found on gravel, clean shifting sand, hard stable sand, and mud substrates; however, they avoid rocky bottoms (Orcutt 1950). Starry flounder are euryhaline and may be found at river mouths and in some cases many miles upstream. They spawn at sea at depths of 11-75 m (Musienko 1970).

Spawning of starry flounder occurs in winter through early spring and takes place in shallow water. Age of maturity for males is two years when they are about 300 mm, whereas as females mature at three years (350 mm). Spawning occurs once per season and in a relatively short period of time. A 565 mm female was reported to release about 11 million eggs (Orcutt 1950).

Starry flounder eggs are pelagic, lack oil globules, and are .89-.94 mm long in California waters (Orcutt 1950) and .97-1.01 mm in Japanese waters (Yusa 1957). At present, early-middle stage eggs of starry flounder cannot be distinguished from early stages of several other pelagic flatfish eggs from plankton samples.

At 12°C development of eggs takes about 68 hours. At colder temperatures (2.0-5.4°C) eggs hatch in about two weeks. Egg and larval development has been documented by Orcutt (1950) and Yusa (1957). Newly hatched larvae are 1.93-2.08 mm, slender, transparent, and pelagic. Estuarine conditions may be important to juvenile starry flounder as large number of 0-1 year age classes have been caught upstream in the Columbia River (Haertel and Osterberg 1967).

The diet of starry flounder consists mainly of benthic organisms. Rogers et al. (1979) reported that they ate anthozoans and gammarid

Table 21. Distribution and abundance of arrowtooth flounder eggs and larvae in the Northeast Pacific Ocean and Bering Sea.

Stage	Location	Time	Gear	Station depths, m	Larval length, mm	Abundance	Reference
Larvae	Bering Sea	Apr-May 1977	bongo[1]	100-2000 (caught at stations >200 m)	8-10	Comprised 1% of all larvae caught, but second most abundant flatfish.	Waldron and Vinter 1978
Larvae	Bering Sea	May-Jun 1971	bongo	1281-3109[2]	6-13	Accounted for 9.0% of all larvae, 87% of all flatfish caught.	Dunn and Naplin 1973
Larvae	Bering Sea	Jun-Sep 1958 Mar 1959	CPN[3]	540-3100	13 (June) 27-38 (July)	Rare	Musienko 1963
Larvae	Kodiak Shelf	Apr-May 1972	bongo		6.1-7.0	Comprised .2% of all larvae.	Dunn and Naplin 1974
Larvae	NE Pacific	Apr-May 1957 Mar-Jul 1958	NPN[4] IKMT[5]			Rare, catches ranged from 1-5 per haul.	LeBrasseur 1970
Larvae	Kodiak Shelf	Oct-Nov 1977 Mar-Apr 1978 Jun-Jul 1978 Oct-Nov 1978 Feb-Mar 1979	bongo	40-1000 (caught at stations >200 m)	7-8	Feb-Mar 1979: Overall mean catch 8.2 per $10m^2$, only flatfish larvae present.	Kendall et al. 1980
					5-10	Mar-Apr 1978: Overall mean catch 7.5 per $10m^2$, second abundant flatfish larvae caught.	"
Eggs	" "	" "	"	"		Feb-Mar 1979: Fourth abundant egg taxa out of 6 species occurring.	"

[1]Bongo net, 60 cm opening, 505μ mesh.
[2]Depths of stations where larvae were caught.
[3]Conical plankton net, No. 140 mesh.
[4]Norpac net.
[5]Isaacs-Kidd midwater trawl, 3′ and 6′.

amphipods while Hunter (1979) reported that they ate clams. According to Cross et al. (1978) polycheates and gammarids predominated in the diet. Skalkin (1963) listed clams, polycheates and sand lance as important foods and Miller (1967) discovered that priapulids and nemertian worms predominated by volume.

History of the Fishery. Starry flounder is not a species exploited by either domestic or foreign fisheries, although flatfish in general are. United States exploitation of flatfish has centered on species found in relatively deep water from the Queen Charlotte area south (landings averaged 22,000 m.t. from 1961-1970, Forrester et al. 1978).

Japanese and Soviet fleets have fished largely in the Bering Sea for yellowfin sole. The Japanese have done some fishing for flatfish in the Gulf of Alaska and up to 87% of the catches (of flatfish other than halibut and arrowtooth flounder) in their trawl fishery are from the Yakutat and Fairweather regions (Table 22). This fishery is outside the zone of maximum abundance of starry flounder, so probably very few of the fish taken by this fishery are starry flounder.

Distribution and Abundance

Adults. In relation to other demersal species, starry flounder are not very abundant in the northeastern Gulf of Alaska. Catches of starry flounder in the study by Hitz and Rathjen (1965) were similar to those of butter sole. Overall, starry flounder ranked as the sixteenth most important species by CPUE (weight), but was common (ranking fourth) in areas that were less than 50 fm deep (Table 12). Within 10 fm increments, starry flounder were mainly caught (CPUE) between 11 and 20 fm and 21 and 30 fm (Alverson 1960).

Larvae and Eggs. Late stage starry flounder eggs have been reported from plankton samples during spring (March 28-April 20) and summer (June 19-July 9) off Kodiak Island (Kendall et al. 1980) and stage I eggs have been collected off Kamchatka on the western Bering Sea in July (Musienko 1963). In both instances, only small numbers of eggs were caught.

Larvae in the Kodiak bay and shelf region were only caught in summer and in low abundance (Rogers et al. 1979; Kendall et al. 1980). Only one 17 mm larvae was reported in July 1976 from Cook Inlet (English 1977).

Starry flounder larvae were relatively more abundant off Oregon where they occurred March-June, ranged from 3-9 mm, and were the fourth most abundant flatfish and eight most abundant larvae in a coastal assemblage of larval fish (Richardson and Pearcy 1977). In Skagit Bay, Washington, larval starry flounder were the predominant flatfish species during March-June (Blackburn 1973).

Table 22. Annual Japanese trawl catches (m.t.) of flatfish other than halibut and arrowtooth flounder in the Fairweather and Yakutat regions, and the Gulf of Alaska, 1969-1974.

Year	Fairweather[1]	Yakutat[2]	Gulf of Alaska[3]
1969	124	160	361
1970	162	31	222
1971	69	127	502
1972	562	903	2,099
1973	1,687	1,662	6,230
1974	249	852	3,524
$\bar{X}$	475.5	622.5	2,156.3

[1] Cape Spencer to Yakutat Bay.
[2] Yakutat Bay to Cape Suckling.
[3] Cape Spencer to Unimak Pass.

Source: Ronholt et al. 1978.

Only late stage starry flounder eggs can be identified and are expected to occur in the Yakutat area during spring and summer. They may initially be distributed nearshore (<50 fm), but will probably be dispersed over the Shelf. Larvae can be expected during summer and distributed over the entire area.

Pacific Halibut (*Hippoglossus stenolepis*)

General Biology. Pacific halibut occur as far south as Santa Rosa Island, California (34°N) and as far north as Norton Sound (63°31'N). Halibut are generally associated with water temperatures of 3-8°C and greatest catches occur over banks where bottom temperatures are within this range (Thompson and Van Cleve 1936). The bathymetric range for halibut is between 15 and 600 fm.

Pacific halibut spawning occurs mostly in the winter in the Northeast Pacific and may begin in fall in the Bering Sea. Halibut spawn at bottom temperatures of 3-8°C and laboratory reared eggs hatch in 12-20 days at 5-8°C (Forrester 1973). Age of first-maturity for female halibut is reported to be 8-16 years with an average age of 12 years. Average age for males is 7-8 years (Bell and St. Pierre 1970). Spawning occurs once a year and number of eggs released is related to length and weight of female halibut. Large females (140-180 cm) may produce 2-3 million eggs (Kolloen 1934). Eggs range in size from 2.9-3.8 mm, have a large colorless yolk without oil globules, and a small perivitelline space. Descriptions and illustrations of eggs and larvae are given by Thompson and Van Cleve (1936).

Spawning takes place in relatively deep water (275-412 m) along the edge of the Continental Shelf and eggs have been found between 40 and 1,488 m with concentrations at 100-200 m (Thompson and Van Cleve 1936; Pertseva-Ostroumova 1961). Eggs and larvae are transported horizontally at depth by subsurface currents and in the Gulf of Alaska are carried offshore in a counterclockwise direction around the gulf. Larvae hatch at 6-7 mm in length (Forrester 1973) and are located deeper than egg concentrations (i.e. $\geq$ 200 m). As larvae develop, they rise in the water column and at 3-5 months of age are at 100 m or less and are carried onshore by surface currents. At 6-7 months (about May and June) larvae have metamorphosed and are on the bottom in shallow coastal bays. Juvenile halibut may remain inshore 1-3 years before moving offshore (Thompson and Van Cleve 1936). Movement of juveniles occurs in directions opposite to drift of eggs and larvae and has been hypothesized as the factor for replenishing halibut populations (Skud 1977).

The diet of halibut consists mainly of fish, crab, and shrimp (Rogers et al. 1979). Hunter (1979) and Novikov (1963) divided halibut into size groupings and in each study, halibut less tha 300 mm long had eaten shrimp (Hunter listed fish and crab also). Those longer than 300 mm switched to fish, although according to Hunter, crab was of secondary importance.

History of the Fishery. The commercial halibut fishery began in 1888 off the coast of Washington and during the early years the bulk of the fishing was in the Southeast Alaska through Columbia areas, but by 1916 the fishery had expanded as far as the Shumagin Islands. The International Fisheries Commission (which in 1953 became the International Pacific Halibut Commission) was formed in 1924 to manage the overfished resource. By 1954 production rose to 43,000 m.t., taken from the entire Halibut Convention Area (Forrester et al. 1978). Both Canada and the United States have historically been active in the fishery. By the late 1970's the total catch was about one-half of the 1954 catch and regulatory area 3A contributed the majority of the total (Table 23). The catch-per-unit-effort (CPUE) for selected statistical areas and regions (1931-1979) is presented in Table 24.

Distribution and Abundance

Adults. The Yakutat region extends from the east side of Prince William Sound to Cape Edward (south of Cross Sound). Within the Yakutat region are statistical areas 20 and 19. Area 20 extends from Sitkagi Bluffs (just north of Yakutat Bay) to an area around the Dangerous River, and area 19 goes from the latter point to a point between Lituya Bay and Icy Point (Fig. 12). Historically the CPUE for the Yakutat region was usually higher than the CPUE for the entire Northeast Pacific (total) and the sector just north of Yakutat (IPHC statistical area 20) has had higher CPUE than the sector to the south (IPHC statistical area 19), but in recent years neither sector has consistently been higher or lower.

Larvae and Eggs. Knowledge of spawning locations in the Northeast Pacific is limited, although major sites are known from Cape St. James, Langara Island, and Frederick Island in British Columbia, and Yakutak, "W" grounds, and Portlock Bank in the Gulf of Alaska. Other spawning sites have been reported near Goose Islands, Hecate Strait, and Rose Spit in British Columbia, and Cape Ommaney, Cape Spencer, Cape St. Elias, Chirikof, and Trinity Grounds in Alaska. Spawning concentrations also occur in the Bering Sea (Skud 1977).

Distribution and relative abundance of halibut eggs and larvae were examined in the Gulf of Alaska by Thompson and Van Cleve (1936). Eggs and early stage larvae were commonly taken at depths greater than 100 fm, but may drift onto shelf waters during larval development. Other plankton surveys in Alaska report halibut larvae in spring in the Bering Sea (18-23 mm; Waldren and Vinter 1978), Cook Inlet (13 mm; English 1977) and Kodiak Shelf (14.4, 17.8 mm; English 1977). In most cases larvae were caught at stations >200 m and in low abundance.

The Yakutat area supports a large spawning population of Pacific halibut; however, since spawning occurs in winter, and at depths >200 m eggs will probably not be taken during the proposed sampling months.

Table 23. Catch of Pacific halibut (lb) and effort (in standard skates, where one skate is 1,800 ft long with 100 hooks) for IPHC regulatory area 3A, 1975-1979.

Year	United States		Canada		Total Catch in North America
	Effort	Catch	Effort	Catch	
1975	1,412	8,841	489	3,772	12,613
1976	1,567	9,052	616	4,130	13,182
1977	1,276	7,842	405	2,717	10,559
1978	1,493	11,276	386	3,100	14,376
1979	1,410	10,031	153	1,638	11,669

Sources: Myhre et al. 1977; International Pacific Halibut Commission annual reports and unpublished data, 1976-1979.

Table 24. Catch per unit effort of halibut from IPHC statistical areas 19 and 20, the Yakutat region, and over all area.

Year[1]	Area 19	Area 20	Yakutat	All areas
1931-1935	69.7	72.7	75.0	62.7
1936-1940	84.0	82.9	88.8	79.7
1941-1945	88.5	102.6	109.1	97.0
1946-1950	76.9	92.1	91.3	98.3
1951-1955	96.0	109.3	108.9	116.2
1956-1960	106.8	105.9	117.3	124.9
1961-1965	100.5	111.8	111.7	110.1
1966-1970	91.5	94.0	95.4	98.7
1971	77.9	96.1	88.3	89.5
1972	85.0	73.0	79.4	80.9
1973	81.2	72.3	73.7	64.9
1974	59.1	56.4	71.0	62.2
1975	68.8	83.4	73.2	63.3
1976	14.5	16.5	58.4	54.0
1977	53.9	48.3	53.8	60.2
1978	82.2	77.9	79.5	67.3
1979	92.1	109.8	105.8	70.8

[1] 1931-1970 are 5-year averages of annual means.

Sources: Myhre et al. 1977; International Pacific Halibut Commission annual reports and unpublished data, 1976-1979.

During spring and summer larvae may "stray" up over the Shelf and be caught within the study area.

Butter Sole (*Isopsetta isolepis*)

General Biology. Butter sole occur from southern California to southeastern Alaska in shallow water but are occasionally at 150-200 fm (274-366 m) in western Alaska (Hart 1973).

Butter sole spawn in late winter to early spring. Eggs are planktonic, spherical, have a narrow perivitelline space, lack oil globules and range in length from .93-1.1 mm ($\bar{x}$ = 1.0 mm; Levings 1968). Hence at early-middle stage of development, eggs of butter sole are indistinguishable from several other flatfish species (Richardson et al. in press). Spawning in Skidegate Inlet, British Columbia occurred at depths of 15-35 fm (Manzer 1949; Levings 1968) and at conditions of 4°C and 25°/oo (Levings 1968).

Larvae are abundant off Washington and Oregon in winter and spring (Richardson et al. in press) and were found in Kodiak bays and shelf during June-August (Rogers et al. 1979; Kendall et al. 1980). Transformation from larval to juvenile characters takes place when larvae are 18-23 mm. Recently transformed benthic juveniles seem to be offshore rather than in bays and other nearshore habitats (Richardson et al. in press). Average length at age two is 143 mm for males and 190 for females. By age 10, females are 394 mm and males average 352 mm (Hart 1943). Eggs and larvae are described and illustrated by Richardson et al. (in press).

The food of butter sole includes marine worms, young herring, shrimp and sand dollars (Hart 1973).

History of the Fishery. Although flatfish have been one of the most important groups of fishes exploited by the United States and Canada, butter sole are not commercially important, whereas arrowtooth flounder, Dover, petrale, English, Rex, and rock sole are. Furthermore, Japanese and Russian efforts have concentrated largely on yellowfin sole in the Bering Sea. There are a lack of catch statistics specifically for butter sole. American catches of flatfish since 1958 have been dominated by the Dover sole (Forrester et al. 1978) and fishing has largely occurred at depths where this species occurs. Hitz and Rathjen (1965) reported that from 1-250 fm, Dover sole was most abundant between 201-250 fm. Furthermore, United States and Canadian efforts have been from the Charlotte area south. For flatfish other than halibut and arrowtooth flounder, the Yakutat area (Cape Suckling to Yakutat Bay) and the Fairweather area (Yakutat Bay to Cape Spencer) ranked first and second, respectively in annual Japanese trawl catches from Cape Spencer to Unimak Pass (Ronholt et al. 1978).

Distribution and Abundance

Adults. Butter sole are not one of the more abundant fishes of the Gulf of Alaska. Hitz and Rathjen (1965) reported that butter sole ranked thirteenth by CPUE (weight) for all depths (1-250 fm) but second for the 1-50 fm interval (Table 12).

Larvae and eggs. Catches of butter sole eggs and larvae have only been reported in a few plankton studies from Alaskan waters. In Kodiak, larvae were in bays in June-August, ranging in length from 3.0-11.0 mm in June to 8.5-21.0 mm in August. They ranked fifteenth in abundance over all times and stations (Garrison and Rogers 1980). In the offshore shelf region butter sole larvae occurred only during the summer cruise (June 19-July 9) and ranked eleventh in abundance (Kendall et al. 1980). In Cook Inlet, larvae were present in early and late May cruises with higher catches in the latter time period. Larvae were small, ranging from 2.1-6.7 mm. No larvae were caught in July or August (English 1977).

Off Oregon and Washington, however, larval butter sole are a dominant member of the ichthyoplankton and ranked fifth in overall abundance in April and May (Waldron 1972) and third in abundance in a coastal assemblage of larval fish off Oregon (Richardson 1977; Richardson and Pearcy 1977).

Butter sole spawning is expected to occur shoreward of 50 fm and possibly within Yakutat Bay during late winter-early spring. Eggs and larvae may be concentrated at nearshore and bay locations during spring sampling (April-May), but probably distributed over the shelf during summer. By October, butter sole larvae will have transformed to juveniles and assumed a benthic habitat, hence they are no longer susceptible to plankton nets.

Dungeness Crab (*Cancer magister*)

General Biology. The Dungeness crab is an important commercial species and occurs from Baja California to Amchitka Island, Alaska. The northeastern Gulf of Alaska supports substantial commercial harvests.

Dungeness crabs inhabit bays, estuaries, and open (coastal) ocean from the intertidal zone to depths greater than 50 fm. They are usually most abundant on sand or mud-sand bottoms (Hoopes 1973). The distribution of these crabs by depth seems to vary with life history stage and season. Butler (1956) found that post-larval stages were abundant on shallow (<5 fm) sand bottoms; McKay (1942) observed juveniles (2-3 3/4") buried in intertidal sands in late winter and in spring, and concluded that adults migrate offshore during winter and return to the nearshore in the spring.

The sex ratio appears to be unequal, with the sexes separated geographically (McMynn 1948, cited in Mayer 1972). Sexual maturity is reached in 2 years for females and 3 years for males (Hoopes 1973). According to various authors, this corresponds to a carapace width of > 110 mm for males and about 100 mm for females (Butler 1960). Butler (1961) reported that both sexes matured at the eleventh or twelfth post-larval instar. Males are polygamous and mating occurs when adults move into shallow water during the spring molt period. Transfer of sperm can only occur after the female has molted and before her new shell has hardened. Females then carry viable sperm in their oviducts throughout the summer. In the fall, eggs pass through the oviduct, are fertilized, and then carried under the female's abdomen (Hoopes 1973). Egg bearing occurs during October to June in British Columbia (McKay 1942) and larvae emerge between December and April off Oregon (Reed 1969, cited in Mayer 1972). The number of eggs deposited by a female is related to size; as many as 1.5 million eggs have been found on a single female (Hoopes 1973).

Eggs hatch into free swimming larvae during the spring, after they have been carried by the female for 7-10 months (Hoopes 1973). The distribution of planktonic larvae is assumed to be associated with the nearshore location of the female in late spring (Mayer 1972). Larvae first hatch as 1.16 mm long zoea with a rostrum and three spines on the front of the head and then progress through five stages by a series of molts taking 3-4 months (Hoopes 1973). The zoea then transforms into a 13 mm long megalops that resembles the juvenile crab, and there is only one megalops stage (Poole 1966, cited in Mayer 1972). When the megalops stage is complete, it settles out as a post-larva or juvenile. This occurs after a larval period of 128-158 days (as indicated by post-larval instars; Poole 1966, cited in Mayer 1972). At Kodiak, larvae spend up to 3 months in the plankton (Alaska Environmental Information and Data Center (AEIDC) 1975), with a peak of larval release in spring or early summer (Kendall et al. 1980). In general, larvae in inshore areas (Kodiak) are within the upper strata of the water column during the day (70% found between 10-30 m) and dispersed into deeper strata at night (50% plus were between 50-90 m), while those larvae in offshore areas are usually deeper at night (Kendall et al. 1980).

During the first year, a juvenile crab may molt as many as six times, thus growth is rapid. After the first year, the carapace width is approximately 25 mm and after the second year it is approximately 102 mm (Hoopes 1973). All of this growth occurs during a 1 to 2 day molting period. Both sexes grow at about the same rate until sexual maturity is reached, after which males grow faster (Hoopes 1973). The increase in size decreases with each molt. Increases are about 40% in the early post-larval stages and 10-15% when the crabs are about 13.0-13.5 cm (McKay and Weymouth 1935). Males may reach as much as 20 cm in carapace width, while females may exceed 15 cm in width. The commercial size at Kodiak is 6 3/4" or roughly 17.1 cm (AEIDC 1975).

Dungeness crabs are carnivores, frequently eating crustaceans (shrimp, crab, barnacles, amphipods, and isopods), clams and polycheates (McKay 1942; Hoopes 1973). Larval stages of this crab are preyed upon by a variety of fish species. Juveniles are canabalized by adults, while juveniles and adults are consumed by many larger fish (Mayer 1972).

History of the Fishery. The fishery for Dungeness crab is one of the older ones in Alaska with commercial harvest at Kodiak, Cook Inlet, Southeast Alaska, Yakutat (Fig. 13), and the Copper-Bering rivers and Prince William Sound. Most fishing is done by crab pot or trap baited with razor clams, squid, or herring in about 5 to 30 fm of water. Different areas allow a different number of pots per boat. In Yakutat, a boat may carry a relatively high number - up to 600 (Mayer 1972). Although the Yakutat crab fishery has been stable since 1960 (except for low harvests of 1975-1977), the fishery is declining in most areas of Alaska (Terry et al. 1980). The catch is possibly influenced by the supply of other species of crab and the fishery for Dungeness crab in the Pacific Northwest (Ronholt et al. 1978). Also, the fishery primarily depends on one year class, so fluctuations occur from year to year (AEIDC 1975). Even so, production in the Yakutat management area averaged over 1.3 million pound for the past 10 years, which is an important contribution to the total harvest in Alaska (Table 25). From 1969 to 1975, 89% of the United States catch (from Cape Spencer to Unimak Pass) came from 24 subareas (Ronholt et al. 1978). Included were Yakutat Bay (2.8% of the total), Yakutat Bay to Dry Bay (7.5%), and Dry Bay to Cape Fairweather (2.2%). See also Table 25 for the catch from 1971-1975 for the entire Fairweather region.

Distribution and Abundance

Adults. The Dungeness crab is widely distributed in the Gulf of Alaska. Hitz and Rathjen (1965) reported that this species largely inhabits depths between 1 and 100 fm. The Yakutat area has large concentrations of Dungeness crab. Maturgo (1972, cited in Anonymous 1976) presented figures which indicated Yakutat (Cape St. Elias to Cape Spencer) had the highest catch-per-unit-effort (174 lbs/hr of trawling) in the Gulf of Alaska. Furthermore, surveys in the early 1960's (reported in Ronholt et al. 1978) show that the Yakutat (Cape Suckling to Yakutat Bay) and the Fairweather (Yakutat Bay to Cape Spencer) regions contain about 20% of the total biomass of Dungeness crab in the Gulf of Alaska (Cape Spencer to the Kenai Peninsula).

Larvae. Since the eggs are carried by the adult crab, they will not be in the plankton. Larvae will probably be largely in nearshore areas in the spring, and their distribution associated with the location of the females at that time. As the season progresses larvae should become more dispersed by the currents and be in offshore areas as well. Since the larval period is about four months, Dungeness crab larvae should be caught by our plankton gear in both the April-May and July-August cruises. We expect zoea to predominate in the former

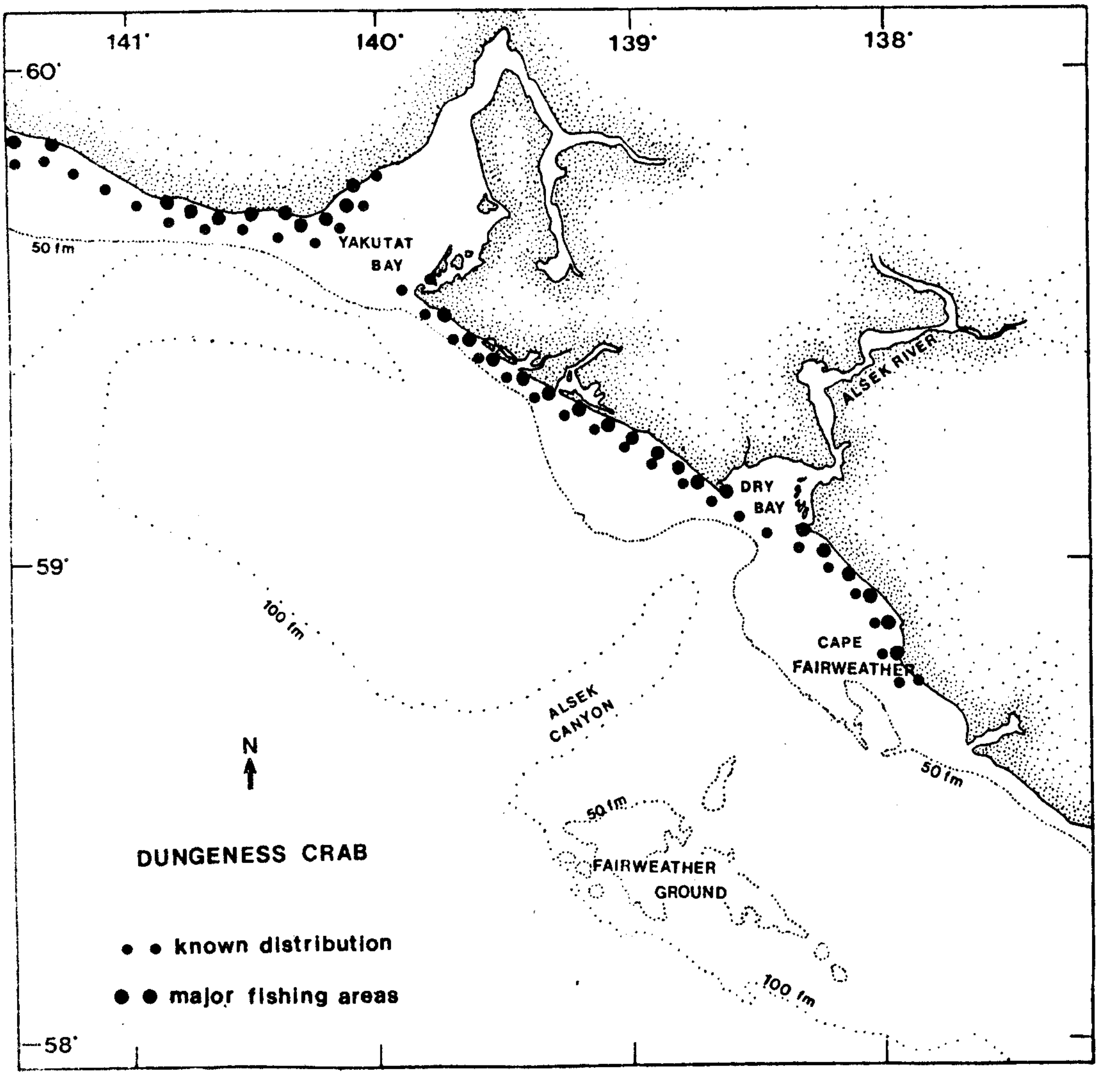

Fig. 13. The distribution and major fishing areas of Dungeness crab in the Yakutat area.

Source: McLean and Delaney 1978.

Table 25. Annual catch (lb x 1000) of Dungeness crab in the Yakutat and Fairweather regions, and the total Alaskan catch.

Year	Yakutat[1]	Fairweather[2]	Alaska
1971	1,669	443	3,749
1972	1,993	1,014	5,448
1973	2,347	1,136	6,423
1974	1,632	240	3,818
1975	541	216	3,034
1976	529	--	--
1977	124	--	--
1978	1,900	--	--
1979	1,496	--	--
1980	859	--	--

[1]Cape Suckling to Cape Fairweather.
[2]Yakutat Bay to Cape Fairweather.

Sources: Terry et al. 1978; A. Brogall, personal communication; Ronholt et al. 1978; Alaska Department of Fish and Game 1975.

sampling period and the megalops stage to be more abundant in the latter period than in the former. We also expect that the larvae will be captured largely in the upper 50 m during the day and slightly deeper during the night.

Tanner Crab (*Chionocoetes bairdi*)

General Biology. The name tanner crab is often used to describe the species of *Chionocoetes*. *Chionocoetes bairdi* is the principle species of the Continental Shelf off Yakutat, but some references to *C. opilio* are made where life history information on *C. bairdi* is lacking.

Chionecetes bairdi is the commerically exploited species in the Gulf of Alaska (commercial harvest began in the late 1960's). It occurs from Puget Sound, Washington to the Bering Sea and from shoal water to a depth of 259 fm (Brown 1971).

The sex ratio is approximately one to one (Hilsinger 1976), but appears to be similar to Wenners (1972) "anomalous" pattern where the ratio changes from differential mortality and growth of one and then the other sex. The age at which tanner crabs mature is not well known because of the difficulty in aging them; however, size of the female at maturity may vary between 71 mm-116 mm. The size and age at maturity is perhaps a function of growth per molt, frequency of molting, and timing of gonad maturation. Maturity of *C. opilio* is reached by the ninth post-megalops molt, at or about age 6 or 7 (Eldridge 1972). It is unknown whether the female can mate after her shell has hardened (Dungeness females cannot). Mating occurs in late winter or early spring in shallow waters (Science Applications, Inc. 1980; Hilsinger 1976) and the fertilized eggs are carried by the female for about 11-12 months, after which, they hatch and larvae are released, usually in two batches (Eldridge 1972a). There is much variation in the number of eggs that are carried. Hilsinger (1976) gives a range of 24,000 to 318,000 eggs per female, and AEIDC (1975) reports a range of 5,000 to 140,000 eggs per female with an average of 30,000 to 80,000. The variation in egg number may be accounted for by varying sizes of the females and by a decrease in clutch size in old crabs (Terry et al. 1980).

Larvae drift with the surface waters and go through four developmental stages; a prezoea stage, two zoea stages, and a megalops stage. In Kodiak, larvae occur in the spring and summer (Science Applications, Inc. 1980). Bright (1967, cited in Eldridge 1972) concluded that in Cook Inlet, larvae develop quickly, about two weeks from the prezoea to the first juvenile stage. Early and late larval stages occur inshore at Kodiak during most of the year, perhaps because of a protracted period of larval release (Kendall et al. 1980). About 98% of these tanner crab larvae in nearshore waters are between 10-50 m during the day, and about 74% are between 50-90 m at night.

Megalops settle out in the summer and immediately cover themselves in debris where they begin to feed on detritus (Eldridge 1972). Most growth work has been done with *C. opilio* and such studies indicate that tanner crab females continue to grow only until sexual maturity is reached and that males continue to grow after they mature, reaching commercial size in two additional molts and maximum size in two further molts (Anonymous 1971, cited in Eldridge 1972). The growth rate decreases with increasing size. The average age of tanner crabs is probably about 12 to 16 years, with a maximu life span of 17 years (Eldridge 1972). Maximum size of females is about 13 cm in carapace width and maximum size of males is about 20 cm (AEIDC 1975).

Chionoecetes feeds largely upon ophiuroids, decapods, amphipods, and bivalves (Eldridge 1972), but Paul et al. (1979) reported that stomach contents typically reflect the benthic species common to any given station and that crabs of different size, sex, and state of maturity consumed similar prey. Tanner crabs are in turn fed upon by many large fish.

History of the Fishery. The tanner crab fishery began in 1968, supplementing the king crab fishery and remained relatively small until technological problems with meat extraction were solved. The total catch rose to almost 64 million lb in 1974. The fishery at Yakutat occurs largely from January through April and catches increased there in 1974 (Table 26; note the discrepancy in the literature for catch data in the Yakutat management area compared to the Fairweather region). The Yakutat management area (Cape Suckling to Cape Fairweather) contributed over 2.5 million lb in 1980 (A. Brogall, personal communication).

Distribution and Abundance

Adults. Tanner crabs are quite common in the northeastern Gulf of Alaska. Hitz and Rathjen (1965) reported that tanner crab were the sixth most abundant species (CPUE) in their trawl samples and that they were most abundant between 51 and 150 fm (Table 12). Logbook data from fishermen in the Bering Sea and Aleutians (Adak Island) to southeastern Alaska show the highest catch per pot was in depths of 100-120 fm (Brown 1971). CPUE data (NMFS exploratory drags, 1950-1968) indicates that tanner crab abundance for the region from Cape St. Elias to Cape Spencer is second only to the Cook Inlet region at 200 lbs/hr of trawling (Maturgo 1972, cited in Anonymous 1976). Tanner crabs are distributed throughout the Yakutat area (Fig. 14), and a high abundance in the Fairweather area (Yakutat Bay to Cape Fairweather) contained an estimated 12% of the total tanner crab biomass in the Gulf of Alaska during June-August, 1962 (Ronholt et al. 1978).

Larvae. Eggs are carried by the female and therefore, will not be captured by plankton gear. Larvae drift with the surface waters during their development, and we may find them throughout the study area in all three sampling periods; larger abundance may occur during the

Table 26. Catches (lb x 1000) of tanner crab in the Yakutat and Fairweather regions, and the total catches in Alaska.

Year	Yakutat[1]	Fairweather[2]	Alaska
1971			12,880
1972	15	29	30,135
1973	207	293	61,719
1974	1,872	620	63,906
1975	2,021	1,160	46,857
1976	1,714	--	--
1977	1,016	--	--
1978	990	--	--
1979	974	--	--
1980	2,528	--	--

[1]Cape Suckling to Cape Fairweather.
[2]Yakutat Bay to Cape Fairweather.

Sources: Terry et al. 1980; A. Brogall, personal communication; Alaska Department of Fish and Game 1975; Ronholt et al. 1978.

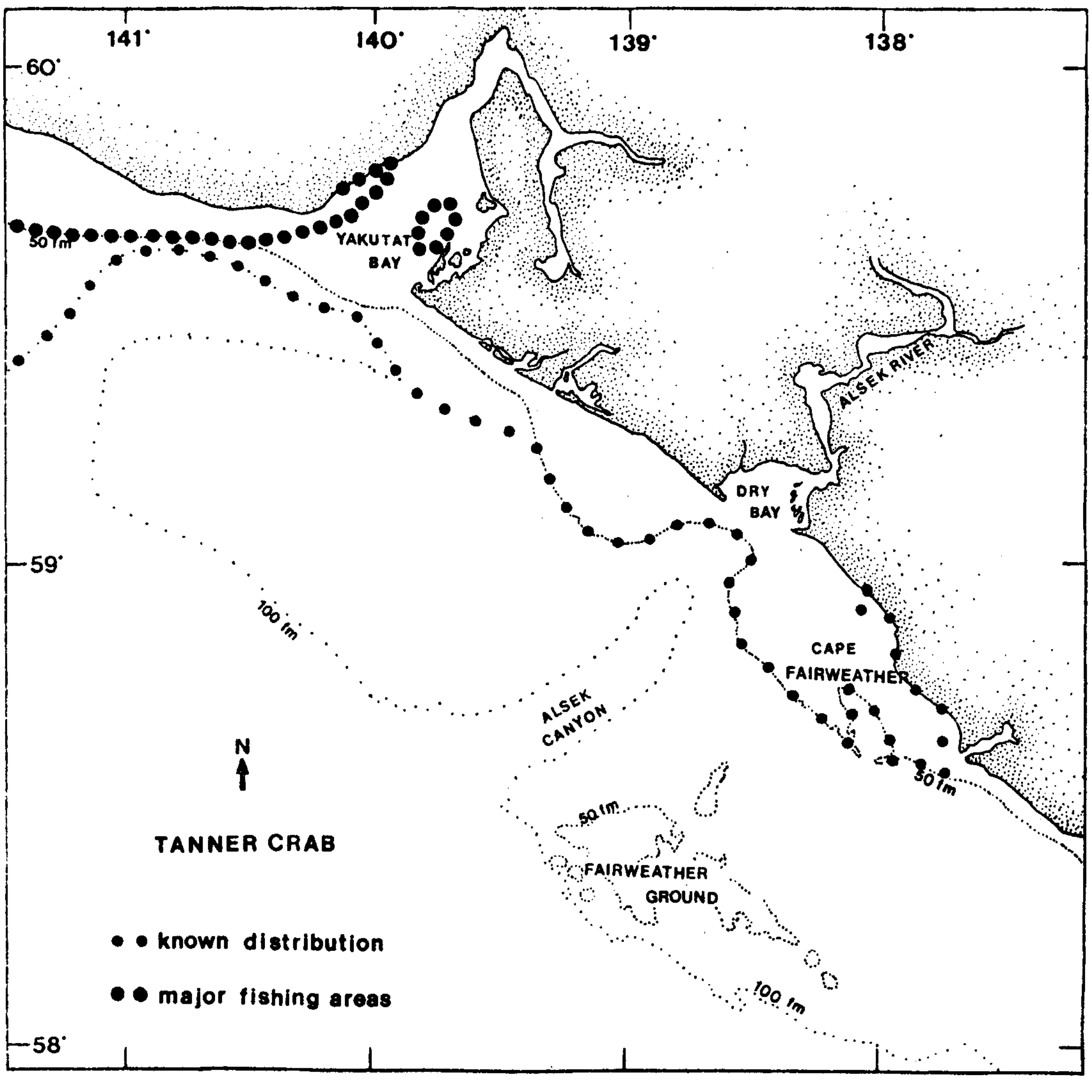

Fig.14. The distribution and major fishing areas of tanner crab in the Yakutat area.

Source: McLean and Delaney 1978.

spring and summer. During the day larvae should be captured mainly in the upper 50 m of the water column and during the night, 50-100 m below the surface.

Northern Pink Shrimp (*Pandalus borealis*)

Pink shrimp were not targeted for this study; however, since they are a potentially important species to the economy of Yakutat, we have included this section.

The shrimp fishery in Alaska has largely been centered around Kodiak. However, during this past season, the fishing effort there was too intense, which resulted in overloading the handling facilities at Kodiak. Shrimp fishing was then initiated in Yakutat Bay. The ADF&G set a quota there of 1.5 million lb and after this was surpassed by 200,000 lb, the bay was closed to the fishery for the year. After the closure of the fishery, experimental trawling in Yakutat Bay indicated a density of about 136,000 lb/sq mile (A. Brogall, personal communication).

Weathervane Scallop (*Patinopectin caurinus*)

General Biology. The weathervane scallop occurs from California to Alaska, with commercially harvestable beds around Kodiak Island and in the Yakutat region (Hennick 1970a).

Scallops inhabit mud, clay, sand, or gravel bottoms, and usually live in a slight depression in the sediment surface. They are most abundant between 20 and 70 fm (AEIDC 1975), with the majority around 50 fm.

Sexes are separate in scallops and the sex composition of mature individuals is approximately one to one (Hennick 1970a). Hennick reported that most scallops are mature when three concentric rings are present on their upper valve. Haynes and Powell (1968) reported that most scallops less than 76 mm are immature. Fertilization is external. Depending on the sex, the eggs or sperm are expelled on different sides of the hinge. Spawning takes place once a year, in June or early July (Hennick 1970a), and is possibly induced by changes in water temperature. Fertilized eggs settle to the bottom and attach for a maturing period of a few days before hatching (AEIDC 1975).

Larvae are from 80 to 200 μ long and drift with the tides and currents for 2 to 3 weeks (AEIDC 1975). They then metamorphose and settle, attaching with the help of byssus threads.

Attached juveniles range in size (valve height) from 6 to 75 mm; by their third year, when many are sexually mature, they may be 7.6 to 12.7 cm in height. Their maximum size is around 23 cm. Scallops caught commercially range from 7 to 11 years old, but some live more than 15 years (AEIDC 1975). Scallops feed by filtering plankton from the water.

History of Fishery. The catches for the Yakutat management area and all of Alaska are presented in Table 27 for 1968-1977. The Yakutat area was important during the first two years of the fishery and then again during 1974-1977 when catches were low. A decline in the resource and adverse market conditions rendered the fishery inactive in 1978 and 1979 (Terry et al. 1980). This past year (largely May-August, 1980), however, the fishery was again active and A. Brogall (personal communication) estimates the harvest to be at about 250,000 lb.

Distribution and Abundance

Adults. In 1968, the *Viking Queen* experimentally fished for scallops from Cape Fairweather to Kodiak Island. Only the Kodiak and Yakutat regions supported commercially harvestable populations (Hennick 1970b). Scallops were more abundant in the Yakutat region but grew slower and were smaller at maturity than the scallops at Kodiak (Hennick 1970a). Figure 15 shows the distribution of sea scallops within the Yakutat area. Alverson (1968) reported that scallop catches were highest at Cape Fairweather, off Icy Bay and east of Cape St. Elias.

Larvae and eggs. Sea scallop eggs are demersal. Veliger larvae are small (80-200 μ) and present in the plankton during the summer. They should be distributed throughout the study area and if any of the larger larvae are captured it will be during the July-August sampling period.

Razor Clam (*Siliqua patula*)

General Biology. The Pacific razor clam (*Siliqua patula*) is an important recreational and commercial species on the West Coast. Populations extend from northern California to the Aleutian Islands, occurring in almost 50 different sites in Alaska.

Razor clams are on sandy surf-pounded beaches and occur in fair numbers to a depth of 30 ft (Cumbow 1978). Densities within a particular habitat are a function of topography, substrate type, and tidal regimes. In general, the majority of clams inhabit areas between -0.91 m and +0.91 m of the mean lower low water mark (Kaiser and Konigsberg 1977). At Yakutat, the estimated upper habitable tide level, relative to mean lower low water, is +1.14 m (Nickerson 1975).

Sexes are separate in razor clams and the spawn ripens in the foot (Cumbow 1978). The number of males and females seems to be equivalent and individuals of both sexes reach maturity at approximately 2.5 years. The influence of growth is greater than the process of maturation in determining the age at which a clam can spawn (Weymouth et al. 1925).

Table 27. Annual catch (lb x 1000) of scallops in the Yakutat area, and the total Alaskan catch, 1968-1977.

Year	Yakutat	Alaska
1968	903	1,734
1969	836	1,888
1970	23	1,440
1971	85	931
1972	128	1,167
1973	174	1,109
1974	357	504
1975	139	436
1976	190	265
1977	22	22
$\bar{X}$	285.7	949.6

Source: Terry et al. 1980.

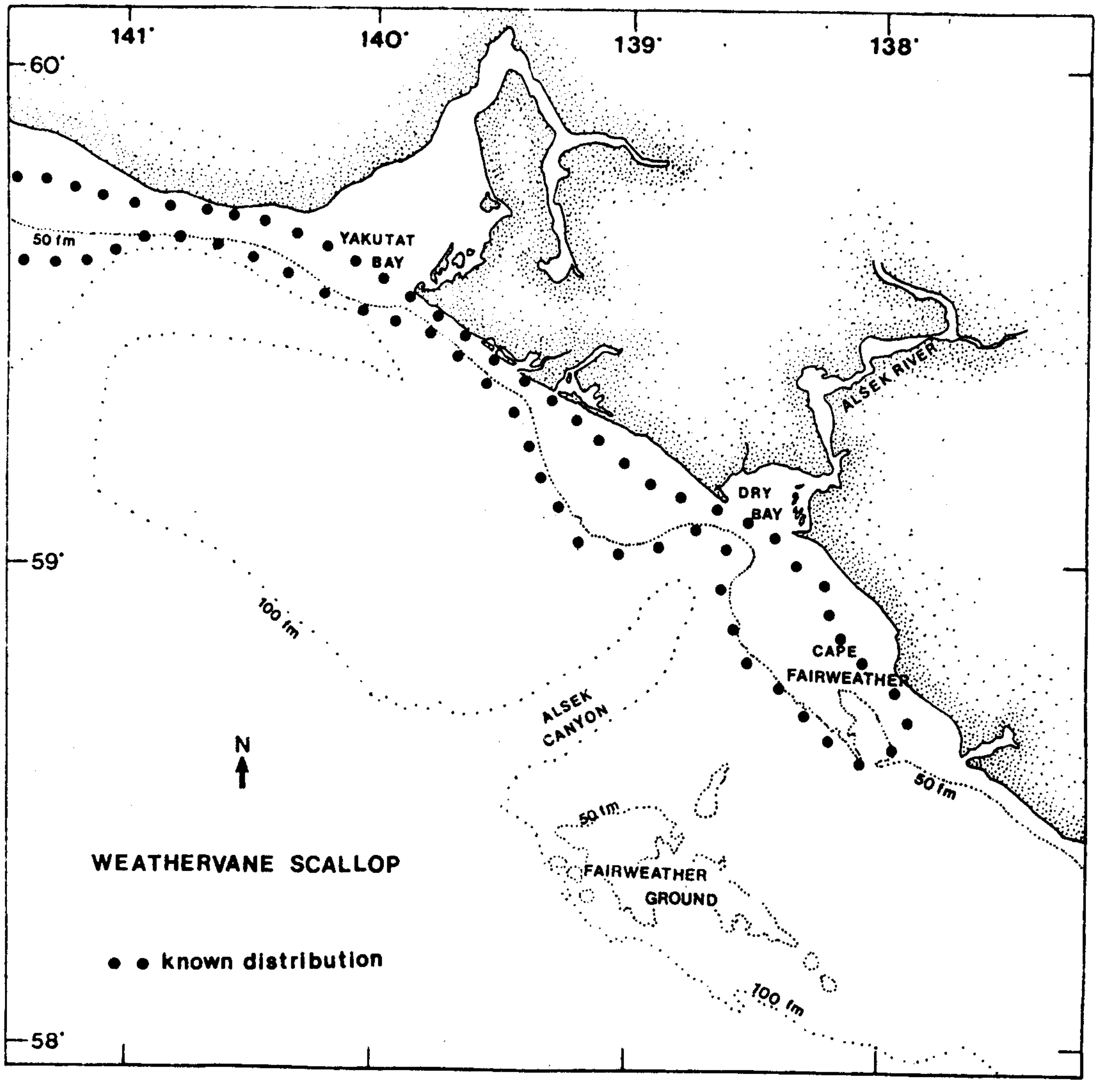

Fig. 15. The distribution of weathervane scallops in the Yakutat area.

Source: McLean and Delaney 1978.

Clams on one section of beach spawn simultaneously (McMillin 1924). The eggs and sperm are discharged through the excurrent siphon. A single female may produce 6-10 million eggs annually (Nosho 1972; Cumbow 1978). Fertilization occurs randomly and fertilized eggs may hatch within a few hours to within a few days (Nosho 1972). The eggs are small; ripe ova measure slightly greater than 90 microns (Nickerson 1975). The onset of spawning occurs when seawater temperatures reach around 13°C (Nosho 1972; Weymouth et al. 1925; Fraser 1930), but varies somewhat with area (Bourne and Quayle 1970), and may continue throughout the summer and fall (Cumbow 1978). Nickerson (1975) reported that razor clams in the Cordova area would spawn if sustained water temperatures of 5.5 to 8.8°C occurred for a period of 30 days followed by an abrupt increase in temperature. Therefore, some spawning may take place from early June to September, but the majority of the activity is in July and August (Weymouth et al. 1925; Nosho 1972; Nickerson 1975).

By 10 days the larva reaches the early swimming stage and by 3 weeks it has the shape of a clam (McMillin 1924). At this time, the entire animal is transparent and a velum extends from within the valves. Two weeks later, very few larvae are in the plankton; each larva has almost doubled in size and a foot has appeared (McMillin 1924). "Settling" seems to occur 8-10 weeks after spawning (Kaiser and Konigsberg 1977). Larvae are distributed by ocean currents and, according to McMillin (1924), most of the last two weeks of the swimming stage is spent in the sand. The length of larval existence of razor clams is longer than for many other molluscs (Weymouth et al. 1925), and the clams settle out at about 325 μ.

Some clams may reach 12.5 mm by their first fall and 89 mm by their second fall (Cumbow 1978), growth is dependent upon location and temperature. In general, Alaskan razor clams grow slower than their counterparts in Washington, but live longer. The life expectancy of razor clams in Washington is about 8 to 11 years, while that of clams in Alaska is about 11 to 19 years (Cumbow 1978; Weymouth and McMillin 1931). Juvenile mortalities may reduce the number of clams that have set to about a third by late fall (Weymouth et al. 1925). Heavy surf causes much of this reduction, and adult mortality is estiamted at about 10% per year (McMillin 1924).

The diet of razor clams consists mainly of diatoms, which are very abundant during the summer months.

History of the Fishery. Commercial razor clamming began in Alaska in 1916 when a small cannery at Cordova went into operation. Historically, Cordova remained a major growing area, along with Cook Inlet and Swikshak. Since 1916, the industry has had it ups and downs. These downs have been caused by poor growing conditions, adverse market conditions, governmental regulations and restrictions (size and poundage limitations, and season closures, etc.), competition from foreign and east coast clam packers, and sanitation problems (Nickerson 1965).

Perhaps the largest blow to the industry came in 1964 when the Alaska earthquake destroyed much of the razor clam habitat. The razor clam harvest in Central Alaska has averaged over 169,000 lb annually from 1960-1969 (Nosho 1972). This is a decline from the 1940's and 1950's and Nosho (1972) feels this may be a result of overfishing, lack of marketing resources, increased productions costs, and/or increased education on the problem of paralytic shellfish poisoning in Alaska.

Cordova is by far the major area for commercial production with harvests during the 1960's averaging over 141,000 lb. Production has fallen since 1969 and from 1970 to 1973, an average of only 31,750 lb was harvested (Nickerson 1975).

Distribution and Abundance

Adults. Yakutat does not have a commercial razor clam fishery because clam beds in the area are inaccessible. Clam beds are probably within a second shelf of breakers that are about one-quarter to one-half mile offshore at a zero tide along the open coast (A. Brogall, personal communication) (Fig. 16). Other sources (Kaiser and Konigsberg 1977; Nickerson 1975) claim that a small bed of clams occurs in a slough near the town of Yakutat and clams there are in subsistence quantities. According to A. Brogall (personal communication), however, they are not razor clams.

Larvae and eggs. Razor clam eggs are very small ($\sim 90\mu$) and quickly hatch into larvae. Therefore, we probably will not find any in our samples. If they are captured, however, the most likely time would be during the July-August sampling period. Larvae are also quite small but our plankton gear should capture some. This could occur during either the summer or fall, but most likely in the summer. Eggs and early larval stages will be mainly close to the shore but can occur throughout the study area because they are dispersed by the ocean currents during a development period of up to 10 weeks.

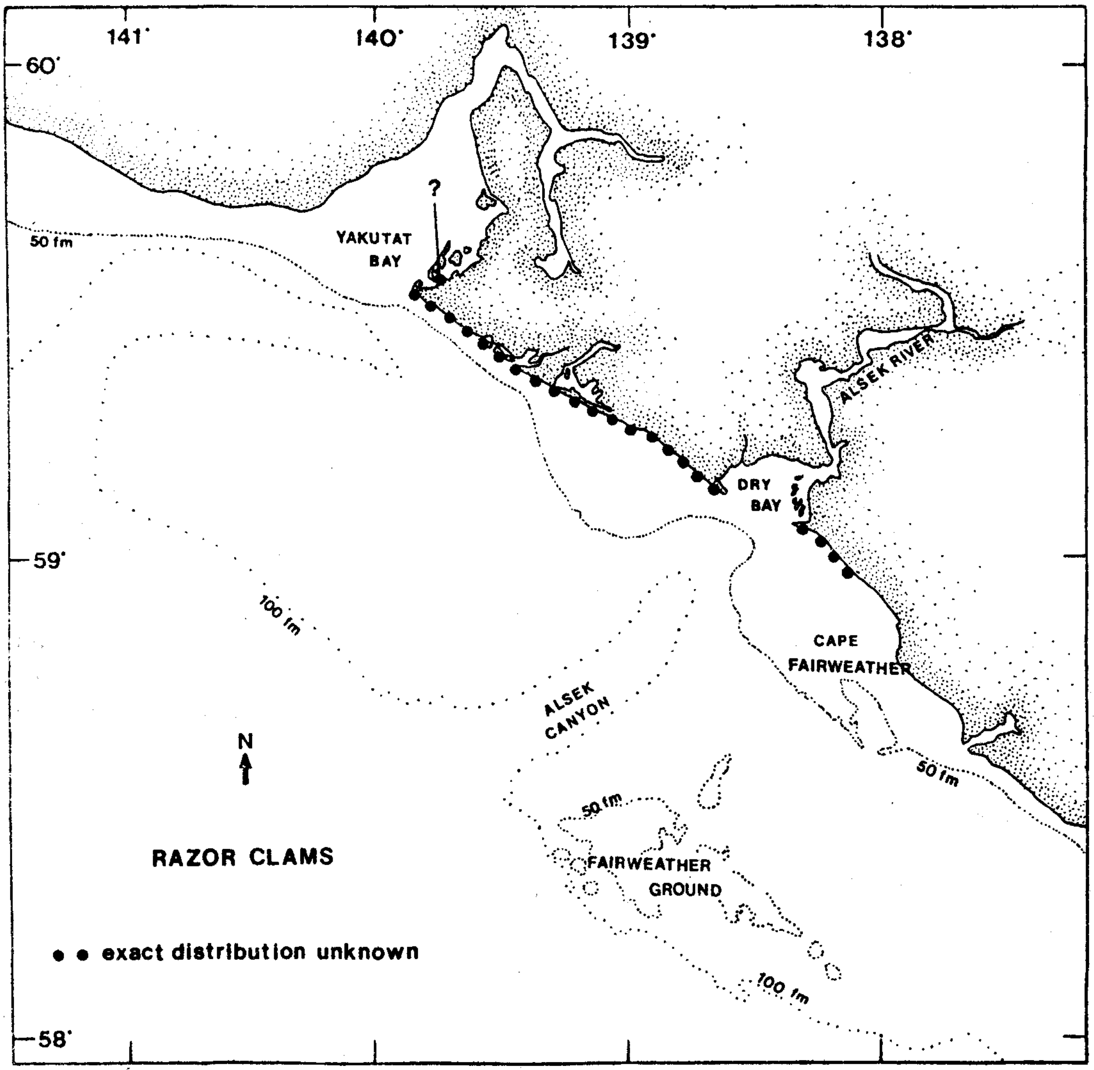

Fig. 16. The distribution of razor clams in the Yakutat area.

Source: McLean and Delaney 1978.

SUMMARY

1) The ichthyoplankton and meroplankton components of the zooplankton communities off Yakutat are virtually unstudied. Inferences on seasonality, reproductive biology, etc. of key species must be drawn from studies in other areas.

2) Pacific sand lance, sablefish, halibut, Pacific cod, and arrowtooth flounder spawn in the winter whereas herring, capelin, walleye pollock, Pacific ocean perch, butter sole, starry flounder, razor clams, weathervane scallops, tanner crab, and Dungeness crab reproduce in the spring or summer. Juvenile salmon and adult forage fish will probably be most abundant in the spring and summer. We expect to sample the greatest diversity and densities of organisms during these warmer seasons of the year.

3) Herring and capelin spawn in bays or on beaches and initially, their larvae will be inshore.

4) Halibut, arrowtooth flounder, and sablefish spawn in deep water offshore. We do not expect to see their larvae inshore. The other species of fish spawn at a variety of depths, hence their larvae will be widely dispersed.

5) Salmon spawn in nearly every stream in the Yakutat area, but the most important spawning areas are the southeast shore of Yakutat Bay (pink salmon) and coastal rivers to the southeast of the bay.

6) There has been a herring fishery in Yakutat Bay only twice in recent years. About 2,000 to 3,000 tons spawn yearly in Yakutat Bay and a larger population spawns in Russell Fjord. Herring serve as important forage fish to other species such as chinook salmon.

7) Pacific sand lance, capelin, and eulachon are probably all abundant off Yakutat, but actual densities are unknown. There is no commercial fishery on any of these species, but they are important sources of food to larger fish, mammals, and birds.

8) The Yakutat area is not a major producer of salmon relative to the rest of Alaska; however, adults on their spawning migrations and juveniles from stocks far outside the Yakutat area mix in waters off Yakutat. Juvenile salmon are most abundant offshore over the Continental Shelf during July and August, although catches of pink and chum salmon are still high in September and October.

9) Generally, there is no domestic (United States or Canadian) commercial fishery by groundfish fleets in the Gulf of Alaska beyond the Queen Charlotte Islands; however, there are plans to develop a groundfish fishery in Yakutat and four other Alaskan communities.

Currently, groundfish stocks off Yakutat are primarily fished by the Japanese.

10) Pacific cod and walleye pollock are abundant and widely distributed in the Gulf of Alaska. Catches by the Japanese in the Gulf of Alaska are, however, relatively insignificant compared to catches in the Bering Sea.

11) Pacific ocean perch and sablefish are both abundant off Yakutat and this area is one of the most important areas to the Japanese fisheries on these two species.

12) The arrowtooth flounder is widely distributed and abundant in the Gulf of Alaska and it is an important species in the domestic fisheries to the south of the Queen Charlotte Islands. The Japanese primarily fish for flatfish in the Bering Sea, so their efforts off Yakutat are negligible.

13) The northern Gulf of Alaska (IPHC's area 3A), which includes Yakutat, is the most significant domestic halibut fishing area.

14) Starry flounder and butter sole are relatively uncommon in the Gulf of Alaska and they are not commercially important species. However, flathead, English, Dover, and rex sole are abundant in the Gulf of Alaska and the last three species are commercially exploited by domestic fleets.

15) There are high concentrations of both Dungeness and tanner crabs off Yakutat and catches in the area are important relative to the overall catches in Alaska.

16) In 1980, there was a shrimp fishery in Yakutat Bay and there are estimated densities of 136,000 lb/sq mile remaining in the bay.

17) The weathervane scallop fishery off Yakutat was active in 1968, 1969, and 1972-1976 followed by a crash caused by low densities of scallops and poor market conditions. The fishery was active again in 1980.

18) The razor clam beds near Yakutat are inaccessible and therefore there is no commercial or sport fishery on them in the Yakutat area.

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