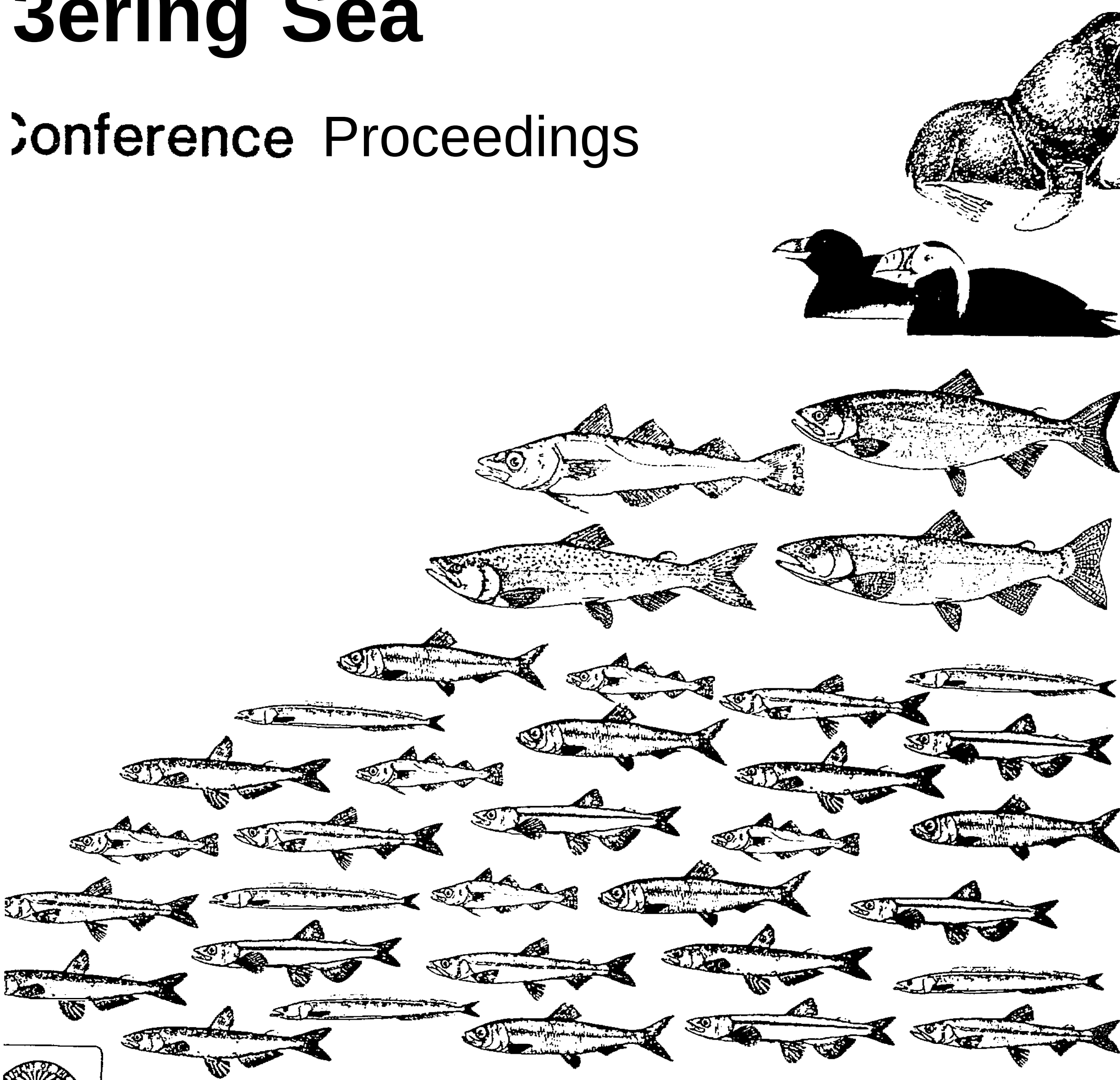
OCS Study
MMS 87-0017

Forage Fishes of the Southeastern Bering Sea

Conference Proceedings



July 1987

U.S. Department of the Interior
MMS Minerals Management Service
Alaska OCS Region

OCS Study MMS 87-0017

FORAGE **FISHES** OF THE SOUTHEASTERN BERING SEA

Proceedings of a Conference

4-5 November 1986
Anchorage Hilton Hotel
Anchorage, Alaska

Prepared **for:**

U.S. Department of the Interior
Minerals Management Service
Alaska OCS Region
949 East 36th Avenue, Room 110
Anchorage, Alaska 99508-4302
Under Contract No. 14-12-0001-30297

Logistical Support and Report Preparation By:

MBC Applied Environmental Sciences
947 **Newhall** Street
Costa Mesa, California 92627

July 1987

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ACKNOWLEDGEMENTS

The work and support of the following staff is gratefully acknowledged Toni Johnson and Bob Meyer of the Minerals Management Service, Alaska OCS Region, who served as conference coordinators; M. J. Allen and R. R. Ware, Marine Scientists with MBC Applied Environmental Sciences; MBC support staff including P. M. Barton, K. L. Mitchell, and V. J. Whitt; Susan Sutter, Anchorage Hilton Hotel Sales Manager; and Marge Kennemer of Anchorage who provided word processing support during the conference.

FORAGE FISHES OF THE SOUTHEASTERN BERING SEA

INTRODUCTION

The Minerals Management Service (MMS) of the U. S. Department of the Interior has a mandate to manage the leasing, exploration, and development of oil and gas resources on the Outer Continental Shelf (OCS). The MMS must oversee these resources in a manner which is consistent with the following needs: 1) to make such resources available to meet the Nation's energy needs; 2) to balance orderly resource development with protection of human, marine, and coastal environments; 3) to insure the public a fair and equitable return on the resources of the OCS; and 4) to preserve and maintain free enterprise competition.

Alaska's Bering Sea produces a substantial fraction of the world's annual harvest of seafoods, with major fisheries for salmon, large shellfish, and groundfish. Anticipation of oil and gas lease sales in the southeastern Bering Sea established a need for a greater understanding of the interrelationships of various components of this marine ecosystem. Since 1974, the Outer Continental Shelf Environmental Assessment Program (OCSEAP) funded by MMS through an interagency agreement with the National Oceanic and Atmospheric Administration (NOAA), has sponsored studies of many Bering Sea ecosystem components. Recent syntheses of these studies, as well as public concerns regarding protection and management of fisheries resources, identified needs for further understanding the importance of forage fishes.

Forage fishes are abundant, small, schooling fishes that serve as prey for many species of fish, seabirds, and marine mammals. In the southeastern Bering Sea these species, which include walleye pollock (*Theragra chalcogramma*), Pacific herring (*Clupea pallasii*), smelts (e.g. capelin, *Mallotus villosus)*, Pacific sand lance (*Ammodytes hexapterus*), and also juvenile salmon (*Oncorhynchus* spp.), are generally less well studied than the demersal fishes, larger salmon, seabirds or marine mammals. Nevertheless, forage fishes play an important part in the Bering Sea ecosystem because of their role as food for the more visible species at higher trophic levels.

For this reason the MMS Alaska OCS Region sponsored a conference on Forage Fishes of the Southeastern Bering Sea. The intent of this conference was to synthesize information on the population dynamics, seasonal movements, and habitat requirements of forage fishes in this area, for use in environmental assessment and studies planning related to proposed oil and gas exploration. MMS, with the assistance of MBC Applied Environmental Sciences, invited 12 fisheries experts to address a group of about 50 scientists and managers who are actively engaged in study or management of the biological and mineral resources of the subarctic environment. The attendees represented Federal, State, and local government agencies, private companies, commercial fishing organizations, and academic institutions of the U. S. and Canada (Appendix A). The conference convened at the Anchorage Hilton Hotel on 4-5 November, 1986. These proceedings summarize the presentations and discussions of that conference.

There were two major themes considered during the conference, Papers presented the first day focused on "Forage Fish Trophic Interactions in the Southeastern Bering Sea". These were followed by a discussion on predator-prey relationships in the coastal environment of this region. On the second day, papers addressed the "Dynamics of Fisheries Oceanography and Forage Fish". A discussion followed on the dynamics of coastal fisheries oceanography and the distribution and relative abundance of forage fish along the north shore of the Alaska Peninsula.

This report includes short papers prepared by the invited technical experts, based on their presentations at the conference, followed by brief summaries of the subsequent discussion sessions. Conference conclusions are highlighted at the end of the report. Background information on the conference, speakers, and participants, as well as selected bibliographies of relevant reports, are included as appendices (Appendices A through D). Scientific and common names of species used in these papers were standardized by the editors to those of established checklists for fishes, birds, and mammals, except where scientific names have been changed by recent taxonomic studies (Appendix E). It should be noted that although the Pacific and Atlantic herring have generally been regarded as subspecies in the past, recent studies indicate that the two forms should be regarded as distinct species.

DYNAMICS OF THE SOUTHEASTERN BERING SEA OCEANOGRAPHIC ENVIRONMENT

H. Joseph Niebauer
Institute of Marine Science
University of Alaska, Fairbanks
Fairbanks, Alaska 99775-1080

The Bering Sea shelf is unique due to its size, its northern connection or “leak” to the Arctic Ocean, its hydrographic structure and its annual ice cover. The hydrographic structure and dynamics are probably similar to other shelves but the immense width (500 km) tends to pull the structure apart so that the features can be more easily observed. The various sources of energy (tidal, wind, fresh water, etc.) tend to be spread over a much larger area.

Over the southeastern shelf the mean flow is low, about 1 to 2 cm/sec toward the northwest. The majority of the horizontal kinetic energy is tidal. Seaward of the shelf break the Bering Sea slope current flows at speeds of approximately 10 cm/sec with frequent eddies. Hydrographic structure on the shelf, which seems little influenced by the slow mean flow, tends to be formed by the boundary input from insolation, cooling, melting, freezing and river runoff, and the lateral exchange with bordering oceanic water masses. Three distinct shelf hydrographic domains plus the oceanic domain can be defined (Figure 1). They are delineated by water depths and separated by fronts which generally parallel the isobaths.

The coastal domain, inshore of the 50 m isobath, is vertically homogeneous due to bottom tidal shear and surface wind shear overcoming the buoyancy input and mixing the water column top to bottom. It is separated from the middle domain or middle shelf by a narrow (about 10 km) front which is the zone of transition in the balance between tidal mixing and buoyance input. Even during the winter when increased mixing due to storms destroys the two-layered structure seaward of the front, there is a stronger density gradient across the 50 m isobath than over the middle shelf.

The middle domain or middle shelf, located between 50 and 100 m, tends to be a strongly stratified two-layered structure in summer, (but nearly homogeneous in winter) due to the vertical separation of the tidal and wind mixing and due to seasonal buoyancy input (insolation and/or ice melt). There is little or no significant advection so that heat content is determined by air-sea interaction and the salt flux that is required to maintain the essentially constant mean salinity is probably due to tidally driven diffusion. The cold (Onto 3°C) bottom layer in the middle shelf domain is formed *in situ.* This middle domain

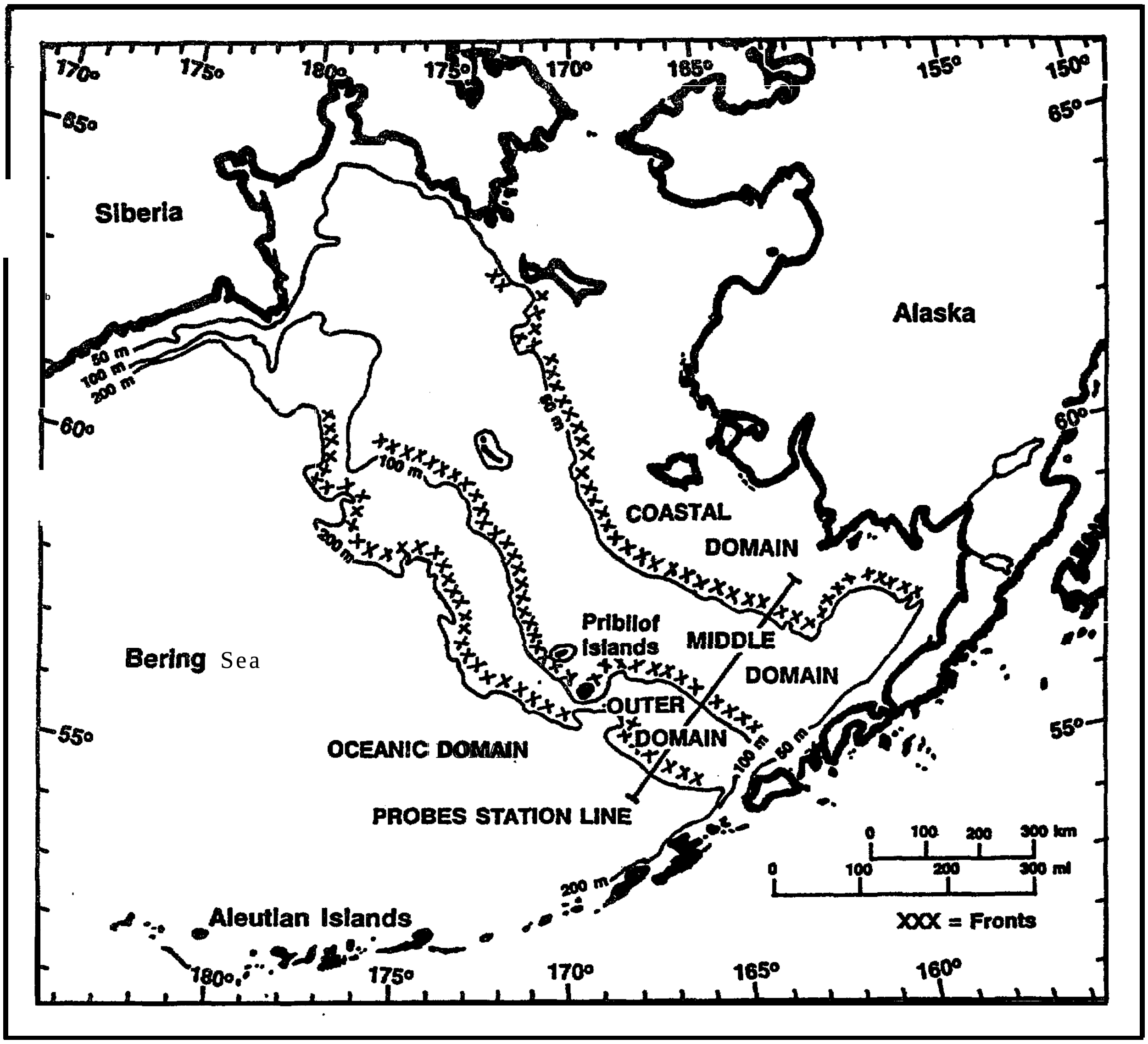

Figure 1. The shelf of the Bering Sea showing the approximate locations (x x x xx) of the inner (ca. 50 m isobath), middle (ea. 100 m isobath), and shelf-break (ea. 170 m isobath) fronts which divide the shelf into distinct oceanographic domains (from McRoy et *al.* 1986).

is separated from the adjacent outer domain by a weak front located in the vicinity of the 100 m isobath in a region where the slope of the shelf steepens.

The outer domain or outer shelf, located between the 100 and about 170 to 200 m (shelf break) isobaths, has surface (wind mixed) and bottom (tidally mixed) layers above and below a stratified interior. The outer shelf/oceanic “water tends to intrude landward along the bottom while the middle shelf water extends seaward in the surface layers so that in the middle front vertical fluxes are enhanced. This interior region of enhanced vertical flux has pronounced fine structure due to the interleaving of warmer but more saline oceanic water intruding shoreward and the cooler less saline shelf water moving seaward. The interleaving occurs at vertical scales of 1 to 25 m.

The shelf break front, which is manifested mainly in enhanced salinity gradients, separates the outer shelf from the oceanic or Bering Slope Current water. This current parallels the shelf break flowing from Unimak Pass to near Cape Navarin at approximately 10 cm/sec providing a transport of approximately 5 Sv[1]. The Slope Current is characterized by mesoscale eddies that appear to be spun up and/or trapped by submarine topography.

On the northern Bering Sea shelf (approximately north of 62°N) including Norton Sound, there are three identifiable water masses. The Anadyr water is the most saline and lies west of St. Lawrence Island and on the west side of the Bering Strait. Alaskan Coastal water lies along the Alaskan coast to the east. In between lies Bering Sea shelf water of intermediate salinity.

Tidal currents dominate the southeastern shelf region, varying from 600/0 of the horizontal kinetic energy in the outer shelf to 90% in the coastal domains. About 80% of the tidal energy is semidiurnal. Farther north the tides are less energetic. The M2[2] constituents (the largest) vary from about 35 cm/sec along the Alaska Peninsula to about 3 cm/sec or less in Norton Sound. Mean flow over the shelf is well described qualitatively by dynamic topography with some low frequency pulses driven by weather systems.

From more than 20 record-years of direct current measurements on the southeast Bering Sea shelf, three current regimes have been identified. These regimes are nearly coincident with the previously described hydrographic domains. In the coastal domain, coastal water from the Gulf of Alaska flows through Unimak Pass then northeastward along the Alaska Peninsula. The flow is counterclockwise in Bristol Bay following the 50 m isobath northward. Currents are strongest near the inner front, paralleling the front at 1 to 5 cm/sec with highest speeds in winter. While fluctuating kinetic energy is dominated by tides (about 96%) there are wind driven events. However, the combination of baroclinic geostrophic currents with residual flow produced by the interaction of the tides with the bottom topography seems to account for the observed mean flow.

In the middle shelf regime or domain which lies between the inner and middle fronts, there is little mean flow (1 cm/see) except near the fronts. There are wind driven pulses corresponding to meteorological forcing at periods of 2 to 10 days that are similar in magnitude to those in the coastal domain. This lack of mean flow along with the strong seasonal pycnocline allows the retention of the cold bottom layer through out the summer.

In the outer shelf regime or domain, between the middle and shelf break fronts, the vector mean flow is statistically significant. The flow is 1 to 10 cm/sec along the isobaths toward the northwest and across the isobaths onshore toward the northeast at 1 to 5 cm/sec. Because the cross shelf flow usually does not extend into the middle shelf regime, the middle front is often a region of surface convergence, and advection is as important as diffusion in cross-shelf fluxes. This outer shelf current regime has more kinetic energy at periods greater than 10 days than the other two inshore regimes

[1] SV = Sverdrup = 10Gms/see)

[2] Principal lunar

probably due to propagation of energy from the Bering Slope Current and associated eddies, although no eddies have yet been found up on the shelf.

Finally, the Bering Slope Current flows northwestward seaward of the shelf break front at along slope speeds of 5 to 15 cm/sec. This water is a mixture of Alaska Stream and Bering Sea water with the Alaska Stream water source being the Aleutian passes. Eddies are frequently found in this current, but seldom, if ever, found propagating up onto the shelf.

The currents on the northern shelf are dominated by the northward flow into the Arctic with temporary reversals caused by storms particularly in winter. The mean flow seems generally to parallel the isobaths with currents 10 to 25 cm/sec in the Bering Strait and east and west of St. Lawrence Island. In Norton Sound the flow is generally weak although instantaneous wind-driven currents of up to 1 m/see have been measured.

Seasonal sea ice extent in the eastern Bering Sea fluctuates over 1000 km between the Bering Strait in the north and the shelf break to the south between summer and winter. (The ice actually retreats an additional several hundred kilometers further north into the Arctic in summer.) The entire basin is ice free in summer (July to September), while maximum ice extent occurs in later winter - early spring (March to April). The ice is formed primarily by freezing within the basin rather than by advection through the Bering Strait. In spring, over 60% of the ice melts *in situ* while the remainder leaves via the various passes and straits.

These physical processes and resulting oceanographic structure, especially ice melt, strongly influence the biological regime in the ice edge zone. It is hypothesized that observed high primary productivity near the retreating Bering Sea marginal ice zone (MIZ) in spring (note that MIZ blooms are spring blooms) was due in part to low salinity melt water increasing the stability of the water column, which prevents phytoplankton from being vertically mixed out of the photic zone.

In addition to the strong seasonal ice cycle, the winter ice extent also shows large interannual variations. Large year-to-year ice cover fluctuations occur in most of the subarctic seas surrounding the Arctic but the largest variation is in the Bering Sea. Analysis of winter sea ice extent in the Bering Sea as well as sea surface temperatures (SST), air temperatures, and surface and upper air winds and pressure patterns have lead to a conceptual model in which deviations from the mean winter atmospheric circulation seem to be the primary driving force behind the large year-to-year fluctuations in all these parameters. The mid-to-late 1960s were a period of southerly flow of air leading to above normal SST and reduced ice cover. A sharp reversal in atmospheric conditions led to a sharp decrease in SST and an increase in ice cover in the early to mid 1970s. Another reversal of air patterns lead to deviated SST and decreased ice in the late 1970s.

More recently it has been suggested that El Niño-Southern Oscillation (ENSO) events are responsible for a significant portion of the multi-year environmental fluctuations in the Bering Sea. The main evidence is a statistical correlation analysis of time series of atmospheric and oceanic parameters for the subarctic Bering Sea region with the Southern Oscillation Index (S01). The analysis suggests that there is significant tele-connection between the tropical Southern Hemisphere (e.g. SOI) and events in the Bering Sea with the northern events lagging the ENSO events by O to 2 years. The signs of the correlation coefficients all suggest that warming in the eastern Bering Sea, as signalled by decreased ice cover, above normal SST and more southerly winds, follows an ENSO event. Analysis of variance shows that linear regressions between the SOI and the northern time series can explain up to 30% of the variation in the Northern Hemisphere data. Higher order analyses explain only a few percent more of the variation.

The actual physical mechanism connecting the ENSO events to the "warming" or "cooling" of the eastern Bering Sea seems to be related to the winter position of the Aleutian Low. In its mean 700 mb winter position, the Aleutian Low is located approximately over the Kamchatka Peninsula between the Bering Sea and the Sea of Okhotsk. However, it has been known since at least the 1960s that during ENSO events the Aleutian Low deepens and is displaced south- and eastward of normal so as to drive warm, moist North Pacific air northward warming the eastern Bering Sea region.

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THE BERING SEA ECOSYSTEM AS A PREDATION CONTROLLED SYSTEM

Taivo Laevastu
Northwest and Alaska Fisheries Center
National Marine Fisheries Service, NOAA
7600 Sand Point Way NE
Seattle, Washington 98115

The Bering Sea ecosystem is a predation-controlled system, as are most other marine ecosystems. The annual production of the fish component of the system is about 0.7 times of mean standing stock. If we assume a steady state, this production is consumed in the ecosystem. A comparative summary of fish utilization in the Bering Sea and North Sea is given in Table 1.

The coastal areas are an integral part of the ecosystem, and no greater or smaller importance can be assigned to coastal ecosystems. However, the benthic component of the ecosystem, which might be larger in coastal areas than in deep water, plays an important role in the production of commercially important species in the sea.

Table 1. Fish biomasses and their utilization in the North Sea and in the Bering Sea.

	Biomass (MT/km^2)	
Category	North Sea	Bering Sea
Total finfish biomass	25.0	37.0
Catch (in 1980)	6.7	1.9
Consumption by mammals	0.1	3.1
Consumption by birds	0.3	1.1
Consumption by rest of the ecosystem (est)	(10.0)	(19.0)

MT = tonnes or metric tons

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MARINE MAMMALS AND FORAGE FISHES IN THE SOUTHEASTERN BERING SEA

Kathryn Frost and Lloyd Lowry
Alaska Department of Fish and Game
1300 College Road
Fairbanks, Alaska 99701

Approximately 26 species of marine mammals are known to or are likely to occur in the Bering Sea/Aleutian Islands region (Lowry *et al.* 1982). Included in the marine mammal fauna are 8 species of baleen whales, 8 toothed whales, 8 pinnipeds, and 2 carnivores. Many species, especially those that are attracted to or excluded by sea ice, appear in the area only seasonally. Others may be resident year-round. Marine mammals occur in all marine habitats including deep water-oceanic, continental slope-shelf break, and the continental shelf and coastal waters. Most species occur primarily on the continental shelf.

The foods and trophic relationships of marine mammals in the Bering Sea have been the subject of several recent reviews (Frost and Lowry 1981, Lowry and Frost 1981, McAlister 198\, Lowry *et al.* 1982). Unless otherwise stated, data referred to in this summary are taken from those references.

In this review we have focused primarily on those species which prey to a large extent on forage fishes. However, marine mammals may also effect forage fish stocks by feeding on their food resources or on their predators. We have therefore included all species which we consider may be ecologically linked to forage fishes.

Of the 26 marine mammal species, four (bearded seal, *Erignathus barbatus*; walrus, *Odobenus rosmarus*; sea otter, *Enhydra lutris*; and polar bear, *Ursus maritimus*) are either benthic feeders or occur almost entirely to the north of the area of consideration. Four others (sperm whale, *Physeter macrocephalus*, and 3 species of beaked whales, Ziphiidae) eat squids and some fishes, but will not be considered further because they occur primarily in deep oceanic waters and are very rare in the southeastern Bering Sea. The basic dietary habits of the remaining species are summarized as follows:

- Feed primarily on forage fishes -- harbor seal (*Phoca vitulina*), spotted seal (*Phoca largha*), ribbon seal (*Histriophoca fasciata*), harbor porpoise (*Phocoena phocoena*)
- Feed on forage fishes and other fishes and squids -- DalI's porpoise (*Phocoenoides dalli*), belukha whale (*Delphinapterus leucas*), killer whale (*Orcinus orca*), northern fur seal (*Callorhinus ursinus*), Steller sea lion (*Eumetopias jubatus*)
- Feed on forage fishes and zooplankton -- fin whale (*Balaenoptera physalus*), minke whale (*Balaenoptera acutorostrata*), humpback whale (*Megaptera novaeangliae*), ringed seal (*Puss hispida*)

- Feed on zooplankton -- blue whale (*Balaenoptera musculus*), sei whale (*Balaenoptera borealis*), right whale (*Balaena glacialis*), bowhead whale (*Balaena mysticetus*)
- Feed on benthic crustaceans and forage fishes -- gray whale (*Eschrichtius robustus*)

There are few hard data available with which to assess specific aspects of the diet of most Bering Sea marine mammals. Those species that are likely to be major predators of forage fishes are listed in Table 1. The most extensive data base available is for the northern fur seal (Perez and Bigg 1981; Perez and Bigg, in press) for which 1,749 samples have been analyzed that were collected in the eastern Bering Sea in June-October (Table 2). In the Unimak Pass subregion, capelin (*Mallotus villosus*) was their primary food followed by squids and walleye pollock (*Theragra chalcogramma*); Pacific sand lance (*Ammodytes hexapterus*) ranked 6th in the diet and Pacific herring (*Clupea pallasii*) 8th. In the Bristol Bay subregion, primary foods were capelin and walleye pollock with Pacific herring ranked 4th in dietary importance. Overall, in the eastern Bering Sea capelin and walleye pollock made up over 55% of the fur seal diet.

There are fewer data on foods of Steller sea lions in the Bering Sea. Walleye pollock, Pacific sand lance, and capelin have been found in the few specimens examined. In 13 sea lions collected between the Pribilof and St. Matthew islands in March-April 1985, walleye pollock and Pacific herring made up 48% of the volume of contents. Sea lions are seen in schools of spawning herring and are presumed to feed on them (ADF&G, unpubl.). In a recent study in the Gulf of Alaska (Pitcher 198 1), walleye pollock was the most important prey in 153 sea lions examined (58% of the stomach contents volume) followed by herring (21 %) and capelin (7%). Squids were commonly present but in small volumes, In general, foods of sea lions in the Bering Sea and Gulf of Alaska include walleye pollock, Pacific sand lance, squids, octopuses, Pacific herring, capelin, salmon (*Oncorhynchus* spp.), greenings

Table 1. Marine **mammals that are major predators of forage fish in the eastern Bering Sea.**

Species	Pacific Herring	Capelin	Pacific Sand Lance	Walleye Pollock
	Forage Fish Species			
northern fur eeal	x	x	X	X
Steller sea lion	S ,X	x	X	X
harbor seal	S,X	S,X	x	X
spotted seal	W,S?	W,S?	x	X
ribbon seal	w	w	X	x
ringed seal	x	x	X	
belukha whale	x	x	x	?
killer whale	x	?	?	?
harbor porpoise	x	x	x	?
Dall's porpoise	x	x	x	X
fin whale		x		x
minke whale	x	x	x	x
humpback whale	X	x	x	x

S - feeds on spawning concentrations
W - feeds on wintering concentrations
X - generally included in the diet

Table 2. Foods of northern fur seals in the Bering Sea.

Prey Rank	Unimak Pass	Pribilof Islands	Bristol Bay to Saint Matthew	Unimak Pass to Pribilofs	Areas Combined
1	capelin	walleye pollock	capelin	squid	squid
2	squid	squid	walleye pollock	capelin	capelin
3	walleye pollock	Pacific herring	squid	walleye pollock	walleye pollock

Table 3. Foods of ❑ orthern sea lions in the Bering Sea assd Gulf of Alaska.

Bering Sea				Gulf of Alaska			
Pribilofs	Unimak Area	Bering Sea	St. Matthew 1s.	1962	1962	1966	1981
Pacific sand lance	capelin	walleye pollock	walleye pollock	squids	squids/ octopus	Pacific sand lance	walleye pollock
Pacific halibut	Pacific sand lance	Pacific cod	Pacific herring	octopus	mollusks	capelin	squids
Pacific Cod	sculpins	Octopus		ehrimpe	Pacific sand lance	salmon	Pacific herring
walleye pollock	walleye pollock	Pacific herring		greenling	rockf ish	rockfish	capelin

Table 4. Foods of harbor seals in the Bering Sea.

	Alaska Peninsula	
Aleutians Spring	October	June
walleye pollock	Pacific sand lance	Pacific herring
octopus	walleye pollock	capelin
Pacific cod	sculpins	

Table 5. Foods of spotted seals in the Bering Sea.

Central		Southeastern	Northern
1976-77	1985	1976-77	1978
walleye pollock	walleye pollock	capelin	Arctic cod
eelpout	Pacific herring	walleye pollock	capelin
	capelin	Pacific herring	saffron cod
	Pacific cod		sculpins
	eelpout		Pacific herring
			Pacific sand lance

(*Oncorhynchus* Spp.), greenings (*Hexagrammos* spp.), sculpin, and Pacific halibut (*Hippoglossus stenolepis*) (Table 3).

The data base for harbor seals is also fragmentary. Published reports indicate that harbor seals eat pollock, capelin, and sand lance, as well as many other types of fishes. In the Bering Sea, walleye pollock, Pacific sand lance, Pacific herring, octopuses, capelin, sculpins, and Pacific cod (*Gadus macrocephalus*) are important foods for harbor seals, depending on the region and season (Table 4). A recent study (Lowry *et al.* 1986) reported on foods in the stomachs of 16 harbor seals collected in Bristol Bay in May-June 1985. Pacific herring and capelin were the major foods of seals collected at Port Moller, Port Heiden, Nelson Lagoon, Ugashik Bay, and Nanvak Bay. Overall, in 269 harbor seals examined from the Gulf of Alaska, walleye pollock, capelin, and Pacific herring were among the top five prey species, while Pacific sand lance was ranked 14th (Pitcher 1980).

Spotted seals collected in spring in the central Bering ate mostly walleye pollock. In the southeastern Bering Sea, capelin was the primary prey followed by walleye pollock and Pacific herring. Pacific herring, capelin, Pacific sand lance, and walleye pollock are also components of the diet in the central and northern Bering Sea along with Arctic cod (*Boreogadus* *saida),* saffron cod (*Eleginus gracilis*), sculpins, and eelpouts (Zoarcidae) (Bukhtiyarov *et al.* 1984; Table 5).

The primary spring food of ribbon seals in the central rind south central Bering Sea was walleye pollock. Capelin were also eaten in both areas. Pacific sand lance and Pacific herring have also been reported in Soviet studies.

Ringed seals are not common in the southeastern Bering Sea. Pacific herring, capelin, and Pacific sand lance are eaten in more northerly areas, but the most important foods are Arctic and saffron cods, and crustaceans.

In spring and summer in inner Bristol Bay, the main foods of belukha whales are salmon and rainbow smelt (*Osmerus mordax*). Their foods at other areas and times are not known. They are frequently seen in association with Pacific herring schools in areas north of Nunivak Island, but not in Bristol Bay (ADF&G, unpubl.). Seaman *et al.* (1982) speculated that walleye pollock are a major food during winter. Capelin, herring, and sand lance are important foods in other regions.

There are no useful data on foods of killer whales and harbor porpoises in the Bering Sea. In other areas they eat forage fishes, including gadids and clupeids.

The diet of Dan's porpoise has been comparatively well-studied. Most of their food consists of squids, lanternf ishes (Myctophidae), and deepsea smelts (Bathylagidae). Walleye pollock, capelin, Pacific sand lance, and Pacific herring have been reported.

Although there are almost no quantitative data for the Bering Sea, minke whales, fin whales, and humpback whales are known to eat schooling fishes as well as euphausiids and copepods. Walleye pollock, capelin, Pacific herring, and Pacific sand lance are all eaten in the Bering Sea/Aleutians area. Recent studies in the western North Atlantic (Overholtz and Nicolas 1979; Payne *et al.* 1986; Whitehead and Glass 1985) have shown that capelin and American sand lance (*Ammodytes americanus*) are very important foods of humpback and fin whales.

Gray whales migrate through nearshore Bristol Bay during May and June and have been reported to feed on Pacific herring (Frost *et al.* 1983). Although benthic organisms are their major foods they are occasionally seen pursuing schools of "bait fish" (Nerini 1984).

The foods of blue whales, sei whales, right whales, and bowhead whales are mostly copepods and euphausiids. Sei whales occasional] y eat fishes including smelt and sand lance.

Marine mammals interact with forage fishes in two ways: 1) by direct predation on fishes; and 2) by (potential) competition with the fishes for the same food resources. Populations of the large baleen whales off Alaska were markedly reduced by commercial whaling during the earlier part of this century. The zooplankton once consumed by those whales may now be available for other species such as forage fishes, marine birds, or other marine mammals. As populations of forage fishes increase, it is possible that they in turn may retard the recovery of the large whales with which they potentially compete for food, while at the same time enhancing populations of seals or other species which prey on them.

Predation by marine mammals on forage fishes can occur primarily on spawning concentrations, or may be spread throughout the year and over a variety of age classes. Predation may, like commercial fisheries, have either a compensatory or decompensatory effect. If the fish prey are dispersed and their availability to marine mammals decreases as their stock size decreases (thus causing the mammals to switch food), then it is unlikely that marine mammals will "overfish" their prey (Sissenwine *et* al. 1984). With reductions in predation, intraspecific competition for food, and cannibalism, fish stocks can then recover or "compensate" through increased production per unit biomass.

If, however, fishes are predictably concentrated during all or part of their life cycle, such as on the spawning or overwintering grounds, it is possible that stock size could be greatly reduced without commensurate reductions in marine mammal predation, thus causing depletion of stocks. In this case predation is decompensatory, resulting in lower production per unit biomass of fish. This situation may have occurred on Georges Banks, where an overfished Atlantic herring (*Clupea harengus*) stock disappeared, despite the fact that fishing was stopped with a remaining biomass estimated at 300,000 MT. Marine mammals, particularly fin whales, which may eat 1 million t of herring per year in that area, may have caused the disappearance of the herring stock (Sissenwine *et al.* 1984).

The distribution of marine mammals may be determined to a great degree by the availability and movements of fishes. For example, marine mammals may follow species such as herring and capelin throughout the entire annual migration, from wintering grounds to spawning areas and back. In some fishes such as herring, spawning dates become progressively later to the north and marine mammals such as belukhas whales and spotted seals may sequentially target these spawning concentrations.

Marine mammals may be greatly influenced by the size and age class composition of fish stocks (Frost and Lowry 1986). Some marine mammals including ribbon seals, spotted seals, and northern fur seals feed primarily on juvenile fishes, in contrast to Steller sea lions which eat larger fish. During the past decade when extensive fishing resulted in a decrease in the abundance of large walleye pollock, Steller sea lions may have been affected more than species feeding on smaller size classes. As the fishery reduced the number of large fish (which are cannibalistic), the availability of small fish to predators may have increased. However, a sea lion accustomed to eating large pollock would have to find and eat many more smaller fish to obtain an adequate daily ration or switch consumption to another prey species.

Annual variation in the abundance and size of an individual age class may have important consequences. For example, in 1976, 1-year-old walleye pollock were small ($\bar{x}$ = 9.5 g) and abundance was low, while in 1974, fish were larger ($\bar{x}$ = 23.7 g) and more abundant. The estimated biomass of Age 1 pollock, the size most often eaten by many marine mammals and sea birds, was about 10 times greater in 1974 than in 1976. Recruitment in Bering Sea Pacific herring stocks in recent years has been very poor, resulting in mostly 5- and 6-year-old fish. For predators that prefer 1- to 4-year-old herring, this may force them to switch to different prey or to change feeding locations. The energetic or physiological implications of such changes are unknown. It has been suggested that a decline in the number of fin whales in Newfoundland may be due to reduced availability of capelin caused by minke whiles. Whereas fin whales prefer 2- or 3-year-old fish, minkes prey on 1- to 2-year-olds, and thus get to the capelin first (Whitehead and Carscadden 1985).

The data needed to demonstrate the direct effects of competition for forage fishes between fisheries and marine mammals are difficult to obtain. It is, however, worth noting that in the Bering Sea three species of marine mammals, Steller sea lions, northern fur seals, and harbor seals, have undergone substantial population declines. Each of those species feeds to a major extent on walleye pollock, the object of a major commercial fishery. The annual Bering Sea catch of walleye pollock has increased over 500% in the last 20 years.

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TROPHIC INTERACTIONS BETWEEN FORAGE FISH AND SEABIRDS IN THE SOUTHEASTERN BERING SEA

Gerald A. Sanger
Alaska Fish and Wildlife Research Center
U.S. Fish and Wildlife Service
1011 East Tudor Road
Anchorage, Alaska 99503

INTRODUCTION

Seabirds are an important component of the marine ecosystem of the eastern Bering Sea and many species are predators of forage fish there. Interest in seabird-fish interactions, however, did not develop until recently. Studies conducted during the Alaska Outer Continental Shelf Environmental Assessment Program (OCSEAP) in the late 1970s documented that seabirds in the southern Bering Sea feed heavily on juvenile walleye pollock (*Theragra chalcogramma*) (Hunt *et al.* 1981, Schneider and Hunt 1984), while in the northern Gulf of Alaska Pacific sand lance (*Ammodytes hexapterus*) and capelin (*Mallotus villosus*) are the main prey (Wehle 1983, Hatch 1986, Sanger 1986a). Juvenile walleye pollock are sometimes important in Unimak Pass and in the western Gulf of Alaska (Krasnow and Sanger 1986, Sanger 1986b, Sanger and Hatch 1987). Other fishes were occasionally found in seabird diets, but these three species are particularly important. However, except for the knowledge that Alaskan seabirds eat these species in varying amounts, little is known about their quantitative relationships.

Alaskan waters are the only major geographic region within the world ranges of sand lance (*Ammodytes* spp.) and capelin with no major fishery for these species at present, Recent interest by Japan and Iceland in a capelin fishery in Alaskan waters could be a harbinger of greater fishing efforts and greater fishing efforts are likely to affect seabird populations.

Recent work in the eastern Bering Sea (Hunt *et al.* 1981; Murphy, E. C., Univ. Alaska, Fairbanks, AK, pers. comm., 1986) has shown that from 1980 through 1985 there was virtually no production of black-legged kittiwakes (*Rissa tridactyla*), although in two of these years some eggs were laid that did not survive to fledgling. Similarly, there has been a decreasing trend in numbers of common murres (*Uris aalge*) in the northern Bering Sea between 1975 and 1983 (Murphy *et al.* 1986). These researchers speculate that declining murre populations could result from lowered winter survival due to decreased availability of juvenile walleye pollock for food, presumably resulting from overfishing of pollock farther south in the Bering Sea.

This report is an abridgement of a much longer paper ("Trophic Interactions Between Commercial Fish and Seabirds in Alaskan Waters," Sanger and Hatch 1987). Although the summary presented here focuses more directly on "forage fish," it is based on the study of fish species that have present or potential commercial value. The overall study objectives are the following:

- To summarize features of the natural history of fish and seabirds that will aid in understanding their ecological relationship;
- To summarize what is known about seabird-fish interactions, and to speculate about what we do not know, and
- To suggest surveys and research that will increase our understanding of seabird-fish interactions in the southeastern Bering Sea.

ALASKAN SEABIRDS AND FISH

Seabirds vary in their diving ability, but most are able to dive to at least 20 m in search of food, and puffins (*Fratercula* spp.) and murres (*Uris* spp.) are able to descend to at least 60 m and 180 m, respectively (Piatt and Nettleship 1985, DeGange and Sanger 1987). Most seabirds in Alaska seem to be opportunistic in their feeding habits and take the most readily available prey of the right size (e.g. Hunt *et al.* 1981, Sanger 1986b). For fish prey, this is generally about 4 to 12 cm. Few seabirds eat a wide variety of prey, while only a few prey species are of major importance to entire seabird communities.

In the southeastern Bering Sea, juvenile walleye pollock, euphausiids, and copepods are the primary seabird prey, depending on species (Bedard 1969, Hunt *et al.* 1981). In the northern Bering and southern Chukchi Seas, these species, plus juvenile Pacific herring (*Clupea pallasii*), Arctic cod (*Boreogadus saida*), and saffron cod (*Eleginus gracilis*) are important in the diets of the black-legged kittiwakes, common murres, thick-billed murres (*Uris lomvia*), and auklets (*Aethia* spp.) which are the seabird species that comprise most of the bird population in the southeastern Bering Sea (Table 1; Bedard 1969, Hunt *et al.* 1981, Drury *et al.* 1981, Springer *et al.* 1984, Schneider and Hunt 1984, Murphy *et al.* 1986). Limited data show that capelin and Pacific sand lance are moderately important throughout much of the Bering Sea, but little is known about their importance in Bristol Bay.

There is also little known about the diets of most seabirds in the Aleutian Islands, although tufted puffins (*Fratercula cirrhata*) and horned puffins (*F. corniculata*) preyed heavily on Pacific sand lance and Atka mackerel (*Pleurogrammus monopterygius*) at Buldir Island (Wehle 1983), and glaucous-winged gulls (*Larus glaucescens*) seem to rely to a large degree on Pacific sand lance and Pacific herring (Trapp 1979; Irons, in press).

Hence, the main fish species with present or potential commercial importance to seabirds in the southeastern Bering Sea and eastern Aleutian Islands are walleye pollock, Pacific sand lance, capelin, Pacific herring, and Atka mackerel. Other species that occasionally show up in the diets of Alaskan seabirds include juvenile salmon (*Oncorhynchus* spp.), Pacific cod (*Gadus macrocephalus*), sablefish (*Anoplopoma fimbria*), and post-larval flatfishes (Pleuronectidae) and rockfishes (*Sebastes* spp.). It seems quite possible that juvenile Pacific herring and salmon may possibly be more important to seabirds in the Bering Sea than suggested by available information.

Table 1. Populations and biomass (metric tons) of major fish-eating birds that breed in the southeastern Bering Sea. Adapted from Alaska Seabird Colony Catalog - Computer Database, November 1986, USFWS, Anchorage, AK 99503.

	Species* and Average Weight (kg)							
	CORM -2.00 kg		GWGU -1.10 kg		BLKI -0.42 kg		COMU -1.0 kg	
	Pop	Biomass	Pop	Biomass	Pop	Biomass	Pop	Biomass
Eastern Aleutians (Umnak 1- Unimak Pass)	9,120	18.24	19,913	21.90	4,296	1.80	15,512	15.51
Unimak Pass - False Pass	640	1.28						
False Pass - Port Moller	3,004	6.01	1,840	2.02	3.964	1.66		
Port Moller - Port Heiden (Cape Seniavin)	12	0.02	7,000	7.70	3,600	1.51	600	0.25
Port Heiden - Kvichak Bay	24	0.05	92	0.10				
Kvichak Bay - Cape Newenham	7,520	15.04	8.518	9.37	367,434	154.32	1,020,300	428.53
Pribilof Islands	15,046	30.09			1,030,000	432.60	230,650	96.87
Totals	35,366	70.73	37,363	41.10	1,409,294	591.90	1,267,062	541.16
% of Total	0.7	1.9	0.7	1.1	25.9	1S.8	23.3	14.5

	TBMU -1.0 kg		TUPU -0.82 kg		Totals		Totals	
	Pop	Biomase	Pop	Biomass	Pop	Biomass	Pop	Biomass
Eastern Aleutians (Umnak 1- Unimak Pass)	38,520	38.62	927,193	760.30	1,014,554	856.28	18.7	22.9
Unimak Pass - False Pas.	-	-	30	0.02	670	1.30	0.0	0.0
False Pase - Port Moller			1,803	1.48	10,611	11.18	0.2	0.3
Port Moller - Port Heiden (Cape Seniavin)					11,212	9.49	0.2	0.3
Port Heiden - Kvichak Bay	-	-			116	0.15	0.0	0.0
Kvichak Bay - Cape Newenham			87,364	71.64	1,491,136	678.90	27.4	18.1
Pribilof Islands	1,621,500	1)621.50	7,000	5.74	2,904,196	2,186.81	53.5	-58.4
Totals	1,660,020	1,660.02	1,023,390	839.18	5,432,495	3,744.10	100.0	100.0
% of Total	30.6	44.3	18.8	22.4	100.0	100.0		

* CORM = cormorant spp.; GWGU = glaucous-winged gulls; BLKI = black-legged kittiwakes; COMU = common murre; TBMU = thick-billed murre; TUPU = tufted puffin

NATURAL HISTORY OF SELECTED SEABIRD PREY

Walleye Pollock

Walleye pollock is a major prey of black-legged kittiwakes, common murres, thick-billed murres, and tufted puffins (Table 2). Juvenile walleye pollock in the diets of gulf of Alaska seabirds in August were about 4 to 8 cm in length (Sanger and Hatch 1987), indicating that they were young-of -the- year fish. Surveys in the southeastern Bering Sea at this time showed that Age-O pollock were abundant along the shelf break while Age-1 and Age-2 pollock are found throughout the water column over all oceanographic domains of the eastern Bering Sea (Lynde 1984), thus increasing their availability to many species of diving seabirds (cf. Hunt *et al.* 198 1). It is likely that walleye pollock become too large for the larger seabirds sometime during Age-2.

Capelin

Capelin are common to abundant in the diets of seabirds (particularly common murres; Table 2) (Sanger *et al.* 1978, Krasnow and Sanger 1986) and pinnipeds (Fiscus and Baines 1966, Pitcher 1980 and 1981) collected during summer in the northern Gulf of Alaska and Unimak Pass. They also account for substantial portions of trawl catches during winter shrimp surveys in bays on the east side of Kodiak Island (L. Watson, Alaska Dep. Fish Game, Anchorage, AK, unpubl. data) at times when common murres are common in the bays (Forsell, J. D., U.S. Fish Wildl. Serv., Honolulu, HI, pers. comm., 1986). The distribution of capelin in seabird food samples from OCSEAP studies corroborate this general distribution pattern.

Table 2. Known or **potential utilization of forage fish by seabirds in the southeastern** Bering Sea. **Adapted from Ainley and Sanger 1979; Hunt *et* al. 1981;** Schneider **and Hunt 1984; Sanger 1986a;** Springer, **pers. comm.)**

Bird Species	Fish Species: Pacific Herring	Capelin	Walleye Pollock	Pacific Sand Lance
cormorant epp.	+	+	x	x
glaucous-winged gull	x	+	+	x
black-legged kittiwake	x	+	X	X
common murre	x	X?	x	x
thick-billed murre			X	-
horned puffin	+	+	x	x
tufted puffin		+	x	x

Utilization: X = major; x = moderate; + = minor; - = none known or suspected

Pacific Sand Lance

The importance of Pacific sand lance in seabird diets in the Gulf of Alaska from southeast Alaska to Buldir Island in the Aleutian Islands (Wehle 1983) suggest that this species is abundant in most coastal waters (Hatch 1984, Sanger 1986a, Sanger and Hatch 1987), although they appear to have a highly clumped distribution (Harris and Hartt 1 977).

Pacific sand lance are also apparently abundant in Bristol Bay (Dick and Warner 1982), Norton Sound, and the eastern Chukchi Sea (Drury *et al.* 1981). The distribution of sand lance in seabird food samples from OCSEAP studies corroborate this general distribution pattern.

Pacific Herring

Age-O and -1 Pacific herring would seem to be the most likely sizes to be eaten by seabirds in the southeastern Bering Sea, although there seems to be little information about any aspect of the biology of young herring in the area. Little seems to be known about migrations, and even the occurrence of Age-1 herring. Age-1 fish occur as a small fraction in Alaskan seine fisheries (Reid 1971), and Age-1 and Age-2 fish winter in shallow protected waters in southeastern Alaska and Prince William Sound (Reid, pers. comm., 1986), where they presumably are eaten by marine birds.

Salmon

Juvenile salmon have occurred very *rarely in* the diets of Alaskan seabirds (Hunt *et al.* 1981, Drury *et al.* 1981, Wehle 1983, Springer *et al. 1984,* Sanger 1986a), despite the fact that pink salmon (*Onchorhynchus gorbuscha*) and chum salmon (O. *keta*) smelts migrate to the sea immediately after they emerge from the gravel in the spring and early summer. The smelts stay close inshore through their first summer (e.g. Hart 1973, Strat y and Haight 1979), where they would seem to be vulnerable to marine birds such as cormorants (*Phalacrocorax* spp.), pigeon guillemots (*Cepphus columba*), and marbled murrelets (*Brachyramphus marmoratus*), which forage nearshore. Similarly, the seasonal occurrence and size of juvenile sockeye salmon (*Oncorhynchus nerka*) would appear to make them appropriate prey for seabirds, but there is little evidence of their occurrence in the diets of Alaskan seabirds (Ogi and Tsujita 1973, Sanger 1986a). In British Columbia, young coho salmon (0. *kisutch*), chum salmon, and sockeye salmon are occasionally eaten by rhinoceros auklets (*Cerorhinca monocerata*) (Vermeer and Westrheim 1984).

SEABIRD-FISH INTERACTIONS, REAL AND SPECULATIVE

In August 1986, diets of nestling tufted puffins were studied at two islands near Unimak Pass as part of a broader investigation of puffin food dependencies on commercial fish from the eastern Aleutians to Kodiak (Sanger and Hatch 1987). Young-of-the-year walleye pollock comprised 75% and 56% by weight of puffin diets at Tangagm and Aiktak Islands, respectively (Figure 1). Two years of similar data from the Simiti Islands in the western Gulf of Alaska (Figure 2) show that utilization of forage fish can change from year to year. These data also underscore the importance of continuing studies for several years to learn normal patterns of annual variation in fish use by marine birds.

In contrast to the breeding failures of kittiwakes (*Rissa* spp.) and declining populations of murres (cf, Murphy *et al.* 1986; Murphy, E. C., Univ. Alaska, Fairbanks, AK, pers. comm., 1986) in the eastern Bering Sea (both of which are piscivorous), populations of planktivorous seabirds such as the *Aethia* auklets may be enhanced (cf. Bedard 1969, Schneider and Hunt 1984). More information is needed.

There is also a need for information about interactions between seabirds and fish in northern Bristol Bay (the site of large seabird colonies at Capes Newenham and Pierce), and, on Alaska state lands, at seabird colonies in Togiak Bay. Togiak Bay has been the site of an expanding fishery for Pacific herring, and the only fishery to date, albeit very small, for capelin in Alaskan waters.

GENERAL DISCUSSION

In general, there are three ways that seabirds and fish may interact tropically 1) birds may eat fish directly, as in common murres eating juvenile walleye pollock; 2) birds and fishes may compete for the same prey species, and a reduction of the population of one may benefit the other (e.g. auklets may have more plankton to eat when planktivorous stages of walleye pollock are reduced); and 3) by-catches and offal dumped overboard from fishery vessels may benefit scavenging species such as the northern fulmar (*Fulmarus glacialis*). However, we are very far from understanding the quantitative nature of trophic relationships between birds and fish. In short, we know that trophic links exist between seabirds and fish, but data and ideas about their degree, geographic extent, annual variations, or seasonality are vague.

Major problems that confound an understanding of this complex problem include the vast geographic extent of the southeastern Bering sea, and the inclement weather which abounds for much of the year. Financial support for basic surveys and research has been meager and inconsistent, with the result that long-term biological data (particularly for

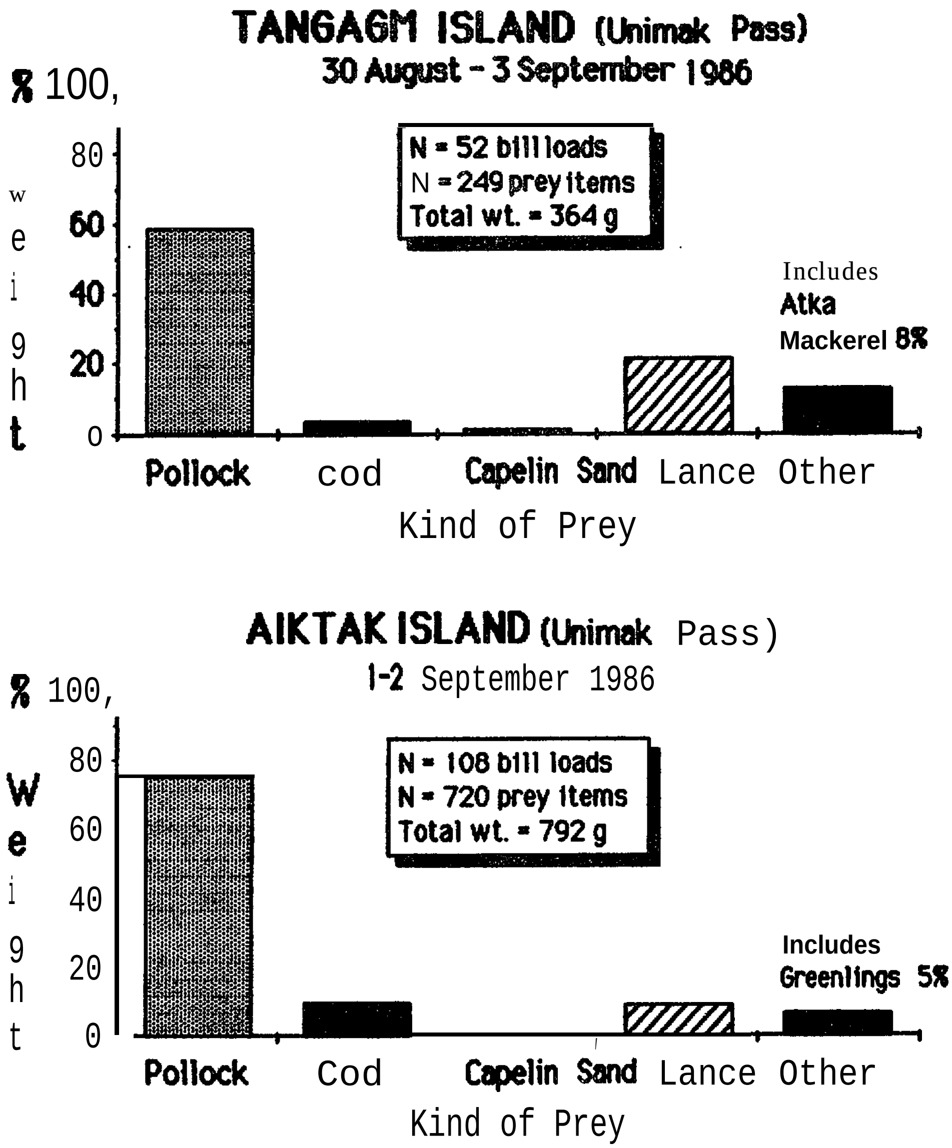

Figure 1. Tufted puffin (*Fratercula cirrhata*) diet composition by weight (g) at Tangagm and Aiktak Islands, Unimak Pass, August to September 1986.

seabirds), are sorely lacking. For example, we are just beginning to realize that it may be "normal" for black-legged kittiwakes to fail to produce young in any given year; it may be the one banner year of production after several poor years that maintains the population. Yet, without an extended series of years of monitoring populations and productivity at key nesting colonies, it is simply impossible to know the "normal" bounds of production and population levels.

For example, the only reason that seabird-fish interactions are well understood in the northeastern Atlantic (Lid 1981, Furness 1982) and in the Humboldt Current (Schaefer 1970) is that many years of data on both fisheries landings and seabird populations are available. At best, we have about six years of data from the northern Bering Sea

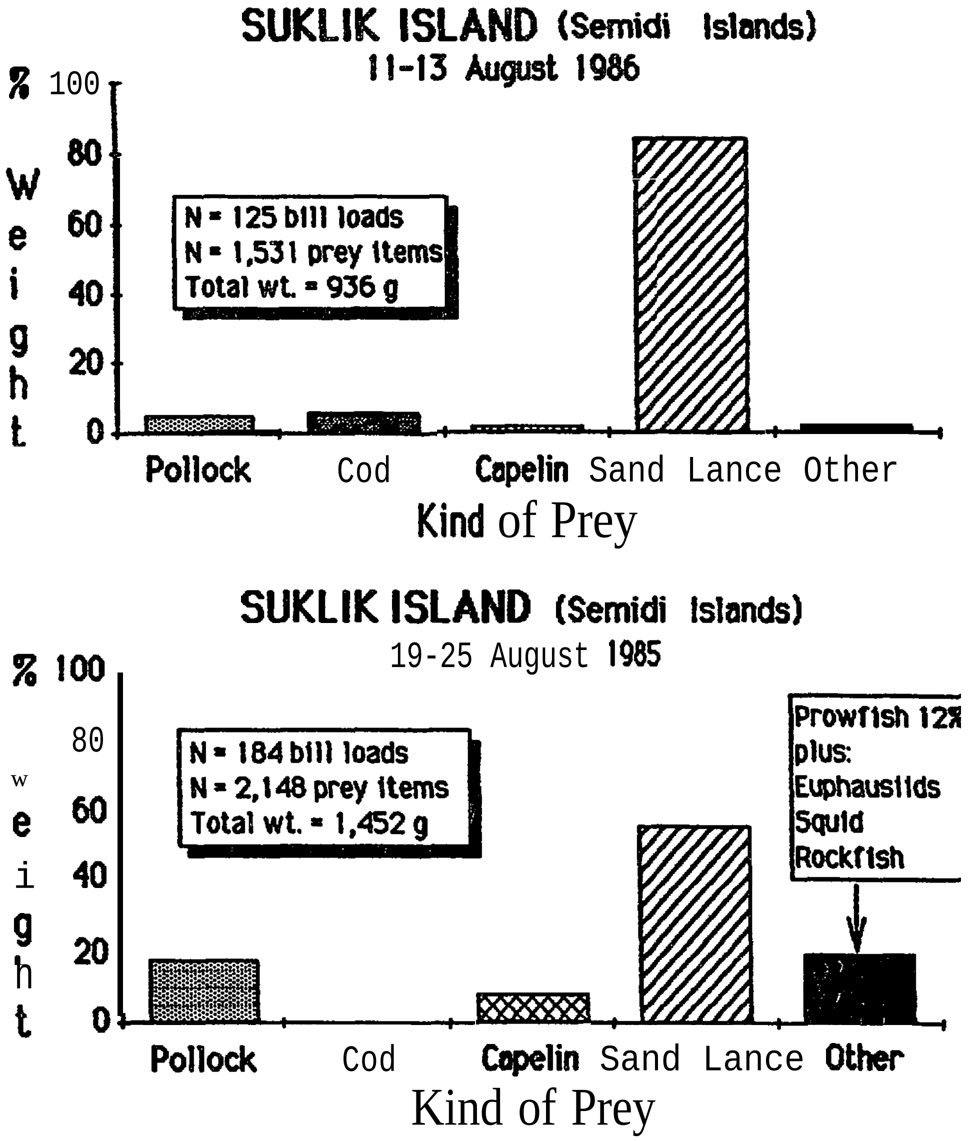

Figure 2. Tufted **puffin (*Fratercula cirrhata*) diet composition by weight (g) at Suklik** Island, western Gulf of Alaska, **August 198S and 1986.**

(Murphy *et al.* 1986, Murphy, pers. comm.), and far less for the southern Bering Sea, and almost none for the Aleutian Islands.

To improve our knowledge of seabird-fish interactions in the Bering Sea, I recommend the following

- Monitor catches of commercial fishes that are linked tropically to seabirds and analyze the geographic distribution of fisheries as related to specific nesting colonies;
- Continue and expand the program of monitoring population levels of seabirds at important colonies (e.g. those at selected islands in the eastern Aleutians, Saint

George Island, Cape Pierce, and Cape Newenham, and the Togiak areas of Bristol Bay);

- At carefully selected seabird colonies, survey surrounding seas for stocks of forage fishes (using hydroacoustic and/or trawling methods and working in cooperation with experienced fisheries biologists) in conjunction with concurrent population monitoring and productivity studies conducted just before and during the breeding season;
- Expand the database on seabird food dependencies during all seasons of the year;
- Encourage the National Marine Fisheries Service to report by-catches of capelin, Pacific sand lance, juvenile Pacific herring, and other forage species separately from the "other species" category in their fishery statistics report;
- Study diets of seabirds in eastern Aleutians and northern Bristol Bay during the summer nesting season; and
- Study seabird diets in nearshore waters of southern Bristol Bay in spring during the out-migration of sockeye salmon smelts.

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DEMERSAL FISH PREDATORS OF PELAGIC FORAGE FISHES IN THE SOUTHEASTERN BERING SEA

M. James Allen
MBC Applied Environmental Sciences
947 Newhall Street
Costa Mesa, California 92627

The continental shelf of the eastern Bering Sea is extremely broad, ranging from 500 to 800 km in width. The waters of the shelf are covered with ice during the winter (except in the extreme southeast) and subzero (usually near - 1.8°C) temperatures are found everywhere beneath the ice from the surface to the bottom. In the summer, however, the waters of this sea are ice-free and consist of three major hydrodynamic domains (which are best developed in the southeast). These include the following 1) An inner shelf zone from shore to 50 m of vertically homogeneous water with warm temperatures of 8 to 12°C; 2) a middle shelf zone from 50 to 100 m consisting of a warm (about 7°C) surface layer over a cold bottom layer with temperatures of -1 to 3°C; and 3) an outer shelf zone from 100 to 200 m with similar surface temperatures but with intermediate bottom temperatures of 3 to 6°C (Ingraham 1981, Kinder and Schumacher 1981).

The southeastern Bering Sea has an extremely diverse fish fauna for its subarctic position in part because it is a region where four faunal provinces (Arctic, Aleutian, Kurile, and Okhotsk) overlap (Allen and Smith, in press). Its fauna consists of pelagic species which occupy the water column over the shelf and demersal (benthic and benthopelagic) species that occur on or near the bottom (Fedorov 1973).

The major pelagic fishes include Pacific herring (*Clupea pallasii* (=*C. harengus pallasi*)), capelin (*Mallotus villosus*), rainbow smelt (*Osmerus mordax*), walleye pollock (*Theragra chalcogramma*), and Pacific sand lance (*Ammodytes hexapterus*). Other schooling species are sometimes important, usually occurring either incidentally in the northern or southern portions of the southeastern Bering Sea or seasonally in nearshore areas. These include the following juvenile salmon (*Oncorhynchus* spp.) -- particularly sockeye salmon (*O. nerka*), but also pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), coho salmon (0. *kisutch*), and chinook salmon (*O. tshawytscha*); smelts -- particularly eulachon (*Thaleichthys pacificus*) and to some extent surf smelt (*Hypomesus pretiosus*); cods -- particularly Arctic cod (*Boreogadus saida*), saffron cod (*Eleginus gracilis*), and juvenile Pacific cod (*Gadus macrocephalus*); and juvenile Pacific sandfish (*Trichodon trichodon*) (Fedorov 1973; Allen, in prep.).

The five salmon species, the rainbow smelt, and the eulachon are all anadromous, spawning in freshwater but spending much of their pre-spawning lives in the ocean. The Pacific herring, capelin, and Pacific sand lance have demersal eggs and generally spawn in nearshore areas intertidally (as in the Pacific herring) or subtidally (Hart 1973, Garrison and Miller 1982). The Pacific sand lance sometimes burrows into the sediments but generally schools in the water column (Hobson 1986). The walleye pollock is often considered to be demersal because it occurs near the bottom during the day as an adult; however, the species occurs nearer the surface at night and occurs in midwater throughout the Aleutian Basin (Allen and Smith, in press). Most of these species are potentially important as forage fish (at least as juveniles) to many species of marine mammals, seabirds, and bony fishes. While marine mammals and seabirds generally represent a predatory threat to forage fish from above, demersal fishes pose a threat from below.

The dominant habitat for demersal fishes living on the shelf consists of sandy and muddy sediments. Rocky bottoms occur more commonly in the inner shelf zone of the mainland and islands and in some areas along the shelf break. Because of the great areal coverage of the soft-bottom habitat and the ease of harvesting the fish living there, the soft-bottom fish fauna supports an intensive, multinational, demersal trawl fishery. It is hence also the focus of population assessment surveys by the National Marine Fisheries Service, resulting in an extensive data base concerning the distribution and abundance of the species.

The demersal fish fauna consists of about 150 to 200 species of fishes, most of which are benthic (seldom swimming into the water column). A number of species, however, are benthopelagic and regularly make use of the bottom and the water column during foraging or for refuge. The dominant species in the demersal fish community (i.e. that portion of the fish fauna that is harvested by bottom trawl) include roundfishes with swimbladders (e.g. walleye pollock, also included above as a pelagic species and a forage fish; and Pacific cod), roundfishes without swimbladders (including greenings, sculpins, eelpouts), and flatfishes. The roundfishes have superior, terminal, or inferior mouths whereas the flatfishes have either large, symmetrical mouths or small, asymmetrical mouths. In general, these morphologies are associated with different foraging behaviors (particularly with regard to the degree to which pelagic or benthic prey are eaten). Thus roundfishes with swimbladders and superior mouths and flatfishes with symmetrical mouths usually feed on nektonic prey, roundfishes with large terminal (or slightly inferior) mouths and swimbladders feed on pelagic and benthic prey, and roundfishes with small terminal or inferior mouths and flatfishes with small asymmetrical mouths feed primarily on benthic prey (Allen, in prep.).

The walleye pollock is the major pelagic predator in the "demersal" fish fauna. It has a swimbladder and a superior or terminal mouth and, as a juvenile, is a forage fish itself. Adults of this species are important predators of their own juveniles (particularly near the shelf break during fall to spring). Because adults of this species usually occur in deeper, offshore waters they are not important predators of inshore and more epipelagic forage fishes.

The Pacific cod is the major benthopelagic predator of forage fish in the southeastern Bering Sea. It has a swimbladder and a large, slightly inferior mouth. This species is primarily a benthic forager as a juvenile but feeds on pelagic fishes as an adult. It is an important predator on walleye pollock and is probably an important predator on pelagic forage fishes in inshore areas (Jewett 1978; Allen, in prep.). The saffron cod (*Eleginus gracilis*), a smaller species, and juvenile Pacific cod, both of which roam the bottom searching for food, probably prey to some extent on juvenile forage fishes, on burrowing Pacific sand lance, on spawning capelin, and on the demersal eggs of littorally spawning forage fishes. This is also true of the whitespotted greenling, (*Hexagrammos stelleri*) (Hobson 1986) which lacks a swimbladder but otherwise forages in a similar manner (Allen, in prep.).

Several species make (or potentially make) extensive forays into the water column in pursuit of prey (primarily pelagic forage fishes), but must return to the bottom when they stop swimming because they lack a swimbladder. These include the sablefish (*Anoplopoma fimbria*), Pacific sand fish, arrowtooth flounder (*Atheresthes stomias*), Pacific halibut (*Hippoglossus stenolepis*), and Greenland halibut (*Reinhardtius hippoglossoides*). The sablefish and arrowtooth flounder primarily remain in deeper areas of the outer shelf and slope and hence are predators primarily on walleye pollock. The Greenland halibut is very important as a predator on the middle-outer shelf (particularly in the northwest) and slope. It makes forays from deep water to the surface and feeds as an adult almost exclusively on forage fishes (primarily capelin and walleye pollock over the shelf). In inshore areas Pacific sandfish and Pacific halibut ambush forage fish near the bottom or chase them into the water column. The Pacific halibut grows much larger and is hence able to feed on a much broader size range of fish. Both sablefish and Pacific halibut also feed on motile benthic prey.

Several species of sculpins ambush forage fish as they swim near the bottom but are unlikely to swim far into the water column in pursuit of their prey. These include the bigmouth sculpin (*Hemitripterus bolini*), plain sculpin (*Myoxocephalus jaok*), great sculpin (*M. polyacanthocephalus*), and warty sculpin (M. *verrucosus* (=*M. scorpius* in part)). The bigmouth sculpin is abundant on the outer shelf and slope and hence preys on walleye pollock. In the southeastern Bering Sea the plain sculpin is most abundant in the inner shelf zone, the warty sculpin in the cold middle shelf zone, and the great sculpin in the outer shelf zone (but also in inner shelf regions along the Alaska Peninsula). Other moderately large sculpins that may feed on forage fishes include the armorhead sculpin (*Gymnocanthus galeatus*), threaded sculpin (G. *pistilliger*), yellow Irish lord (*Hemilepidotus jordani*), and butterfly sculpin (*H.* (=*Melletes*) *papilio*). Of these species the threaded sculpin is most abundant on the inner shelf, the armorhead and butterfly sculpins on the middle shelf, and the yellow Irish lord on the outer shelf. The threaded sculpin may also capture burrowing Pacific sand lance or feed on the demersal eggs of forage fishes.

Several species of flatfishes with small asymmetrical mouths include burrowing Pacific sand lance or the demersal eggs of forage fishes in their diet. These include the starry flounder (*Platichthys stellatus*), yellowfin sole (*Pleuronectes* (=*Limanda*) *aspera*), rock sole (*Pleuronectes* (=*Lepidopsetta*) *bilineata*), and possibly the longhead dab (*Pleuronectes* (=*Limanda*) *probiscidea*) and Alaska plaice (*Pleuronectes quadrituberculatus*).

The most important predators on pelagic forage fishes in terms of their abundance in the inner shelf zone are the yellowfin sole, rock sole, saffron cod, Pacific cod, and walleye pollock. Of these species the Pacific cod is most likely to be an important predator on juveniles and adults, the walleye pollock on larvae, and the remaining species on demersal eggs or burrowing Pacific sand lance. On the middle and outer shelf walleye pollock, Pacific cod, and Greenland halibut are the major predators while walleye pollock and, to some extent capelin, are the major forage fishes (Allen, in prep.).

Hence, although the demersal fish diversity is high, predation on juveniles and adults of small pelagic fishes in the southeastern Bering Sea is restricted to a relatively few demersal species.

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DYNAMICS OF COASTAL SALMON IN THE SOUTHEASTERN BERING SEA

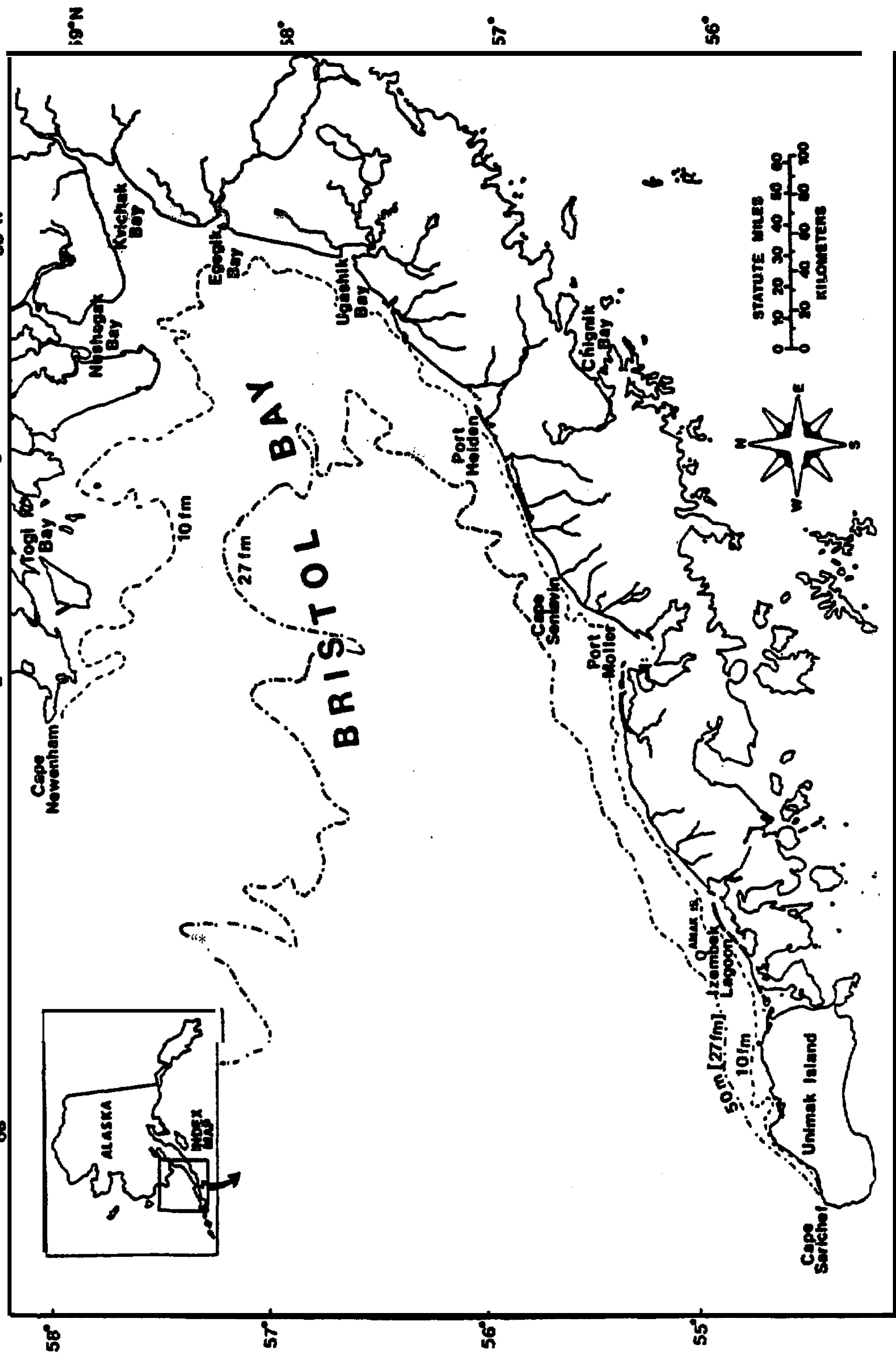
Donald E. Rogers
Fisheries Research Institute, WH-10
University of Washington
8039 23rd Street, NW
Seattle, Washington 98195

Bristol Bay (Figure 1) contains the world's largest concentration of Pacific salmon. The average annual run of adult salmon during 1974-1983 numbered 36.5 million fish. Sockeye salmon (*Oncorhynchus nerka*), which averaged 29.9 million (82%), were by far the most numerous; however, chum salmon (O. *keta*) runs averaged 2.6 million and pink salmon (O. *gorbuscha*) runs in even-numbered years averaged 6.4 million (they are scarce in odd-numbered years). Coho salmon (*O. kisutch*) and chinook salmon (O. *tshawytscha*) combined constituted only 2% (0.8 million) of the average annual run of salmon.

During the late 1960s the Bureau of Commercial Fisheries studied the seaward migration of juvenile sockeye salmon along the north side of the Alaska Peninsula mainly based on purse seine sampling. The seaward migration was largely near the coast (out to about 15 km) as far seaward as Port Moller. Beyond Port Moller they appeared to disperse farther offshore. With the potential oil development on the north Aleutian shelf, there was a need for additional information on the coastal distribution of salmon along the Alaska Peninsula, especially to determine (1) the nearshore abundance of sockeye salmon (not covered by earlier studies), and (2) the distributions of the other salmon species.

A purse seine and beach seine were used to sample juvenile salmon from about Port Heiden to Izembek during 26 June to 12 September 1984. Catches of juvenile salmon were relatively small with nearly equal numbers of sockeye, chum, and coho salmon. We expected to catch considerably greater numbers of sockeye. The average catch of salmon in 71 purse seine sets was only eight fish and even lower catches of salmon were made in 47 beach seine hauls; an average of one was taken per haul and no pink or chinook salmon were caught. With such small catches, the onshore-offshore distributions could hardly be described.

A small purse seine was added in 1985 to sample the bays and waters nearer the beach and sampling was conducted from Ugashik to Izembek during 16 June - 28 July. The large purse seine caught an average of about 94 salmon per set (97 sets), and sockeye salmon made up 93.50/0 of the catch. The small seine caught an average of 49 salmon per set (34 sets) and sockeye and chum salmon each constituted about 45% of the catch. The beach seine averaged 119 salmon per set with chum salmon constituting 81.5% and pink salmon 17% of the catch. It was evident that the smaller pink and chum salmon juveniles utilize the nearshore areas to a much greater extent than do larger sockeye juveniles.



1. Bristol Bay and the Alaska Peninsula.

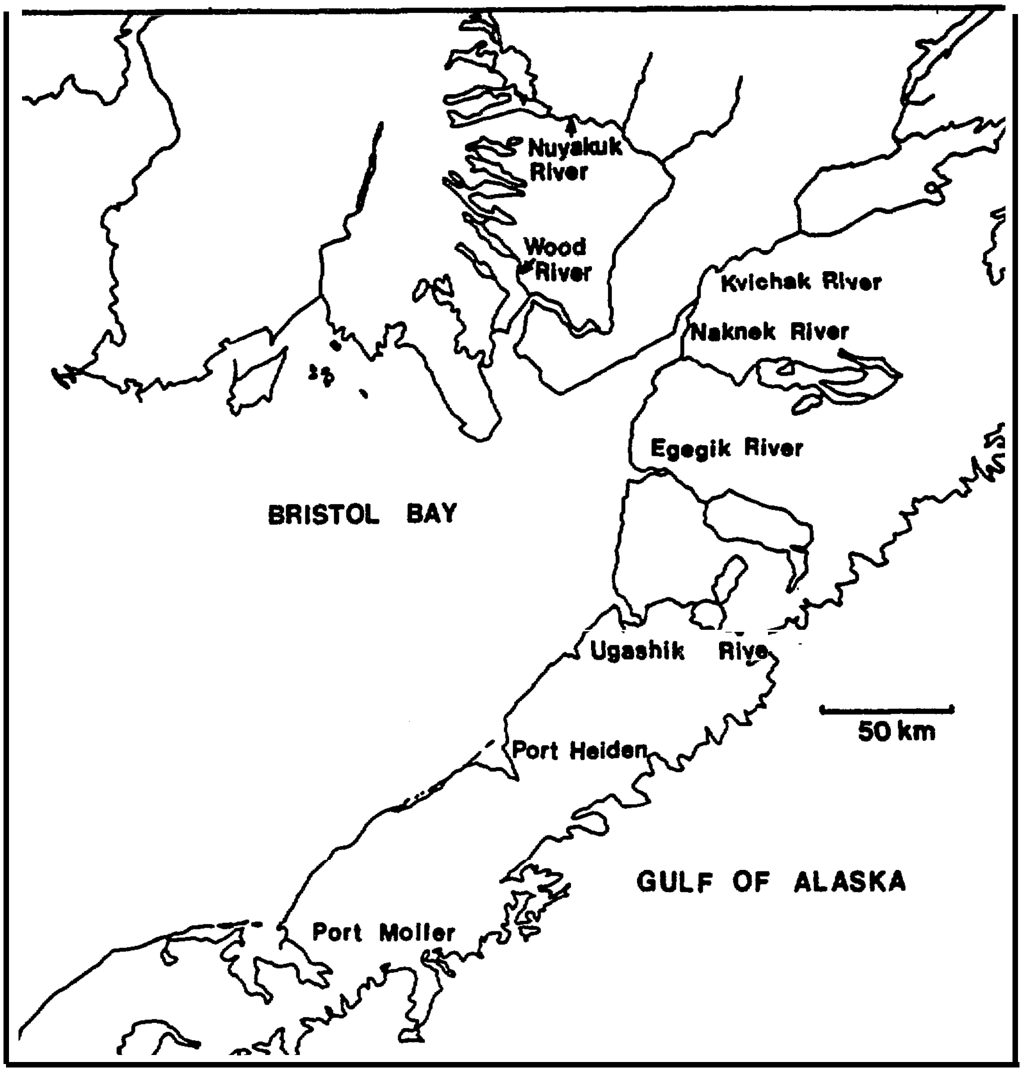


Figure 2. Bristol Bay rivers with smelt enumeration projects.

The year-to-year variation in juvenile sockeye salmon abundance and distribution along the North Peninsula coast was described from the daily estimates of smelt migrations made by the Alaska Department of Fish and Game (Figure 2), the distances from enumeration sites to points along the peninsula, the mean lengths of smelts, and an assumed swimming speed of one body length per second.

Since 1976, the annual number of juvenile sockeye migrating into Bristol Bay (excluding North Peninsula stocks) ranged from about 217 million (1985) to about 640 million (198 l). The estimated number of seaward migrants in 1984 (440 million) was about double the number in 1985, yet our catches were many times greater in 1985 (Figure 3). This was because 1984 was an early spring and most of the migration was seaward of our sampling by the time we began.

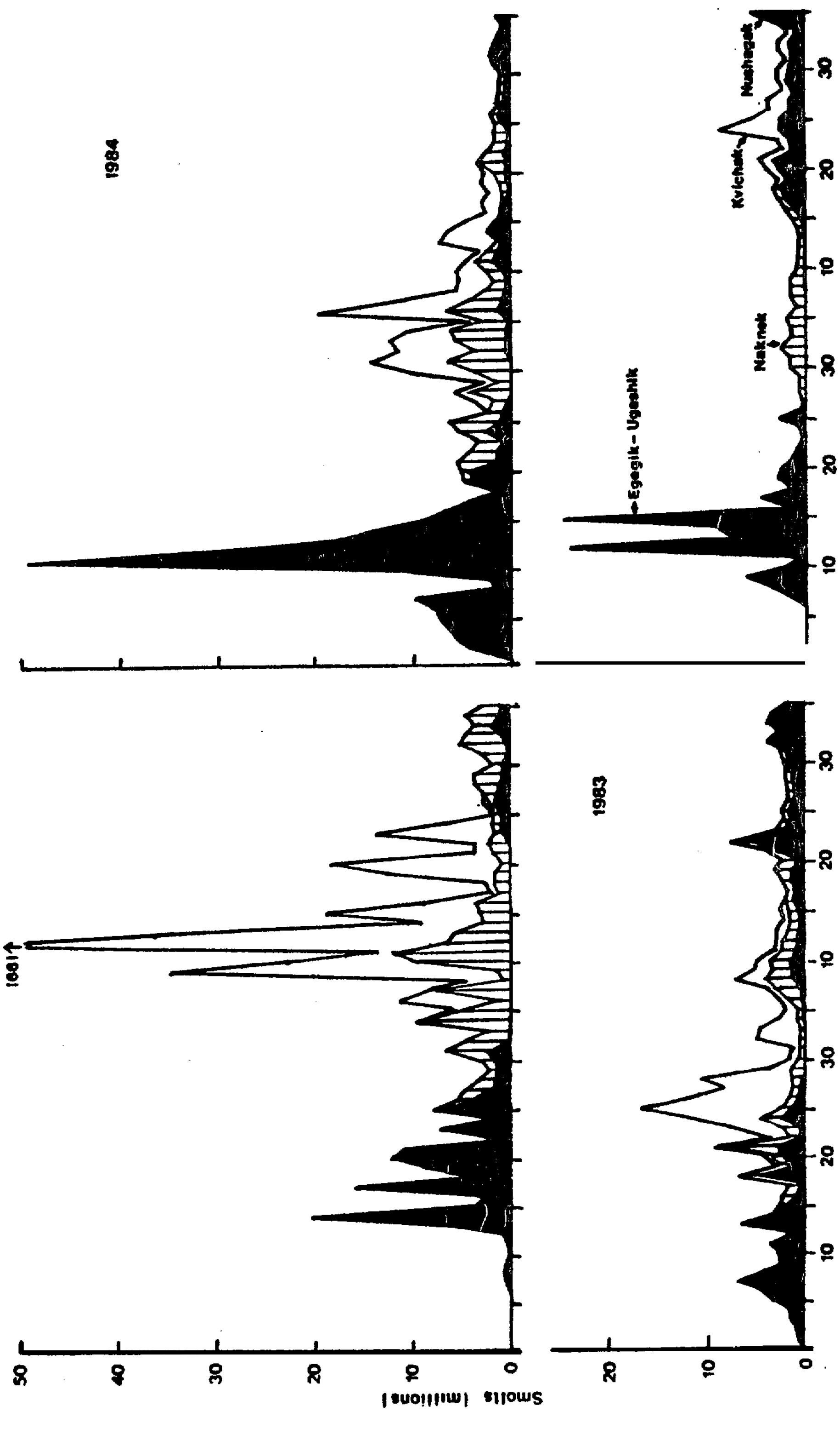


Figure 3. Simulated daily abundances of sockeye salmon smolts past Port Heiden through August 1982-85.

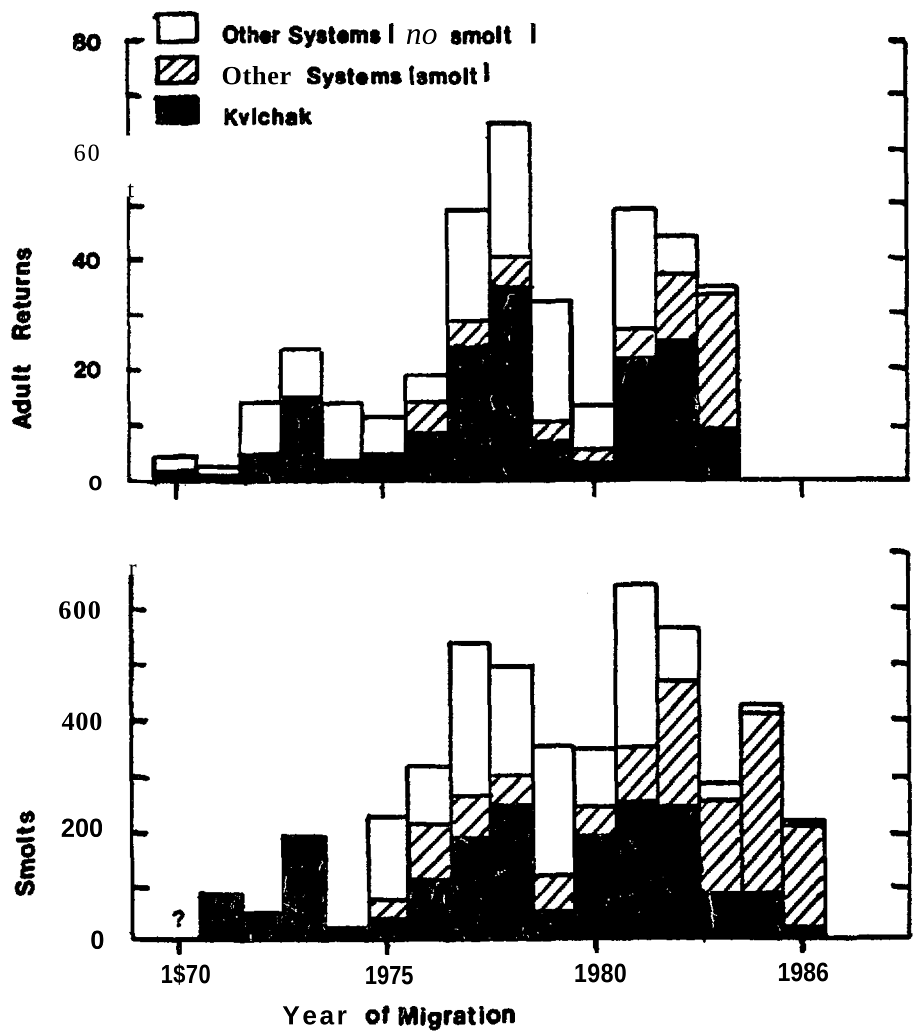


Figure 4. Annual estimates of sockeye salmon smelts and the adult returns by year of seaward migration (numbers in millions of fish).

The order in which smelts leave the major lake systems and the duration of the migrations seem to be maintained from year to year, but the timing of the onset of migrations is dependent on spring weather. Sockeye smelts from Egegik, Ugashik, and Naknek are generally larger than those from the more interior Kvichak and Nushagak systems, and if swimming speed is a function of size, then the distributions of Ugashik and Egegik smelts probably do not overlap those of the Kvichak and Nushagak stocks at least as far seaward as Port Moller.

Only about 40/0 to 170/0 of the juvenile sockeye that migrate to sea survive to return as adults (Figure 4), and it is generally thought that most of the mortality occurs during the first summer at sea. For the Kvichak stock, marine survival is correlated with the size of the seaward migrants -- larger smelts survive better than smaller smelts. The cause of this differential survival is not apparent within their first months at sea (in Bristol Bay). For the Wood River stock, their marine survival is related to temperatures at seaward migration -- better survival at warmer temperatures. Again, the cause is not apparent. We need to know much more about predators on juvenile salmon and the abundances of their food organisms and how these vary from year to year to begin to understand the dynamics of coastal salmon in the southeastern Bering Sea.

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FORAGE FISH USE OF INSHORE HABITATS NORTH OF THE ALASKA PENINSULA '

Jonathan P. Houghton
Dames and Moore
155 N. E. 100th Street
Seattle, Washington 98125-0981

This two-year study was conducted by Dames & Moore in association with Fisheries Research Institute (FRI), University of Washington, and was performed under NOAA Contract 84-ABC-00 122. While the study's primary focus was on juvenile salmon (*Oncorhynchus* spp.), the gear employed was effective at sampling a variety of forage species; only the data on forage fish are reported here. Primary objectives of this research were to

- Describe the species composition of demersal and pelagic fish assemblages in nearshore, intertidal, and estuarine habitats of the study area; and
- Determine relative abundances of species by habitat, area and season (spring, summer, and fall).

The general approach of this study was to allocate limited resources of sampling effort and time to maximize the collection of new information on the movement and abundance of commercially significant fishes in nearshore habitats (e.g. within 50-m isobath).

In 1984, the study area extended from False Pass to Ugashik Bay in waters extending from shore or the surface to 30 m deep (Figure 1). It encompassed two estuaries (Port Heiden and Port Moller) and a coastal lagoon (Izembek Lagoon), as well as exposed coastal and inshore habitats. Limited sampling was also conducted in Ugashik Bay. Sampling was focused at depth-stratified stations (5, 10, 20, and 30 m) on six transects spaced throughout the study area to include three with associated embayments and three from exposed beaches. Depending on station characteristics, each was sampled by one or more of the following gear types: purse seine or tow net (targeting pelagic species); otter trawl or beam trawl (targeting demersal fish); beach seine (targeting littoral fish assemblages).

In 1985, the study area was the same as in 1984, except that only transects off Ugashik, Port Heiden, Port Moller, and Izembek Lagoon were sampled (Figure 1). A new offshore station was added and the three stations farthest offshore (numbered O, 1, and 2) were stratified by distance offshore at 24, 16, 8 km in 1985, versus the depth stratification approach of 1984. In contrast to the 1984 sampling with five gear types, only the beach seine, purse seine, and a new gear type (small purse seine) were used in 1985 to place more emphasis on pelagic species.

Three sampling cruises were undertaken in 1984 (late June to mid July, late July to mid August, late August to mid September). In 1985, one 6-week cruise occurred from

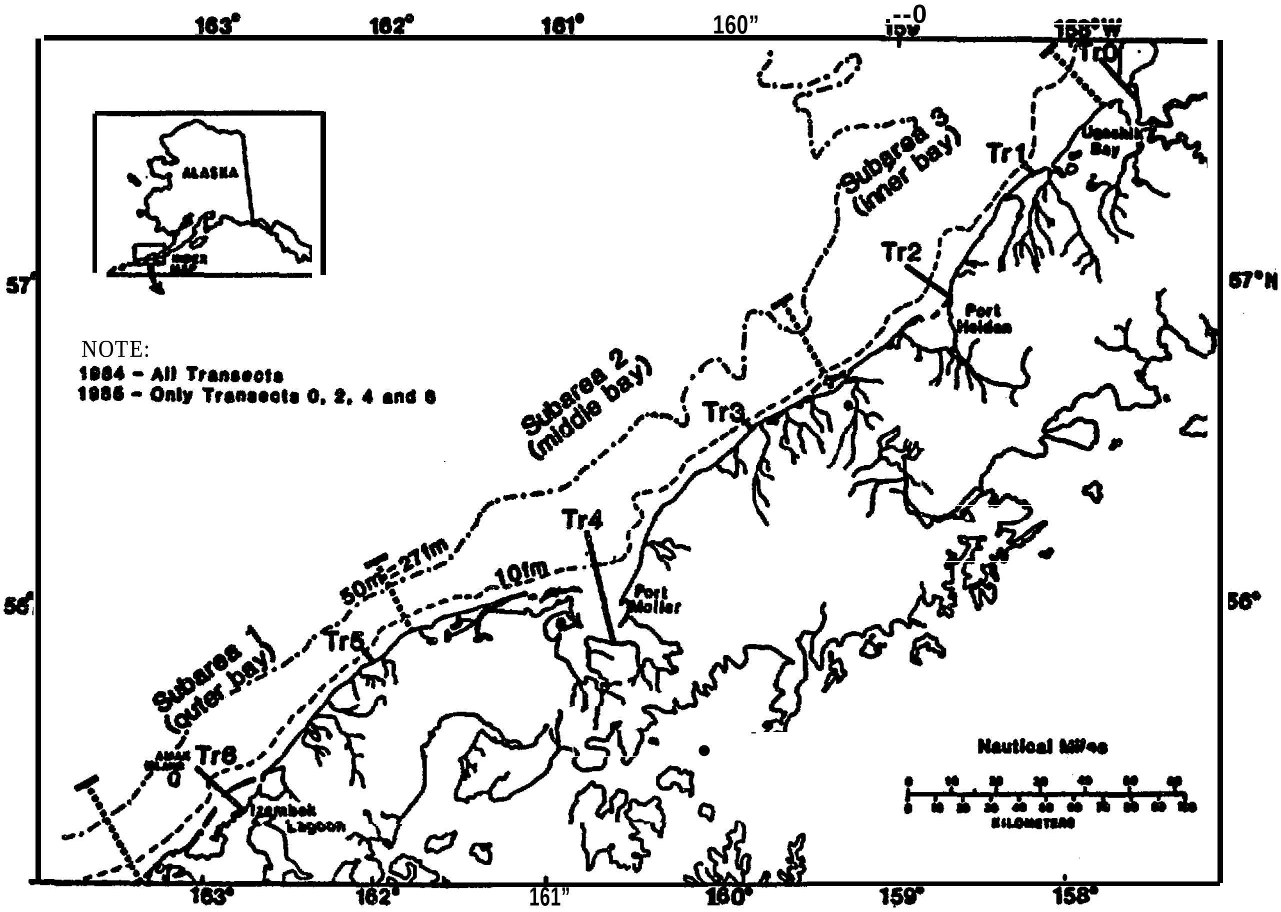

Figure 1. Study subareas and transect location.

mid June to the end of July. Sampling was conducted using vessels of 16.7 m and 8.8 m and two smaller vessels. A total of 277 sets of all gear types was made in 1984, while 172 sets were made in 1985. All fish captured were either processed on board or preserved for later analysis.

Weather and surface sea temperatures were strikingly different between 1984 and 1985. Generally poor to harsh weather was experienced during the three cruises in 1984, while much calmer weather was generally present in the study area during the single extended cruise in 1985. Sea surface temperatures for similar areas and times of year were from 1 to 2°C colder in 1985 than in 1984. Salinities for comparable areas and times were quite similar between these two years.

The main difference between the 1984 and 1985 results was the change in catch ratios of demersal to pelagic fish assemblages due to the elimination of the otter and beam trawls in 1985. Because 1985 sampling began and ended earlier, and because 1985 had a cooler than normal springtime water temperatures, several species that were common or abundant in 1984 were very poorly represented in 1985 catches. For example, while juvenile salmonids made up less than 1% of all fish caught in 1984, these fish made up 52% of the total catch in 1985, Young-of-the-year Pacific cod (*Gadus macrocephalus*) were a strong, numerical dominant in 1984 but were not captured in 1985.

Of the 88,436 fish taken in the 1984 survey, by far the most dominant species was Pacific sand lance (*Ammodytes hexapterus)* which comprised 62.50/o of all fish captured. Sand lance was the most abundant species in both the beach seine and tow net and ranked second (to Pacific cod) in purse seines and fourth in otter trawls. In 1985, sand lance appeared to be somewhat less abundant in the nearshore portions of the study area, yet they still were the numerical dominant in beach seine catches and the second most abundant species (to juvenile sockeye salmon, *Oncorhynchus nerka*) in the large purse seines (32% of all fish in all gears). These results seem to confirm this species' role as one of the important forage fishes in this part of the Bering Sea. Densities appeared greatest in the inshore waters inside the 6-m isobath; in large purse seines there was also a general trend toward increased catches nearer shore. Sand lance were widely yet irregularly distributed throughout the study area with significant concentrations encountered in beach seines in and outside of Port Moller during the first cruise (late June to mid July, 1984) and in 1985, as well as in Izembek Lagoon otter trawls during the third cruise (late August to mid September, 1984) and beach seines in 1985. Sand lance seemed to prefer relatively flat protected beaches. They were less abundant on inner bay (Ugashik and Port Heiden) transects.

Three distinct size classes of Pacific sand lance were evident in our catches in 1984. In Cruise 1, the mode in beach seines was 7.1 to 8.0 cm (Figure 2), while a large size class (12. 1 to 13.0 cm) dominated purse seine catches offshore. These two size groups were evident in the respective gears in Cruise 2, but a new group (4.1 to 6.0 cm) appeared in the beach seines. The intermediate-sized group dominated beach seines, and otter trawls during Cruise 3 but was somewhat larger (i.e. 5.0 to 7.1 cm). The intermediate-sized group was also strong in purse seine catches which, unlike the other gear types, included all three size groups in Cruise 3.

In 1985 beach seine catches, a single dominant size class (i.e. 8.0 to 10.0 cm) of Pacific sand lance was present (Figure 3). Offshore in the large purse seine there were four distinct size classes with peaks at about 9.5, 12.5, 16.5, and 19.5 cm during the mid June to early July period (Figure 4). In mid to late July purse seine catches, these size classes were much less distinct. General catch patterns in the various gear types and stations indicate an inshore movement of Age 1 and 2 sand lance in early summer, with an offshore movement beginning in late August.

The second most abundant pelagic, non-salmonid species in both the 1984 and 1985 catches was the rainbow smelt (*Osmerus mordax*), which comprised about 9% of the total catch in each year. Like the Pacific sand lance, rainbow smelt were most abundant in nearshore gear. Their catch distribution was very patchy with respect to beach slope, substrate, and exposure. Highest catches were taken in Ugashik tow nets and in Port Heiden beach seines. There was a general trend for decreasing abundance with distance down the peninsula. Numbers taken in beach seines declined with time through the summer of 1984, while increasing in offshore purse seine catches.

Length-frequency patterns in 1984 (Cruises 1 and 2; late June through mid August) show several year classes present with strong peaks at 9.1 to 10.0 cm and 15.1 to 16.0 cm in August. By Cruise 3 (late August to mid September), only the smaller size class was abundant on the beaches (Figure 5). In early 1985 (mid June to early July), this same year class (now peaking at 12.0 to 13.0 cm) was dominant in beach seines. During early to late July, a second broad size class (5.0 to 9.0 cm) recruited to the beach seines (Figure 6).

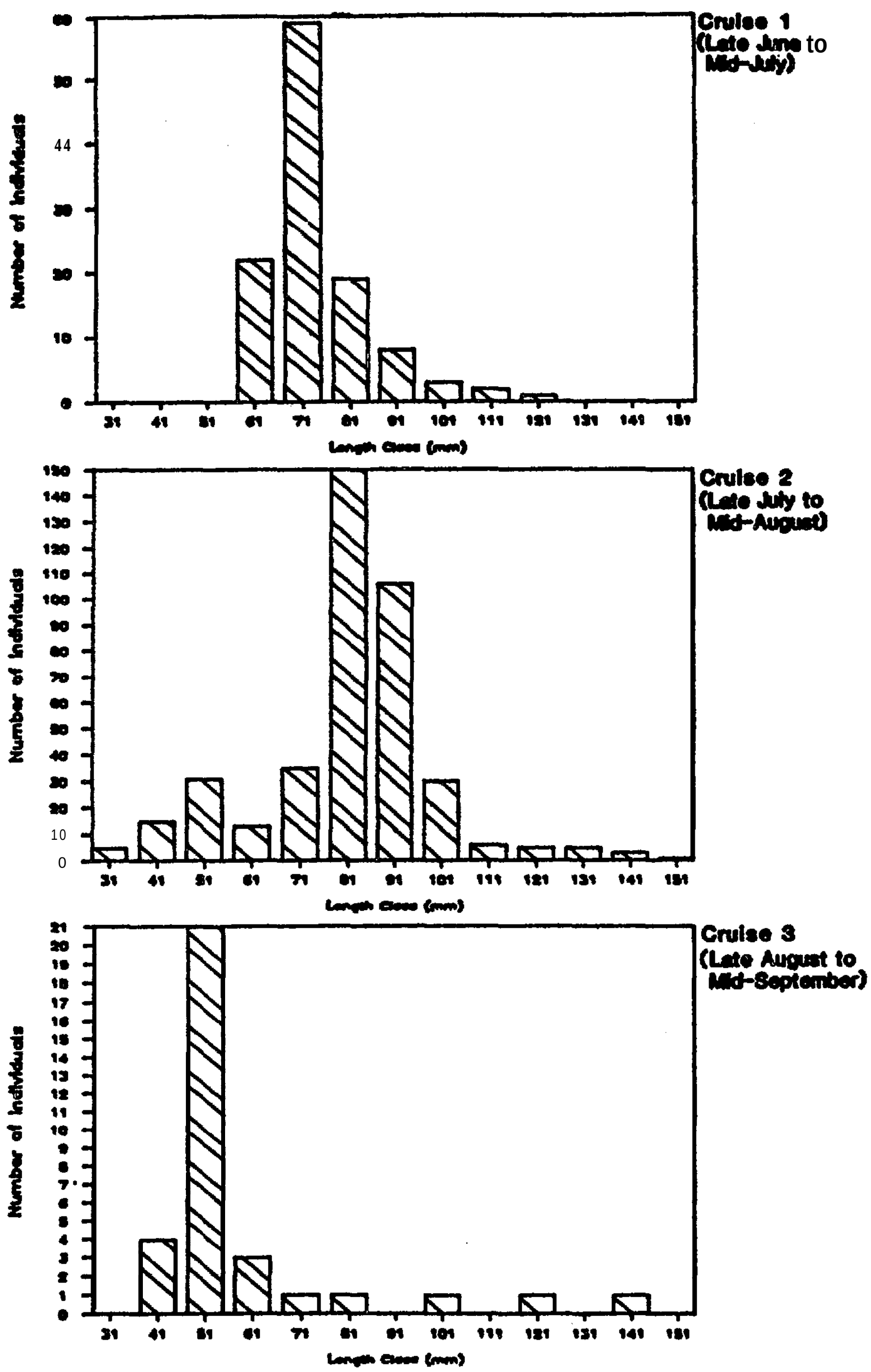

Figure 2. Length-frequency of Pacific sand lance In beach seines (all transects and stations combined), 1984.

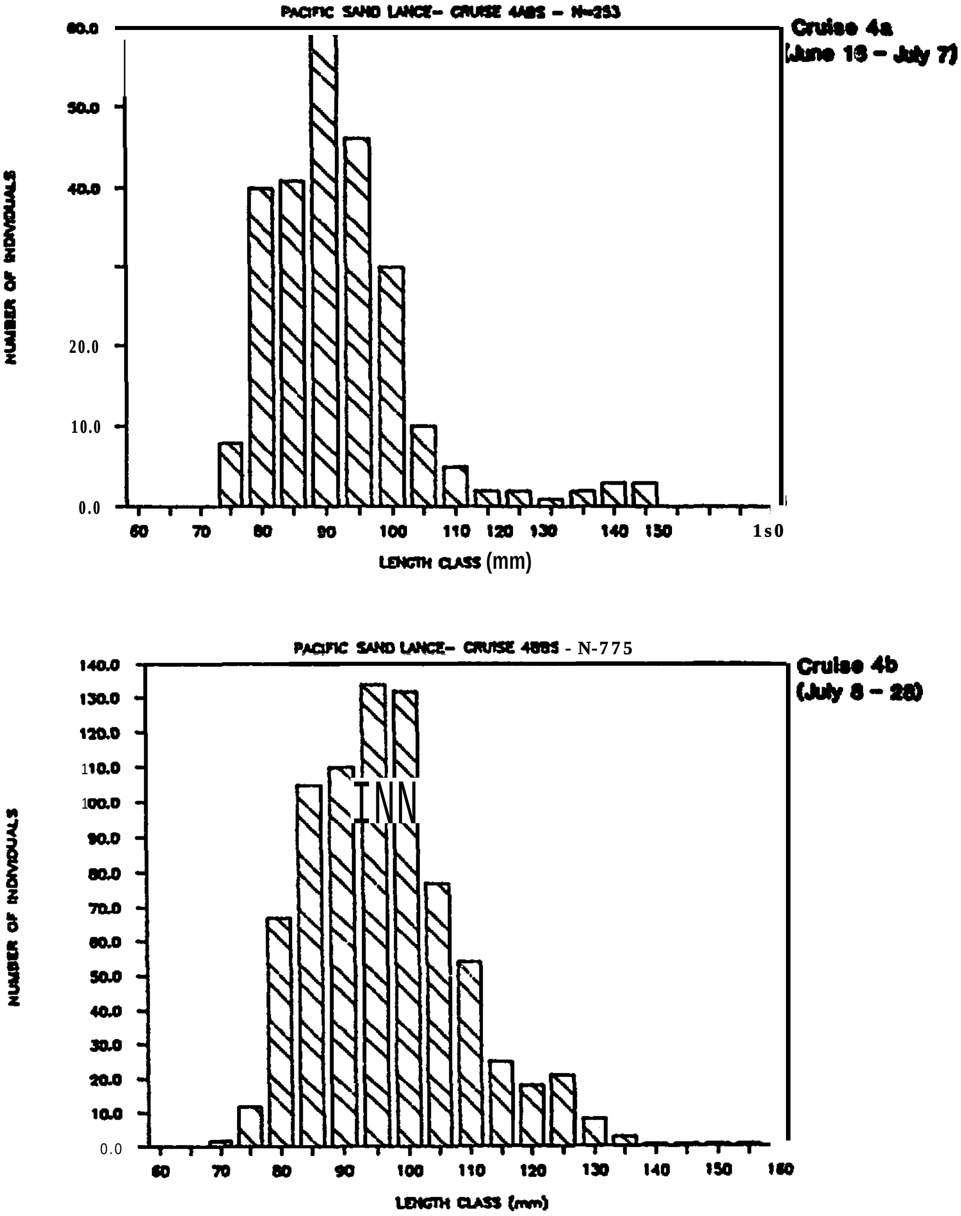

Figure 3. Length-frequency of Pacific sand lance in beach seines (all transects and stations combined), 1985.

The third most abundant fish taken in the pelagic habitat in 1984 was juvenile Pacific cod which ranked first in purse seine and second in otter trawl catches. While often not considered to be a forage fish, *per se,* this species, by virtue of its abundance and distribution is certainly a significant potential food resource for higher trophic levels in the study area and perhaps is an analog, in this sense, to walleye pollock (*Theragra chalcogramma*) in more offshore waters. Catches in the second and third cruises in 1984

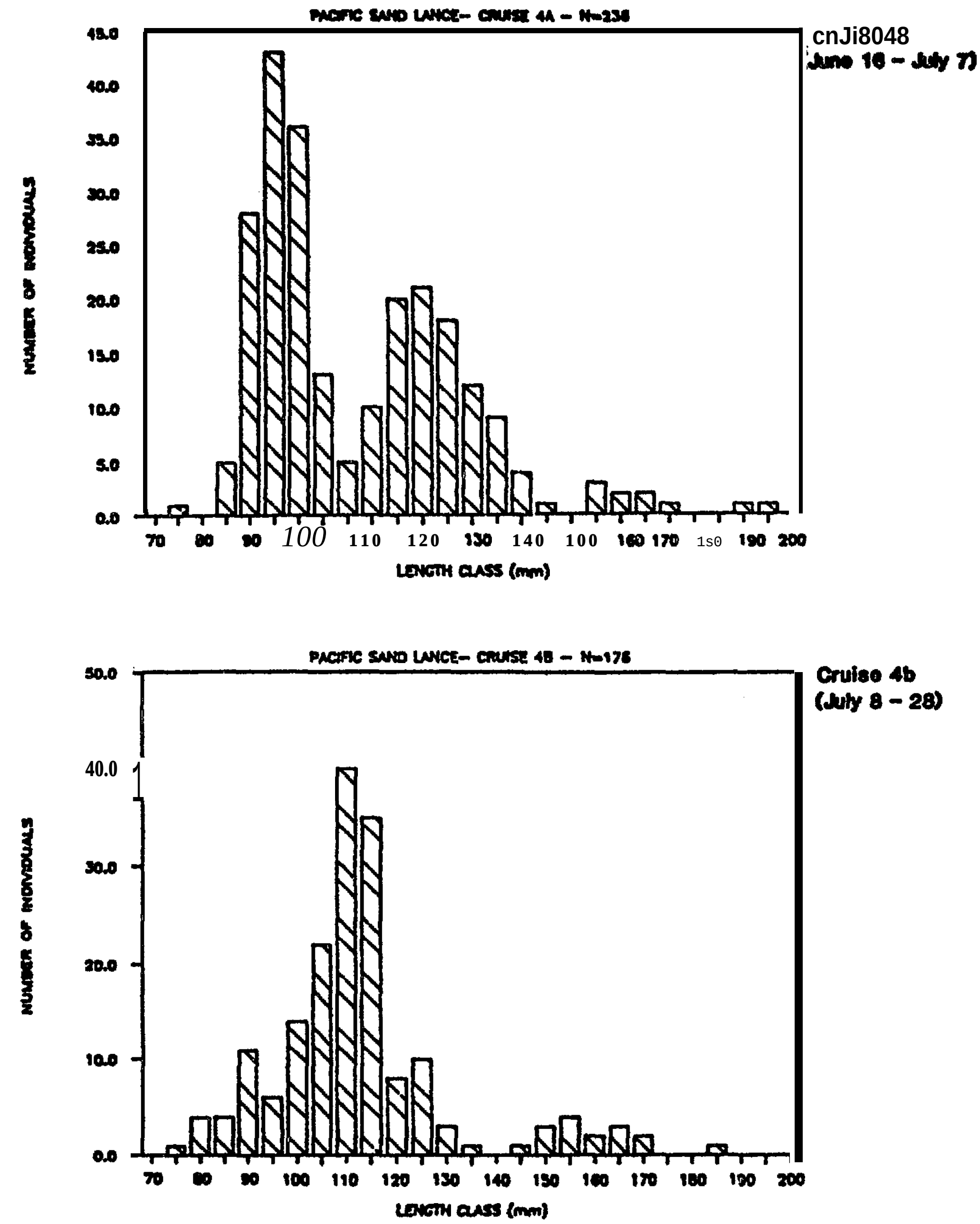

Figure 4. Length-frequency of Pacific sand lance in purse seines (all transects and stations combined), 1985.

greatly exceeded those in the first cruise, partly at least due to recruitment to the gear. In the earlier 1985 sampling, few cod were captured.

Like Pacific cod, walleye pollock was taken in both pelagic and demersal gear. Although it generally is considered a demersal species, juvenile walleye pollock ranked fourth in 1984 purse seine catches. This species has been noted to be the most important prey species for many important Bering sea animals. Interestingly, this species was

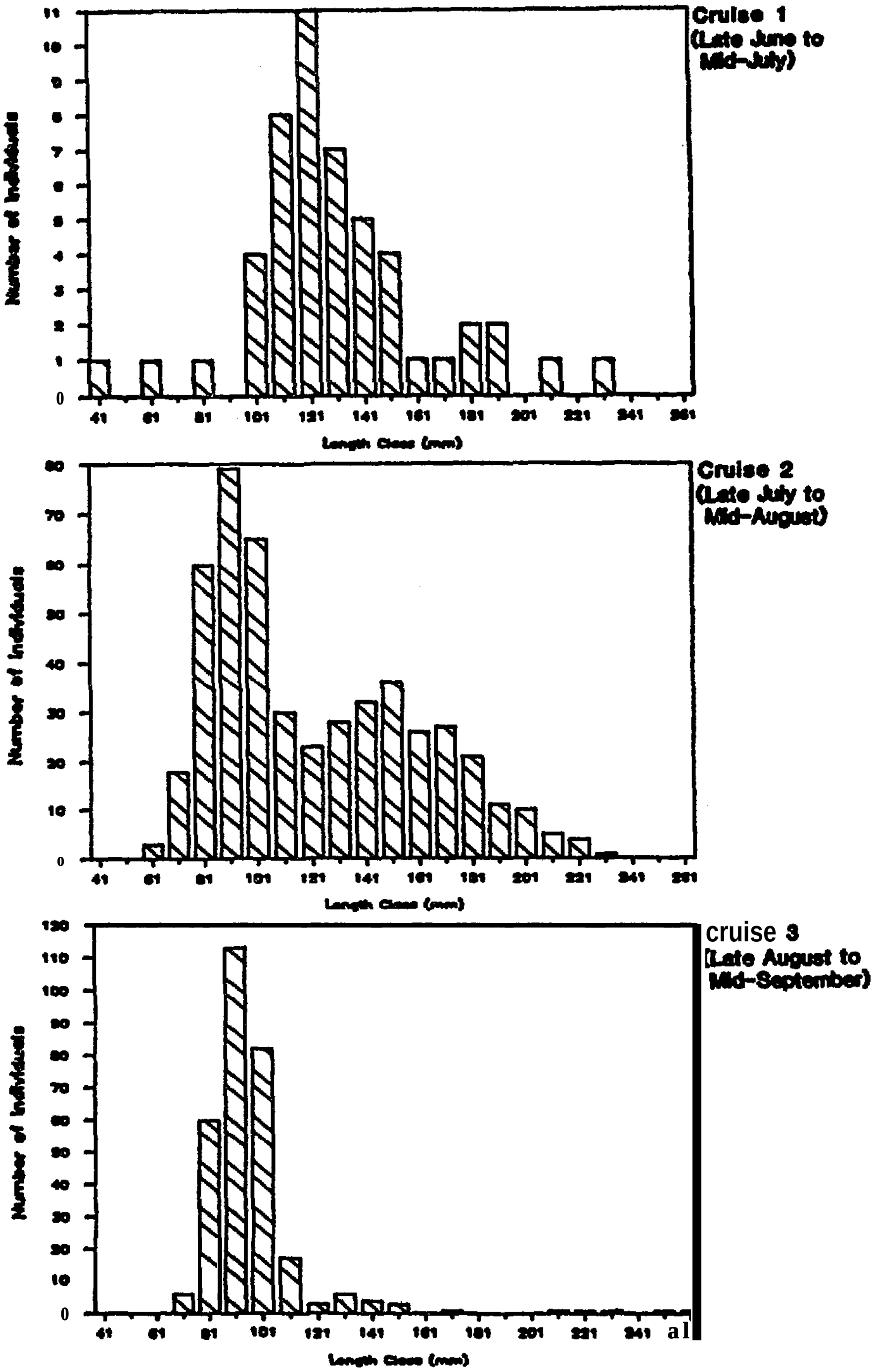

Figure 5. Length-frequency of rainbow smelt in beach seines (all transects and stations combined), 1984.

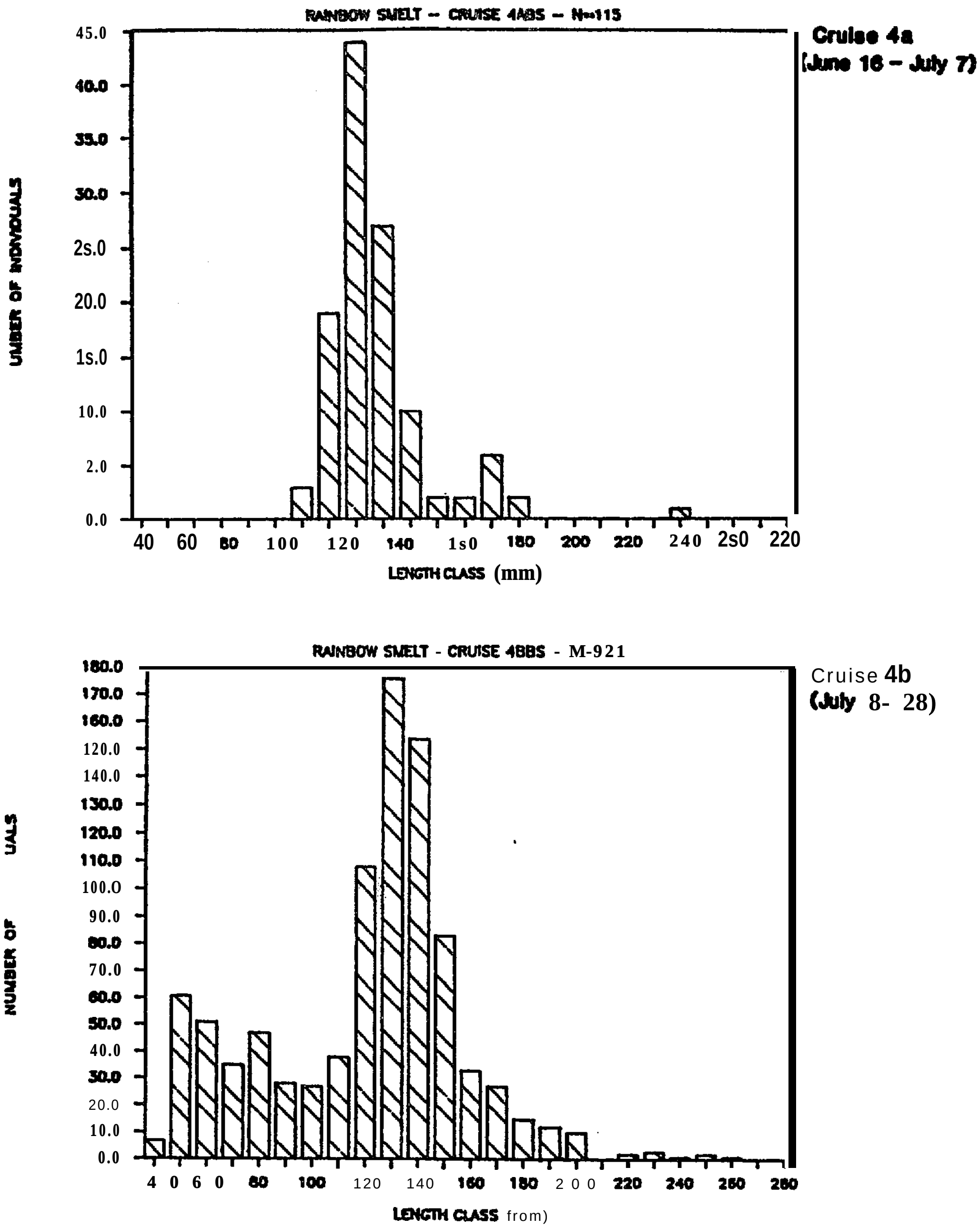

Figure 6. Length-frequency of rainbow smelt in beach seines (all transects and stations combined), 1985.

captured in the pelagic habitat only in Cruises 1 and 2, and only on transects removed from association with embayments. Walleye pollock were also only caught at offshore stations; all were early post-larvae in the 3.5 to 6.7 cm size range. They were scattered in otter trawl catches with a few fish in each survey. Trawl-caught pollock tended to be substantially larger than purse-seine-caught fish; by the late-August to mid-September 1984 cruise, walleye pollock in the 8.0 to 10.0 cm range began to dominate in otter trawls, perhaps having recently undergone a transition from a pelagic to a demersal life style.

Pacific herring (*Clupea pallasii*) were taken in surprisingly small numbers in all three gear types fished in 1985 (total catch 55 fish). In 1984, all but 8 of the 750 herring taken were from the tow net, which was not fished in 1985. It is likely that in neither year were we sampling early enough to sample periods of peak adult herring abundances (associated with spawning) in the study area. Recruitment of young-of-the-year (3.7 to 5.5 cm) to tow net catches in Port Moller late in 1984 suggests local rearing of herring from spring spawning in Port Moller; however, little is known of the early life history of herring in the Bering Sea.

Capelin (*Mallotus villosus*) were taken primarily in the large purse seine in 1985 (106 fish), whereas no capelin were taken in this gear in 1984. Assuming that the large purse seine is an adequate gear for this species, one must conclude that sampling began too late in 1984 to capture capelin. Capelin still were not very numerous in 1985, suggesting that we missed the majority of capelin in the study area where they reportedly occur in large spawning concentrations earlier in the spring.

Pond smelt (*Hypomesus olidus*) were taken in greater numbers (96 fish) in 1985 beach seines than in 1984 (27 fish). No other gear types captured pond smelt in either year, indicating the anticipated pattern of a close association with beach habitats. Most were taken at Ugashik in July 1985.

Other "lesser" species of forage fish were taken in our sampling and may be of local importance in coastal areas. For instance, surf smelt (*Hypomesus pretiosus*) was the third most abundant species taken in beach seines in 1984. They were only present in late summer and fall sampling and none were taken in the earlier 1985 sampling. They were also only taken in Port Moller and in Moffett (Izenbek) Lagoon. Two size classes were present, centered around 4.0 to 6.0 cm and 16.0 to 20.0 cm.

Eulachon (*Thaleichthys pacificus*) were taken in very low numbers in beach seines inside Port Moller in the first cruise (late June to mid-July) in 1984, but were not taken subsequently or in 1985. Large spawning runs are occasionally reported in the nearby Bear River.

In summary, there is large spatial and temporal variability of forage fish in the study area. Movements and habitat preferences appear to vary by species, age class, and time of year, probably in response to established life history needs for spawning, maximizing growth, and perhaps minimizing predation.

FORAGE FISHES IN THE SHALLOW WATERS OF THE NORTH ALEUTIAN SHELF

Peter Craig
LGL Ecological Research Association
2950 Fritz Cove Road
Juneau, Alaska 99801

The shallow coastal waters of the southeastern Bering Sea support a diverse and abundant fish fauna -- nearly 100 species have been collected in waters less than 50 m deep. Along the northern shore of the Alaska Peninsula, the principal forage fishes are Pacific sand lance (*Ammodytes hexapterus*), followed by Pacific herring (*Clupea pallasii*), young-of-year walleye pollock (*Theragra chalcogramma*), rainbow smelt (*Osmerus mordax*), and capelin (*Mallotus villosus*).

In coastal waters forage fishes rely largely on zooplankton as a food source (as do other vertebrate consumers including seabirds, other fishes, and marine mammals which consume zooplankton directly or indirectly through forage fish). The general cycle of energy flow through this nearshore pelagic food web is as follows. A spring bloom of phytoplankton occurs in April/May, followed by blooms of herbivorous zooplankton (copepods, euphausiids) in June/July. This, in turn, is followed by large-scale immigrations of vertebrate consumers into the study area, and these consumers are abundant from spring through mid summer. By August/September, vertebrates (and jellyfish) deplete the supply of zooplankton, whereupon the birds, marine mammals, and forage fishes move elsewhere, and biological activity returns to relatively low levels until the next spring.

During the summer period, schools of Pacific sand lance are found in all nearshore habitats, including pelagic and demersal zones of protected and exposed shoreline habitats. Their distribution and abundance are highly variable, but they are most abundant in July (Figure 1) in waters less than 20 m deep (Figure 2). They consume a variety of zooplankton but euphausiids are the main prey in winter and copepods in summer (Table 1; Figure 3). Sand lance diets differed greatly between years, largely in response to differences in prey abundance which, in turn, reflected differences in the origin of water masses present in the nearshore domain. While sand lance feed year-round, most consumption occurs in winter and spring, and thus apparently occurs outside our study area.

Schools of Pacific herring and capelin are most abundant along the shoreline of the Alaska Peninsula in late May and early June (Figure 4) particularly in the Port Moller area where the y spawn. Few, however, were caught by us, indicating that their residence time in the nearshore waters of our study area is relatively brief. The diets of both large herring (mean size 28.2 cm) and small herring (9. 1 cm) in nearshore waters were generally similar. Copepods, crustacean and decapod larvae, and chaetognaths were their main prey (Table 2).

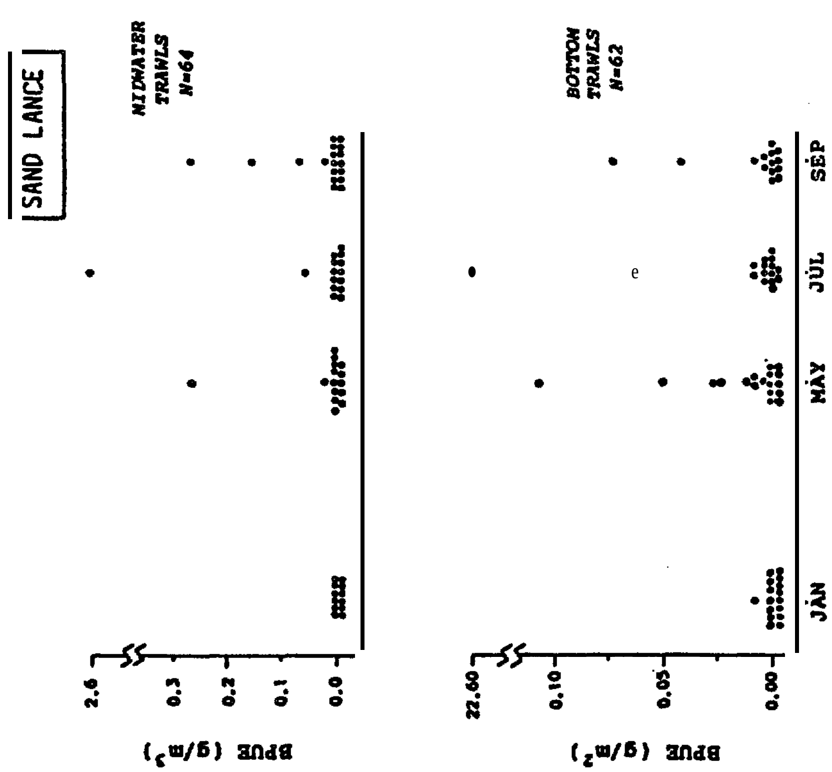

Figure 1. Pacific sand lance: seasonal BPUE in midwater trawls (top) and bottom trawls (bottom).

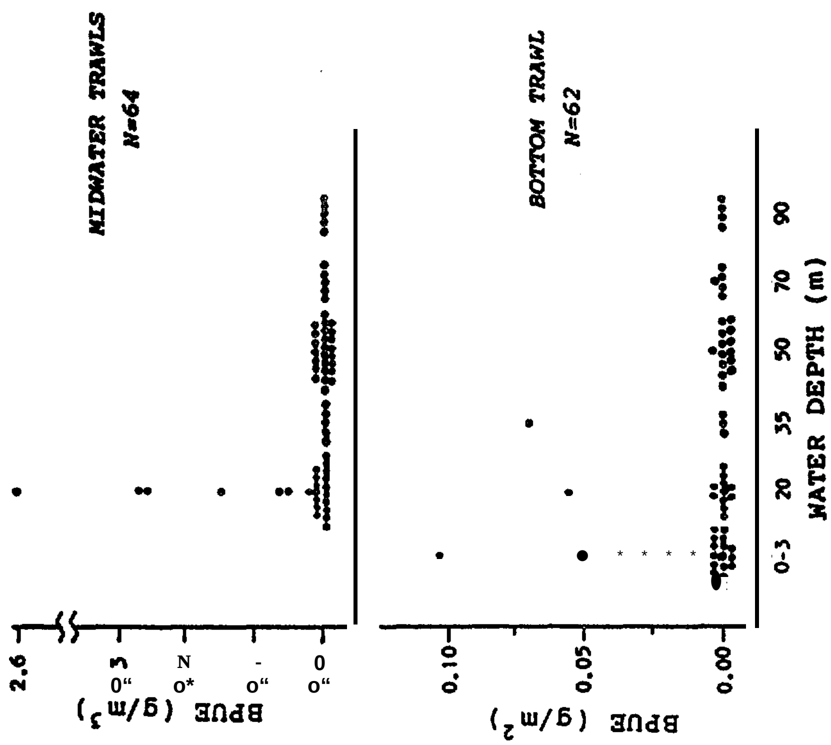

Figure 2. Pacific sand lance: BPUE at various water depths, dates combined (January-September).

Table 1. Seasonal diets of Pacific sand lance.

	Seasonal* Diet Composition (% Weight)		
Food Item	Winter	Spring	Summer
Copepod		**26**	
Euphausiid (Total)	**(100)**	**(40)**	‘0
Thysanoessa inermie	**30**	**18**	
T. raechii	19		
Miscellaneous	51	20	
Amphipod		**7**	
Mysid		7	
Crustacean		11	
Other		11	10
Average Contents (mg)	12	12	**3**
Mean Fish **Size**	101	12s	104
Number of Fish Examined	9	110	169

* Winter (January 1985; Spring (May 1984 and 1985); Summer (July 1985, September 1984)

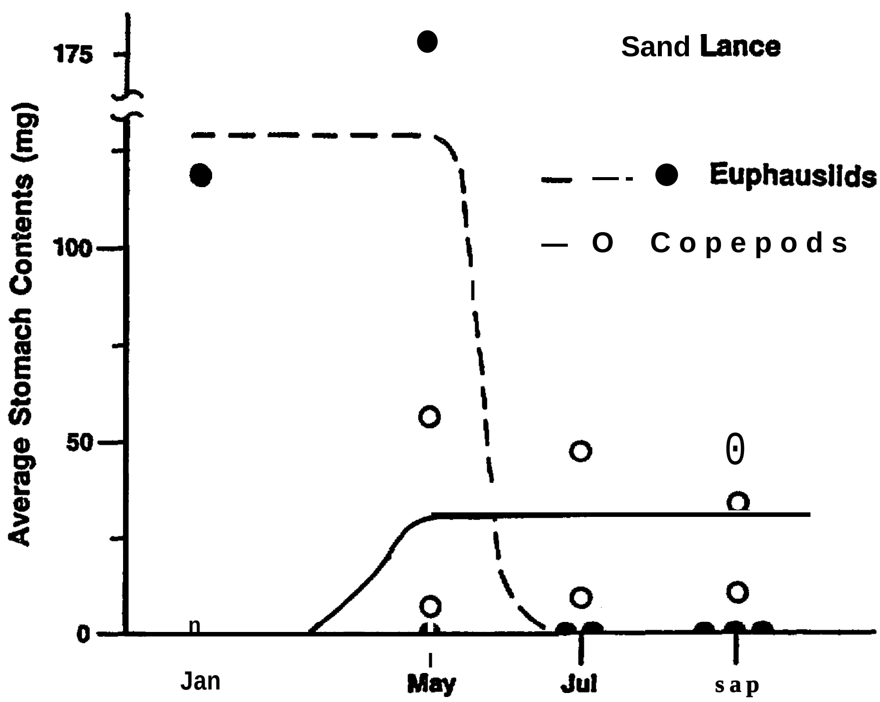

Figure 3. Seasonal Importance of euphausiids and copepods in the diets of Pacific sand lance.

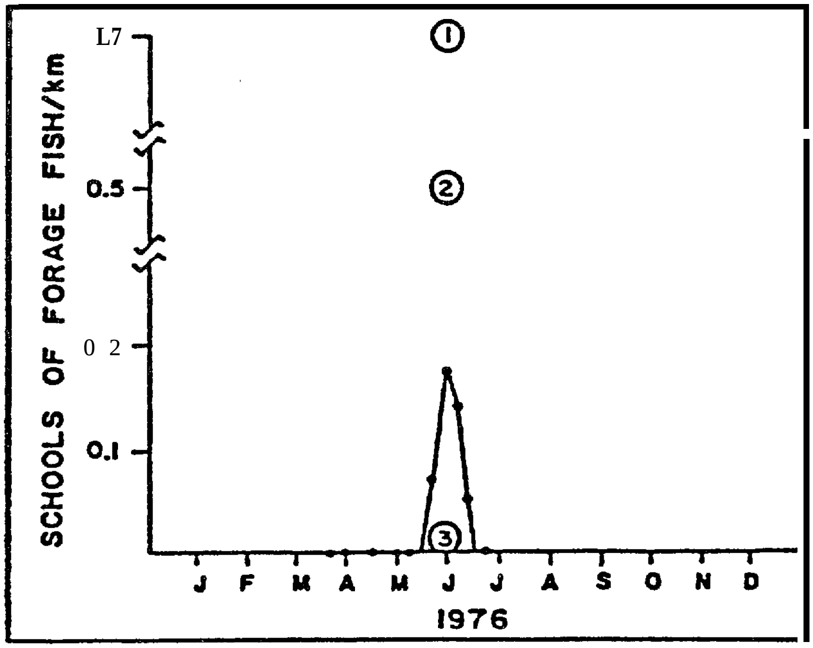

Figure 4. Average number of forage fish schools (Pacific herring, capelin) along the northern shore of the Alaska Peninsula from Unimak Island to Port Heiden (ADF&G census areas 1-5) (from Barton *et al.* 1977). Also shown are maximum numbers at 1) Point Heiden, 2) Izembek area, and 3) Bechevin Bay area.

Table 2. Pacific herring diets in coastal waters of the North Aleutian Shelf.

	Diet Composition (% Weight)	
Prey	Jul 1985	Sep 1984
Copepod	26	32
Crustacean Larvae	52	1
Decapod Larvae	6	41
Euphausiid	13	3
Chaetognath		21
Amphipod	1	
Barnacle Larvae	1	
Mysid		1
Jellyfish	1	
Average Contents (mg)	600	45
Average Fish Size (mm)	282	91
Sample Location	1C	6C
Number of Stomachs	30	19

Rainbow smelt are most abundant along the northern shore of the Alaska Peninsula in September in waters less than 20 m. Medium-sized smelt (11,0 cm) consumed mostly amphipods and mysids, with about twice as much feeding in May than September. Larger smelt (18.4 cm) ate more fish and shrimp, and fewer amphipods than did the smaller smelt.

When forage fishes are considered collectively, the occurrence of these highly mobile species is a dynamic feature of the study area. From early spring to late summer, there is a series of activity pulses as each species moves through 'the 'region (Figure 5). The net result is an abundant and presumably dependable supply of food for predator species.

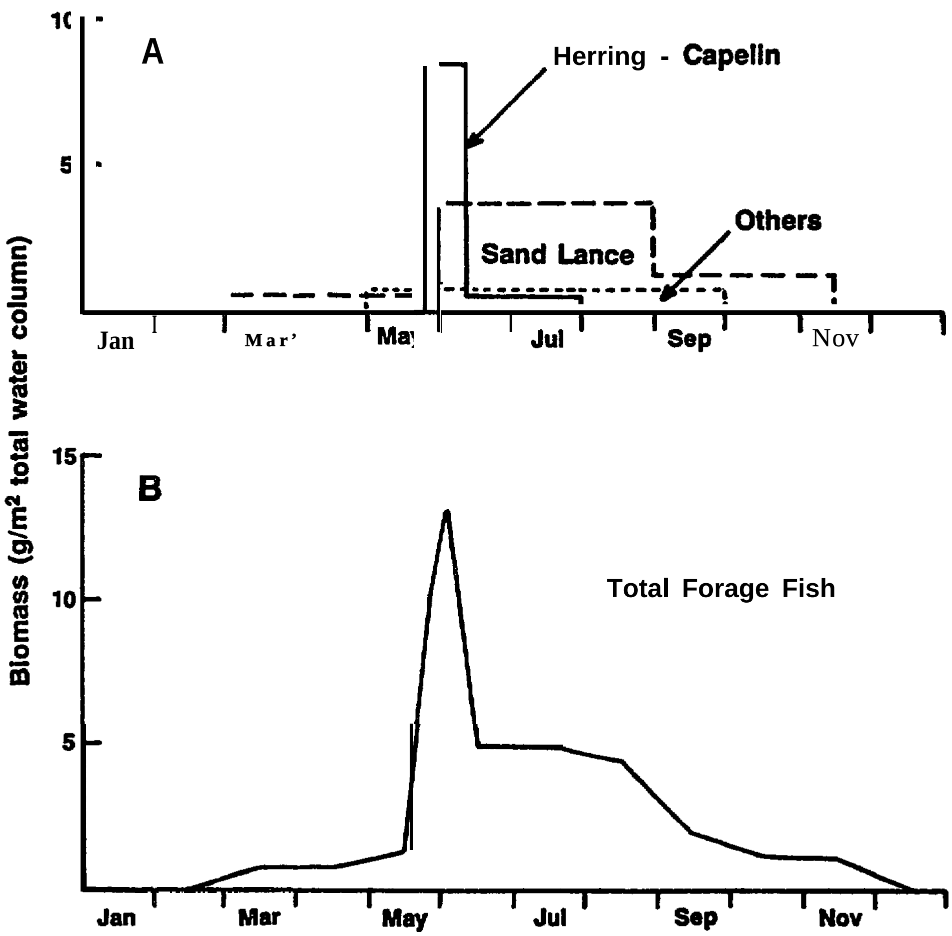

Figure 5. Estimated seasonal biomass of forage fishes in shallow waters of the North Aleutian Shelf, based on data collected in 1985 and 1986, and assumptions presented elsewhere (LGL 1987).

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POPULATION DYNAMICS OF PACIFIC HERRING (*Clupea pallasii*), CAPELIN (*Mallotus villosus*), AND OTHER COASTAL PELAGIC FISHES IN THE EASTERN BERING SEA

Vidar G. Wespestad
Northwest Alaska Fisheries Center
National Marine Fisheries Service
7600 Sand Point Way, NE
Seattle, Washington 98115

Population dynamics is the study of life processes in a population of animals in order to quantify changes in population size. The two basic processes in population dynamics are growth and removals. Growth has three components individual weight gain, the addition of new individuals through reproduction, and gains from immigration. Removals consist of natural death, fishing removals, and emigrations from the stock. In fisheries, the primary use of population dynamics is to analyze the response of stocks to fishing, to estimate the size of the stock, and potential yields from it. Methodology has grown very sophisticated, however data available for many species is rudimentary or completely lacking.

The eastern Bering Sea contains about 300 fish species of which 20 are commercially exploited. The majority of commercially exploited species has been extensively studied for at least 10 years and a reasonably good data base has been assembled on these species. The non-commercial species which include most of the species considered to be forage fish have not been as well studied as commercial species. The primary data available for these species are haul species composition records from fisheries observers on fishing vessels and from Northwest and Alaska Fisheries Center (NWAFC) annual groundfish surveys. Data are also available from stomach samples of fish, birds, and marine mammals. These data provide information on distribution and relative abundance of the species but data for examination of the population dynamics of these species generally are not collected.

The data collected by observers on foreign vessels and by NWAFC biologists in the groundfish surveys does not provide significant information on the small pelagic species which comprise the forage fish group. These fish are generally not quantitatively sampled because they either occur in surface or intermediate depths above the level of bottom trawls or are not retained in the large meshes of commercial trawls.

In the eastern Bering Sea the principal small pelagic species are walleye pollock (*Theragra chalcogramma*), Pacific herring (*Clupea pallasii*), capelin (*Mallotus villosus*), Pacific sand lance (*Ammodytes hexapterus*), and rainbow smelt (*Osmerus mordax*). These species have been identified as major recurring species in food composition studies. The walleye pollock is generally considered to be a commercial species, but in the juvenile stage (Ages O-2) pollock is the single most abundant food item in the diets of many species. Pacific herring are also exploited commercially and preyed upon. Capelin is presently not exploited to any great extent although small amounts have been harvested in recent years. Pacific sand lance and rainbow smelt are not exploited in the Bering Sea, but they are fished in other areas. The amount of information on these species is proportional to the amount of commercial exploitation (Table 1). Walleye pollock, which provides about 95% of the Bering Sea harvest, has the most extensive database. Pacific herring were studied extensively by Soviet exploratory fishing expeditions in the early 1960s and since 1977 annual data collections have been made by Alaska Department of Fish and Game (ADF&G) during the spring roe fisheries which occur on spawning grounds along the western Alaska coast. The data base for capelin and rainbow smelt is nearly non-existent.

I do not intend to review the population dynamics of walleye pollock in this paper. This species has been the focus of several studies and reviews (Wooster 1983, Ito 1984). However, it should be noted that this species is a significant forage fish. Hunt *et al.* (198 1) estimates the consumption of walleye pollock by birds to be 150,000 MT. If most of these pollock are Age-1 pollock (14 cm length and 22 g weight) then the number consumed is about 7 billion individuals. The 20 year average of Age-2 pollock abundance is about 11 billion individuals so bird predation alone reduces the population by 35?40 in a pollock's second year of life. Though there is a good deal of information on walleye pollock most of it pertains to the adult population and additional information is needed on the juvenile stage.

Table 1. Life history parameters of walleye pollock and small pelagic species of the eastern Bering Sea.

Parameter	Species					
	Walleye Pollock	Pacific Herring	Capelin	Pacific Sand Lance	Rainbow Smelt	Eulachon
1985 harvest (tons)	1,647,650	23,000	126	0	0	0
Range	Outer Shelf/ Slope	Shelf/Slope	Coast Shelf?	Coast?	Coast Shelf	Coast Shelf
Spawning Period	Feb-Mar	May-Jun	May-Jul	Winter?	May-Jun	May-Jun
Location	Outer Shelf	Coast	Coast Shelf?	Coast?	Rivers Estuaries	Rivers
Maximum Age (years)	18	15	4	5 Kodiak	9 White Sea	5 Canada
Age 50% Maturity (Females)	4	3	2	2-3	2-3	3
Maturity Length (cm)	35	22	13	13	19-23	14-20
M (natural mortality)	.3	.4	1.3?	High?	High?	High spawning
K (growth coefficient)	.29	.22	.42?	?	?	?
Fecundity* (50% mature)	78	25	6-22	3-22	50	17-40

*N = 1000 eggs

Pacific Herring

Population dynamics of the Pacific herring are fairly well understood through research activities conducted there and from the literature of other Pacific herring stocks. The biology and population dynamics of eastern Bering Sea herring has been reviewed by Wespestad (1982), Wespestad and Barton (1981), and Fried and Wespestad (1985). However, there are still many outstanding questions on this species such as causes of recruitment variation, stock structure, and migration.

Capelin

Capelin are abundant and form the basis of large fisheries in the North Atlantic Ocean, but in the North Pacific Ocean there are no indications of large populations of capelin. The Soviet Union harvests a large portion of the annual Atlantic capelin stock, but FAO (Food and Agriculture Organization, United Nations) statistics since 1972 show that in the northwest Pacific Ocean capelin catches have never exceeded 5,000 MT. ADF&G aerial surveys in the Togiak area of Bristol Bay during the Pacific herring spawning period observe schools of capelin which spawn in the same area but slightly later than herring. In these surveys the biomass of capelin is thought to be equal to that of herring (M. Nelson, Alaska Department of Fish and Game; Dillingham, AK, pers. comm., 1986) which in recent years would indicate a population of about 500,000 MT. However, while these data suggest that capelin are relatively low in abundance in the eastern Bering Sea, they are indirect indicators and studies directed toward capelin may provide a better basis for estimation.

Pahlke (1985) reviewed the literature on capelin and summarized the data available for capelin off Alaska. He found that most of the capelin data available has been collected from spawning fish in coastal areas. Additional distributional data are available from research cruises and food habit studies of birds and mammals.

Pahlke found that capelin in the eastern Bering Sea predominantely spawn at Ages 2 or 3 and a few fish survive to spawn at Age 4. Very few capelin survive spawning so there can be significant interannual variation in spawning biomass depending on the ages of maturity. The age of maturity for capelin spawning in the Barents Sea has been shown to be a function of growth rate and fast growing cohorts reach maturity at the earliest age and slow growing ones at a later age. Thus it is possible to have both a slow growing cohort and a fast growing one mature in the same year with a resulting large spawning biomass followed by several years of low spawning biomass abundance.

The capelin spawn along the coast in the intertidal zone in areas of coarse sand and fine gravel 0.5 to 1.0 mm in size. The known centers of spawning are in Norton Sound, northern Bristol Bay, and along the Alaska Peninsula. The larvae remain near the spawning grounds and then appear to disperse offshore in summer. Soviet and Japanese larval fish surveys have found concentrations of larval capelin to the west of Cape Newenham and between Unimak Pass and the Pribilof Islands.

The life history from hatching to maturation and spawning is largely unknown. Hydroacoustic and trawl surveys in the southeastern Bering Sea suggest that capelin are not widespread on the shelf and may remain in coastal waters (Figure 1). However, studies of food habits of bird and marine mammals near the spring ice edge suggest the distribution may be more wide spread, In the Barents Sea the capelin spawn along the

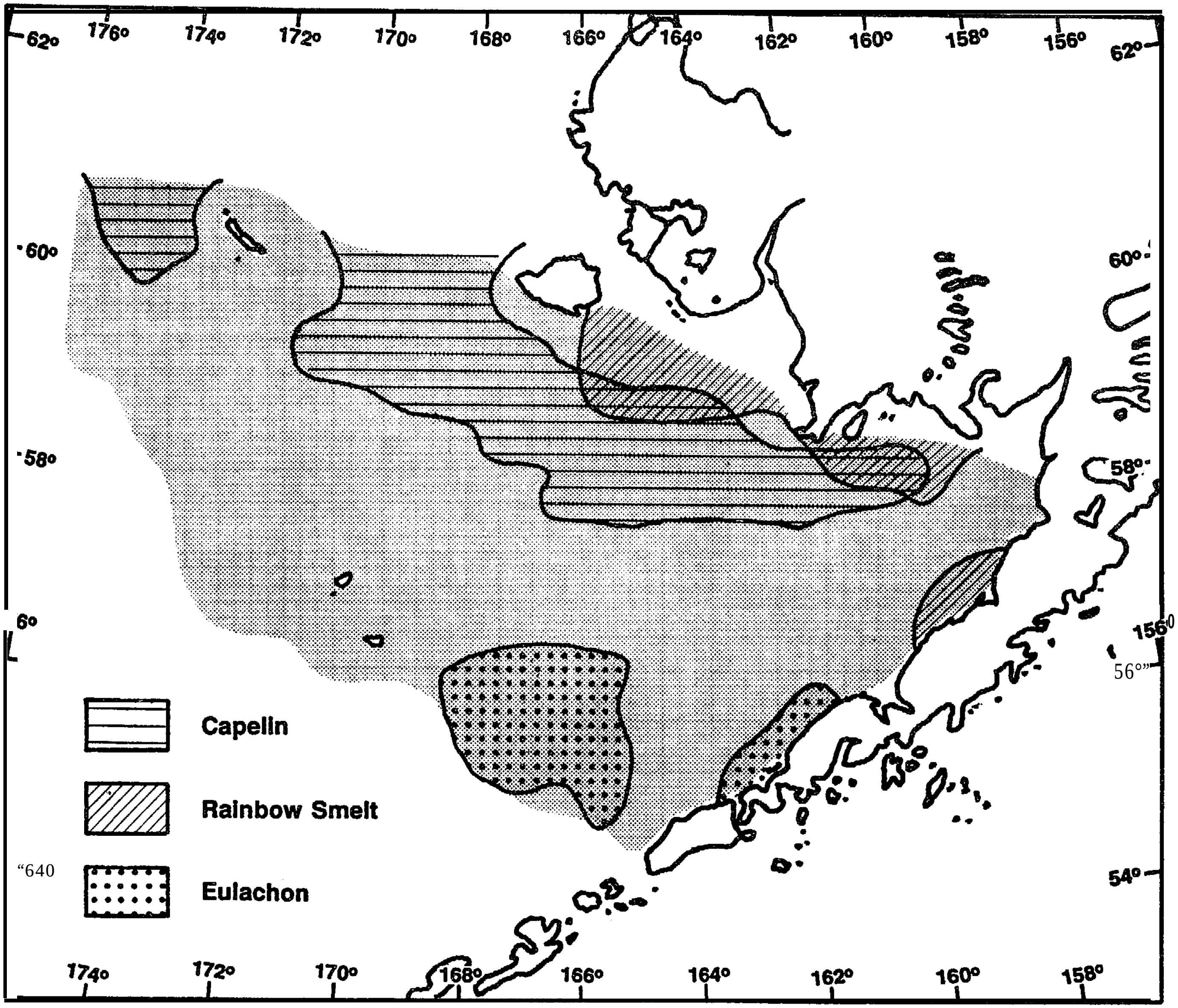

Figure 1. Distribution of capelin, rainbow smelt, and eulachon in Northwest and Alaska Fisheries Center summer groundfish trawl surveys.

Norwegian coast and the larvae drift northeast into the central Barents Sea. As they grow they move toward the polar front which is the feeding area of immature and maturing fish. In the autumn the capelin move south to the coast in advance of the winter ice. The mature fish move to the coast to spawn while the immature fish remain offshore and move back to the polar front as the ice recedes. This migration pattern may occur in the eastern Bering Sea and the bulk of the capelin resource could be located in the northern Bering Sea beyond the area of the groundfish fisheries and surveys.

Pacific Sand Lance

Pacific sand lance in the Bering Sea have been found to occur in depths from shore to 100 m, but their greatest abundance is at depths inside of 50 m. Sand lance do not possess an air bladder and rest on the bottom when not feeding. Usually they bury in the bottom and have been found to prefer fine gravel to coarse sand substrates. Due to their behavior and small size they are not often seen in trawl samples. As a result very little is known about their distribution and abundance. Pacific sand lance may be abundant along the Alaska Peninsula since they have been found to comprise 5 to 39% of the food of juvenile sockeye salmon (*Oncorhynchus nerka*) and coho salmon (0. *kisutch*) leaving Bristol Bay. Pacific sand lance has also been found to be a major food of northern fur seals (*Callorhinus ursinus*) in the Unimak Pass area.

Pacific land lance mature at Ages 2 to 3 in the Kodiak area at a size of 13 cm. Spawning is believed to occur during the winter months and active spawning has been observed on Kodiak in October. The eggs are deposited in sand and gravel where the larvae remain until the yolk sac is absorbed. After the yolk sac stage the larvae become pelagic until metamorphosis to the adult form (at a length of 3 to 4 cm).

The population dynamics of the species is not well understood, although mortality and growth rates must be high given the short life span.

Rainbow Smelt

The rainbow smelt is anadromous and ascends rivers to spawn shortly after the spring ice breakup. After spawning they return to the sea to feed. After hatching the smelt larvae drift with the current into the estuary where they grow and recruit to the adult population. NWAFC surveys show that rainbow smelt occur off Kuskokwim Bay, the Togiak area, and off Port Heiden (Figure 1). Rainbow smelt probably occur in many other nearshore areas especially near major rivers.

Rainbow smelt biology has been extensively studied in other areas, but few data are available from the Bering Sea. In the White Sea rainbow smelt survive through Age 9 and mature at Ages 2 to 3 at a size of 19 to 23 cm.

Eulachon (*Thaleicthys pacificus*)

Eulachon is another anadromous smelt species found in the Bering Sea. NWAFC groundfish surveys consistently find concentrations of this species along the outer continental shelf between Unimak Island and the Pribilof Islands (Figure 1). Eulachon are also taken off the Alaska Peninsula between Unimak Island and Port Moller. As with the other small pelagic fishes their abundance is unknown; however, several authors report large spawning runs in rivers on the Alaska Peninsula.

Eulachon live to Age 5, but most die following first spawning at Age 3. Maturity occurs at a length of 14 to 20 cm (Age 3) and the mature fish enter spawning rivers to spawn in May and June.

In summary, major forage fishes in the eastern Bering Sea include walleye pollock, Pacific herring, capelin, Pacific sand lance, rainbow smelt, and eulachon. With the exception of the walleye pollock and Pacific herring, the population dynamics of these species are not well-known. Most of these species are relatively short-lived and generally mature early. Because of their small size and pelagic habits, they are not well-represented in NWAFC demersal trawl surveys; hence, additional surveys using different sampling methods are needed to better describe their distribution and population dynamics.

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THE HISTORY OF PACIFIC HERRING (*Clupea pallasii*) FISHERIES IN ALASKA

Fritz Funk
Division of Commercial Fisheries
Alaska Department of Fish and Game
P. O. Box 3-2000
Juneau, Alaska 99802-2000

INTRODUCTION

Although harvests of Pacific herring (*Clupea pallasii*) fisheries in the Bristol Bay and Bering Sea have increased dramatically in recent years, herring fisheries are some of the oldest commercial fisheries in Alaska. The history of the commercial exploitation of herring in this area can be divided into three major phases: 1) the early salt-cure fisheries; 2) foreign trawl and gill net fisheries; and 3) domestic roe fisheries. While the salt-cure phase lasted almost 45 years, the overall tonnage of these early fisheries was insignificant in comparison to the large commercial operations which began to develop during the 1960s (Figure 1). The. total tonnage from all of the Bering Sea herring fisheries rarely exceeded 1500 MT (metric tons) prior to the late 1950s.

The peak harvest of over 145,000 MT occurred in 1970, almost all due to the Soviet and Japanese trawl fisheries which began developing in the late 1950s. Since that time with the elimination of the high seas foreign trawl fisheries and the more. stringent regulatory policies of the Alaska Board of Fisheries, the harvest has averaged about 31,000 MT for the entire eastern Bering Sea.

CHRONOLOGY OF PACIFIC HERRING FISHERIES OF THE EASTERN BERING SEA

Subsistence Fisheries

Local communities have a long history of utilization of Pacific herring for subsistence purposes. Archaeological evidence of herring fisheries in Norton Sound dates back to at least 500 BC. A large number of eastern Bering Sea coastal villages continue to rely heavily on herring for subsistence, although herring harvests at most locations are less than 3 MT, except on Nelson Island where about 75 MT are harvested annually.

Domestic Salt-Cure Fisheries

Pacific herring fisheries in Alaska got their start in the southeastern panhandle in the 1870s. The product in the early years was salted and cured, with reduction plants following soon after for converting the product into fish meal and oil. Herring fisheries expanded northward into Prince William Sound in 1913 and into the Kodiak area in 1937.

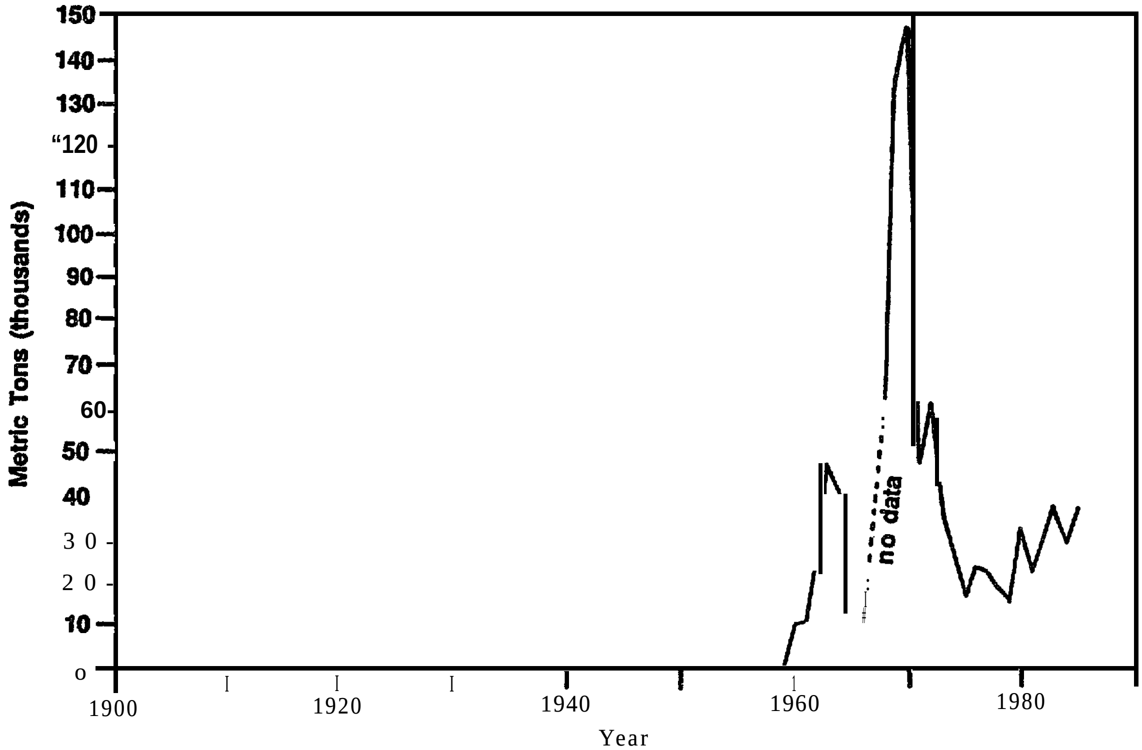

Figure 1. Commercial Pacific herring harvest In the eastern Bering Sea, 1906-1985,

In the eastern Bering Sea commercial exploitation of Pacific herring began just after the turn of the century. A small fishery supplied salted herring to Nome during the gold rush days, beginning in 1906 in Grantley Harbor on the Seward Peninsula and lasting until 1917. Another fishery developed in Golovnin Bay in Norton Sound about 1916 and lasted until 1941.

Out on the Alaskan Peninsula, a salt herring operation began operating in 1928 at Dutch Harbor and continued until 1946. Domestic fisheries for Pacific herring in the eastern Bering Sea declined in the mid- 1940s due to low prices resulting from a decline in the demand for salt-cured herring.

Foreign Trawl and Gill Net Fisheries

The second major phase of commercial exploitation of Pacific herring developed very rapidly in the late 1950s when Soviet trawlers found substantial quantities of herring wintering north and west of the Pribilof Islands. Data from the Soviet trawl fishery in the early years is scarce, but by 1960 the Soviets landed about 10,000 MT. The Soviets dominated the fishery in the early 1960s and were largely responsible for the large peak catch in 1970. The Japanese fishery peaked in 1968 at 38,000 MT. With the passage of the Fishery Conservation and Management Act, the foreign trawl fisheries for herring were eliminated from the eastern Bering Sea as herring were declared to be fully utilized. The last foreign catches were recorded in 1978.

The Soviet fishery used strictly trawl gear and operated in the Bering Sea north and west of the Pribilof Islands. The Japanese fishery used trawls in the same area, but also fished gillnets in the spring closer to shore in Norton Sound and in the Togiak area. Most of the foreign harvest was taken by trawl gear.

Sac Roe Fisheries

The domestic sac roe fisheries in Bristol Bay began to develop in 1977, prompted by shortages of roe in traditional harvesting areas and a favorable dollar/yen exchange rate. A total of 2,500 MT were landed in that first year, with catches escalating quickly to almost 30,000 MT by 1980. Purse seines and gillnets are the primary gears used to harvest herring for sac roe. Separate harvest quotas are established for each major spawning stock of herring. Major fisheries have occurred along the north shore of the Alaska Peninsula, upper Bristol Bay, Togiak, Security Cove, Goodnews Bay, Cape Romanzoff, Norton Sound, and further north in the Port Clarence and Kotzebue Districts. Herring spawning activity and subsequent sac roe fisheries begin in early May to early June in the Bristol Bay area, mid to late June around Cape Romanzoff and Norton Sound, and end in July or August in Port Clarence and Kotzebue Sound. Harvests in the Togiak District of Bristol Bay area are much greater than in other areas.

Roe-on-Kelp Fisheries

Roe-on-kelp herring fisheries are far smaller than sac roe fisheries, harvesting 159 MT of spawn in 1986, the equivalent of about 1,300 t of spawning herring. The major fishery occurs in the Togiak area with smaller amounts coming from Norton Sound. Roe-on-kelp fisheries tend to be risk-prone ventures as markets are subject to considerable fluctuation, and buyers often find that product quality is unsuitable because of silt contamination and insufficient egg deposition density. Market failures and poor quality completely prevented the 1985 roe on kelp fishery.

Potential Offshore Trawl Fisheries

While Pacific herring are available for harvest in wintering concentrations north and west of the Pribilof Islands, where they were previously utilized by the foreign trawl fisheries, these wintering stocks are thought to be the same stocks that migrate to the western Alaskan coasts to spawn in the spring. The available information on herring movements indicates that fish from most of the coastal spawning areas congregate in the Pribilof area during the winter and proceed from there more or less directly to spawning grounds in spring (Figure 2). Following spawning, movements proceed in a general clockwise direction along the coast until stocks again head offshore into the wintering areas. Since at least some user groups feel that the inshore-spawning stocks are fully utilized, domestic trawl fisheries on the offshore wintering stocks have not yet been allowed.

Current Stock Status

Pacific herring present some difficult stock assessment problems, particularly in the Bering Sea. In some other areas of the state, acoustic echo integration is used to determine the biomass of overwintering schools. Unfortunately, the overwintering area in the Bering Sea is large, the stocks from different spawning grounds are mixed, and ice compounds the difficulties of acoustic assessment efforts. In other areas of the state, it is possible to more easily assess stocks that use wintering grounds that are almost adjacent to their spring spawning grounds.

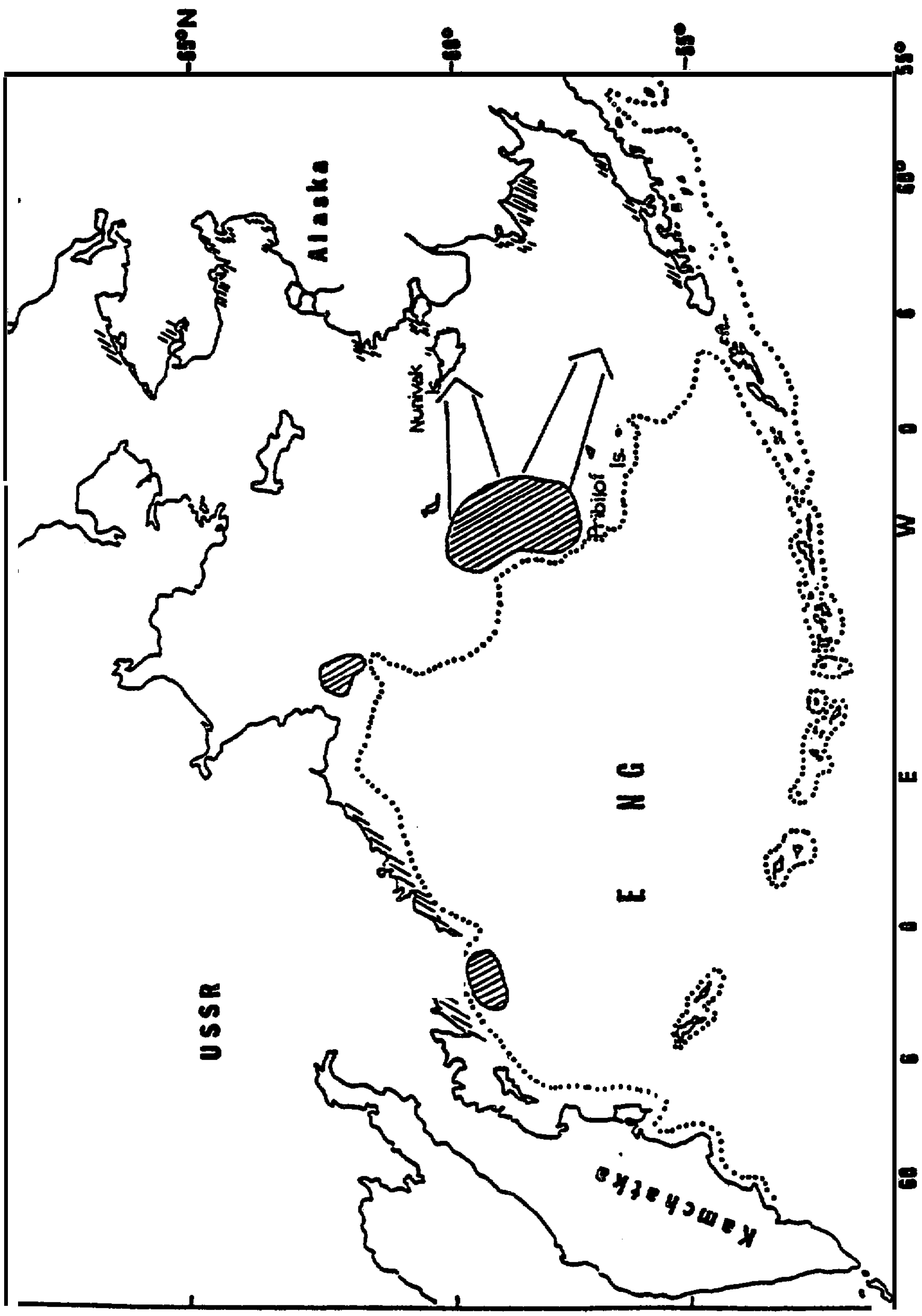

Figure 2. Location of the spawning and winter grounds (oval areas) of main eastern and eastern Bering Sea Pacific herring stocks and routes of migration of eastern stocks to spawning areas.

In some areas of Southeast Alaska, diving surveys of spawning grounds are relied upon to estimate the number of eggs deposited and from that the number of spawning females is back-calculated based upon fecundity sampling. Fishery or survey CPUE (catch-per-unit-effort) is not generally felt to provide reliable estimates of stock abundance due to the highly aggregated stock distribution. Most of the fishing effort is spent in search time and is difficult to quantify.

Aerial surveys and supplemental techniques are currently used to provide stock assessment information for the eastern Bering Sea area. Estimates of school size from aerial surveys, combined with ground surveys of egg deposition and kelp bed coverage are supplemented by age distributions derived from test fishing with variable mesh gillnets.

With the accumulation of a time series of catch-at-age information from the commercial fishery, cohort analysis techniques can be applied to determine back-calculated stock biomasses. The Alaska Department of Fish and Game is hoping to investigate the feasibility of using cohort analysis as a stock assessment tool in the near future.

The 1985 spawning biomass in surveyed areas was about 180,000 MT. The 1986 biomass is down somewhat from that number. Problems with Bering Sea stocks are forthcoming unless some new recruitment occurs in the fishery. Most of the biomass in the fishery is now concentrated in older age classes, where mortality is high. Barring substantial new recruitment to the fishery in the near future, harvests in upcoming years will probably be curtailed.

CAPELIN (*Mallotus villosus*)

While the potential for substantial capelin fisheries exists in Alaska, the fishery has not yet developed to any extent. Potential spawning concentrations that may be of harvestable size range from Kodiak to Norton Sound (Figure 3). Capelin biology is not well understood in Alaska, with even basic age and growth information only becoming available recently. Harvestable concentrations of capelin have occurred in the Togiak area, but marketing problems have precluded fisheries in years when capelin stocks were abundant, and lack of availability of capelin stocks has precluded fisheries in other years when processors were prepared to handle capelin.

Competition for resources has been hypothesized among Pacific herring and capelin stocks in the eastern Bering Sea. If herring stocks continue to decline, circumstantial evidence in support of the competition hypothesis may be available from the eastern Bering Sea if capelin stocks are observed to increase.

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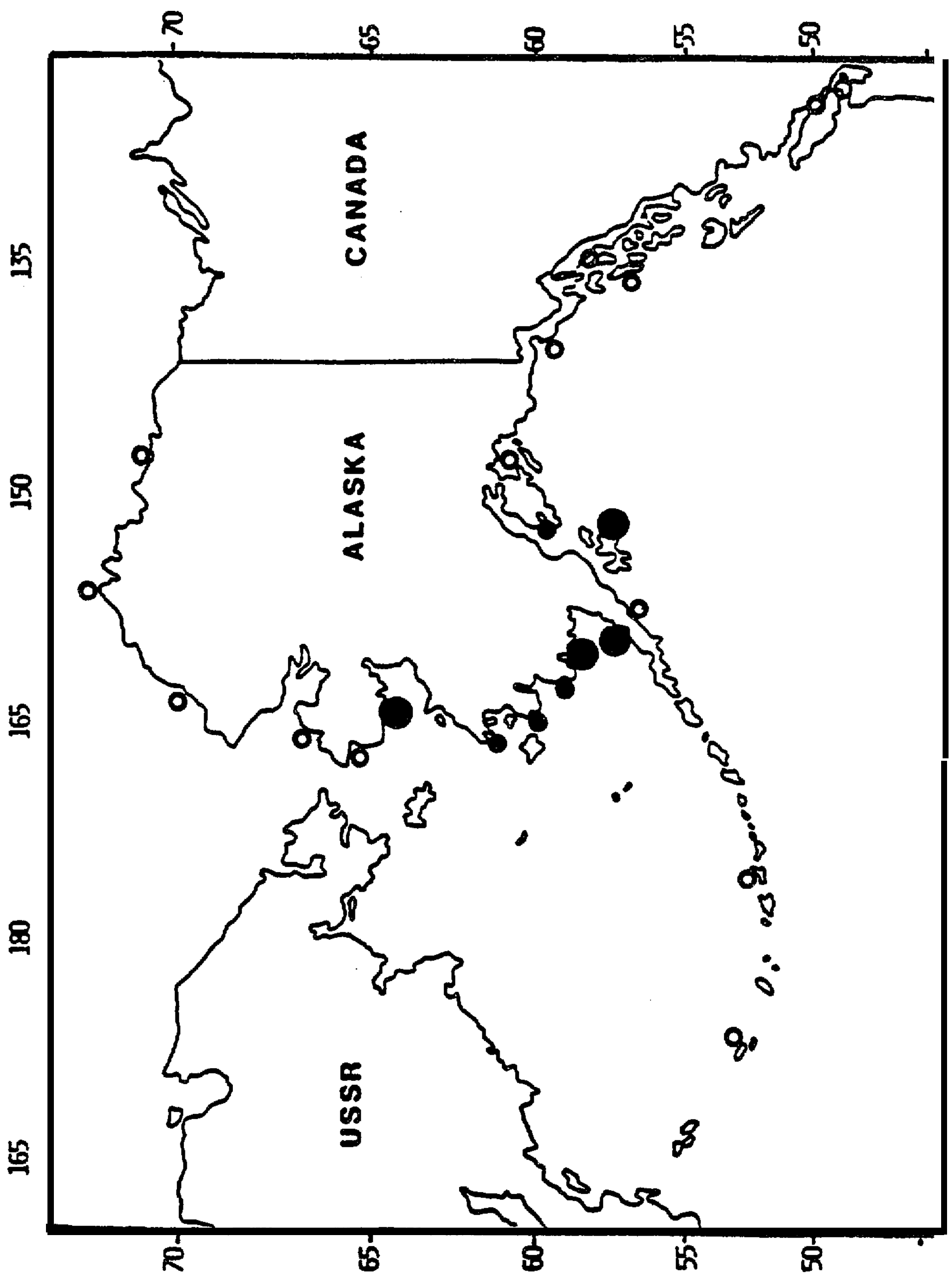

Figure 3. Locations of capelin spawning in the Northeast Pacific Ocean: ● = large recurring populations; ● = small recurring populations; O = infrequently.

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ENVIRONMENTAL- DEPENDENT STOCK-RECRUITMENT MODELS FOR PACIFIC HERRING (*Clupea pallasii*)

Max Stocker
Pacific Biological Station
Canada Department of Fisheries and Oceans
Nanaimo, British Columbia V9R 5K6
Canada

Pacific herring (*Clupea pallasii*) range from southern California to Arctic Alaska in the northeast Pacific, and from Korea to Kamchatka in the northwest Pacific (Blaxter 1985). Herring are pelagic planktivores. Schooling is standard behavior. Herring migrate onshore in the winter-spring before they spawn in protected intertidal and subtidal waters (Hay 1985). The demersal eggs adhere to vegetation. Larvae hatch after 6 to 18 days incubation (Haegele and Schweigert 1985). Juveniles recruit to the spawning population from Age 2 to 5. The maximum age may be over 20 years but ages over 10 years are uncommon in fished populations.

Pacific herring have been fished off the coast of British Columbia since 1877 (Pearse 1982). A domestic reduction industry developed in the 1930s after the collapse of a Pacific sardine (pilchard) (*Sardinops sagax)*, fishery. The 1962-63 season was the peak of the reduction fishery, with about 240,000 MT landed. After 1965 the stocks collapsed, and the reduction fishery was closed indefinitely in 1968 (Hourston 1980; Pearse 1982).

The sac-roe (ovaries) fishery for Pacific herring began after partial stock recovery in the early 1970s. This fishery targets on sexually mature, prespawning herring. The egg skein is processed into Kazunoko, a Japanese delicacy (Trumble and Humphreys 1985). Fishing occurs in late February through April. The objective of harvesting fish with maximum prespawning ovary development, combined with too many fishing vessels, creates an intense, often frenzied fishery. Season openings are measured in hours and minutes. An entire fishing season may consist of one purse seine set or a few hours of gill netting. Two other fisheries also exploit herring. A small food and bait fishery has persisted since the 1960s and a new fishery for roe-on-kelp is emerging in British Columbia.

There are complex mechanisms that cause fluctuations in the recruitment of Pacific herring. The magnitudes of recruitment have been highly variable over the period of 1951-1982. This study identifies environmental factors associated with variation in recruitment. I postulate that deviations from average recruitment are a result of changes in density-independent mortality caused by environmental conditions. A modified Ricker spawning stock-recruitment model (Tang 1985) is used to account for the density-independent mortality.

Ricker (1954) described the spawning stock-recruitment relationship as: $R = aS[\exp(-bS)]$; where R is the recruitment, S is spawning stock, $\underline{a}$ is the density-independent mortality, and $\underline{b}$ is related to density-dependent mortality and specifies the replacement spawning stock size. It is assumed that deviations from predicted recruitment are a result of changes in the $\underline{a}$ parameter over time, and $\underline{a}$ is considered to be a function of environmental conditions $a'(t) = g[X^1(t),X^2(t),...,X^m(t)]$; where Xi(t) are environmental variables at time t (i.e., sea surface temperature) affecting density-independent mortality at time t (Tang 1985). Substituting the second equation into the first equation yields a modified Ricker stock-recruitment model.

I used "exploratory correlation" (Ricker 1975; Stocker *et al.* 1985), to select significant environmental variables for inclusion in the model. I correlated the recruitment estimates from an age structured model (Haist *et al.* 1985) with monthly mean values of environmental variables thought important in the early life history of Pacific herring.

Environmental variables analyzed for the five Pacific herring populations included monthly means of sea surface temperature, sea level, salinity, river discharge, and transport. Of the five populations analyzed (Figure 1), only three populations showed significant correlations between recruitment and environmental variables: Strait of Georgia/Johnstone Strait (Table 1); west coast of Vancouver Island (Table 2); and Prince Rupert district or North Coast (Table 3).

Spawning stock and recruitment data (Haist *et al.* 1985) have been fitted to obtain estimates for the modified Ricker stock-recruitment model using multiple linear regression. For the Strait of Georgia/Johnstone Strait, the linear model with February-March mean sea surface temperature, February-March mean Fraser River discharge, and November-December mean sea level explained only 27.2% of the variance in environmental conditions (Table 4). Similarly, for the west coast of Vancouver Island, and the Prince Rupert District the linear models explained 57.9% and 45.4?40 of the variance in environmental conditions, respectively (Tables 5 and 6).

Figures 2 and 3 summarize results of the modified Ricker spawning stock-recruitment models. Plots of the observed and predicted recruitments are shown for the three coastal areas (Figure 2). Herring recruitments depend on both spawning stock size and environmental conditions (Figure 3). For all three populations good recruitment is produced when environmental conditions are favorable. For the west coast of Vancouver Island population, recruitment is density-dependent at higher spawning stock sizes. The Strait of Georgia/Johnstone Strait, and the Prince Rupert district populations do not show this strong density dependence. For all three populations, recruitment decreases very rapidly at low spawning stock sizes.

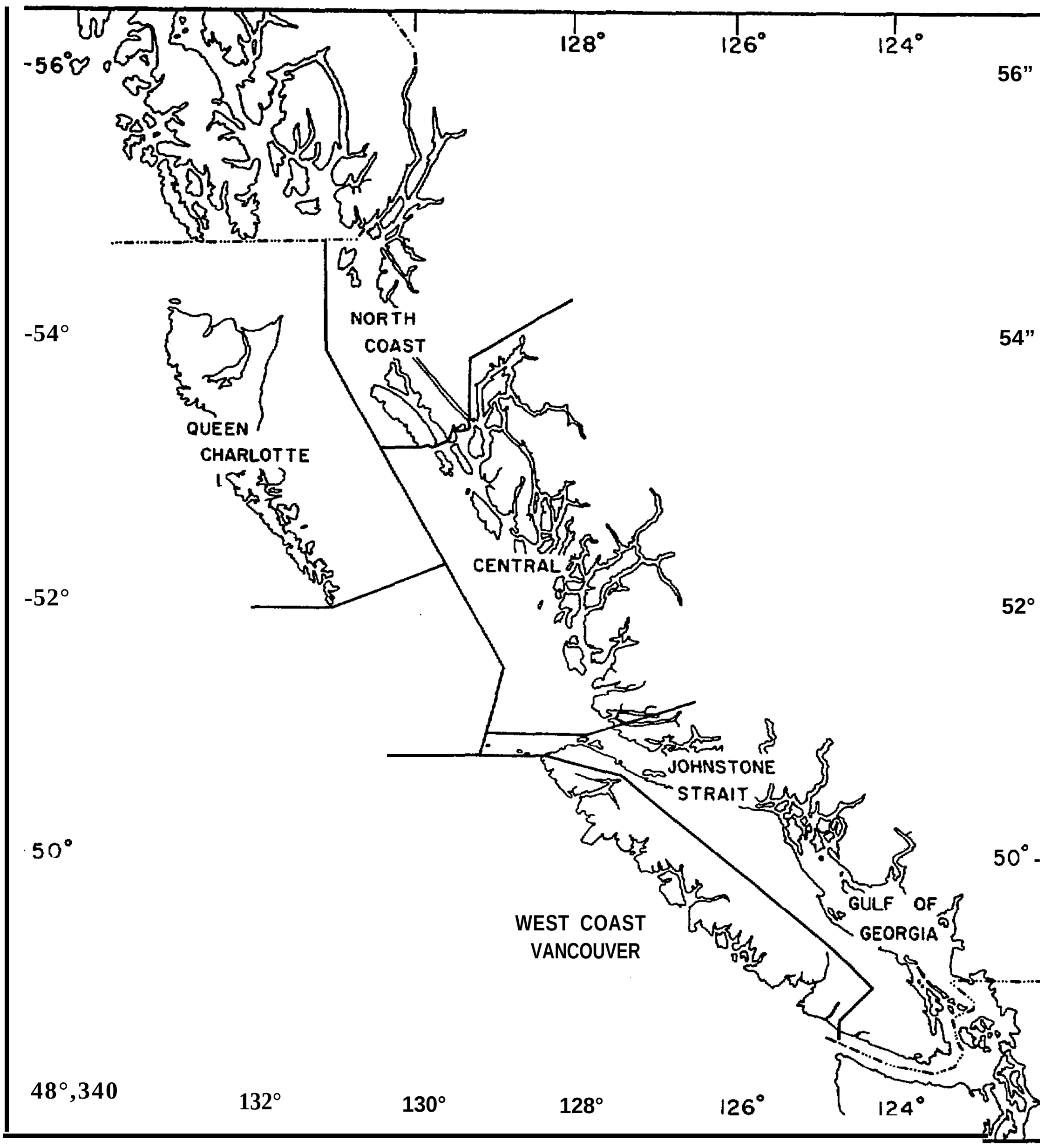

Figure 1. Pacific herring stock groupings for age-structured **model analysis, and surplus production model analysis (from Haist *et al.* 1985).**

Table 1. Correlation coefficients of environmental variables with recruitment estimates for the Strait of Georgia/ Johnston Strait Pacific herring populations. SST, Feb-Mar mean sea surface temperature. Entrance Island; FRASER, Feb-Mar mean discharge, Fraser River at Hope; SLEV, Nov-Dec mean sea level, Point Atkinson.

Variable	N	r	$\hat{F}$ (df)	$P(F>\hat{F})$
SST	32	-0.383	5.15 (1,30)	0.031
FRASER	32	-0.339	3.91 (1,30)	0.057
SLEV	32	-0.443	7.32 (1,30)	0.011

Table 2. Correlation coefficients of environmental variables with recruitment estimates for the West Coast of Vancouver Island Pacific herring population. SST, Feb-Apr, Sep-Dec mean sea surface temperature, Amphitrite Point; SAL, March mean salinity, Amphitrite Point; SLEV, Jun-Jul mean sea level, Tofino.

Variable	N	r	$\hat{F}$ (df)	$P(F>\hat{F})$
SST	31	-0.643	20.52 (1,29)	<0.001
SAL	31	-0.431	6.64 (1,29)	0.015
SLEV	31	0.374	4.71 (1.29)	< 0.001

Table 3. Correlation coefficients of environmental variables with recruitment estimates for the Prince Rubert District Pacific herring population. SST, May-Sep mean sea surface temperature, Cape St. James; TRANS, sum of Jan and Feb Ekmao Transport, 54N134W; SLEV, January mean sea level, Prince Rupert.

Variable	N	r	$\hat{F}$ (df)	$P(F>\hat{F})$
SST	32	0.533	11.91 (1,30)	< 0.002
TRANS	32	0.671	24.57 (1,30)	0.001
SLEV	32	0.395	5.35 (1.29)	< 0.028

Table 4. Parameter estimates (a_i) from multiple regression model for the Strait of Georga/Johnstone Strait for the period 1951-1982. ([$\hat{F}$(3,28) =3.49], [$P(F>\hat{F})$<0.29, r=0.522].

Variables	Coefficient	t-ratio	P(two-tail)
Intercept	a_0=125.6130	2.73	0.011
SST	a_1= -3.6800	-2.07	0.048
FRASER	a_2= 0.0015	0.36	0.722 NS
SLEV	a_3=-29.0105	-1.99	0.056

SS * Not Significant

Table 5. Parameter estimates (a_i) from multiple regression model for the West Coast of Vancouver Island for the period 1951-1982. ([$\hat{F}$(3,27) =12.40], [$P(F>\hat{F})$<0.001, r=0.761].

Variables	Coefficient	t-ratio	P(two-tail)
Intercept	%"351.2230	2.14	0.042
SST	a_1=-14.0361	-4.59	< 0.001
SAL	a_2= -4.7451	2.93	0.007
SLEV	a_3=-26.0664	-0.42	0.678 SS

NS = Not Significant

Table 6. Parameter estimates (a_i) from multiple regressio modei for the Prince Rubert District for the period 1951-1982. ($\hat{F}$(3,28)=7.76], [$P(F>\hat{F})$<0.001, r=0.674].

Variables	Coefficient	t-ratio	P(two-tail)
Intercept	a_0=108.5180	0.61	0.547 NS
SST	a_1= 8.1320	1.86	0.073
TRAMS	a_2= 0.0954	2.90	0.007
SLEV	a_3=-49.74%	-1.07	0.294 NS

NS = Not Significant

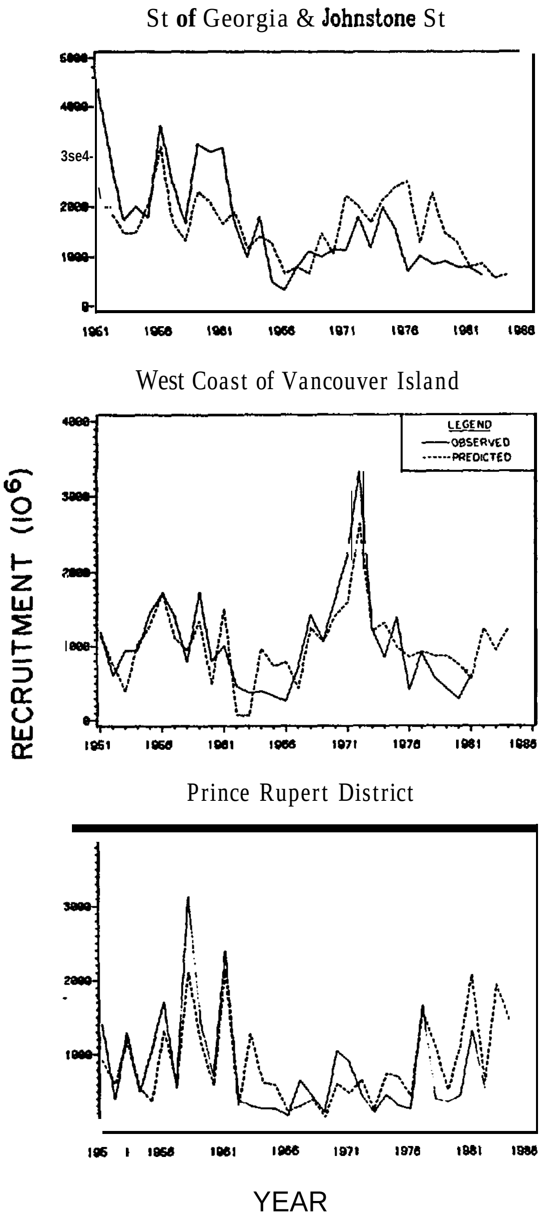

Figure 2. Observed and predicted recruitments of the modified Ricker stock-recruitment model for three coastal areas of British Columbia, 1951-1984.

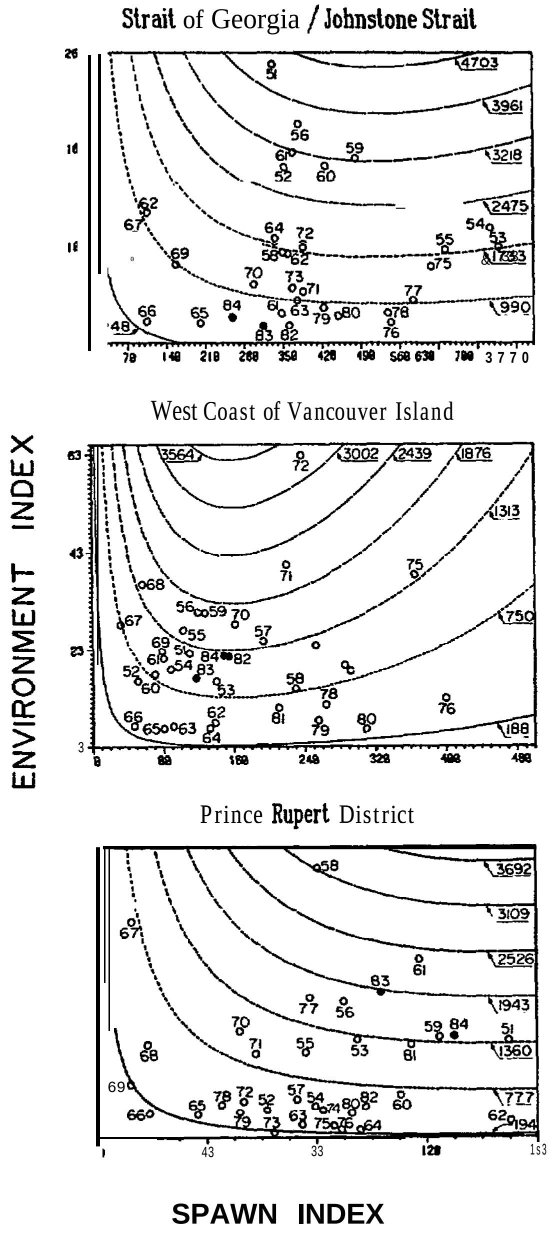

Figure 3. Recruitment isopleths of environmental conditions (a't) on spawning stock size; recruitment: (o) observed, and (.) forecast.

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ATLANTIC HERRING (*Clupea harengus*) MOVEMENT ALONG THE SCOTIAN SHELF AND MANAGEMENT CONSIDERATIONS

Wayne T. Stobo
Marine Fish Division
Bedford Institute of Oceanography
P. O. Box 1006
Dartmouth, Nova Scotia B2V 4A2
Canada

INTRODUCTION

The value of herring tagging studies aimed at elucidating stock structure is often disputed for a variety of reasons, including the fact that recovery information often does not indicate consistent patterns of movement, and it has not been well documented that herring are capable of homing. There are may constraints on the interpretation of the results of herring tagging studies that must be recognized and accounted for in experimental design and execution (Stobo, 1983). The purpose of this paper is to examine some results of tagging experiments on the Scotian Shelf, discuss 'homing' in Atlantic herring (*Clupea harengus*), and comment on the implications of such behaviour for effective management, or assessing potential environmental impacts on the resource.

THE NEED FOR REPLICATION

Herring are rather fragile fish, and consequently, high recovery rates cannot be expected. The highest long-term recovery rate (ie. recoveries made at least two weeks after release) of Atlantic herring in the northwestern Atlantic was only 4.10/o (Figure 1). It therefore becomes obvious that for any herring tagging study to yield sufficient information to elucidate stock structure, large numbers of herring must be tagged; and the greater the number of potential recovery areas, the greater the required number of releases. Otherwise, a conclusion of random movement will be inevitable.

However, even then tagging results may not provide clear-cut stock definition. The stock interrelationships of Atlantic herring are highly complex with different stocks often intermingling on common feeding grounds and even on spawning grounds. Such mixing can easily confound the interpretation of tagging experiment results. For example, two tagging experiments, one in 1974 and one in 1977, were carried out off southwest Nova Scotia. Both were intended to tag spawning fish, but in 1974 only pre-spawning aggregations could be found. The subsequent recoveries (Figures 2 and 3) show quite different results although in both experiments the majority of recoveries were made in the Bay of Fundy area.

In comparison, 14.0%, 70.5%, and 15.5% of the tag recoveries were made in Northwest Atlantic Fisheries Organization (NAFO) Subareas 5-6, Subdivision 4X, and Subdivisions 4RVW, respectively, in the 1974 study, while in the 1977 study the comparable percentages were 6.0%, 53.19'0, and 40.9°/0, When the recoveries made in the area of

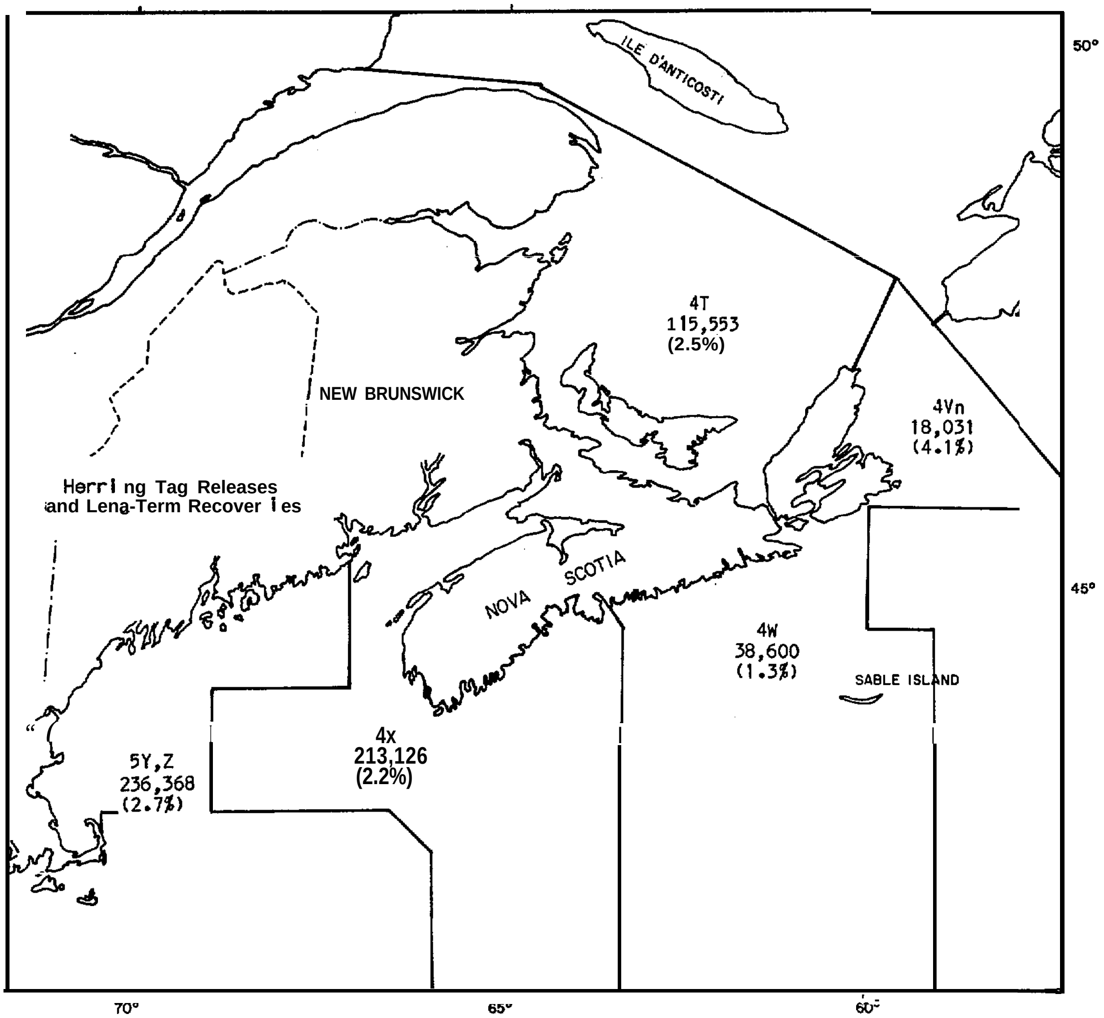

Figure 1. Atlantic herring tab releases in NAFO areas between 1973-1981. The percentage returns (excluding recoveries made within two weeks of release) are given in parentheses.

tagging (4X) were excluded (Table 1), the differences between the results are further emphasized. The recoveries in Subareas 5-6 were 47.40/0 from the 1974 study, but only 12.8% from the 1977 study.

The differing results of the two studies, in conjunction with the information on stage of sexual maturity, has led to the hypothesis that during the feeding and pre-spawning period, the Bay of Fundy has a large admixture of Gulf of Maine and Scotian Shelf stocks. As the fish near the "ripe and running" sexual maturity stage they begin to segregate. The Gulf of Maine herring move westward towards their spawning grounds. The Subdivision 4WX herring stay in the southwest Nova Scotia area to spawn, and subsequently move eastward to overwinter. The fact that a proportion of the fish tagged in 1977 still moved westward may indicate the degree of straying involved or it may mean that Gulf of Maine fish, which spawn about a month later, were still in the Bay of Fundy area at the time of spawning for southwest Nova Scotia herring. Either possibility illustrates the complexity of the stock interrelationships.

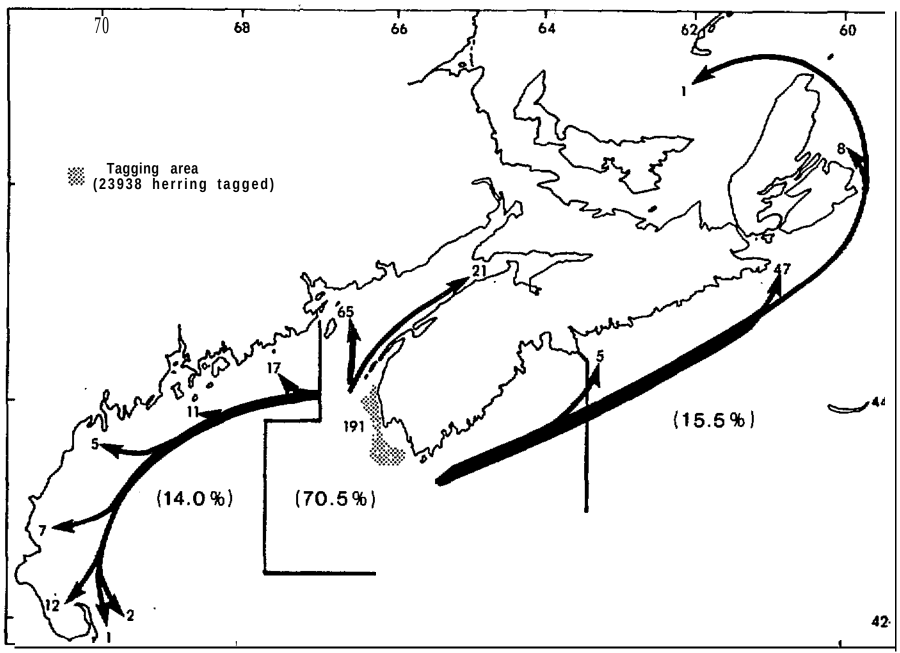

Figure 2. Distribution of tag recoveries of Atlantic herring from tagging experiments conducted off Southwest Nova Scotia in August 1974. Tags recovered within two weeks of release are excluded; recoveries are combined over years. Percentage of recoveries made in NAFO areas given In parentheses.

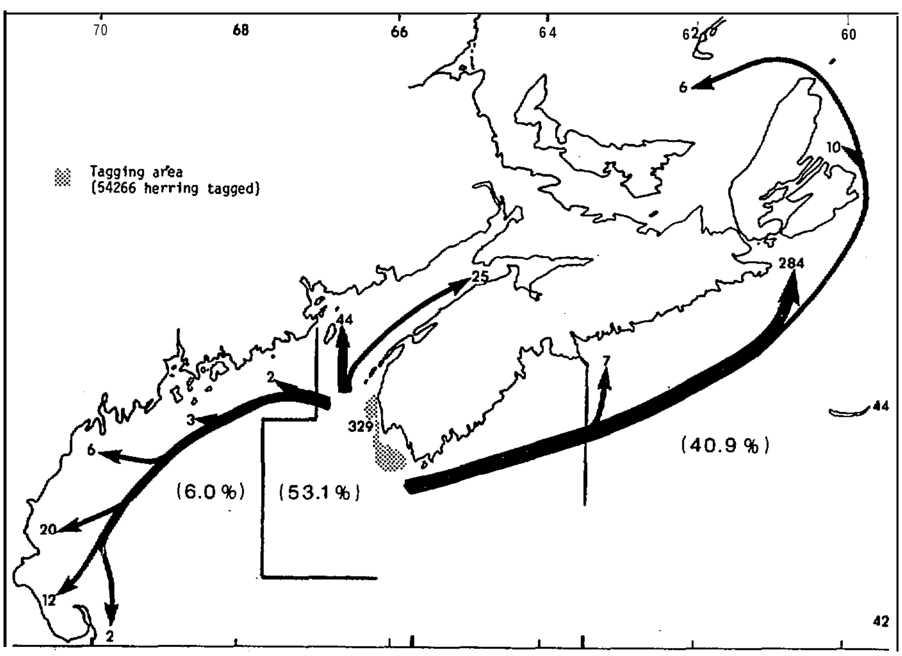

Figure 3. Distribution of tag recoveries of Atlantic herring from tagging experiments conducted off Southwest Nova Scotia In August-September 1977. Tags recovered within two weeks of release are excluded; recoveries are combined over years. Percentage of recoveries made In NAFO areas given In parentheses.

Another example of the complexity of the stock interrelationships are the results of three tagging studies conducted in Sydney Bight on overwintering, adult herring. In the three successive years of the tagging study, the fishery moved progressively northward and thus so did the tagging operations (Figures 4, 5, and 6; Table 2). In 1977, the fishery was concentrated close inshore with the majority of the catch being taken in the southern area. In 1978, the majority of the catch in Subdivision 4Vn was taken further offshore and more to the west. In 1979/80, the fishery was concentrated to the north and northwest.

The distribution of tag recoveries exhibit a similar movement, with an increasing proportion of the tag recoveries made outside of the area of release being made to the north and northwest. The proportion of the total tag recoveries taken to the southwest, decreases from 80% in 1977 to only 5.8% in 1979/80 while the proportion taken to the north and northwest increases from 2.5'% to 10.0% (Figures 4, 5 and 6). Excluding the numbers of tags recovered in Subdivision 4Vn, the change is from 97.0% to 36.7% and 3.0% to 63.4% for the southwest versus north/northwest, respectively (Table 2).

In this case, the differing results of the three studies, along with detailed knowledge of relatively small scale changes in the geographic distribution of the fishery, has led to the hypothesis that the Subdivision 4Vn area is an overwintering area for several stocks. It is now believed that some proportion of herring stocks from NAFO Subdivisions 4T, 4V, and 4WX overwinter and intermix in the Subdivision 4Vn area; those in the northern part largely belong to Subdivision 4T, those in the southern part largely belong to Subdivision 4WX stocks, and the Subdivision 4Vn "local" stocks mix throughout. The consequence of this complexity has resulted in a biological recommendation to close the overwintering fishery in Subdivision 4Vn, thus restricting exploitation of these stocks to their summer distributions.

The examples presented above of the results of tagging studies of the southwest Nova Scotia stock complex and the Sydney Bight complex illustrate the necessity for detailed knowledge of the fisheries and biological status of the fish. Tagging studies must be replicated and the results interpreted in the light of such knowledge.

HOMING IN ATLANTIC HERRING

As mentioned above, little documentation exists to entrench the idea that Atlantic herring have definite migration patterns (ie. are capable of homing). Results of tagging studies, such as those shown above, upon simplistic interpretation could indicate random movement. However, such an interpretation does not correlate well with the existence of discrete spawning beds and highly discrete and predictable fisheries, of a fairly stable magnitude, over long time periods.

In an attempt to address the issue of homing, the recovery results of the 1974 and 1977 tagging studies in southwest Nova Scotia and those in 1977 and 1978 in Chedabucto Bay are summarized. The geographic distributions of the recoveries are presented for each successive summer (June-October period) and winter (November-March period) after release. The results from the southwest Nova Scotia studies are given in Figures 7 and 8 and Table 3. As can be seen from the distribution of summer recoveries (Figure 7), the majority of recoveries in successive summers following release are of the Bay of Fundy, the feeding and pre-spawning area for the southwest Nova Scotia fish. In the first summer after release, 94.7% of the recoveries were made in the Bay of Fundy environs

Table 1. Comparison of recovery rates of Atlantic herring from the 1974 and 1977 southwest Nova Scotia tagging studies made outside of the area of tagging, NAFO Subdivision 4X.

Year	Number Tagged	Total Recoveries	Recoveries Outside NAFO Subdiv. 4X	
				4RVW
1974	23938	393 (1.6)	55 (47.4%)	61 (52.6%)
1977	54266	750 (1.4)	45 (12.8%)	307 (87.2%)

Table 2. Comparison of recovery rates of Atlantic herring from the Sydney Bight tagging studies, 1977-1980, made outside of the area of tagging, Subdivision 4Vn.

Year	Number Tagged	Total Recoveries	Recoveries Outside NAFO Subdiv. 4Vn	
			4WX	4RT
1977	3082	120 (3.9)	96 (97.0%)	3 (3.0%)
1978	3994	147 (3.7)	25 (61.0%)	16 (39.0%)
1979/80	10585	451 (4.31	26 (36.7%1	45 (63.4%)

Table 3. Comparison of distribution of recoveries of Atlantic herring by NAFO Subdivision, from the 1974 and 1977 southwest Nova Scotia tagging studies for each summer (June-October) and winter (November-March) after release. Percentages given in parentheses. The percentage of total recoveries recovered in the more circumscribed area of tagging are also given in parentheses.

Season of Recovery	Recoveries by Region			
	Total	SA 5-6		4RVW
1st summer	401	13 (3.2)	377 [94.7(78.8)	11 (2.7)
2nd summer	51	13 (25.0)	36 (70.6(41.2))	2 (3.9)
3rd summer	22	2 (9.1)	20 (90.9(54.6))	O
4th-7th summer	7	0	7 (100.0(28.6))	o
1st winter	363	44 (12.11	12 (3.3(o))	307 (84.6)
2nd winter	42	7 (16.7)	5 (11.9(0))	30 (71.4)
3rd winter	11	0	3 (27.3(0))	8 (72.7)
4th-7th winter	7	0	1 (14.3(0))	6 (85.71

Table 4. Comparison of distribution of recoveries of Atlantic herring by NAFO Subdivision from the 1977 and 1978 tagging studies off the Chedabucto Bay area (NAFO Subdivision 4W) for each summer (June-October) and winter (November-March) after release. Percentages are given in parentheses.

Season of Recovery	Recoveries by Region				
	Total	SA 5-b	4x	W	4RTV
1st winter	57	3 (5.31	1 (1.2)	38 (66.7)	15 (26.3)
2nd winter	12	0	0	7 (58.31	5 (41.7)
1st summer	135	4 (3.0)	121 (89.6)	5 (3.7)	5 (3.7)
2nd summer	34	1 (2.9)	29 (85.3)	4 (11.8)	O
3rd summer	1	0	0	1 (100.0)	o

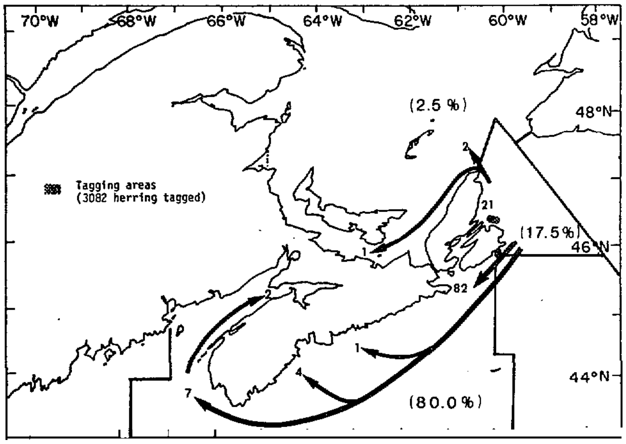

Figure 4. Distribution of tag recoveries of Atlantic herring from tagging experiments conducted off Sydney Bight in November-December 1977. Tags recovered within two weeks of release are excluded; recoveries are combined over years. Percentage of recoveries made in NAFO areas are given in parentheses.

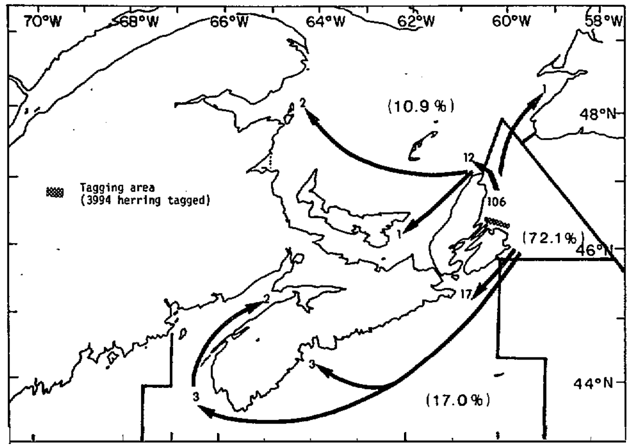

Figure 5. Distribution of tag recoveries of Atlantic herring from tagging experiments conducted off Sydney Bight in November 1978. Tags recovered within two weeks of release are excluded; recoveries are combined over years. Percentage of recoveries made in NAFO areas are given in parentheses.

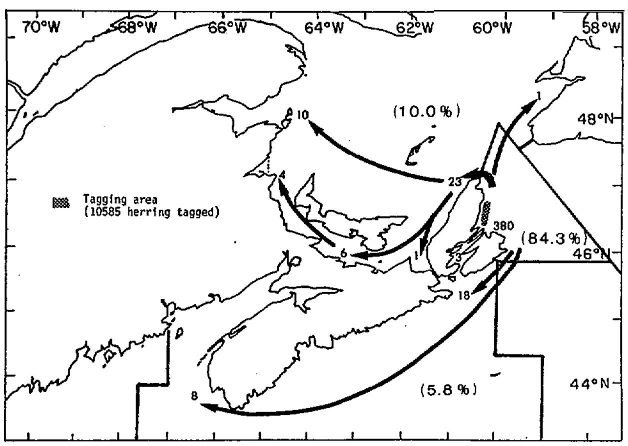

Figure 6. Distribution of tag recoveries of Atlantic herring from tagging experiments conducted off Sydney Bight in December 1979 and January 1980. Tags recovered within two weeks of release are excluded; recoveries are combined over years. Percentage of recoveries made in NAFO areas are given in parentheses.

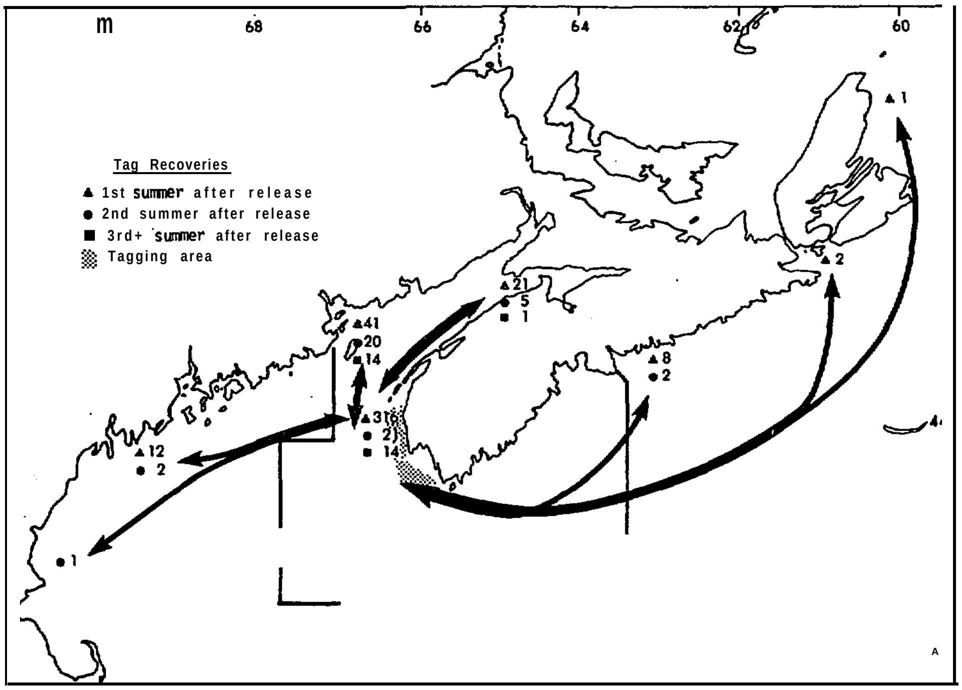

Figure 7. Summer distribution **of tag recoveries of Atlantic herring from tagging experiments conducted off Southwest Nova Scotia in August 1974 and August-September 1977. Recoveries made during year of tagging are excluded; recoveries are combined for the two operations and presented for the 1st, 2nd, and 3rd (and subsequent) summers (June-October) after release.**

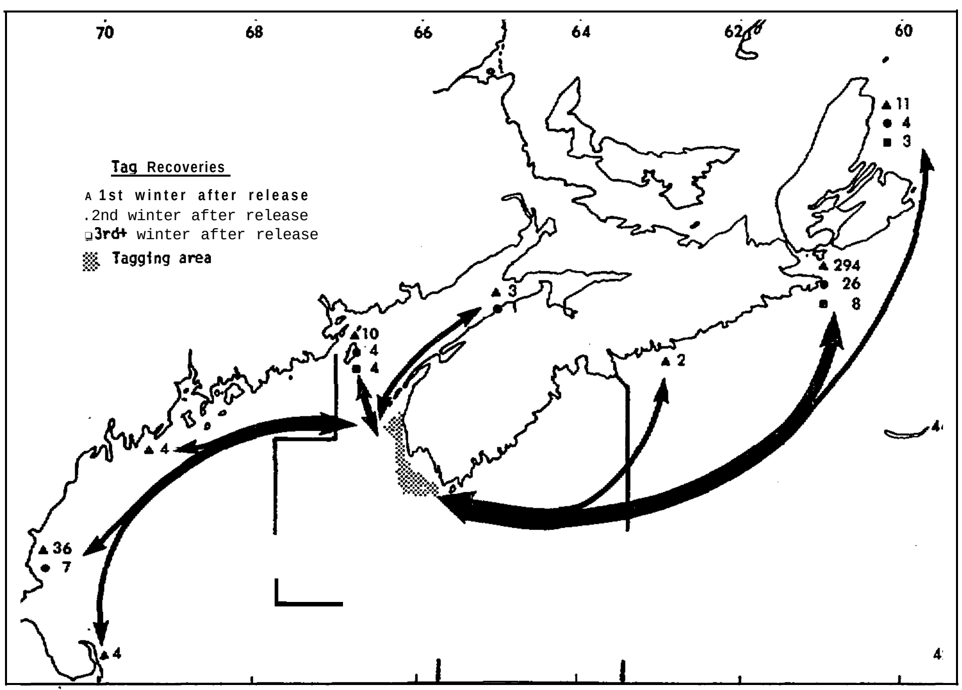

Figure 8. Winter distribution of tag recoveries of Atlantic herring from tagging experiments conducted off Southwest Nova Scotia in August 1974 and August-September 1977. Recoveries are combined for the two operations and presented for the 1st, 2nd, and 3rd (and subsequent) winters (November-March) after release.

and 78.8% were made in the area of release, off southwest Nova Scotia (Table 3). In subsequent summers between 70% and 100% of the recoveries were made in the Bay of Fundy environs with 28.5 to 54% being made in the area of release, off southwest Nova Scotia. The winter recoveries show a consistent pattern of movement year after year with the greatest proportion of recoveries (71 to 86%) being made in the Chedabucto Bay area.

The recoveries of fish tagged off Chedabucto Bay during the winter fishery in 1977 and 1978 (Figures 9 and 10) again indicate a tendency for herring to maintain a consistent migration pattern from year to year. During the first and second winters after tagging, over 93% of the recoveries were made off eastern Nova Scotia (Table 4), with over 58% being taken in the area of release. The summer distributions indicate a consistent major movement (over 85% of all recoveries) into the Bay of Fundy area during the two successive summers (Table 4). There is only a very limited movement into the Gulf of Maine area.

The data presented above suggest that between 70 to 100% ($\bar{x}$ = 88.9%) of the fish off southwest Nova Scotia in summer will return to the Bay of Fundy environs in successive years and that between 71 to 86% ($\bar{x}$ = 78.6%) of these fish overwinter in the Chedabucto Bay area. The results from the tagging studies off Chedabucto Bay suggest that between 85 to 90% ($\bar{x}$ = 87.5%) of these fish use the Bay of Fundy area as a feeding and spawning area. These results suggest that homing does occur in Atlantic herring and that they do maintain a consistent migratory pattern.

IMPLICATIONS OF THESE RESULTS TO HERRING TAGGING STUDIES AND MANAGEMENT

Tagging Studies

- Large numbers of herring must be tagged in order to obtain sufficient recoveries to shed light on the stock relationships. The more geographic areas of probable dispersal, the larger numbers required.

- Replication is necessary to observe potential between year variations since small changes in environmental conditions can modify the timing of movements and thus appearance in traditional fishing areas.

- To delineate stock structure, spawning herring must be tagged. Since feeding areas are often closely associated with spawning areas, tagging prior to peak spawning will probably confound the definition of migration patterns.

- Lastly, and not mentioned above, considerable effort must be placed on tag recovery and ensuring that accurate recovery locations are provided. This can only be assured by continuous advertising, reasonable rewards for tags, and co-operation from the fishing industry. The latter can be best achieved by convincing them of the benefits of knowing the stock relationships.

Management

- Since Atlantic herring stocks often intermingle in feeding and overwintering areas, it is usually impossible to properly partition fishing mortality to

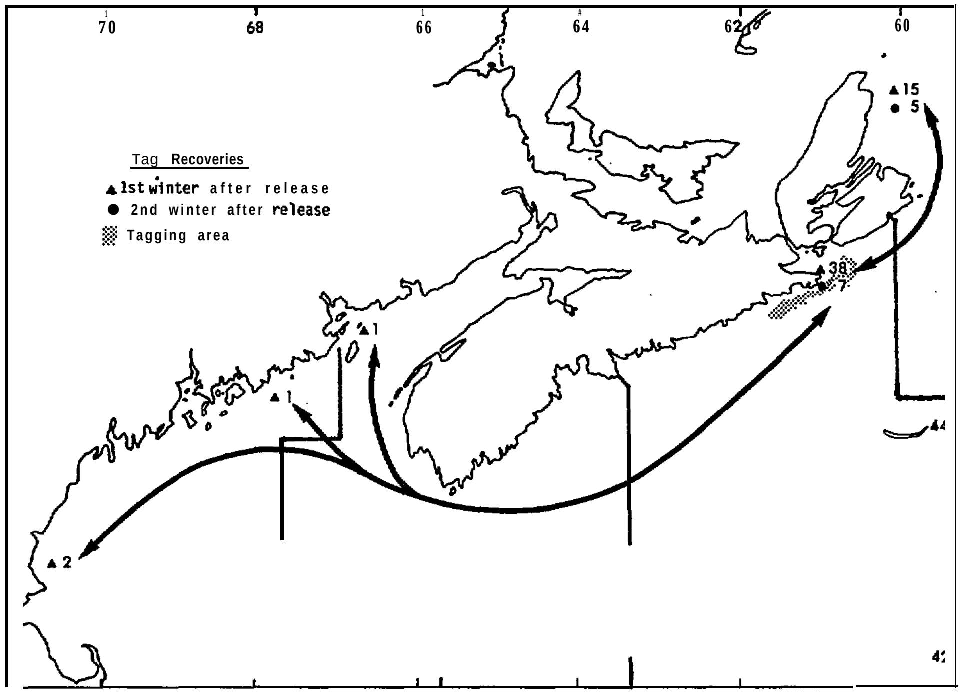

Figure 9. Winter distribution of tag recoveries of Atlantic herring from tagging experiments conducted off eastern Nova Scotia in January 1977 and January, November-December 1978. Recoveries are combined for the two operations and presented for the 1st, 2nd, and 3rd (and subsequent) winters (November-March) after release.

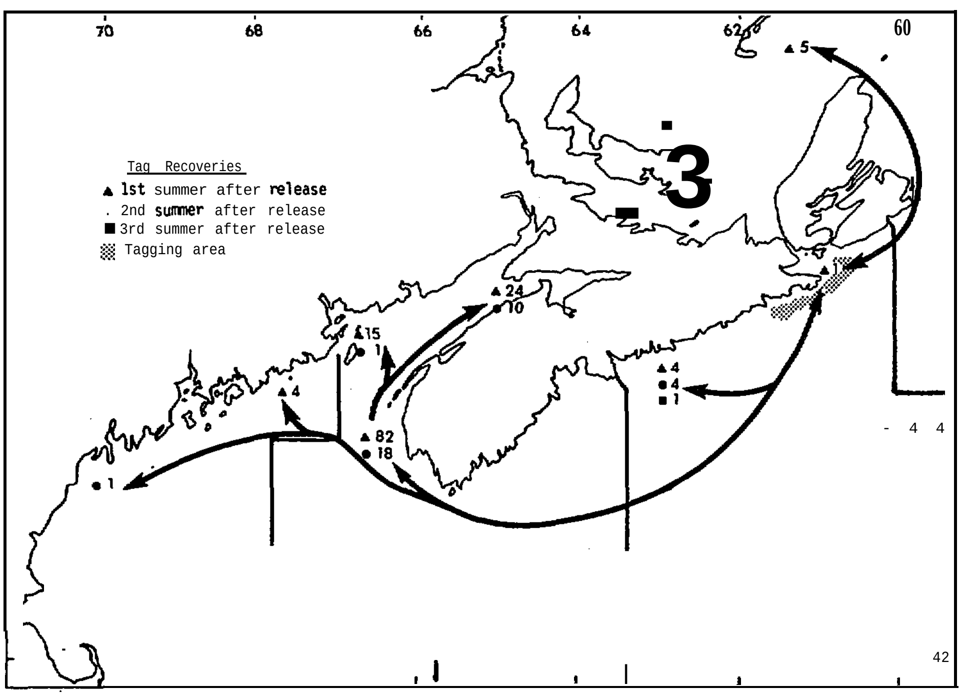

Figure 10. Winter distribution of tag recoveries of Atlantic herring from tagging experiments conducted off eastern Nova Scotia in January, November-December 1978. Recoveries are combined for the two operations and presented for the 1st, 2nd, and 3rd (and subsequent) summers (June-October) after release.

- Herring do maintain regular and predictable migration patterns and consequently fisheries can be directed at most phases of their annual cycle. Hence managers must be able to account for all fisheries exploiting each stock to avoid overexploitation.

- Not knowing stock structure and relative degree of intermixing can result in overestimating sustainable yields of individual stocks (ie. double counting the resource).

- Herring migrate relatively long distances thus exploitation could occur over an extensive geographic range.

- Large stocks will provide higher sustainable yields than small stocks and when two stocks of substantially different biological potential are randomly mixed, exploitation rates should be similar. But when annual variability in migration rates to intermingling areas occurs, coupled with fairly standard commencement dates of traditional fisheries, the danger exists that in some years the small stock could sustain the majority of the fishing mortality ascribed to both stocks in that geographical area. This would probably result in severe over-exploitation of the small stock since *q* (matchability) usually increases in schooling species with population decline. Thus special consideration must be given to fisheries operating on intermingling stocks, especially if a combination of large and small stocks are involved.

- Due to this increase in *q* with decreasing population size, there is often a lag of some years between when population over-exploitation occurs and when it becomes evident in fisheries assessments; often managers are reluctant to accept that "gut feeling" of biologists that over-exploitation is occurring because the fishery still appears to be healthy.

- Herring are an important forage fish for many pelagic and demersal fish species and marine mammals. Single species management action and/or over-exploitation of the herring resources could adversely affect sustained yields of the predator species.

- Environmental catastrophes, such as oil spills, though remote from specific fishing areas, could affect the short-term future of those fisheries due to the extensive migratory movements of many herring stocks.

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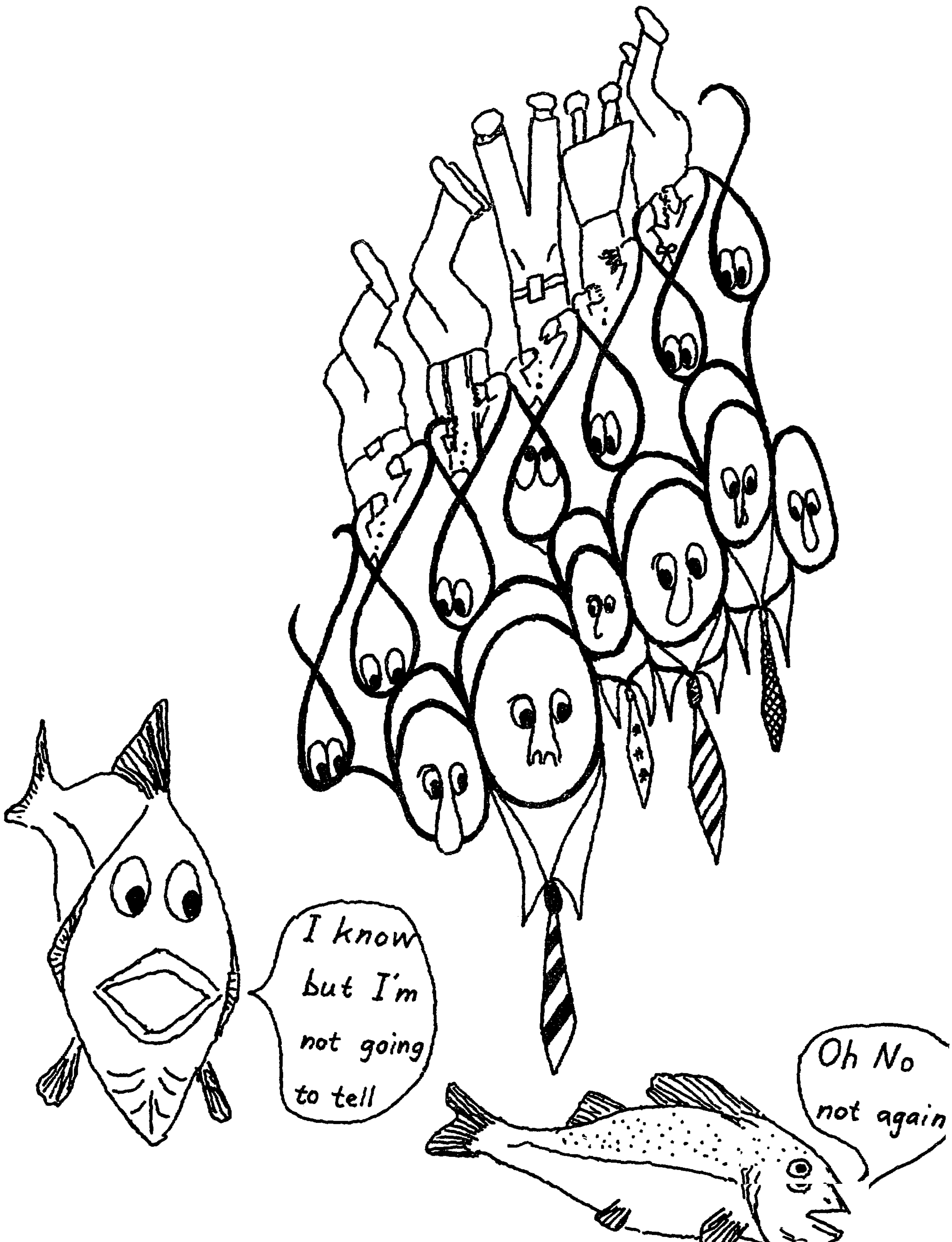
Stobo, W. T. **1976.** Some techniques and procedures used to tag herring in **ICNAF** Subarea 4. **Internatl. Comm.** Northw. **Atl.** Fish, Res. Dec. 76/101. Serial No. 3924.

Watson, J. E. 1963. A method for tagging immature herring. U.S. Fish. **Wildl.** Serv. **Spec. Sci.** Rep. - Fisheries No. 451.


I know but I'm not going to tell
Oh No not again

DISCUSSION

PREDATOR PREY RELATIONSHIPS IN THE SOUTHEASTERN BERING SEA

Ecosystem models are designed to incorporate all available knowledge of an ecosystem into a working model. The model can then be used to examine the causes and magnitudes of population fluctuations, energy flow through the system, and the effects of fishing, industrial, oil and gas, or other activities on species populations. These models attempt to provide structure to our knowledge and show the interrelationship of species and processes in the ecosystem. The models may be altered with the addition of new biological information and, in turn, help to direct biological research. In all cases, the simulation produced requires validation, which is difficult to obtain in open-ocean systems. Ecosystem models may be useful in describing existing information and possible outcomes of present day processes, but they are often inadequate in precisely forecasting future situations. It is difficult to evaluate the influence of variability, precision, accuracy, and adequacy of the biological parameters on the forecasting potential of such models without dealing with specific species and problems.

In general, conference participants considered the major forage species in the southeastern Bering Sea to include wane ye pollock, Pacific herring, rainbow smelt, Pacific sand lance, and capelin, although other species including juvenile salmon and benthic fishes are also important as forage. Major high-level predators in the system include northern fur seals, harbor seals, Steller sea lions, and belukha whales; shorttail shearwaters, common murres, thick bill murres, black-legged kittiwakes, and tufted puffins; and fish (e.g. Pacific cod). In the event of a major decrease in the stock size of a specific forage fish species, it was felt that some or most predator species would be able to switch to other forage species; however, the effect of such a change on their biology is unknown without understanding more about the nutritional value of the prey species. The standing stock (total biomass) of predators should not be the only criterion used for judging the importance of a predation because sea birds (which have a small standing stock) have greater conversion rates than marine mammals (which have a large standing stock).

DYNAMICS OF COASTAL FISHERIES OCEANOGRAPHY, AND THE DISTRIBUTION AND RELATIVE ABUNDANCE OF FORAGE FISH ALONG THE NORTH SHORE OF THE ALASKA PENINSULA

The strength of a year class (or cohort) is determined by the degree to which its abundance departs from the average expected abundance of a cohort of a given age. A strong year class is apparent as a peak in the age or size composition of a population that continues to be apparent in successive years (but at successive ages). Year-class strength is affected by physical and biological variables in the environment. Most (about 98%) of the mortality of marine fishes occurs in the egg stage and the life history strategies of the fishes are generally adapted to cope with intense mortality at this period. However, the mortality that occurs during the larval and early juvenile stages is often most crucial in determining the strength of a year class. A change in the mortality rate of 10% or more could have a major effect on a population. Intense mortality on a peak year class could reduce the fishery for several years.

The strength of a year class is dependent on physical and biological variables. In the southeastern Bering Sea it is thought that predation is the most important factor affecting the year class strength of forage fishes, although most examples of predation as a controlling force were from studies elsewhere in the world. Predation by marine mammals and seabirds and the effects of commercial fisheries are difficult to separate and not well documented in Alaska. The effects of predation are primarily local, Other biological parameters are hard to document in the field; for example, the effects of low food supply on forage fishes is uncertain as few starving fish are taken. Many models exist in fisheries oceanography y which predict current patterns, temperature regimes, etc. Most, however, can only effectively forecast conditions over a short time (e.g. six hours for wind direction, three days for local transport direction). Variation in extent of ice cover, temperature, and runoff are thought to have little effect on year class strength, although they could effect the timing of spawning. The best way to forecast year class strength would be to do pre-recruit studies, possibly by examining the stomach contents of predators.

Certain life history traits of pelagic forage fishes make them susceptible to predation or environmental perturbations. Their schooling behavior, which may serve to minimize predation by fishes, may maximize predation by marine mammals. By schooling they are highly and predictively concentrated and hence an easy target to marine mammals, which often follow schools for days. The littoral demersal spawning habits of some species (in particular, Pacific herring) may be affected by unusual beach disturbances, including oil spills. Unfortunately, little is known about the life histories of several species in this region, including capelin, rainbow smelt, and Pacific sand lance.

The rank of the forage fish discussed, in terms of their importance as prey, their significance to commercial fisheries, and the knowledge of their life history, is as follows: 1) walleye pollock, 2) Pacific herring, 3) capelin, and 4) Pacific sand lance. Squid, although not covered in this conference, may be of equal or greater importance as prey as any of the forage fish species. In terms of sensitivity to environmental perturbation, the forage fish ranking is: 1) Pacific herring, 2) capelin, 3) Pacific sand lance, and 4) walleye pollock. Both the Pacific herring and the capelin have specific spawning habitats (i.e. intertidal and shallow subtidal zone) that may be sensitive to oil spills and other similar disturbances. The most sensitive area in the region, in terms of potential effects of human activities on forage fish, is Togiak Bay, an important Pacific herring spawning area. It is followed by Port Moller.

CONCLUSIONS

1. Major forage fishes in the southeastern Bering Sea, in terms of importance, include the walleye pollock (*Theragra chalcogramma*), Pacific herring (*Clupea pallasii*), capelin (*Mallotus villosus*), Pacific sand lance (*Ammodytes hexapterus*), and rainbow smelt (*Osmerus mordax*). Other schooling species are sometimes important (usually either seasonally or locally) or occur incidentally in the north or south.

2. Most of these forage fishes school, have relatively short life spans, short maximum lengths, and are locally very abundant. Most species have demersal eggs, but the walleye pollock has pelagic eggs, Some species spawn in freshwater streams (e.g. salmon, *Oncorhynchus* spp.; rainbow smelt; eulachon, *Thaleichthys pacificus*), some spawn in shallow water along the beach (Pacific herring, capelin, Pacific sand lance), and the walleye pollock spawns in deep water along the continental shelf.

3. Forage fishes are prey to marine mammals, seabirds, and larger bony fishes in the southeastern Bering Sea. Major marine mammal predators include northern fur seals (*Callorhinus ursinus*), Steller sea lions (*Eumetopias jubatus*), harbor seals (*Phoca vitulina*), and belukha whales (*Delphinapterus leucas*). Major seabird predators include short-tailed shearwaters (*Puffinus tenuirostris*), black-legged kittiwakes (*Rissia tridactyla*), tufted puffins (*Fratercula cirrhata*), common murres (*Uris aalge*), and thick-billed murres (U. *lomvia*). Major bony fish predators include maturing coho salmon (*Oncorhynchus kisutch*). and chinook salmon (0. *tshawytscha*), Pacific cod (*Gadus macrocephalus*), walleye pollock, and Greenland halibut (*Reinhardtius hippoglossoides*). Demersal eggs of littorally spawning forage fishes could be eaten by yellow fin sole (*Pleuronectes* (=*Limanda*) *aspera*), rock sole (P. (=*Lepidopsetta*) *bilineata*), and longhead dab (P. (=*Limanda*) *proboscidea*) and a variety of invertebrates and shorebirds.

4. Of the major forage fishes, walleye pollock is one of the most important species in the commercial trawl fishery of the southeastern Bering Sea. The Pacific herring is the target of a purse seine and gillnet fishery for sac roe, and an intertidal fishery for eggs-on-kelp. Capelin could be a target of a commercial fishery in the future. Pacific sand lance and rainbow smelt are not commercially important.

5. The most important forage fishes for further study include Pacific herring, capelin, and Pacific sand lance. The walleye pollock is relatively well-studied compared to these species. The most sensitive species to environmental perturbation are the Pacific herring and capelin, both of which have relatively specialized intertidal or shallow subtidal spawning sites.

6. The most important areas, in terms of being crucial to populations of forage fishes in the Bering Sea, include Togiak Bay and Port Moller, with the former being the most important spawning area for Pacific herring.

7. Predation is thought to be the most important factor controlling the abundance of forage fishes, with physical variation in the environment playing a relatively minor role. Although mortality is highest in the earliest life history stages (eggs and larvae), variability in mortality among early juveniles (prerecruits) probably is most

important in determining year-class strength. A strong year class may carry a population for a number of years. A change in the mortality rate of 10% among small juveniles could have a long-lasting effect on the population. Pre-recruit surveys provide the most promise in forecasting stock size on the short term.

8. Although the role of forage fishes in the ecosystem of the southeastern Bering Sea has been considered in existing ecosystem models for the region, relatively little is known about the biology of most forage fish species (other than walleye pollock) found there. Future studies on forage fishes in the eastern Bering Sea should focus on determining the abundance, population dynamics, movements, trophic relationships, and on describing habitat, environmental requirements, early life history, and spawning location.

9. Ecosystem models could be substantially improved by field collection of additional information on the biology of forage fish species. With proper field validation and verification, the models could more effectively direct future research.

APPENDIX A

CONFERENCE PARTICIPANTS

CONFERENCE PARTICIPANTS

Bering Sea Forage Fish Conference
November 4-5, 1986
Anchorage, Alaska

ALLEN, M. James
MBC Applied Environmental Sciences
947 Newhall Street
Costa Mesa, CA 92627
(714) 646-1601

BECKER, Paul
OCSEAP Alaska Office
National Oceanic & Atmospheric Administration
701 C Street
Box 56
Anchorage, AK 99513
(907) 271-3032

BEESON, Don
Icicle Seafoods Inc.
3424 W. International Airport Road
Anchorage, AK 99502
(907) 248-4044

COHEN, Roz
Branch of Environmental Studies (MS644)
Minerals Management Service
Washington, DC 20240
(202) 343-7744

COMSTOCK, Earl
Bering Sea Fisherman's Association
632 Christensen Drive
Anchorage, AK 99501
(907) 279-6519

CRAIG, Peter
LGL Ecological Research Association
2950 Fritz Cove Road
Juneau, AK 99801
(907) 789-7311

CRANE, Michael
NESDIS
National Oceanic and Atmospheric Administration
707 A Street
Anchorage, AK 99501
(907) 271-4063 and 257-2741

FROST, Kathryn J.
Alaska Department of Fish and Game
1300 College Road
Fairbanks, AK 99701
(907) 456-5156

FUNK, Fritz
Division of Commercial Fisheries
Alaska Department of Fish and Game
P. O. BOX 3-2000
Juneau, AK 99802-2000
(907) 465-4210

GLOCK, Jim
North Pacific Fishery and Management Council
411 W. 4th Avenue
Anchorage, AK 99501
(907) 274-4563

HAHN, Brad
Division of Habitat Protection
Alaska Department of Fish and Game
333 Raspberry Road
Anchorage, AK 99518-1599
(907) 267-2347

HOUGHTON, Jonathan P.
Dames and Moore
155 N. E. 100th Street
P. O. Box 75981
Seattle, WA 98125-0981
(206) 523-0560

JARVELA, Laurie
OCSEAP Alaska Office
National Oceanic and Atmospheric Administration
701 C Street
Box 56
Anchorage, AK 99513
(907) 271-3016

LAEVASTU, Taivo
Northwest Alaska Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE, BIN Cl 5700
Seattle, WA 98115
(206) 526-4216

LEBIDA, Bob
Division of Commercial Fisheries
Alaska Department of Fish and Game
333 Raspberry Road
Anchorage, AK 99518-1599
(907) 344-0591

MALLOY, Larry
Division of Commercial Fisheries
Alaska Department of Fish and Game
211 Mission Road
Kodiak, AK 99815
(907) 486-4791

MENDENHALL, Vivian
U. S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, AK 99503
(907) 786-3517

MORRIS, Byron
National Marine Fisheries Services
National Oceanic and Atmospheric Administration
701 C Street
Box 43
Anchorage, AK 99513
(907) 271-5006

MUNDY, Phil
Division of Commercial Fisheries
Alaska Department of Fish and Game
P. O. Box 3-2000
Juneau, AK 99802
(907) 465-4210

NIEBAUER, H. Joseph
Institute of Marine Science
University of Alaska, Fairbanks
107 ONR Building
Fairbanks, AK 99701
(907) 474-7832

PETERSON, Larry
U. S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, AK 99503
(907) 786-3352

PAWLOWSKI, Bob
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
701 C Street
Box 43
Anchorage, AK 99513
(907) 271-3472

ROGERS, Donald E.
Fisheries Research Institute, WH- 10
University of Washington
Seattle, WA 98195
(206) 543-7628

SANGER, Gerald A.
U. S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, AK 99503
(907) 786-3518

STOBO, Wayne T.
Marine Fish Division
Bedford Institute of Oceanography
P. O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2
Canada
(902) 426-3316

STOCKER, Max
Pacific Biological Station
Canada Department of Fisheries and Oceans
Nanaimo, BC V9R 5K6
Canada
(604) 756-7200

THORSTEINSON, Lyman
OCSEAP Alaska Office
National Oceanic and Atmospheric Administration
701 C Street
Anchorage, Ak 99513
(907) 271-3585

TRASKY, Lance
Division of Habitat
Alaska Department of Fish and Game
333 Raspberry Road
Anchorage, AK 99518-1599
(907) 267-2346

WARE, Rick R.
MBC Applied Environmental Sciences
947 Newhall Street
Costa Mesa, CA 92627
(714) 646-1601

WESPESTAD, Vidar G.
Northwest Alaska Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE, BIN C15700
Seattle, WA 98115
(206) 526-4279

MINERALS MANAGEMENT SERVICE
Alaska OCS Region
949 E. 36th Street - Rm. 110
Anchorage, AK 99508-4302

BOYD, Tom
Environmental Assessment Section
(907) 261-4622

DUBSKY, Paul
Environmental Assessment Section
(907) 261-4655

EMERSON, Ray
Environmental Assessment Section
(907) 261-4652

GOTTLIEB, Judy
Leasing and Environment
(907) 261-4045

HANSEN, Don
Environmental Assessment Section
(907) 261-4656

HOLLAND, Ken
Environmental Operations Section
(907) 261-4598

IRVINE, Gail
Environmental Assessment Section
(907) 261-4658

JOHNSON, Toni
(Conference Coordinator)
Environmental Studies Section
(907) 261-4632

KENNEY, Dale
Environmental Studies Section
(907) 261-4623

KLEIN, Steve
Environmental Assessment Section
(907) 261-4677

MEYER, Robert
(Conference Coordinator)
Environmental Studies Section
(907) 261-4625

NEWBURY, Tom
Environmental Operations Section
(907) 261-4604

PRENTKI, Dick
Environmental Assessment Section
(907) 261-4656

ROBERTS, Dick
Environmental Assessment Section
(907) 261-4662

WEINHOLD, Bob
Environmental Assessment Section
(907) 261-4665

WENDLING, Frank
Field Operations
(907) 261-4510

WHEELER, Gary
Environmental Assessment Section
(907) 261-4684

APPENDIX B

CONFERENCE AGENDA

Bering Sea Forage Fish Conference
November 4-5, 1986
The Anchorage Hilton Hotel
Anchorage, Alaska

AGENDA

Day 1 Theme:	Forage Fish Trophic Interactions in the Southeastern Bering Sea
8:30-8:45 a.m.	Welcoming Remarks Minerals Management Service - Toni Johnson/Robert Meyer
8:45-9:00 a.m.	Workshop Introduction MBC Applied Environmental Sciences - Rick Ware/M. James Allen

Technical Presentation (25 min. for each presentation + 15 minutes for questions)

900-940 a.m.	History of the Herring and Capelin Fisheries in Alaska - Alaska Department of Fish and Game -Fritz Funk
940- 10:20 a.m.	Dominant Forage Fish, Abundance and Distribution - Dames and Moore - Jonathan Houghton
10:20- 10:40 a.m.	Morning Break
1040- 11:20 a.m.	Avifauna - Fish Trophic Interactions U. S. Fish and Wildlife Service - Gerald Sanger
11:20- 12:00 a.m.	Trophic Interactions of Marine Mammals and Forage Fish - Alaska Department of Fish and Game - Kathryn J. Frost
12:00- 1:00 p.m.	Lunch
1:00 - 1:30 p.m.	Feeding Relationships of Important Bering Sea Demersal Fishes - MBC Applied Environmental Sciences - M. James Allen
1:30-210 p.m.	The Bering Sea Ecosystem as a Predator-Controlled System - National Marine Fisheries Service - Taivo Laevastu
2:10-250 p.m.	Forage Fishes: Trophic Interactions and Energy Transfer - LGL - Peter Craig
2:50-4:30 p.m.	Panel Discussion

Theme: Predator Prey Relationships in the Coastal Regions (North Shore of the Alaska Peninsula) of the Southeastern Bering Sea

Bering Sea Forage Fish Conference
November 4-5, 1986
The Anchorage Hilton Hotel
Anchorage, Alaska

Day 2 **Theme:**	Dynamics of Fisheries Oceanography and Forage Fish
8:30-8:45 a.m.	Review of Day 1 Proceedings Minerals Management Service - Robert Meyer

Technical Presentations: (25 minutes for each presentation + 15 minutes for questions)

8:45 - 9:25 a.m.	Dynamics of the Southeastern Bering Sea Oceanographic Environment - University of Alaska - Joe Niebauer
9:25 - 1005 a.m.	Dynamics of Coastal Salmon in the Southeastern Bering Sea - University of Washington - Donald Rogers
10:05- 1025 a.m.	Morning Break
10:25- 11:05 a.m.	Herring Movement Along the Scotian Shelf and Management Considerations - Bedford Institute of Oceanography - Wayne Stobo
11:05- 11:45 a.m.	Population Dynamics of Forage Fish - National Marine Fisheries Service - Vidar Wespestad
11:45- 1:00 p.m.	Lunch
1:00-200 p.m.	Environmental Dependence - Stock Recruitment Models for Pacific Herring - Pacific Biological Station - Max Stocker
200-2:20 p.m.	Break
220-430 p.m.	Panel Discussion
Theme	Dynamics of Coastal Fisheries Oceanography and the Distribution and Relative Abundance of Forage Fish Along the North Shore of the Alaska Peninsula
4:30-5:00 p.m.	Conference Wrap-Up

APPENDIX C

SPEAKER BIOGRAPHIES

SPEAKER BIOGRAPHIES

ALLEN, M. James; Senior Scientist
MBC Applied Environmental Sciences
947 Newhall Street
Costa Mesa, CA 92627

Education

Ph. D., Scripps Institution of Oceanography, University of California, San Diego, 1982; Functional structure of soft-bottom fish communities of the southern California shelf.
M. A., University of California, Santa Barbara, 1967.
B. A., University of California, Santa Barbara, 1967.

Bering Sea Research or Related Studies

Organization of demersal fish communities and feeding habits of demersal fishes in the eastern Bering Sea; zoogeography and taxonomy of Bering Sea and northeastern Pacific fishes; life history and distribution of commercially important fishes and invertebrates of the northeastern Pacific.

CRAIG, Peter; Fish Biologist
LGL Ecological Research Association
2950 Fritz Cove Road
Juneau, AK 99801

Education

Ph. D., University of California, Santa Barbara, 1973.

Bering Sea Research or Related Studies

Distribution, abundance and food habits of fishes in nearshore waters (0-50 m) of the North Aleutian Shelf; compilation and synthesis of fish information for the Unimak Pass and Eastern Aleutian Islands, Norton Sound, and Yukon Delta areas.

FROST, Kathryn J.; Marine Mammals Biologist
Alaska Department of Fish and Game
1300 College Road
Fairbanks, AK 99701

Education

M.S., University of California, Santa Cruz, 1977; intertidal and subtidal ecology.
B.S., Tulane University, New Orleans, LA, 1970.

Bering Sea Research or Related Studies:

Trophic interactions of ice associated seals; coastal distribution of marine mammals in Bering Sea; distribution, abundance and mortality of Belukha whales; food habits of Beluka whales; natural history of ice associated seals; natural history of gadid fishes; otolith studies of forage fishes, primarily gadids; fishery marine mammal interactions in belukha whales.

FUNK, Fritz; Marine Finfish Biometrician
Division of Commercial Fisheries
Alaska Department of Fish and Game
P. O. Box 3-2000
Juneau, AK 99802-2000

Education

M.S., Fisheries, University of Washington, Seattle, WA, 1981.
B. S., Zoology, University of Wisconsin, 1975.

Bering Sea Research or Related Studies:

Served as member of Bering Sea/Aleutian and Gulf of Alaska GROUNDFISH plan teams for North Pacific Fishery Management Council for past three years. Recently assigned to statewide Alaska herring stock assessment.

HOUGHTON, Jonathan P.; Senior Fishery Biologist
Dames and Moore
155 Northeast 100th Street
Seattle, WA 98125-0981

Education

Ph.D., University of Washington, Seattle, WA, 1972,

Bering Sea Research or Related Studies:

Assessment of variety of small-scale coastal development projects; also directed larger studies of anadromous fish in Chukchi, Cook Inlet, and Bering areas.

LAEVASTU, Taivo; Ecosystem Modeler
REFM Division
Northwest and Alaska Fisheries Center
National Marine Fisheries Service, NOAA
7600 Sand Point Way NE, BIN Cl 5700
Seattle, WA 98115

Education

Ph.D. Oceanography, University of Helsinki, Finland, 1961.
M.S. University of Washington, Seattle, WA, 1954.

Bering Sea Research or Related Studies:

Ecosystem modeling and fisheries oceanography of the Eastern Bering Sea; numerical modeling in oceanography and meteorology; oceanographic forecasting; sea-air interactions; marine chemistry.

NIEBAUER, H. Joseph, Assistant Professor of Marine Science
Institute of Marine Science
107 O'Neil Building
University of Alaska, Fairbanks
Fairbanks, AK 99775-1080

Education

Ph. D., University of Wisconsin, Madison, WS, 1976; Wind driven coastal upwelling in Lake Superior.
B.S., University of Wisconsin, Madison, WS, 1967.

Bering Sea Research or Related Studies:

PROBES Project; interactions (bio/phys) oceanography in the marginal ice zone, Bering Sea; Sea Grant Studies - El Niño sea surface temperatures in the Bering Sea.

ROGERS, Donald E; Research Professor
Fisheries Research Institute, WH- 10
University of Washington
8039 23rd N.W.
Seattle, WA 98117

Education

Ph. D., University of Washington, Seattle, WA, 1967; Estimation of pelagic fish populations from net catches and echo-sounding.
M.S., University of Washington, Seattle, WA, 1961; Comparison of food of sockeye salmon fry and three-spine sticklebacks.
B. S., California State Polytechnic College, San Luis Obispo, CA, 1958.

Bering Sea Research or Related Studies:

Advisory to Alaska Department of Fish and Game, International North Pacific Fisheries commission, North Pacific Fishery Management Council and several fishing companies, and fishermen's organizations; 15 years as principal investigator on various research projects (salmon, herring, nearshore fishes) for NOAA, NMFS, ADF&G, NPFMC, PSPA (industry), consulting companies, Indian tribes, and fishermen's organizations.

SANGER, Gerald A.; Research Wildlife Biologist
Alaska Fish and Wildlife Research Center
U. S. Fish and Wildlife Service
1011 East Tudor Road
Anchorage, AK 99503

Education

B.S., Fisheries Biology, Humboldt State University, 1959.

Bering Sea Research or Related Studies:

Feeding ecology of Alaskan marine birds for OCSEAP focusing on Gulf of Alaska; currently project leader for studies of seabird fisheries interactions in Alaska, focusing on dependence of nestling puffins on juvenile pollock.

STOBO, Wayne T.; Research Scientist
Marine Fish Division
Bedford Institute of Oceanography
P. O. Box 1006
Dartmouth, Nova Scotia B2V 4A2
Canada

Education

Ph. D., 1972, Breeding biology and territoriality of the Ipswich sparrow.
M.S., 1969; Effect of pollution on growth and distribution of yellow perch.
B.S., 1962.

Research or Related Studies:

10 year study on herring population dynamics (assessment) and migration major migration studies on cod, haddock and pollock on Scotian Shelf; ongoing responsibility for grey seal and harbor seal population dynamics and assessment on Scotian Shelf. Other research interests include major responsibilities for directing research of fisheries groups section head and acting division chief.

STOCKER, Max; Research Scientist, Herring Section
Pacific Biological Station
Canada Department of Fisheries and Oceans
Nanaimo, B.C. V9R 5K6
Canada

Education

Ph.D., 1979, Population Dynamics of exploited animal populations.
M.S., 1975
B.S., 1973

Bering Sea Research or Related Studies:

Pacific herring population dynamics; other research interests include stock identification.

WESPESTAD, Vidar G.; Fishery Research Biologist
Northwestand Alaska Fisheries Center
National Marine Fisheries Service, NOAA
7600 Sandpoint Way, NE, Bin Cl 5700
Seattle, WA 98115

Education:

Ph.D., University of Washington, 1987, Population dynamics of **eastern Bering Sea herring and the influence of climatology on recruitment,**
M.S., Colorado State University, Fort Collins, CO, 1975, Effects of water drawdown on **biota in** mountain reservoirs.
B.S., Fishery Biology, Colorado State University, 1973.

Bering Sea Research or Related **Studies:**

Early life history of herring, population dynamics of herring; other research interests include dynamics and **yield** of **groundfish in** the eastern **Bering** Sea.

APPENDIX D

SELECTED BIBLIOGRAPHY OFRELATEDSTUDIES REPORTS

SELECTED BIBLIOGRAPHY OF RELATED STUDIES REPORTS*

Barton, L. H. 1978. Finfish resource surveys in Norton Sound and Kotzebue Sound. *In*: Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 475-313.

Bax, N. J. 1985. Simulations of the effects of potential oil spill scanarios on juvenile and adult sockeye salmon (*Oncorhynchus nerka*) migrating through Bristol Bay, Alaska. NWAFC processed report 85-03. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 1:455-595.

Cimberg, R. L. 1984. Ecological characterization of shallow subtidal habitat in the north Aleutian shelf. Final Report. 201 p.

Favorite, F. 1979. Dynamic aspects of environmental/biota interactions (unpubl.) Final Report NWAFC 78-20.481 p.

Fredin, R. A. 1985. Pacific cod in the eastern Bering Sea: A synopsis. NWAFC Processed Report 85-05. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 2597-662.

Fukuhara, F. M. 1985. Biology and fishery of southeastern Bering Sea red king crab (*Paralithodes camtschatica* Tilesius). NWAFC Processed Report 85-11. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 2801-982.

Fukuhara, F. M. 1985. Estimated impacts of hypothetical oil spill accidents off Port Moller, Port Heiden, and Cape Newenham on eastern Bering Sea yellowfin sole. NWAFC Processed Report 85-15. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 2103-128.

Gallagher, A. F. 1984. Documentation of the biological impact of an oil spill model, Bios, Part 2 Fish feeding and contamination through consumption - subroutine fedoil. Program Documentation Report No. 22. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 1:211-240.

Gallagher, A. F., and N. B. Pola. 1984. The uptake and deputation of petroleum hydrocarbons in marine species, a simulation study of the uptake and deputation of petroleum hydrocarbons and its effect on selected marine species in the Bristol Bay ecosystem. NWAFC Processed Report 84-16. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 1:241-317.

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* This bibliography was selected by searching on Bering Sea Fish, in OCSEAP Comprehensive Bibliography, July 1986, consisting of principal investigator reports from studies funded by MMS.

Honkalehto, T. 1985. Recovery of three Bering Sea type fish populations from catastrophic larval mortality -- a simulation approach. NWAFC Processed Report 85-13. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 2711-752.

Kim, S., and A. W. Kendall, Jr. 1983. The numbers and distribution of walleye pollock eggs and larvae in southeastern Bering Sea. NWAFC Processed Report 83-22. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 1:49-93.

Laevastu, T., and F. Fukuhara. 1984. Quantitative determination of the effects of oil development in the Bristol Bay region on the commercial fisheries in the Bering Sea. NWAFC Processed Report 84-06. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 1:95-179.

Laevastu, T., and F. Fukuhara. 1985. Oil on the bottom of the sea, a simulation study of oil sedimentation and its effects on the Bristol Bay ecosystem. NWAFC Processed Report 85-01. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 1:395-454.

Laevastu, T., R. Marasco, N. Bax, R. Fredin, F. Fukuhara, A. Gallagher, T. Honkalehto, J. Ingraham, P. Livingston, R. Miyahara, and N. Pola. 1985. Evaluation of the effects of oil development on the commercial fisheries in the eastern Bering Sea (summary report). *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 1:1-47.

Livingston, P. A. 1985. Food habits of Bristol Bay species which might be affected by oil development, a study on the variability in demersal and pelagic food habits. NWAFC Processed Report 85-12. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 2753-799.

McCain, B. B., H. O. Hodgins, A. K. Sparks, and W. D. Gronlund. 1981. Determine the frequency and pathology of marine fish diseases in the Bering Sea, Gulf of Alaska, Norton Sound, and Chukchi Sea. *In*: Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 13:1-63.

Miyahara, R. K., and W. J. Ingraham, Jr. 1984. Physical factors affecting the fate of a petroleum spill in the southeastern Bering Sea. NWAFC Processed Report 84-20. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 1:319-393.

NOAA/OCSEAP. 1984. Outer continental shelf environmental assessment program. Final Reports of Principal Investigators, Vol. 25.499 p.

NOAA/OCSEAP. 1985. Outer continental shelf environmental assessment program. Final Reports of Principal Investigators, Vol. 2.427 p.

NOAA/OCSEAP. 1985. Outer continental shelf environmental assessment program. Final Reports of Principal Investigators, Vol. 32.522 p.

NOAA/OCSEAP. 1986. Outer continental shelf environmental assessment program. Final Reports of Principal Investigators, Vol. 36, Part 1:1-595, Part 2596-1128.

NOAA/OCSEAP. 1986. Outer continental shelf environmental assessment program. Final Reports of Principal Investigators, Vol. 38.743 p.

Pace, S. 1984. Environmental characterization of the north Aleutian shelf nearshore zone Characterization, processes, and vulnerability to development. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 38:1-473.

Pace, S. 1984. Environmental characterization of the north Aleutian shelf nearshore region: Annotated bibliography and keyword index. in Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 38:475-743.

Pola, N. B. 1985. Modelling the biological impact of an oil spill: Bios model. NWAFC Program Documentation No. 24. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 2:983-1037.

Pola, N. B., R. K. Miyahara, and A. F. Gallagher, Jr. 1985. Spatial and temporal extent of hydrocarbon contamination in marine species of Bristol Bay. NWAFC Processed Report 85-08. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 2633-710.

Rogers, D. E. 1978. Determination and description of knowledge of the distribution abundance, and timing of salmonids in the Gulf of Alaska and Bering Sea, a supplement to the final report. *In*: Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 1:205-235.

Smith, R. L., A. C. Paulson, and J. R. Rose. 1978. Food and feeding relationships in the benthic and demersal fishes of the Gulf of Alaska and Bering Sea. *In*: Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 1:33-107.

Swan, N. P. 1984. Biological impact of an oil spill (Bios) model documentation, Part 1: Fish migrations and exposure to contamination. Program Documentation No. 21. *In*: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 1:181-210.

Truett, J. C., P. C. Craig, D. R. Herter, M. K. Raynolds, and T. L. Kozo. 1983. Ecological characterization of the Yukon River delta. Final Report 32299-443.

Truett, J. C., and M. K. Raynolds. 1984. Ecological characterization of the Yukon River delta: Annotated bibliography. Final Report 32:445-522.

Waldron, K. D., and B. M. Vinter. 1978. Ichthyoplankton of the eastern Bering Sea: Abstract. *In*: Environmental Assessment of the Alaskan Continental Shelf, Final Reports 1:236-237.

Warner, L M., and P. Shafford. 1981. Forage fish spawning surveys -- Southern Bering Sea. *In*: Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 101-64.

Wolotira, R. J., T. M. Sample, and M. Morin. 1979. Baseline studies of fish and shellfish resources of Norton Sound and the southeastern Chukchi Sea. *In*: Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 6258-572.

APPENDIX E

LIST OF COMMON AND SCIENTIFIC NAMES

LIST OF COMMON AND SCIENTIFIC NAMES

Common and scientific names of species and families mentioned in papers in this volume (i.e. "Forage Fishes of the Southeastern Bering Sea")[1].

SPECIES	COMMON NAME
OSTEICHTHYES	BONY FISHES
Clupeidae	herrings
Clupea harengus[2]	Atlantic herring
C. pallasii[2]	Pacific herring
Sardinops sagax	Pacific sardine
Bathylagidae	deepsea smelts
Osmeridae	smelts
Hypomesus olidus	pond smelt
H. pretiosus	surf smelt
Mallotus villosus	capelin
Osmerus mordax	rainbow smelt
Thaleichthys pacificus	eulachon
Salmonidae	trouts
Oncorhynchus spp.	salmon
O. gorbuscha	pink salmon
O. keta	chum salmon
O. kisutch	coho salmon
O. nerka	sockeye salmon
O. tshawytscha	chinook salmon
Myctophidae	lanternfishes
Gadidae	cods
Boreogadus saida	Arctic cod
Eleginus gracilis	saffron cod
Gadus macrocephalus	Pacific cod
Theragra chalcogramma	walleye pollock
Scorpaenidae	scorpion fishes
Sebastes spp.	rockfishes
Anoplopomatidae	sablefish
Anoplopoma fimbria	sablefish

SPECIES	COMMON NAME
Hexagrammidae	greenings
Hexagrammos spp.	greenings
H. stelleri	whitespotted greenling
Pleurogrammus monopterygius	Atka mackerel
Hemitripteridae	spinulated sculpins
Hemitripterus bolini	bigmouth sculpin
Cottidae	sculpins
Gymnocanthus galeatus	armorhead sculpin
G. pistilliger	threaded sculpin
Hemilepidotus jordani	yellow Irish lord
H. papilio[3]	butterfly sculpin
Myoxocephalus jaok	plain sculpin
M. polyacanthocephalus	great sculpin
M. verrucosus	warty sculpin
Zoarcidae	eelpouts
Trichodontidae	sandfishes
Trichodon trichodon	Pacific sandfish
Ammodytidae	sand lances
Ammodytes spp,	sand lances
A. americanus	American sand lance
A. hexapterus	Pacific sand lance
Pleuronectidae	right-eyed flounders
Atheresthes stomias	arrowtooth flounder
Hippoglossus stenolepis	Pacific halibut
Platichthys stellatus	starry flounder
Pleuronectes aspera[4]	yellowfin sole
P. bilineata[4]	rock sole
P. proboscidea[4]	longhead dab
P. quadrituberculatus	Alaska plaice
Reinhardtius hippoglossoides	Greenland halibut
AVES	BIRDS
Procellariidae	shearwaters
Fulmarus glacialis	northern fulmar
Puffinus tenuirostris	short-tailed shearwater
Phalacrocoracidae	cormorants
Phalacrocorax spp.	cormorants

SPECIES	COMMON NAME
Laridae	gulls
Larus glaucescens	glaucous- winged gull
Rissa spp.	kittiwakes
R. tridactyla	black-legged kittiwake
Alcidae	auks
Aethia spp.	auklets
Brachyramphus marmoratus	marbled murrelet
Cepphus columba	pigeon guillemot
Cerorhinca monocerata	rhinoceros auklet
Fratercula spp.	puffins
F. corniculata	horned puffin
F. cirrhata	tufted puffin
Uris spp.	murres
U. aalge	common murre
U. lomvia	thick-billed murre
MAMMALIA	MAMMALS
Ursidae	bears
Ursus maritimus	polar bear
Odobenidae	walruses
Odobenus rosmarus	walrus
Otariidae	fur seals and sea lions
Callorhinus ursinus	northern fur seal
Eumetopias jubatus	Steller sea lion
Mustelidae	otters
Enhydra lutris	sea otter
Phocidae	seals
Erignathus barbatus	bearded seal
Histriophoca fasciata[5]	ribbon seal
Phoca largha	spotted seal
P. vitulina	harbor seal
Pusa hispida[5]	ringed seal
Eschrichtiidae	gray whales
Eschrichtius robustus	gray whale
Balaenopteridae	rorquals
Balaenoptera acutorostrata	minke whale
B. borealis	sei whale
B. musculus	blue whale
B. physalus	fin whale
Megaptera novaeangliae	humpback whale

SPECIES	COMMON NAME
Balaenidae	right whales
Balaena glacialis	right whale
B. mysticetis	bowhead whale
Delphinidae	dolphins
Orcinus orca	killer whale
Phocoenidae	porpoises
Phocoena phocoena	harbor porpoise
Phocoenoides dallii	Dall's porpoise
Monodontidae	narwhals and belukhas
Delphinapterus leucas	belukha whale
Physeteridae	sperm whales
Physeter macrocephalus	sperm whale
Ziphiidae	beaked whales

1 The common names of fishes are those of the American Fisheries Society (Robins *et al.* 1980) as are the scientific names (except where these have been changed in more recent studies). The taxonomic sequence is that of Nelson (1984). The common and scientific names of birds are those of the American Ornithologists' Union (1983). The scientific names and, generally the common names, are those of Rice (1977), except where noted. Several invertebrate groups (squid, octopus, copepods, and euphausiids) were mentioned in a general sense and are not included.

2 Although Robins *et al.* (1980) considers the Atlantic and Pacific herring to be subspecies (and hence are called *Clupea harengus harengus* and *C. harengus pallasi*, respectively), recent biochemical studies (Grant 1986) have shown them to be distinct species. The correct name for the Pacific herring is *Clupea pallasii*, as this was the name used in the original description of the species. Grant (1986) mistakenly spelled the name with a single terminal *i*.

3 This species is *Melletes papilio* in Robins *et al.* (1980) but Peden (1978), a paper which was apparently not seen by the AFS committee, placed the species in *Hemilepidotus*.

4 Sakamoto (1984) places *Limanda aspera*, *Limanda proboscidea*, and *Lepidopsetta bilineata* of Robins *et al.* (1980) in the genus *Pleuronectes*.

5 Although Rice (1977) placed the ribbon seal and the ringed seal in the genus *Phoca*, De Muizon (1982) places the ribbon seal in *Histriophoca* and the ringed seal in *Puss*. D. Rice (Natl. Mar. Mammals Lab., NMFS, NOAA, Seattle, WA) agrees with this placement (pers. commun. to M. J. Allen, May 12, 1987).

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