APPENDIX L

APEX: 96163L

Synthesis and Analysis Gulf of Alaska of Small-Mesh Trawl Data
1953 to 1996
and Gulf of Alaska Forage Fish Icthyoplankton Analysis
1972 to 1996

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Abstract

Large declines of apex predator populations (murres, kittiwakes, harbor seals, and Steller sea lion) have occurred in the Gulf of Alaska since the 1970s. Changes in composition and abundance of forage species may be responsible for the decline of these predator populations and their chronic low population levels. In an effort to delineate changes in forage species and a trophic regime shift, if any, over the last several decades, we have gathered together historical fishery-independent scientific survey data to address this question. This report includes three manuscripts submitted for publication from recent analysis of information and data from small-meshed trawl studies conducted in the Gulf of Alaska by the Alaska Department of Fish and Game and the National Marine Fisheries Service and its predecessor agencies from 1953 through 1996. Nearly 10,000 individual sampling tows are in the current database of the two agencies. The need for moving this project into a monitoring status is discussed. Preliminary analysis of an icthyoplankton time series is presented with relevancy toward APEX project goals.

Introduction

This project pursues analysis of small-mesh trawl sampling results from near-shore surveys in the Gulf of Alaska conducted by the National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G). The data for analysis was collected starting in 1953 and continues through 1996. This report includes two manuscripts that will be published this summer dealing with specific areas and analysis that was completed during the past project year. Only general background material concerning this part of the project will be discussed in this section. The reader is referred to the two enclosed manuscripts for details of the methodology and analysis used with this portion of the data. Additional items discussed in this narrative is the need for moving this project data collection into the monitoring category and analysis of the icthyplankton time series for Shelikof Strait.

Recently there has been information presented that the Gulf of Alaska ecosystem has undergone some abrupt and significant changes (Piatt and Anderson, 1996). The extent and degree of these changes is poorly documented and is important in determining future strategies for management of the marine ecosystem. Analysis of the historic data is a first step in gaining an appreciation for the rapid and abrupt changes that have occurred in the marine species complex in the last five decades. The data from small-mesh shrimp trawl cruises provides an opportunity to review changes in the composition of forage species that occurred through time in the Gulf of Alaska.

Historically, there is evidence of major abundance changes in the fish/crustacean community in the western Gulf of Alaska. Fluctuations in Pacific cod availability on a generational scale was reported for coastal Aleutian communities by Turner (1886). Similarly, landings from the near-shore Shumagin Islands cod fishery (Cobb, 1927) showed definite periods of high and low catches with the fishery peaking in late 1870s. King crab commercial catches in the Gulf of Alaska show two major peaks of landings, one in the mid 1960s and another in 1978-1980 (Blau, 1986). All of the area was closed to fishing in response to low population levels in 1983 (Blau, 1986) and has yet to reopen. By the 1960s there was evidence of high pandalid shrimp abundance in these same areas (Ronholt 1963). One of the highest densities of pandalid shrimp known in the world was to spur the development of a major shrimp fishery (Anderson and Gaffney, 1977). By the late 1970s the shrimp population density had declined radically and was accompanied by a closure of the shrimp fishery and the return of cod to inshore areas (Albers and Anderson, 1985). Catches of almost all salmon stocks of Alaskan origin suddenly increased to unprecedented levels in the 1980's (Francis and Hare, 1994, Hare and Francis, 1995). These changes, witnessed over the last century, imply dynamic fluctuations in abundance of commercially fished species. Managers, fisherman, and processors should be aware of these dynamics and their impacts on the ecology and economy.

Area of Coverage

The study area includes the continental shelf (0 - 200 m.) and upper slope (201 - 400 m.) from 144° W. longitude (in the vicinity of Kayak Island) westward to 168° W. longitude (vicinity of Unalaska Island, eastern Aleutians). This area is characterized as having a relatively broad shelf which is punctuated with numerous islands, separated by deep gullies and large inlets, sounds, and fjords. Most of the data was collected in trawlable locations associated with the numerous gullies and bays that are associated with this bathymetry. The study area covers the entire affected zone of the EVOS.

Icthyoplankton Analysis

Our small-mesh trawls catch most of the species of direct interest to the APEX project except for one critical component, Pacific Sand Lance. We do however capture sand lance larvae in significant numbers during our icthyplankton surveys, both by bongo and neuston sampling gear. FY97 was the first year we have attempted to quantify the changes in relative density of sand lance larvae. Some of the preliminary analysis of this new aspect of the project is discussed.

Sand lance and capelin which together make up a significant amount of the forage base in the Gulf of Alaska have a high affinity for near-shore sediments for spawning. Potential damage to these critical near-shore habitats could have occurred as a result of the EXXON Valdez oil spill, especially along the fine sediment Katmai coast and sandy beaches on the eastern coast of Kodiak Island. We propose to study the early life history and variation in production before and after the spill of sand lance larvae from NMFS collected icthyoplankton data base. Additional studies will be proposed to fund work on analyzing the capelin portion of this data.

Sand Lance are one of the main prey for marine birds, further, 0+ sand lance are a major component of nestling diet and may indicate a linkage between ocean production and nesting success of seabird colonies (Bertram and Kaiser 1993). We propose to study past abundance and test hypothesis concerning changes in abundance of the early life history of sand lance in the vicinity of Kodiak. We propose to analyze a long-term database (1972 - 1995) of an icthyoplankton collection containing sand lance for the Kodiak and Shelikof region of the Gulf of Alaska to develop hypothesis concerning observed changes in density and distribution. Preliminary analysis will focus on the critical spawning (Oct -Jan) and over wintering (Nov - March) state of sand lance and how it might relate to larval survival and year-class strength.

Methods

Larval sand lance were collected from lower Cook Inlet to Unimak Pass with two types of sampling devices. The neuston layer was sampled using a "Sameoto sampler" (Sameoto and Jaroszyinski, 1969), with an opening of .3m by .5m and a mesh of 0.505mm. The water column from near-bottom to the surface was sampled using a MARMAP bongo sampler (Posgay and Marak, 1980) with 0.6m diameter opening and either 0.333 or 0.505mm mesh nets. Depths and position were recorded for each deployment of the sampling gear. Samples of sand lance and other planktonic species were preserved using 5% formalin-seawater solution buffered with either calcium carbonate or sodium tetraborate. Specimens were separated, counted, and up to 50 individuals of sand lance were measured to the nearest 0.1mm SL (Rugen, 1990).

Results

Out of the sixty-six taxa identified in the neuston samples, *Ammodytes hexapterus* were the fifth most abundant in terms of number caught for all sampling made between April 1972 and May 1986 (1,546 neuston stations sampled). For the bongo samples they were the second most abundant during the same time period (2,414 bongo samples) out of 118 taxa. In the months of March through the early part of May Pacific sand lance were the single most abundant species in bongo samples. This peak abundance of sand lance larvae in the spring samples is also reflected well in the neuston samples where their peak relative abundance was found during the first half of June. Sand lance were absent from neuston samples after August and from bongo samples after June sampling periods.

Large numbers of larvae from bongo samples were spatially located close to Kodiak Island with higher concentrations located to the northeast and southwest of the island in March. This distribution pattern held steady in later time periods except for a tendency of larvae to even out there distribution in Shelikof strait. Larvae captured with neuston nets showed relatively large catches later in the year and were found close to Kodiak Island or above the slope. Lengths of larvae were larger in the neuston tows (9.6-29.7 mm SL) than in the bongo samples (5.4-18.7 mm SL).

Discussion

Pacific sand lance are one of the most, important larval fish components of the icthyoplankton around Kodiak Island during the spring period. The only larval fish component that outnumbers sand lance in bongo samples was the walleye pollock, *Theragra chalcogramma*. The analysis of total numbers of larvae captured showed that pollock larvae were nearly 20 times more abundant (233,762) overall than sand lance (13,739). The next most abundant species was *Bathymaster* sp. only accounted for 80 total individuals caught in the 1972-1986 bongo samples.(Rugen, 1990)

Walleye pollock, *Theragra chalcogramma*, are also a locally prominent component of the icthyoplankton during the same period as sand lance larvae and may compete with them for food. Distribution of pollock larvae is concentrated in lower Shelikof strait during the March which is quite different then that of sand lance during the same time period. Also there is indication that as the larvae age and attain a larger size sand lance are more commonly found in the neuston layer than pollock (Bodeur and Rugen, 1995) which suggests a different vertical distribution in the water column. Therefore it seems likely that sand lance may only be a competitor with pollock during the early spring at only a few localized areas mainly in lower Shelikof strait.

Future Direction of Analysis

1. Determine relative year-class strength of sand lance in study area. Do this by examining larval size data and adjusting for differences in hatch dates and growth between years.

2. Inshore migration dynamics and vertical distribution changes and how these might relate to year-class strength.

3. Examin neuston samples to determine timing of in-shore migration.

4. Compare density estimates from neuston samples with those of the same yearset for bongo sampling to investigate the feasability of determining a relative survival index amoung year-classes.

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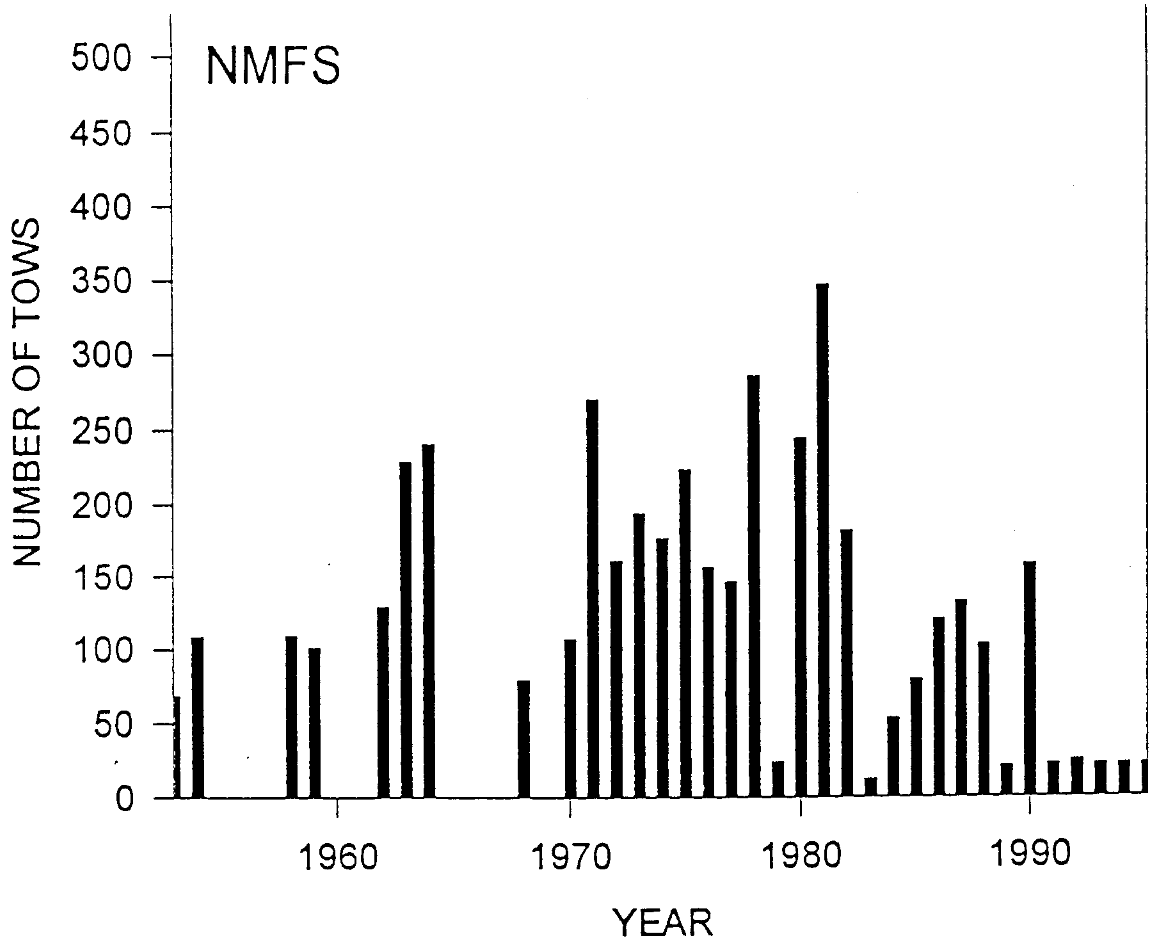
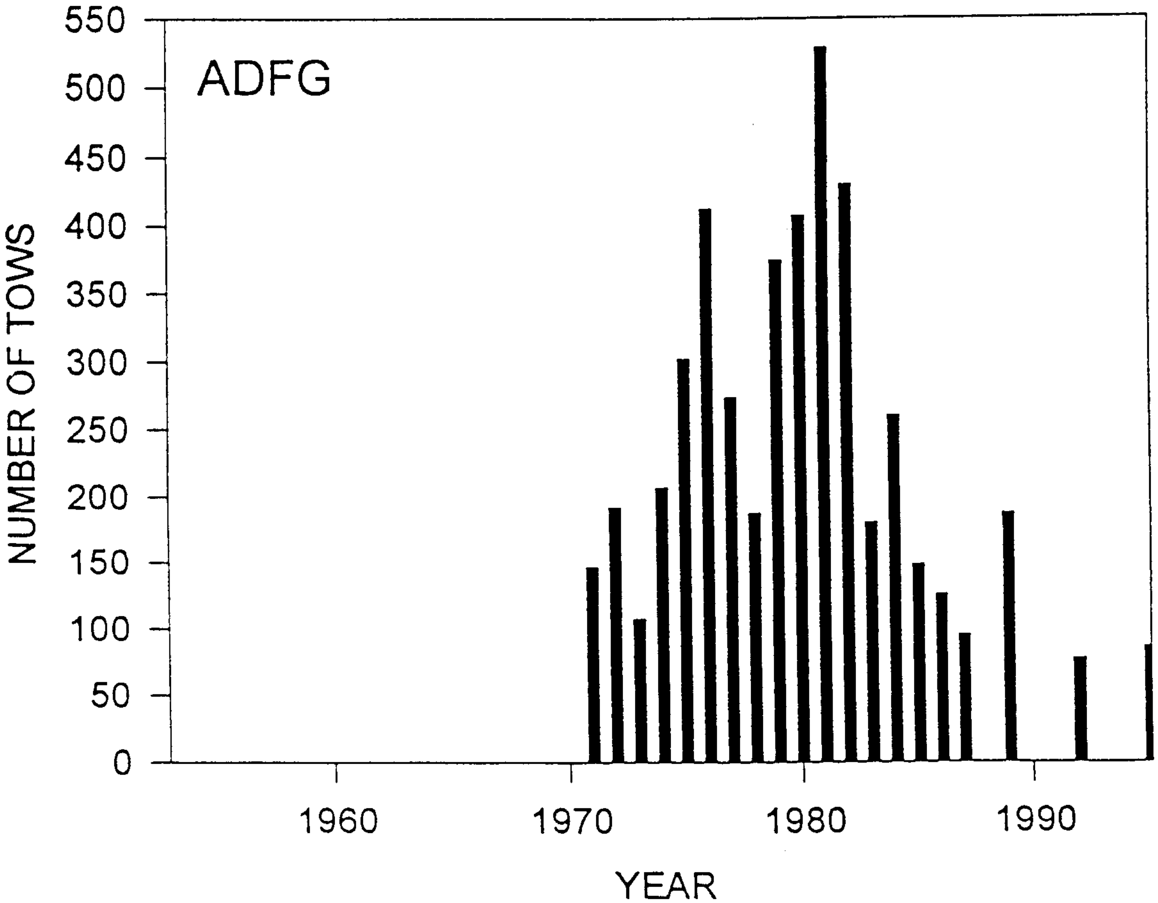
FIGURES

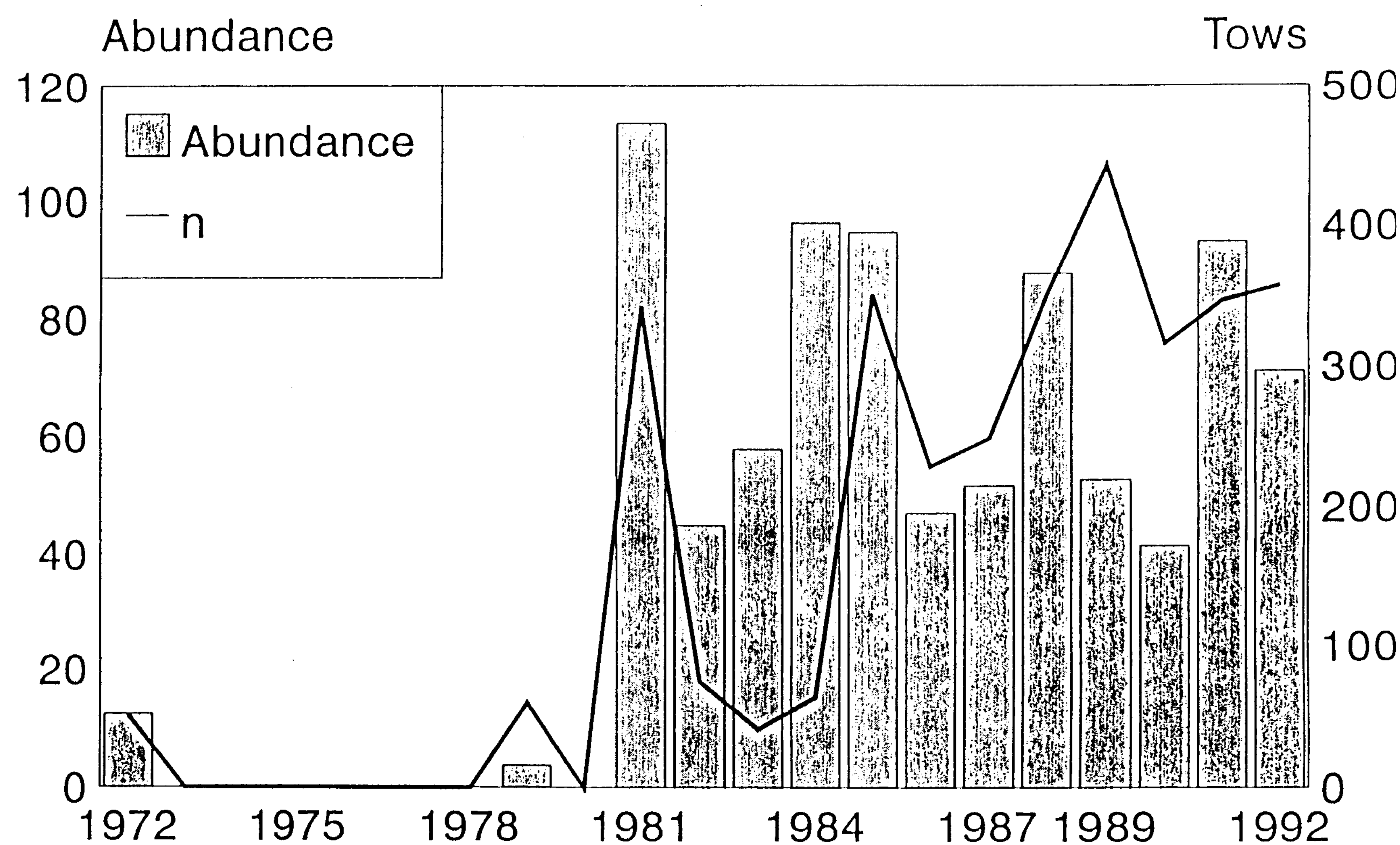
Figure 1. Annual number of small-mesh survey sampling from 1953 to 1994 in the Gulf of Alaska by NMFS and ADFG. All NMFS tows since 1990 conducted in Pavlof Bay only.

Figure 2. Relative density of Pacific sand lance larvae in the Kodiak - Shelikof Strait region 1971 - 1992. Density values in numbers per 10 $meter^2$.


NMFS
NUMBER OF TOWS
0
50
100
150
200
250
300
350
400
450
500
1960
1970
1980
1990
YEAR


ADFG
NUMBER OF TOWS
0
50
100
150
200
250
300
350
400
450
500
550
1960
1970
1980
1990
YEAR

.6 m Bongo 1972-92



March - June (number per 10 sq. meters)

APPENDIX

Three manuscripts submitted by project investigators for inclusion in: Proceedings of the Role of Forage Fishes in Marine Ecosystems. Expected publication date is summer 1997. These manuscripts are submitted as completed portion of project studies for FY96 & FY97.

Exxon Valdez Oil Spill
Restoration Project Annual Report

Analysis of Small-Mesh Trawl Data

Restoration Project (APEX) 96163L

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Analysis of Small-Mesh Trawl Data

Restoration Project(APEX) 96163L
Annual Report

__Study History__: Restoration Project 96163L was initiated as part of the APEX project that is studying the relationship between changes in forage species composition and marine birds in the spill affected area. Large declines of apex predator populations (murres, kittiwakes, harbor seals, and Steller sea lion) have occurred in the Gulf of Alaska since the 1970s. Changes in composition and abundance of forage species may be responsible for the decline of these predator populations and their chronic low population levels. In an effort to delineate changes in forage species and a trophic regime shift, if any, over the last several decades, we have gathered together historical fishery-independent scientific survey data to address this question. This part of the annual report includes one manuscript submitted for publication from recent analysis of information and data from small-meshed trawl studies conducted in the Gulf of Alaska by the Alaska Department of Fish and Game and the National Marine Fisheries Service and its predecessor agencies from 1953 through 1996.

__Abstract__: Twenty-four years (1972-95) of shrimp trawl survey catch data was analyzed in order to reveal changes in the species composition of demersal biomass in the Gulf of Alaska. A shrimp-dominated crustacean species community (mostly *Pandalus goniurus* and *P. borealis*) came to an end in the late 1970's and has not yet regained its former level of biomass. Changes in community structure continued with the decline of capelin (*Mallotus villosus*) in the late-1970s, followed by a build-up of gadid fishes in 1978-83 and pleuronectid fishes in 1984 to the present. Overall, the biomass index, as represented by shrimp sampling trawl, has declined to less than one-half of its former size under the recent fish-dominated environment. This epibenthic regime shift was accompanied by a rapid increase in water temperature which may largely be responsible for the observed abrupt temporal change in species composition.

__Key Words__: Regime Shift, Gulf of Alaska, Forage Species, osmerids, capelin, pandalid shrimp, gadids, pleuronectids, epibenthic, benthic, biomass index, community structure.

__Citation__: Anderson, P.J., J.E. Blackburn, and A.B. Johnson. 1997. Declines of Forage Species in the Gulf of Alaska, 1972-95, as an Indicator of Regime Shift. *In* Baxter, B.R. (ed) Proceedings of the Symposium on the Role of Forage Fish in the Marine Ecosystem. Alaska Sea Grant College Program AK-SG-97-01, 1997 (In Press).

Declines of Forage Species in the Gulf of Alaska, 1972-95, as an Indicator of Regime Shift

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*Abstract

Twenty-four years (1972-95) of shrimp trawl survey catch data was analyzed in order to reveal changes in the species composition of demersal biomass in the Gulf of Alaska. A shrimp-dominated crustacean species community (mostly *Pandalus goniurus* and *P. borealis*) came to an end in the late 1970's and has not yet regained its former level of biomass. Changes in community structure continued with the decline of capelin (*Mallotus villosus*) in the late-1970s, followed by a build-up of gadid fishes in 1978-83 and pleuronectid fishes in 1984 to the present. Overall, the biomass index, as represented by shrimp sampling trawl, has declined to less than one-half of its former size under the recent fish-dominated environment. This epibenthic regime shift was accompanied by a rapid increase in water temperature which may largely be responsible for the observed abrupt temporal change in species composition.

*Introduction

Simultaneous and abrupt declines of crustacean populations, most notably shrimp of the genus Pandalus, and smelt of the family Osmeridae, have occurred in the Gulf of Alaska along with increasing densities of gadid fishes and many species of pleuronectid flatfishes. These concurrent changes in several species suggest that they are causally connected in affecting commercial (Anderson 1991) and non-commercial species (Piatt and Anderson 1996) alike, and thus represent a regime shift (Steele 1996). Implicit in the concept of a regime shift is that changes occur throughout the ecosystem and a new community structure is formed. A crustacean/forage fish epibenthic community changed to the current regime dominated by fishes during a brief time period between 1978 and 1981 in the central and western Gulf of Alaska. This shift is well documented by results from a long-term small-mesh trawl survey series conducted before and after the shift (Piatt and Anderson 1996). This paper describes the results from these surveys and presents hypotheses for the observed regime shift.

*Methods

Data used in this study were collected during small-mesh trawl surveys which targeted shrimp as their primary species. The data set is a compilation of nearly 10,000 trawl samples by the National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G). Most of the sampling was done with a small-mesh net with 32 mm stretched mesh throughout

(Anderson 1991). Survey tows were conducted during daylight in water deeper than 50 m since preliminary surveys had shown low shrimp densities in shallow water (Anderson 1991). Most tows covered an average length of 1 to 2 km.

Survey catches were sorted by species and all species were weighed separately. Occasionally, catches were so large that subsampling of the catch was employed after the method described by Hughes (1976). Subsamples were counted to obtain the average weight of individuals. All shrimp, juvenile fish (mostly Pleuronectidae) were combined, weighed, and subsampled for species composition. The subsampled species groups were then counted and weighed to the nearest gram using a triple-beam scale. The extrapolated juvenile weights of each species were added to those of the adults of the same species.

Organism counts and weights were converted to density values expressed as either number or kilograms caught per kilometer towed by the sampling gear (catch per unit of effort [CPUE]). Converting density values in this way minimizes possible bias associated with sampling tows of unequal distance or duration. Abundance comparisons for species among years and areas all use CPUE rather than actual catch values.

Sampled locations were mapped using the computer program ARCINFO and data distribution was outlined graphically to define the sampled area over the time series. Species density by area was determined by combining CPUE values for each area by year and computing the mean. Eight bays were chosen for detailed study

(Fig. 1) representing a broad coverage of the Gulf of Alaska inshore bay ecosystem.

We have abstracted major components from the total biomass in order to simplify our analysis for density trends. Two groups of forage species, which include shrimps mainly of the family Pandalidae and smelts of the family Osmeridae made up of mostly capelin *Mallotus villosus,* and to a lesser extent eulachon *Thaleichthys pacificus*, and small amounts of other miscellaneous smelts composed the forage species complex. For this study, we consider the smelts and shrimps as trophospecies, a species group that shares similar prey and predators. Flatfishes (Pleuronectidae) were treated as a group and include five species, arrowtooth flounder (*Atheresthes stomias*), flathead sole (*Hippoglossoides elassodon*), yellowfin sole (*Pleuronectes asper*), rock sole (*Pleuronectes bilineatus*), and Pacific halibut (*Hippoglossus stenolepis*). Gadid fishes include Pacific cod (*Gadus macrocephalus*) and walleye pollock (*Theragra chalcogramma*). All other species, which made up the remainder of the catch biomass, was treated as a combined element for this study.

*Results

Combined biomass of all species declined in seven of the eight study areas to the lowest CPUE during the 1985-89 period. One area, Two-headed Island gully, showed low total biomass during the early 1970-74 time period. Since most of the data for this time period had to be discarded due to incomplete catch sorting, we feel that the low total biomass for this period distorts the results. If this data point is discarded, then the trend of low overall abundance of all organisms fits the same pattern observed for the other areas (Table 1). All areas sampled showed an increase in total biomass as measured by our sampling gear in the latest period (1990-95).

In order to remove fluctuations associated with seasonal on-shore and off-shore movements of biomass components, we selected catch data from the August through November time period to study changes in total biomass. Anderson (1991) hypothesized that shrimp density was most stable at this time of year because of mating aggregations. Ketchen (1961) indicated that inshore cod populations were probably more available in the summer and fall because of wamer temperatures before winter cooling. Highest total biomass was 493.1 kg/km (mean CPUE n=873, SD=470.2) during the 1972-80 time period before declining to 176.1 kg/km (mean CPUE n=342, SD=158.3) in 1985-88. Based on the recent 1991-95 sampling period total biomass has recovered to 373.6 kg/km (mean CPUE n=215, SD=229.3) (Fig. 2).

The two main forage species groups, shrimp and osmerids, declined from relatively high levels of abundance in 1970-84 to uniformly low abundance during 1985-95. Three areas, Chiniak, Pavlof, and Ugak Bays, all showed high levels of osmerids and shrimp simultaneously. In two areas, Pavlof and Chiniak Bays, high forage species abundance was coincident with high total biomass. Chignik bay showed highest osmerid abundance earlier than observed maximum shrimp abundance (Table 1).

In the Osmerid group, capelin alone composed 84% of total group biomass prior to 1981 and declined thereafter leaving eulachon the major species in the group. Capelin maximum mean CPUE for late summer and fall surveys was in 1972 at 23.7 kg/km; other peaks in abundance occurred in 1976 at 21.2 kg/km and again in 1980 at 15.9 kg/km. Abundance has remained at less than 0.1 kg/km since 1987 and shows no sign of recovery (Fig. 3).

Results indicate a close relationship between high total biomass and high forage species abundance. In contrast, low total biomass is related to both low abundance of forage species and high levels of flatfish abundance (Table 1). In order to explore these observed relationships, we used a "slug trace" plot (Ramsey 1988) to illustrate periods of biomass regime shift for our study areas. This technique uses bivariate time plots of the studied species groups in two dimensions accompanied by a univariate scatter plot. The relationship between the two forage species is shown in Figure 4. The arrow line on the corresponding plots signals the regime shift observed in the survey data. It is clear from these plots that the relationship of shrimp and osmerid abundance changed between 1976-83, signaling the shift to a new community structure.

*Discussion

A major shift in the physical regime of the Gulf of Alaska occurred in 1976-77 (Royer 1989, Kerr 1992, Trenberth and Hurrell 1995) and is reflected in the observed shift in species composition data from trawl surveys of inshore bays over a broad region in this study (Fig. 5). Other studies have shown increased landings of Pacific salmon (Beamish and Bouillon 1992), possibly due to enhanced ocean survival which may be the direct result of increased zooplankton abundance (Brodeur and Ware 1992) or more favorable temperature. Kodiak Island near-shore (10.7 m) water temperature in March averaged -0.48 to 2.01 degrees C during 1971-76, 2.90 to 5.09 degrees C during 1977-88, and 2.14 to 3.33 degrees C during 1989-94 (S. F. Blau, pers. comm.). Increases in near-shore water column temperature may possibly affect productivity for shrimp and forage fish in a negative way. Aquatic communities integrate the totality of environmental factors that they are exposed to. Our contention is that the physical regime shift co-occurred with the shift from the crustacean/forage fish regime to the current epibenthic community now dominated by cod, pollock, and pleuronectid flatfishes, and was the primary mechanism that caused the epibenthic community shift.

Shrimp declined uniformly throughout all study areas, but one species (*Pandalus goniurus*) that was formerly a significant part of the shrimp biomass became nearly extinct (Fig. 6) while the other primary species (*P. borealis*) has declined, but not to levels of near-extinction. This observed change demonstrates that some species are more vulnerable to being extinguished from the near-shore ecosystem as a result of regime shift. This species was not heavily targeted by commercial shrimpers, and declines after closure of commercial fisheries continued. We hypothesize that the near-extinction of *P. goniurus* was caused by sustained higher winter temperatures that took place in the late 1970s (Royer 1989). This species is found in relatively shallower waters than *P. borealis* and is subject to areas of high residual winter cooling. These distribution traits along with abrupt changes in winter temperatures may explain the region-wide regime shift.

Influxes of Pacific cod into the inshore bays and gullys where dense shrimp and osmerid populations occurred was a destabilizing factor on those populations and was partially responsible for the observed ecosystem regime shift in the Gulf of Alaska. Cod were virtually absent in inshore bays during the early 1970s (Albers and Anderson 1985) (Fig. 5). We believe that warming water column temperatures may allow cod to remain in our study areas throughout the winter instead of migrating offshore when temperatures are cooler (Ketchen 1961). This increased contact with the forage base probably contributed further to the observed decline of shrimps and osmerids that continued well after the end of most in-shore shrimp trawl fisheries in the late 1970s (Albers and Anderson 1985).

In conclusion, our analysis shows a marked decline in the available biomass after the shift from the crustacean regime to the regime dominated by fishes (Fig. 2 and 5). The declines in epibenthic biomass, as observed in this study, were opposite of the increase in landings and abundance of many species of Pacific salmon (Beamish and Bouillon 1993). Also coincident with the regime shift was a change in the higher trophic levels and composition of zooplankton (Brodeur and Ware 1992). Since many forage species, including capelin and shrimp, are planktivores this observed change in plankton composition could explain the uniform decline of these species.

Abrupt changes in the physical regime with concurrent or slightly delayed reaction from the epibenthic ecosystem had an extreme effect on the inshore fishing fleet and processing of the central and western Gulf of Alaska. The regime shift, as described in this paper, occured rapidly and may shift again from a fish-dominanted to another community regime. These species composition shifts are preceded by changes in the physical environment. Monitoring water column temperature and changes in the epibenthic organisms in many areas of the Gulf of Alaska could be used to forecast future changes and perhaps lead to less disruption in the fishing industry when these regime shifts occur.

*Acknowledgements

This project was partially supported by the Alaska Predator Ecosystem Experiment (APEX) which was funded by a grant from the Exxon Valdez Oil Spill Trustee Council. We thank Tamara Olson (Natural Resource Research and Consulting) for conducting the GIS analysis. Finally, we also thank the crew and scientists from the ADF&G and NMFS who spent many months at sea collecting the data for our analysis.

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Table 1. Mean catch in kilograms per kilometer trawled of selected species groups by study area and selected time periods (ns = not sampled).

Period	Total	Shrimp	Osmerids	Flatfish	Cod
Alitak Bay					
1970-74	ns	358.63	ns	ns	ns
1975-79	312.32	233.38	7.00	22.3	0.56
1980-84	221.44	106.75	6.12	27.61	16.14
1985-89	113.24	14.25	0.57	19.95	9.96
1990-95	141.11	2.81	0.31	27.08	17.68
Chignik Bay					
1970-74	483.45	345.31	5.22	11.54	1.56
1975-79	476.31	360.88	3.52	10.83	18.36
1980-84	333.71	94.99	2.64	60.37	45.04
1985-89	134.70	16.73	0.40	54.71	6.90
1990-95	210.03	38.90	1.91	80.49	6.48
Chiniak Bay					
1970-74	ns	ns	ns	ns	ns
1975-79	490.43	253.69	2.74	88.52	5.47
1980-84	303.54	126.48	0.78	95.86	13.90
1985-89	166.16	17.34	0.77	78.08	5.91
1990-95	320.62	23.40	0.29	163.30	5.64
Kiliuda Bay					
1970-74	ns	362.29	.07	2.85	0.09
1975-79	511.95	366.80	7.24	36.15	9.91
1980-84	345.52	34.92	27.97	59.08	22.34
1985-89	260.56	9.18	1.08	108.70	22.10
1990-95	476.97	7.56	7.67	141.91	15.30

Table 1. Continued

Marmot Bay					
Period	Total	Shrimp	Osmerids	Flatfish	Cod
1970-74	ns	171.78	ns	ns	ns
1975-79	229.10	110.11	2.72	29.40	2.22
1980-84	298.08	89.07	6.36	117.83	9.39
1985-89	177.36	18.75	0.21	59.75	18.98
1990-95	262.05	54.78	0.12	104.38	5.95
Pavlof Bay					
1970-74	795.59	695.35	21.25	5.20	0.03
1975-79	735.57	373.63	11.73	22.21	225.69
1980-84	402.90	20.49	6.70	70.40	141.84
1985-89	289.18	6.31	0.09	131.04	20.39
1990-95	441.78	14.67	0.04	159.53	32.73
Two-headed					
1970-74	199.05	537.24	4.64	8.45	8.46
1975-79	406.39	297.52	7.44	28.47	13.16
1980-84	319.08	95.68	17.53	75.09	18.28
1985-89	314.45	9.82	1.10	147.45	19.10
1990-95	401.24	20.60	0.39	126.46	4.82
Ugak Bay					
1970-74	ns	90.24	ns	ns	ns
1975-79	304.93	209.60	29.72	23.64	0.27
1980-84	337.13	111.59	13.45	43.54	72.47
1985-89	240.70	9.88	3.70	73.13	20.45
1990-95	ns	ns	ns	ns	ns

*List of Figures

1. Location of bays and near-shore sampling sites for small-mesh trawl surveys 1970-95. Note: "Chignik-Castle" is a group of three bays; Chignik, Kujulik, and Castle Bays.

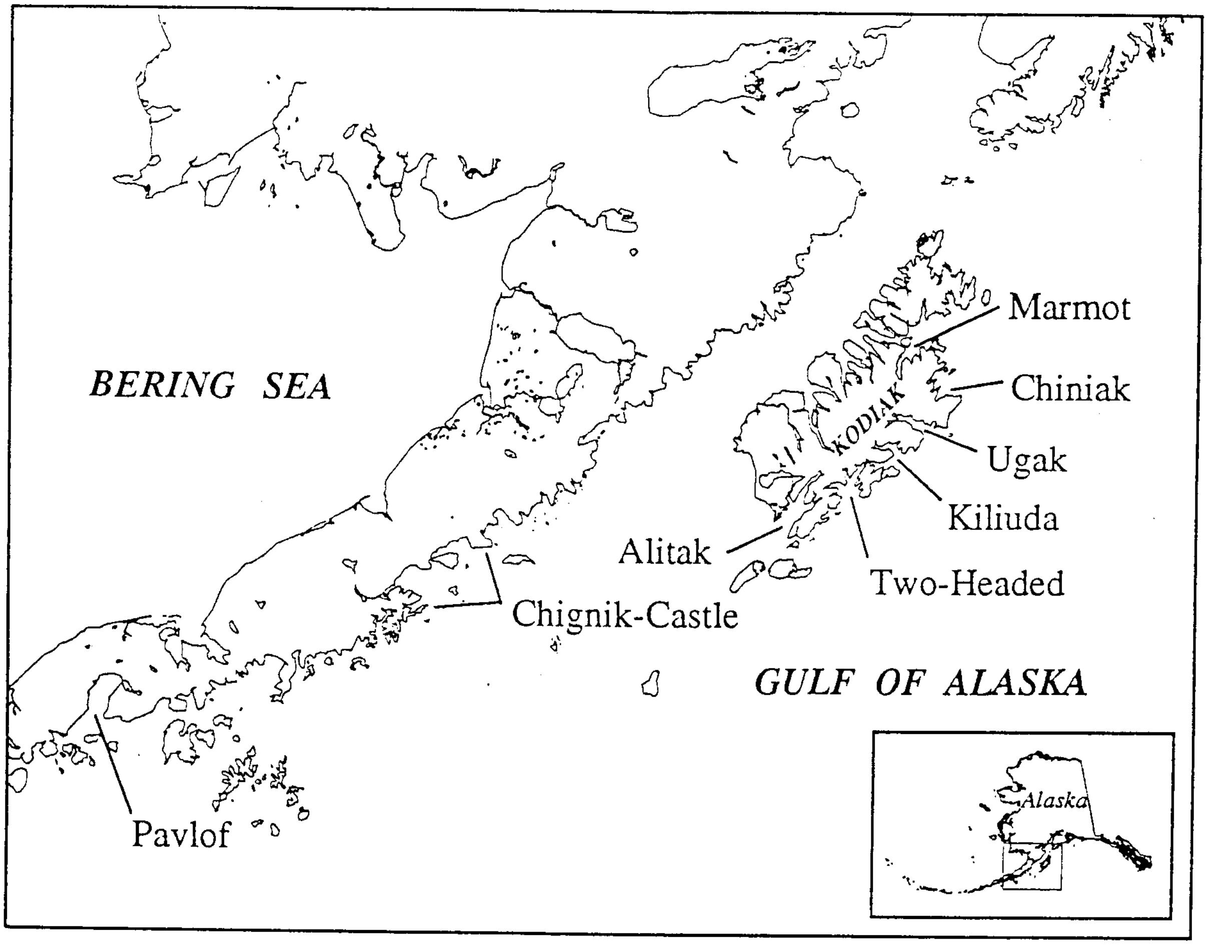
2. Mean CPUE (expressed as kilograms caught per kilometer trawled) of total biomass for the months August through November, 1972-95 . All 8 sampling sites combined.

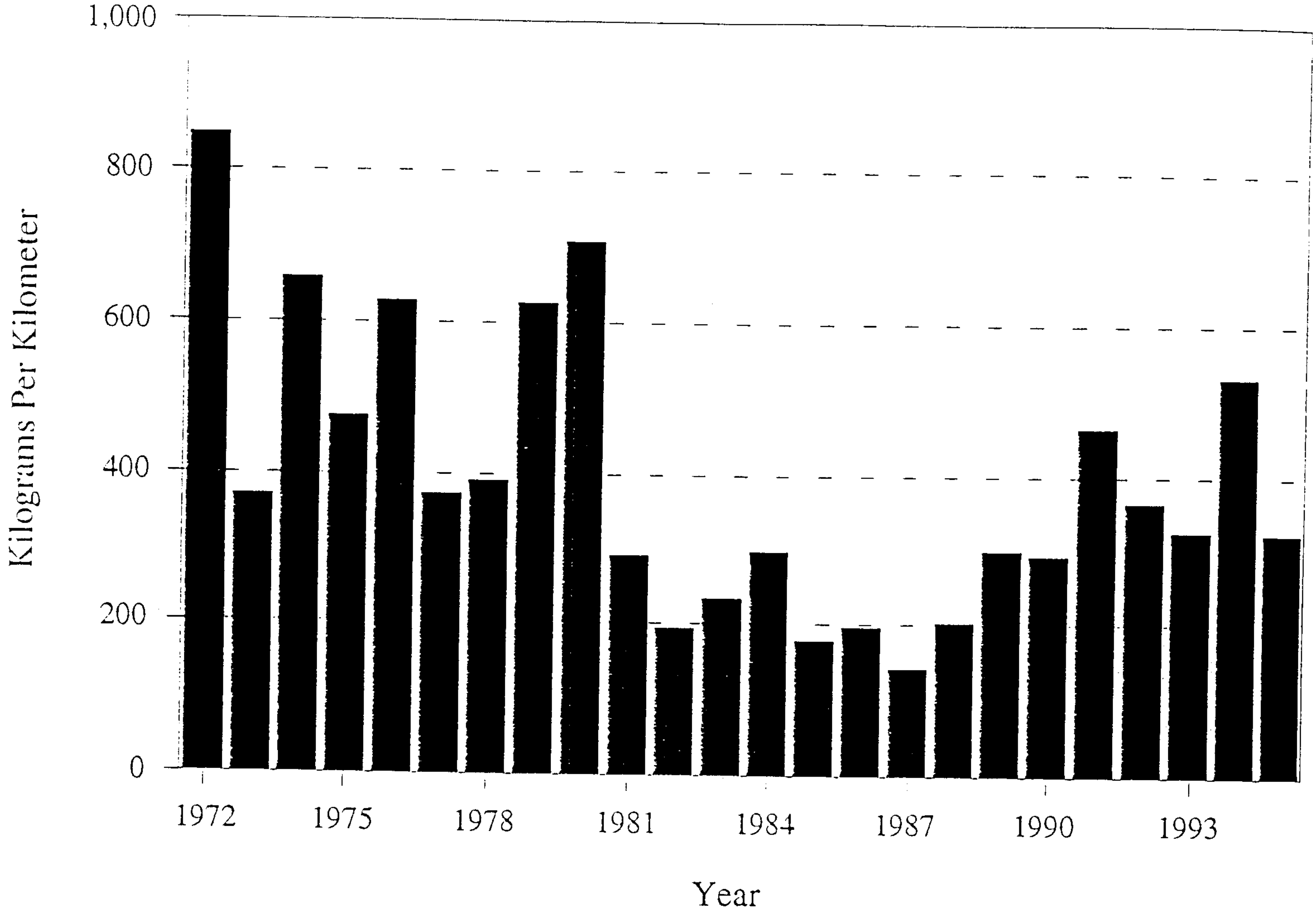
3. Mean CPUE of capelin from August through November trawl surveys in all sampling locations combined.

4.Slug traces of shrimps and Osmerids from several bays; regime shift identified by arrow line on scatterplots. (Please note difference in scales of mean CPUE for species groups in bivariate time plots).

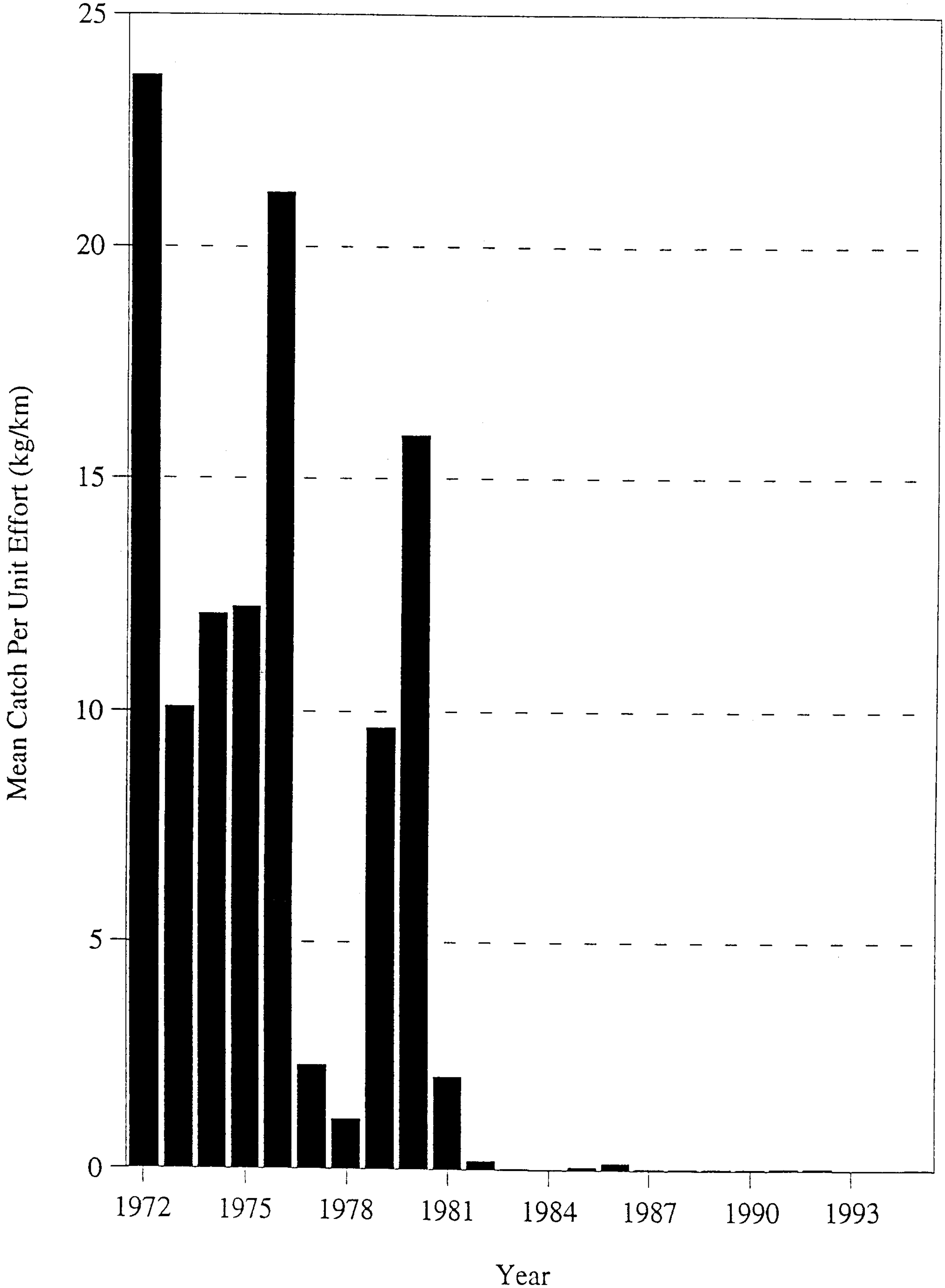
5. Species composition represented by proportional contribution in August through November total biomass in all sampling sites combined.

6. Mean CPUE of *Pandalus borealis* and *P. goniurus* from all sampling areas, 1972-95.

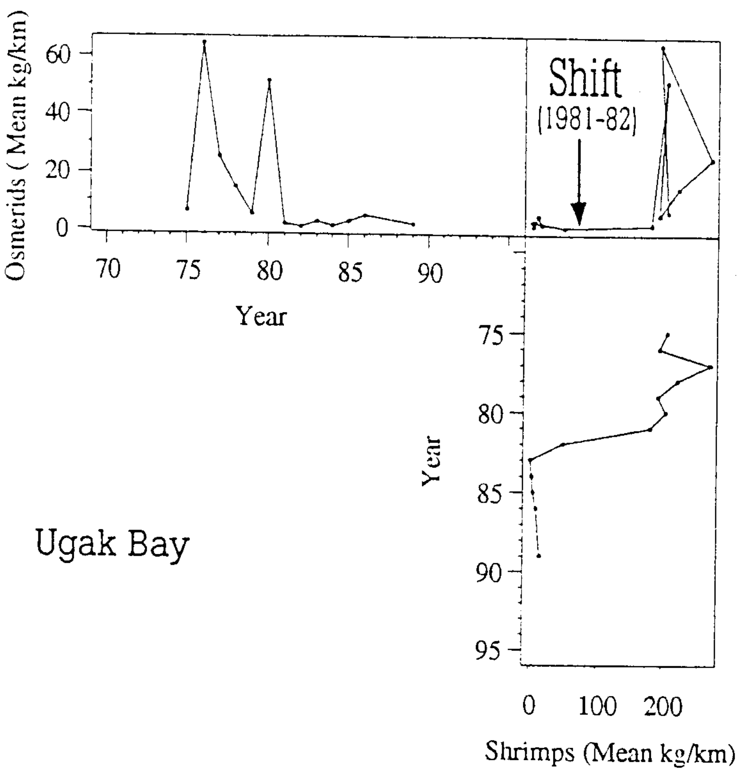

Marmot
BERING SEA
Chiniak
KODIAK
Ugak
Kiliuda
Alitak
Two-Headed
Chignik-Castle
GULF OF ALASKA
Alaska
Pavlof

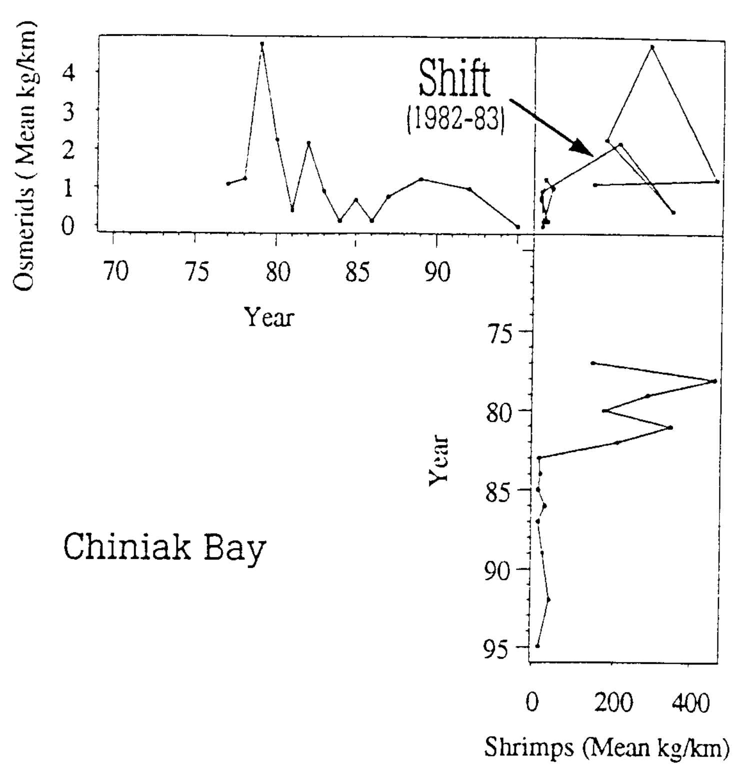


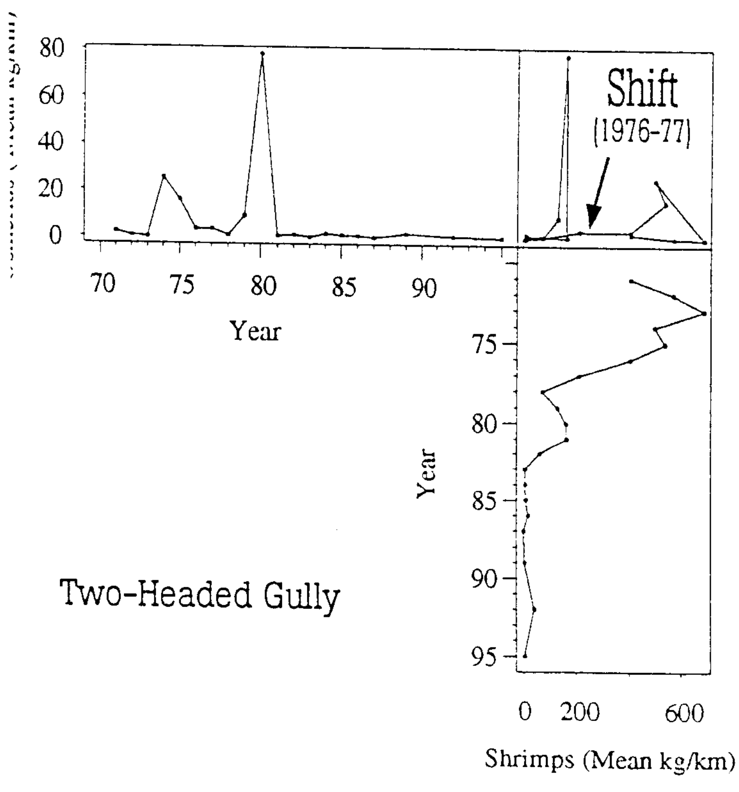
1,000
800
600
400
200
0
Kilograms Per Kilometer
1972
1975
1978
1981
1984
1987
1990
1993
Year

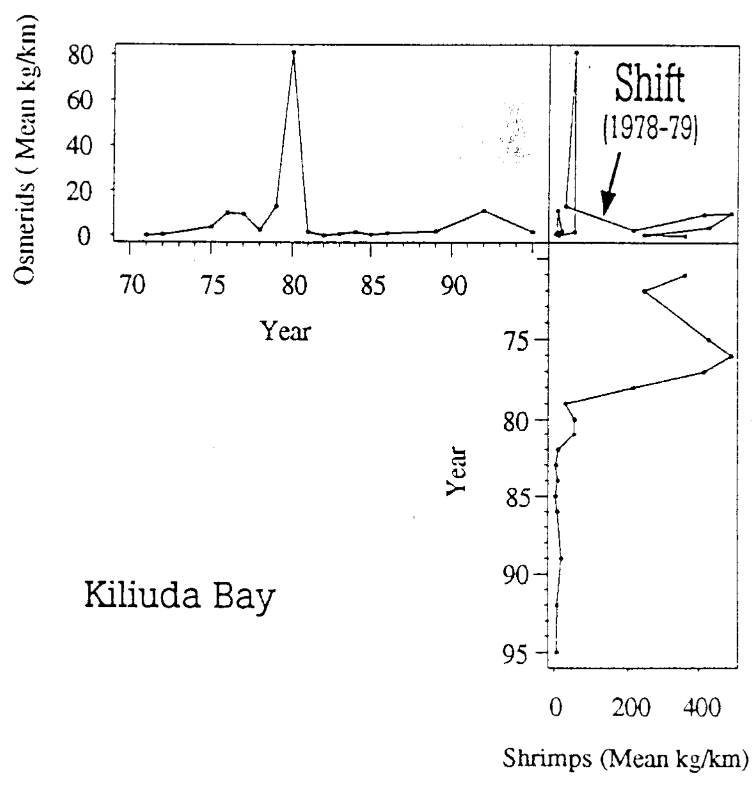


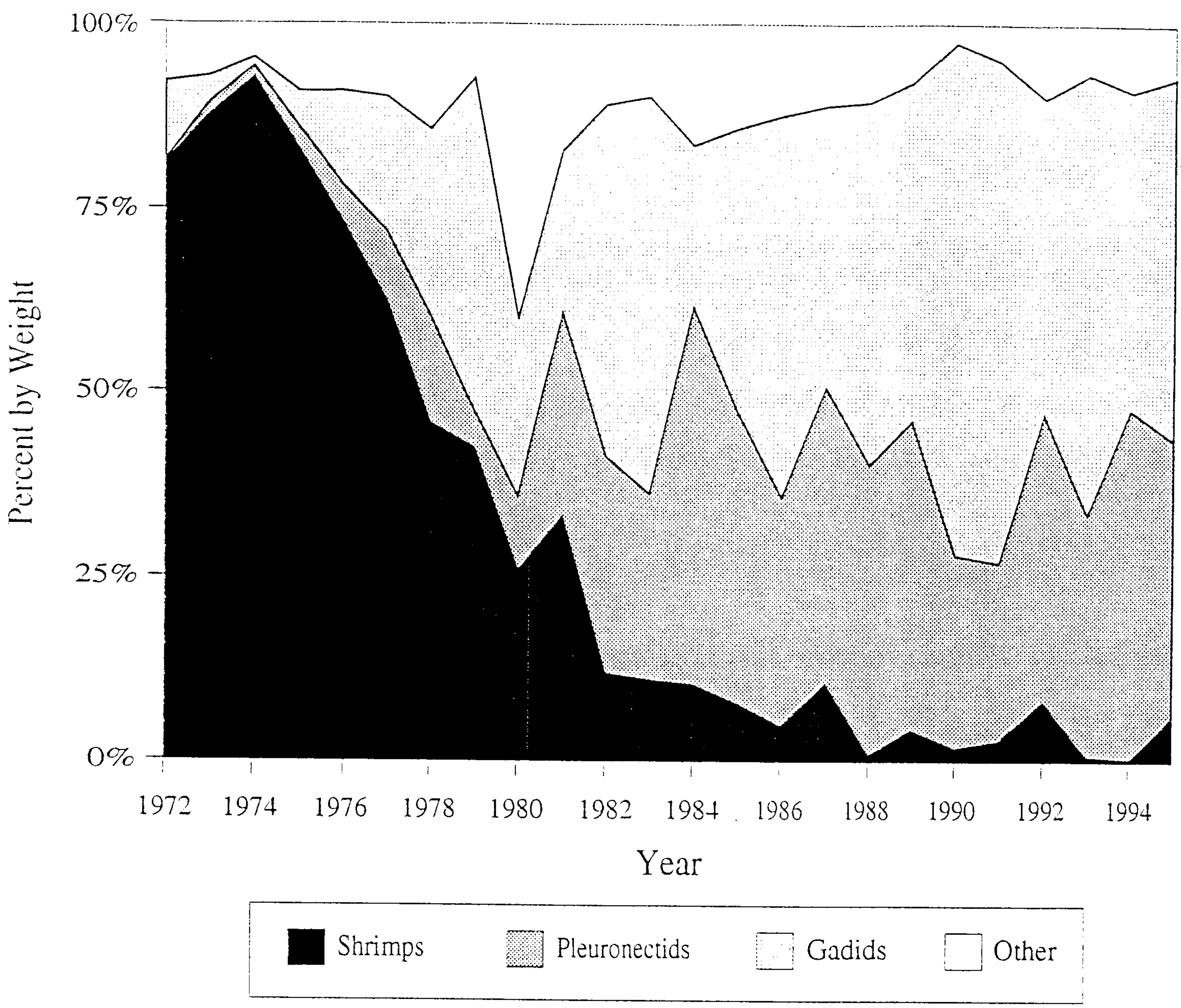
Mean Catch Per Unit Effort (kg/km)
25
20
15
10
5
0
1972
1975
1978
1981
1984
1987
1990
1993
Year


Osmerids (Mean kg/km)
Year
Shift
(1981-82)
Year
Shrimps (Mean kg/km)
Ugak Bay

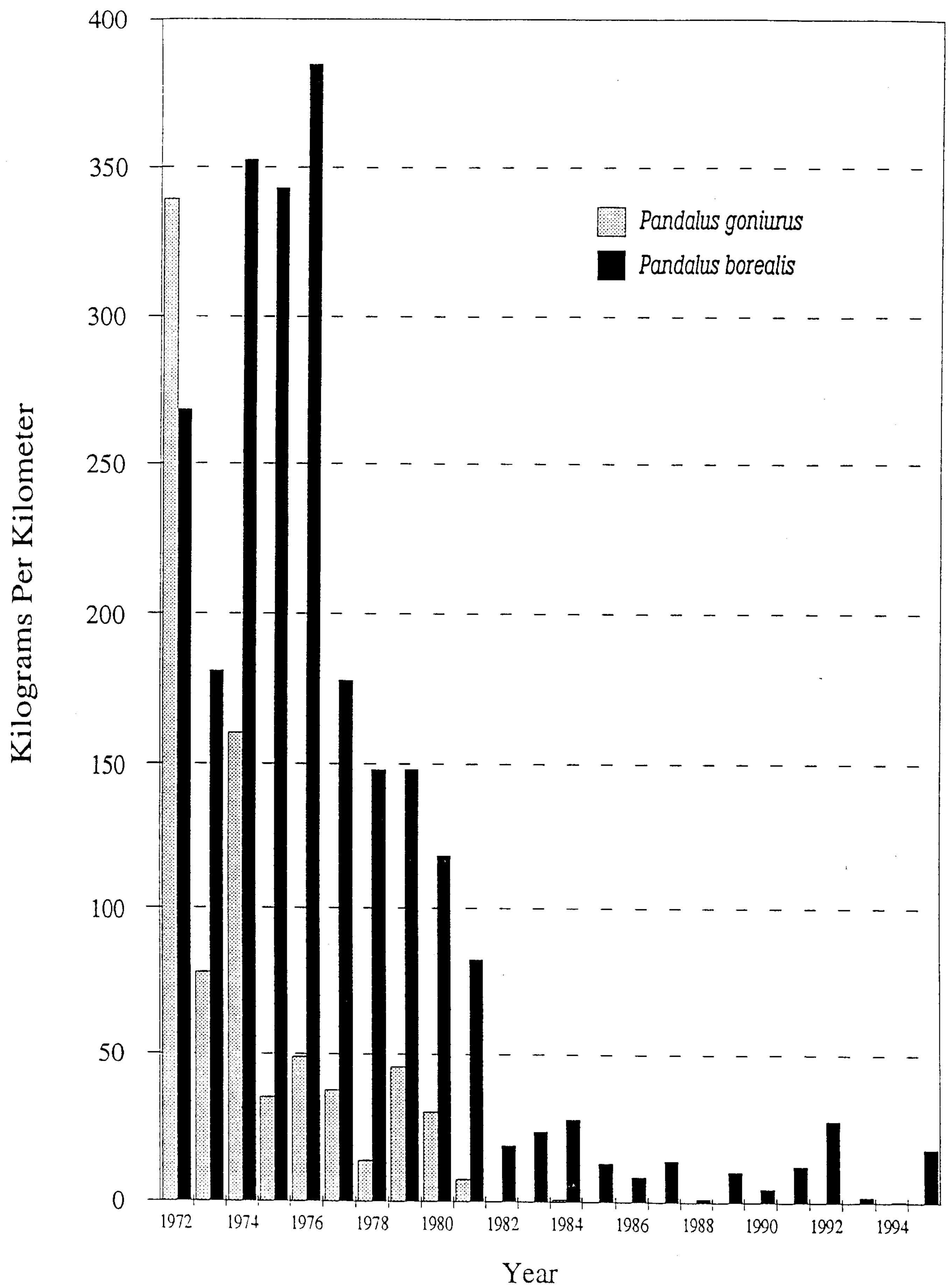

Osmerids (Mean kg/km)
Year
Shift
(1982-83)
Year
Shrimps (Mean kg/km)
Chiniak Bay


Year
Shift
(1976-77)
Year
Shrimps (Mean kg/km)
Two-Headed Gully


Osmerids (Mean kg/km)
Year
Shift
(1978-79)
Year
Shrimps (Mean kg/km)
Kiliuda Bay



100%
75%
50%
25%
0%
Percent by Weight
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
Year
Shrimps
Pleuronectids
Gadids
Other



400
350
300
250
200
150
100
50
0
Kilograms Per Kilometer
Pandalus goniurus
Pandalus borealis
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
Year

Exxon Valdez Oil Spill
Restoration Project Annual Report

Analysis of Small-Mesh Trawl Data

Restoration Project (APEX) 96163L

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March 1997

Analysis of Small-Mesh Trawl Data

Restoration Project(APEX) 96163L
Annual Report

Study History: Restoration Project 96163L was initiated as part of the APEX project that is studying the relationship between changes in forage species composition and marine birds in the spill affected area. Large declines of apex predator populations (murres, kittiwakes, harbor seals, and Steller sea lion) have occurred in the Gulf of Alaska since the 1970s. Changes in composition and abundance of forage species may be responsible for the decline of these predator populations and their chronic low population levels. In an effort to delineate changes in forage species and a trophic regime shift, if any, over the last several decades, we have gathered together historical fishery-independent scientific survey data to address this question. This part of the annual report includes one manuscript submitted for publication from recent analysis of information and data from small-meshed trawl studies conducted in the Gulf of Alaska by the Alaska Department of Fish and Game and the National Marine Fisheries Service and its predecessor agencies from 1953 through 1996.

Abstract: A Twenty year (1976-95) of shrimp trawl survey catch data was analyzed in order to reveal changes in the species composition of demersal biomass in Kachemak Bay. A shrimp-dominated crustacean species community (mostly *Pandalus goniurus* and *P. borealis*) came to an end in the late 1970's and has not yet regained its former level of biomass. Despite a complete closure of the commercial shrimp fishery in 1987, no rebuilding of shrimp resource has occurred. Walleye pollock occurrence declined to 22% in the mid-1980's, and have since increased to over 90% of tows in the 1990's. Smelt, as a group, declined from 893.1 per tow in 1978 to 8.9 per tow by 1989. Capelin have appeared to increase their distribution in the sampled area in recent surveys while relative abundance has declined.

Key Words: Kachemak Bay, Forage Species, osmerids, capelin, pandalid shrimp, gadids, Walleye pollock, biomass index, community structure.

Citation: Bechtol, W.R. 1997. Changes in Forage Fish Populations in Kachemak Bay, Alaska, 1976 to 1995. *In* Baxter, B.R. (ed) Proceedings of the Symposium on the Role of Forage Fish in the Marine Ecosystem. Alaska Sea Grant College Program AK-SG-97-01, 1997 (In Press).

Changes in Forage Fish Populations in Kachemak Bay, Alaska, 1976 to 1995

Note: This manuscript is currently under review as a contribution to the Proceedings from the Symposium on the Role of Forage Fishes in Marine Ecosystems, to be published by the Alaska Sea Grant College Program.

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INTRODUCTION

Relationships between different components of the Kachemak Bay marine ecosystem are poorly understood, yet fish and shellfish populations in this area have undergone significant changes since the mid-1970's. For example pandalid shrimp (*Pandalus* sp.) and red king crab (*Paralithodes camtschaticus*), once commercially important in this area, declined to low levels in the 1980's and have shown no evidence of rebuilding even though the fisheries have been closed since that time (Davis 1982; Gustafson 1994; Kimker 1996;). In particular, the collapse of the pandalid shrimp resource, especially the failure of this population to rebuild after a decade without commercial fishing pressure, indicated the magnitude of ecosystem change and the need to examine changes in other marine species. For example, some fish species, such as walleye pollock (*Theragra chalcogramma*), were reported to have dramatically increased.

A 20 year database of ADF&G surveys with small-mesh bottom trawls existed for the Cook Inlet area. Although the primary goal of these surveys was to assess pandalid shrimp resources (e.g. Gustafson 1994), some information was also collected on other captured species. As part of an *Exxon Valdez* oil spill study, the Alaska Predator Ecosystem Experiment (APEX; Duffy 1996), I examined the occurrence and abundance of fishes captured during these trawl surveys. This paper presents results of my analyses on selected species that might be described as either forage fish, i.e., species that might serve as an important prey item for other marine organisms , or as species potentially having a significant impact on the available forage base.

METHODS

From 1976 to 1995, the Alaska Department of Fish and Game (ADF&G) conducted bottom trawl surveys to assess shrimp populations in Kachemak Bay, Alaska, an embayment centered approximately at 59°35'N, 151°52'W in the northern Gulf of Alaska (Figure 1). Spring surveys were conducted annually in May from 1976 to 1993, then shifted to alternate years beginning in 1993. Fall surveys occurred annually from 1976 to 1990, and a single winter survey occurred in 1979. ADF&G made 16 to 45 tows within a season and year stratum, with a total of 1,200 survey tows in the historical database (Table 1).

Surveys involved tows of a 32 mm mesh net with a mouth rising 18.3 m and a 17 m tickler chain (Davis 1982). Tows were typically 1.0 nautical mile long. Following each tow, the tared catch weight was obtained as the catch was dumped on deck. Prior to 1989, all large non-fish objects were removed from the catch and the remaining catch was subsampled to estimate the shrimp to non-shrimp composition. In many cases the species composition of the non-shrimp catch was only described qualitatively. Beginning in 1989, the tared catch weight was obtained, then the entire catch was sorted, counted, and weighed by species or major species group with the total catch subsampled as necessary.

For this analysis, field data sheets were processed into an electronic database. All data were summarized according to shrimp and non-shrimp components. Subsample data on species composition were entered if available. However, sampling emphasis and methods changed somewhat over the survey time series. In particular, little sampling effort was applied to non-shrimp species during the mid-1980's and quantitative data were not recorded for non-shrimp species during most survey tows. If quantitative data were not available, qualitative data were entered during my subsequent analysis. All catch data were converted to 1.0 nm equivalents and summarized within a tow and season. General fish catch was estimated as kg/nm and percent catch composition. I calculated frequency of occurrence and mean tow abundance for three fish families, eelpouts (Zoracidae), poachers (Agonidae), and smelt, excluding capelin (Osmeridae); and four fish species, capelin (*Mallotus villosus*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), and Pacific tomcod (*Microgadus proximus*). I calculated frequency of occurrence for one more family, ronquils and searchers (Bathymasteridae), but did not estimate mean tow abundance because this family was encountered in catches only infrequently.

RESULTS

Relative and Absolute Increases in Fish Catches

Fish comprised an increasing portion of the mean tare weight in Kachemak Bay shrimp surveys since 1976. As the shrimp population declined in the 1980's, the fish component of Cook Inlet shrimp survey catches increased dramatically from less than 20% of the catch biomass in the late 1970's to more than 80% in recent years (Figures 2 and 3). Fish contribution in the fall was generally greater than in the spring. Although representing only a single winter assessment, fish composition in the 1979 winter survey was greater than any other seasonal contribution prior to the fall of 1981.

The aggregate catch biomass of all fish species also changed substantially over time as fish biomass per tow was again greater in fall than spring, and the single winter catch in 1979 was greater than spring or fall catches prior to 1981 (Figure 4). Spring fish catches generally averaged less than 60 kg/nm through 1983, then doubled to nearly 120 kg/nm in 1986 and 1987, and in the 1990's ranged from 264 to 395 kg/nm. Fall fish catches ranged from 87 to 112 kg/nm in the 1970's, and from 123 to 665 kg/nm between 1980 and 1990. The mean winter catch in 1979 was 163 kg/nm. Thus, not only has the overall finfish component of the survey catches increased, but the total fish biomass also increased. In addition, in years when multiple surveys were conducted, more fish were available in the fall than in the spring.

Frequency of Occurrence

The frequency of occurrence changed dramatically for all families and species examined (Table 2; Figure 5). Although the occurrence of ronquils and searchers increased slightly in the 1990's, these species were present in less than 10% of the tows. Poachers occurred in 10% or less of the survey tows during the late 1970's, but increased to nearly 25% of all survey tows since 1989. Eelpouts occurred in a maximum of 35% of the annual survey tows prior to 1981, but have steadily increased since 1989, reaching a peak of 77% of the tows in the 1995 survey. Capelin and other smelt species are more typically regarded as forage fish (NMFS 1996). The annual occurrence of capelin was quite variable during 1976 to 1983, ranging from 0% to 31% with a mean frequency of 8.4%. The annual occurrence of capelin during 1987 to 1993 exhibited similar variability, ranging from 6% to 29% with mean occurrence increasing to 14.4%. No capelin were reported from the 1995 survey. The occurrence of the three gadid species has also increased in recent years. Neither Pacific cod nor Pacific tomcod exceeded 10% of the annual survey tows for most years prior to the mid-1980's. Although some variability is evident, the occurrence of both species increased dramatically in recent years. The peak occurrence of Pacific cod in tows , 53%, was reported from the 1993 survey while the peak occurrence of Pacific tomcod, 92%, was reported from the 1992 survey. Both historically and in recent years, walleye pollock has been the most frequently occurring gadid species. Prior to 1981, walleye pollock occurred in 41% to 71% of tows during annual surveys. Walleye pollock occurrence declined to 22% of tows during annual surveys in the mid-1980's, and increased to over 90% of the tows in 1990's surveys. In fact, this species occurred in 100% of tows in both the 1991 and 1995 surveys.

Mean Catch Abundance

Mean catch abundance, expressed as the average number of fish-per-tow, changed considerably during the survey time series for the families and species examined (Table 3; Figure 6). Many species exhibited peak mean abundance in late 1977 or 1978, and again in 1989. Catches of walleye pollock have been the greatest, and one of the most variable, of all the fish examined from the Kachemak Bay surveys. Walleye pollock abundance ranged from a low of 34.1 per tow in 1993 to a high of 1,280.5 per tow in 1977. For most years in which forage fish data were available, pollock catch rates exceeded 300 catch per tow. Pacific tomcod mean abundance, while also quite variable, was generally greater in the 1990's than in the 1970's. The peak catch of Pacific tomcod was 115.6 per tow in 1989. Although Pacific tomcod catch rates declined to 6.1 per tow in 1992, they have increased to 30.7 per tow in the 1995 survey. Pacific cod abundances have been greater in the 1990's, averaging 11.4 per tow after 1988, than for previous years, which averaged 2.6 per tow. However, the catch abundance of Pacific cod has generally declined since 1989, falling to only 2.0 per tow in 1995. Catch rates of both poachers and eelpouts peaked in 1989, but have been relatively low in recent years, particularly for eelpouts. Mean capelin abundances peaked at 280.4 per tow in 1978, declined to 1.4 per tow in 1989, increased to 13.4 per tow in 1992, and has since declined precipitously; no capelin were reported during the 1995 survey. Smelt exhibited a similar trend. This group declined from a peak of 893.1 per tow in 1978 to 8.5 per tow in 1989, and then increased to 19.5 per tow in 1992 before decreasing to 2.7 per tow in 1995.

DISCUSSION

It is apparent that some major changes have occurred within the Kachemak Bay ecosystem during 1976 to 1995, the time series encompassed by ADF&G surveys with small-mesh bottom trawls. From 1969 to 1982, pandalid shrimp harvests ranged from 1,800 to 2,800 mt annually, then decreased to 200 to 1,400 mt during 1983 to 1986 (Figure 2). Despite a complete closure of the commercial fishery since 1987, the shrimp population has failed to rebuild (Gustafson 1994). In contrast, the mean fish contribution to survey tows and the aggregate fish biomass both increased beginning in the mid-1980's (Figures 3 and 4). In years when surveys were conducted in more than one season, fish catches were greater in fall than spring. I could not determine from available information whether these seasonal changes in fish catches resulted from growth of young fish, mortality of older fish, or migration patterns. The lack of reliable forage fish abundance data during the entire time series inhibited a more complete understanding of ecosystem changes. In particular, survey data from the mid-1980's reflected a limitation in the sampling technique and should be regarded as suspect. In addition, the species I included in this analysis comprise only a portion of the Kachemak Bay biomass and some species, such as flatfish, may have increased over the time series while pelagic species such as Pacific herring have decreased (W. Bucher, Alaska Department of Fish and Game, Homer, Alaska, personal communication).

Substantial interannual variation in both frequency of occurrence and mean catch abundance was apparent for most fishes examined. Pacific cod, Pacific tomcod, and walleye pollock generally occurred more frequently in tows made during the 1990's than in previous years, but their mean catch rates have actually declined since 1989 (Figures 5 and 6). An increasing frequency of occurrence coupled with decreasing catch rates may be the result of a large number of small, young fish (i.e. an abundance year class) growing, subject to annual mortality, into fewer, but wider-dispersed large, old fish. The recent trend in walleye pollock abundance may illustrate this well. The relatively large catches of this species obtained in 1989 and 1990 would correspond to age-1 and -2 walleye pollock from the strong 1988 year class also documented in Gulf of Alaska commercial fisheries (Hollowed et al. 1996). The decline in Kachemak Bay survey catches of walleye pollock would result from mortality and migration of this large year class. Some pre-recruit indices for walleye pollock in the Gulf of Alaska suggest that the 1994 year class may be more abundant than the 1988 year class (Hollowed et al. 1996). If the 1994 year class is also abundant in Cook Inlet, age-2 walleye pollock should be very abundant in the 1997 Kachemak Bay trawl survey catches.

Although the frequency of occurrence of poachers in survey tows increased from about 4% prior to 1981 to nearly 25% after 1988, mean catch rates have remained below 10 per tow in the 1990's. This suggests that poachers may have expanded their distribution with little increase in overall abundance. Eelpouts also appeared more frequently in tows while their catch rates declined between early and more recent portions of the survey time series. This may again indicate an expanded distribution with little or no increase in abundance.

Smelt, an important forage species for fish, birds and marine mammals (NMFS 1996), were commonly captured throughout the survey time series. Smelt frequency of occurrence in recent years was exceeded only by walleye pollock and Pacific cod. However, the relative abundance of smelt declined over the time series, indicating these species have also become more widely dispersed but not relatively more abundant. Capelin, the only smelt for which data was recorded at the species level, followed a similar pattern. Capelin appeared to increase their distribution in recent years, while their relative abundance has declined even more extensively and this species was not recorded from a single tow during the 1995 survey.

Despite the limitations of the historical trawl survey data, analyses indicated that the biomass of many fish species increased while biomass for many invertebrate species, notably pandalid shrimp and red king crab (Gustafson 1994; Kimker 1996), decreased. In addition, not all fishes continued to increase in abundance. For example, Pacific cod and walleye pollock, both large gadid species, increased in distribution and relative abundance, but the relative abundance of important forage species such as capelin and smelt decreased (Figures 5 and 6). Thus, large predatory fishes appear to have benefited from ecosystem changes while small forage fishes, as well as shrimp and crabs, appear to have been adversely affected. It is possible that the ecosystem has now reached a relative stability in which predator species suppress the production of prey species that are limited in abundance (May 1977).

Unfortunately, the trawl survey was not originally designed to monitor fishes, and sampling for fishes have been somewhat inconsistent. While I feel that observed trends in distribution and abundance reflect the true underlying population and not just sampling artifacts, one must be careful in using this data set to examine fishes. Only slight modifications to these surveys in the future would greatly improve their usefulness for examining fish populations. For example, random sampling of the entire survey catch instead of only the target species, and obtaining information on fish size, particularly for the gadid species, could provide valuable information on the population dynamics of many fishes.

ACKNOWLEDGMENTS

Alan Davis, Richard Gustafson, and Alan Kimker were responsible for most of the data collection. I'd like to extend my appreciation to the *Exxon Valdez* Oil Spill Trustee Council for partial funding under APEX project 96163L, and also to the efforts of John Piatt for funding coordination. Carla Milburn and Richard Gustin provided the bulk of computer data entry from archived field data sheets. Scott Meyer, Ted Otis, and Steve Fried reviewed this manuscript.

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Table 1. Number of tows by season during bottom trawl surveys for pandalid shrimp in Kachemak Bay, Alaska, from 1976 to 1995.

	Number of Tows					Number of Tows			
Year	Winter	Spring	Fall	Total	Year	Winter	Spring	Fall	Total
1976		36	33	69	1986		36	46	82
1977		40	36	76	1987		38	37	75
1978		37	32	69	1988		44	38	82
1979	38	41	32	111	1989		45	44	89
1980		40	33	73	1990		43	44	87
1981		40	32	72	1991		44		44
1982		40	34	74	1992		38		38
1983		40	16	56	1993		36		36
1984				0	1994				0
1985			37	37	1995		30		30
					Total	38	668	494	1,200

Table 2. Mean frequency of occurrence for selected fish during trawl surveys in Kachemak Bay, Alaska from 1976 to 1995.

Year	Pollock	Pacific Cod	Pacific Tomcod	Poachers	Capelin	Ronquils/ Searchers	Eelpouts	Smelt
	Percent Occurrence							
1976	42.0	14.5	1.4	10.1	4.3	0.0	26.1	34.8
1977	71.1	9.2	0.0	7.9	0.0	0.0	32.9	31.6
1978	59.4	2.9	0.0	1.4	7.2	2.9	20.3	66.7
1979	40.5	2.7	1.8	2.7	30.6	0.9	9.0	55.9
1980	42.5	5.5	0.0	1.4	21.9	0.0	19.2	52.1
1981	4.2	0.0	1.4	0.0	1.4	0.0	1.4	1.4
1982	1.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0
1983	12.5	10.7	0.0	0.0	1.8	0.0	1.8	1.8
1984	No Survey							
1985	21.6	16.2	Data Lacking					
1986	36.6	14.6	Data Lacking					4.9
1987	76.0	37.3	18.7	0.0	9.3	1.3	0.0	13.3
1988	80.5	48.8	18.3	2.4	6.1	0.0	2.4	11.0
1989	86.5	60.7	36.0	23.6	7.9	2.2	31.5	36.0
1990	83.9	72.4	44.8	21.8	11.5	8.0	33.3	44.8
1991	100.0	63.6	31.8	27.3	20.5	9.1	47.7	50.0
1992	92.1	92.1	23.7	10.5	28.9	0.0	44.7	68.4
1993	97.2	86.1	52.8	25.0	16.7	8.3	55.6	72.2
1994	No Survey							
1995	100.0	86.7	40.0	33.3	0.0	6.7	76.7	53.3

Table 3. Mean catch of selected fish species during trawl surveys in Kachemak Bay, Alaska from 1976 to 1995.

Year	Pollock	Pacific cod	Pacific Tomcod	Poachers	Capelin	Eelpouts	Smelt
			Mean Catch (fish/nautical mile)				
1976	318.2	10.3	0.1	1.0	0.9	15.4	8.7
1977	1,280.5	1.3	<0.1	4.2		54.5	37.4
1978	1,238.7	1.1	<0.1	1.0	280.4	51.9	893.1
1979	305.0	0.2	0.2	4.1	52.2	34.5	121.4
1980	173.0	0.1	<0.1	0.6	11.8	20.9	38.7
1981	6.1		3.2			0.3	
1982				Data Lacking			
1983				Data Lacking			
1984				No Survey			
1985				Data Lacking			
1986				Data Lacking			
1987				Data Lacking			
1988				Data Lacking			
1989	620.8	27.3	115.6	36.8	1.4	74.0	8.5
1990	817.3	18.9	79.7	6.3	2.1	33.5	11.3
1991	89.7	6.4	17.5	4.6	12.1	7.8	17.0
1992	459.6	10.9	6.1	0.3	13.4	8.2	19.5
1993	34.1	2.7	7.8	0.3	0.4	1.2	3.3
1994				No Survey			
1995	82.5	2.0	30.7	2.0	0.0	3.5	2.7

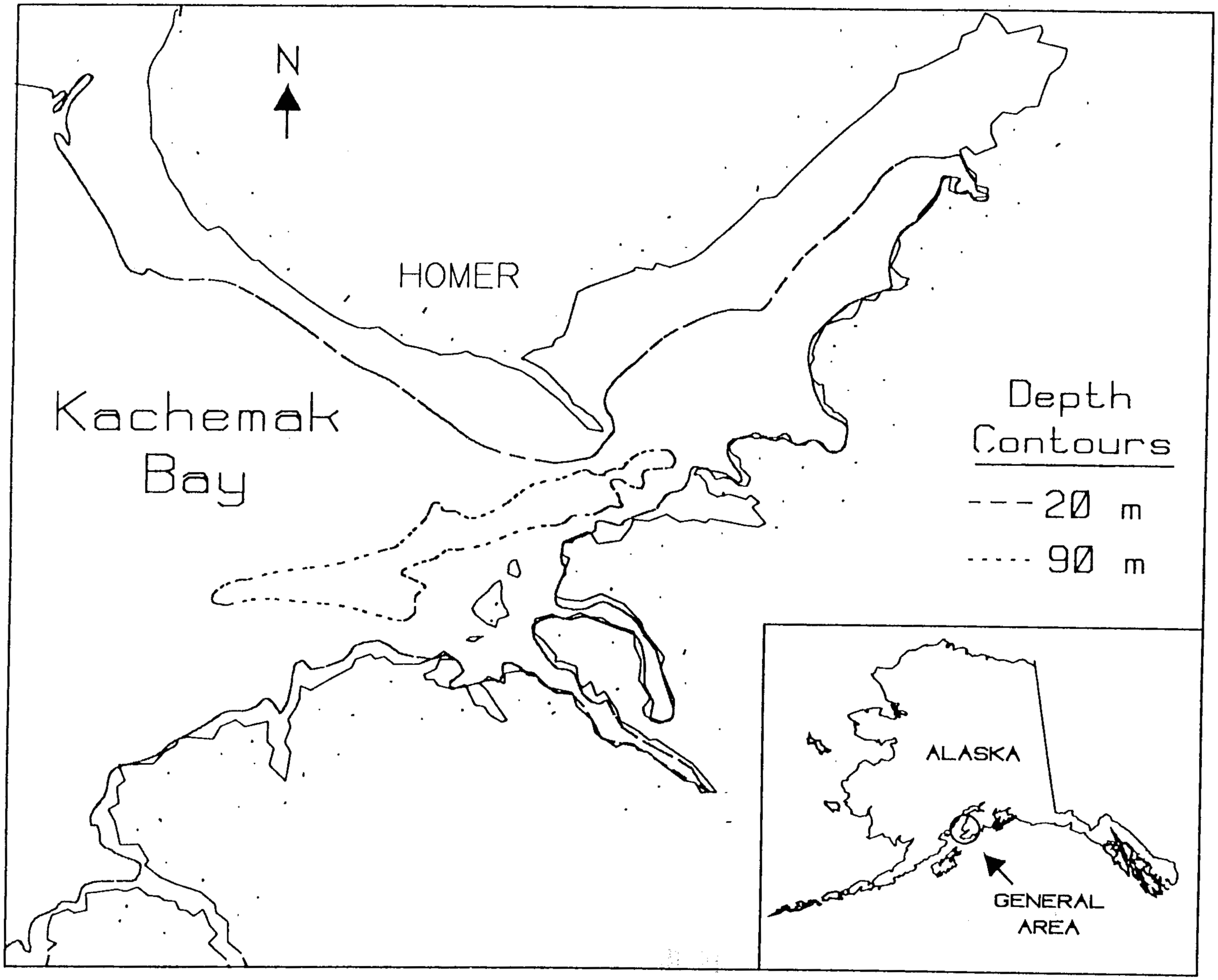

Figure 1. General study area for trawl shrimp surveys of Kackemak Bay, Alaska during 1976 to 1995.

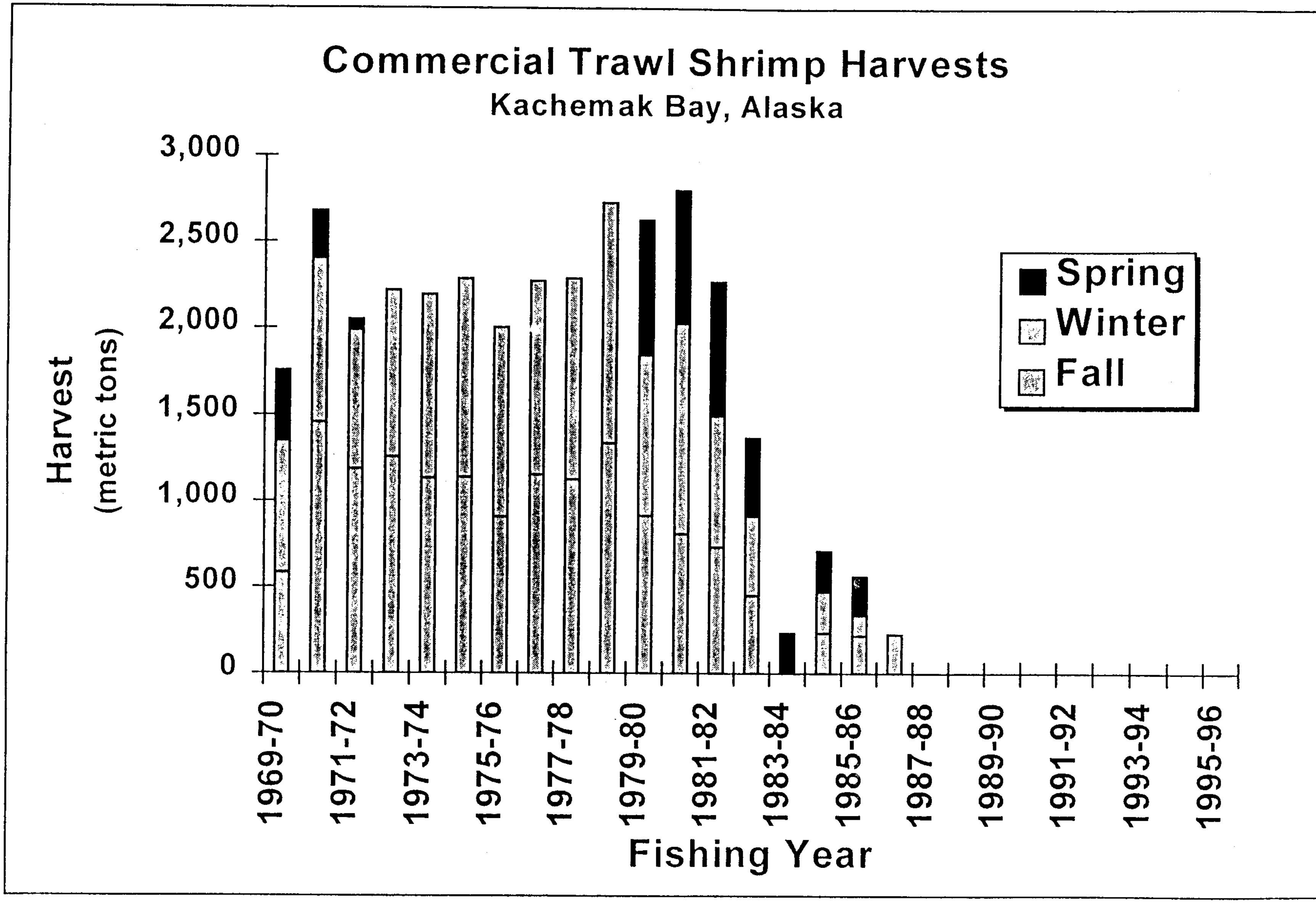

Figure 2. Commercial trawl shrimp harvests from Cook Inlet, Alaska during 1969 to 1996.

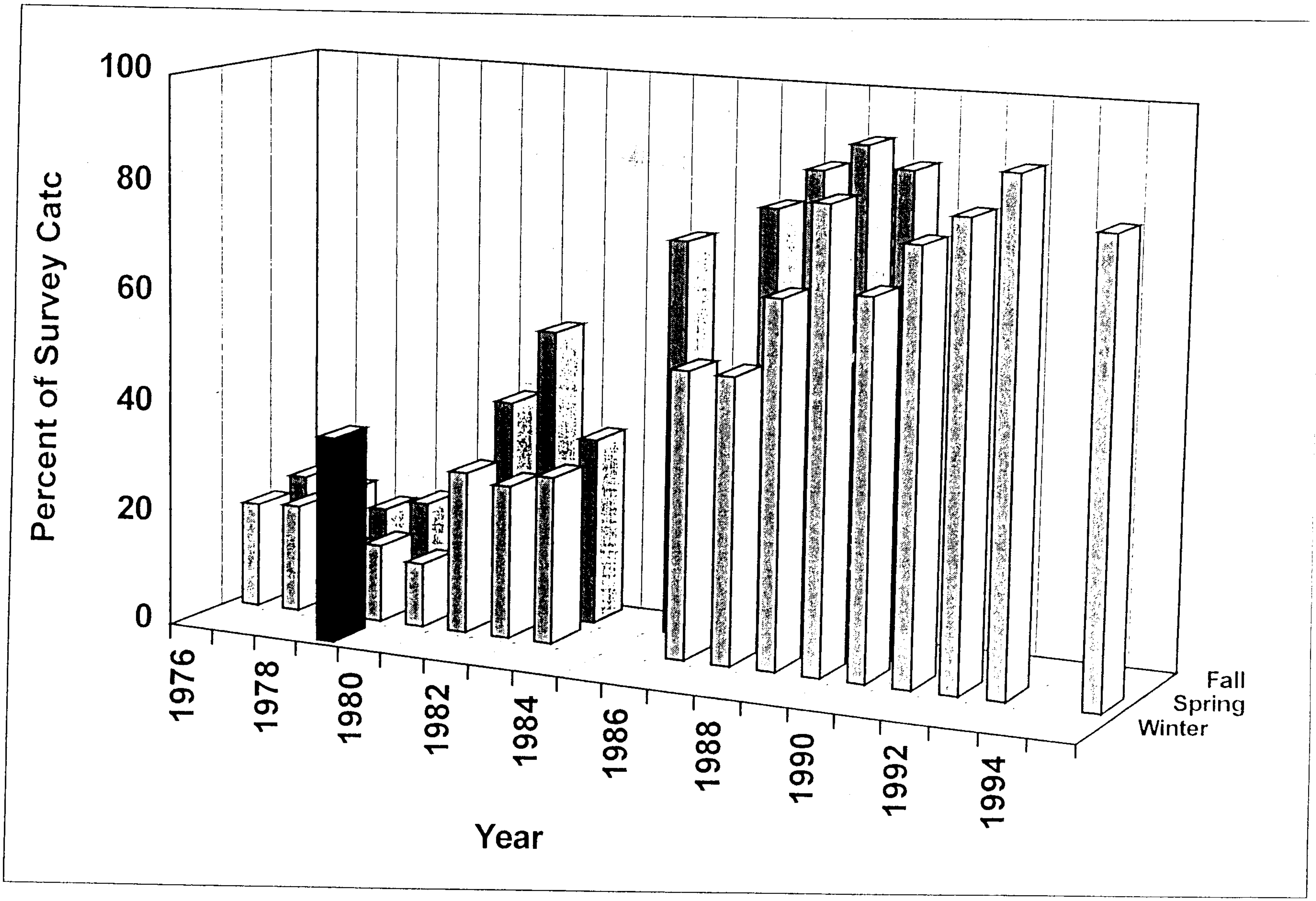

Figure 3. Changes in the fish component of trawl survey biomass in Kachemak Bay, Alaska from 1976 to 1995.

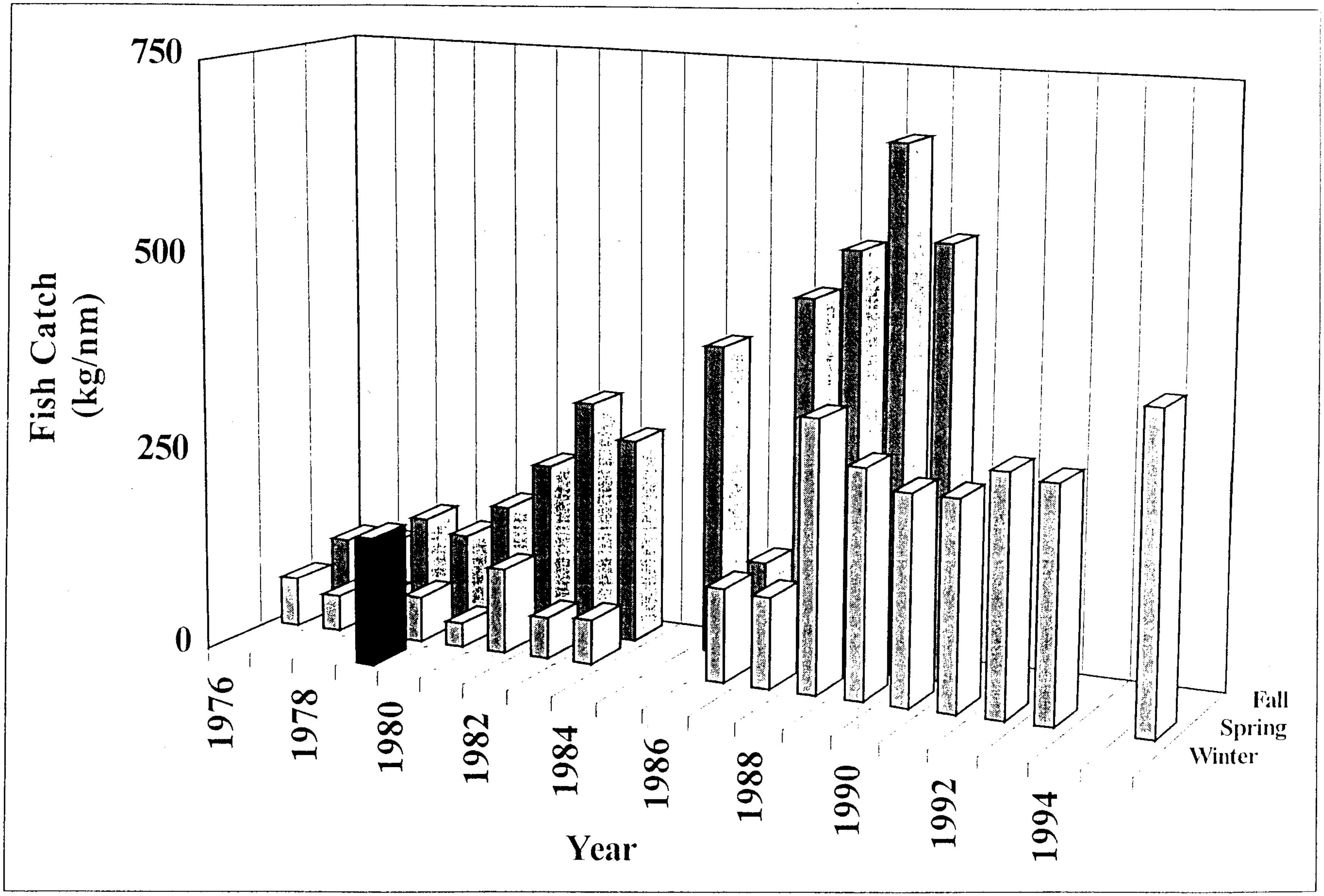

Figure 4. Changes in mean fish biomass during trawl surveys of Kachemak Bay, Alaska from 1976 to 1995.

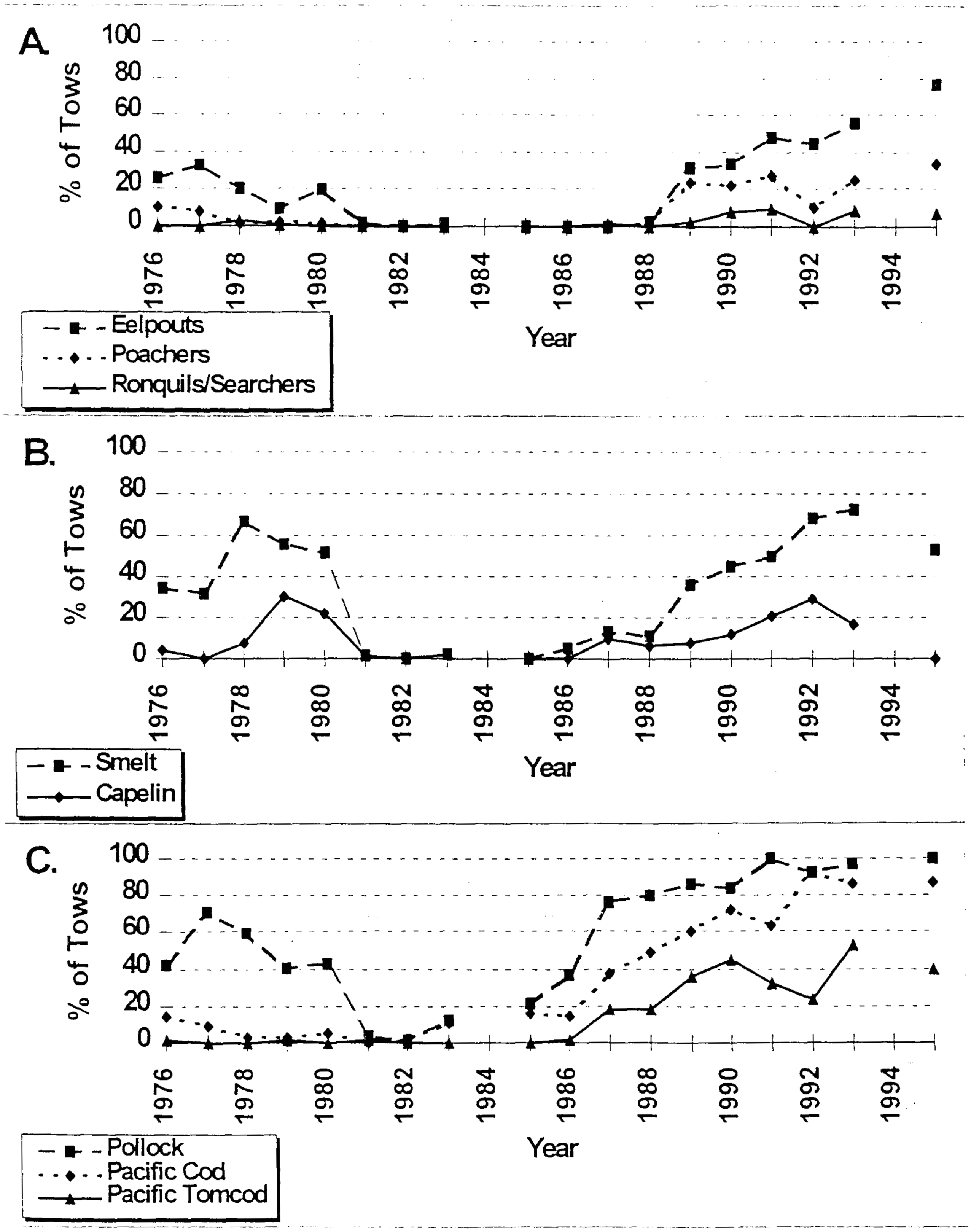

Figure 5. Frequency of occurrence for selected fish species during trawl surveys in Kachemak Bay, Alaska from 1976 to 1995.

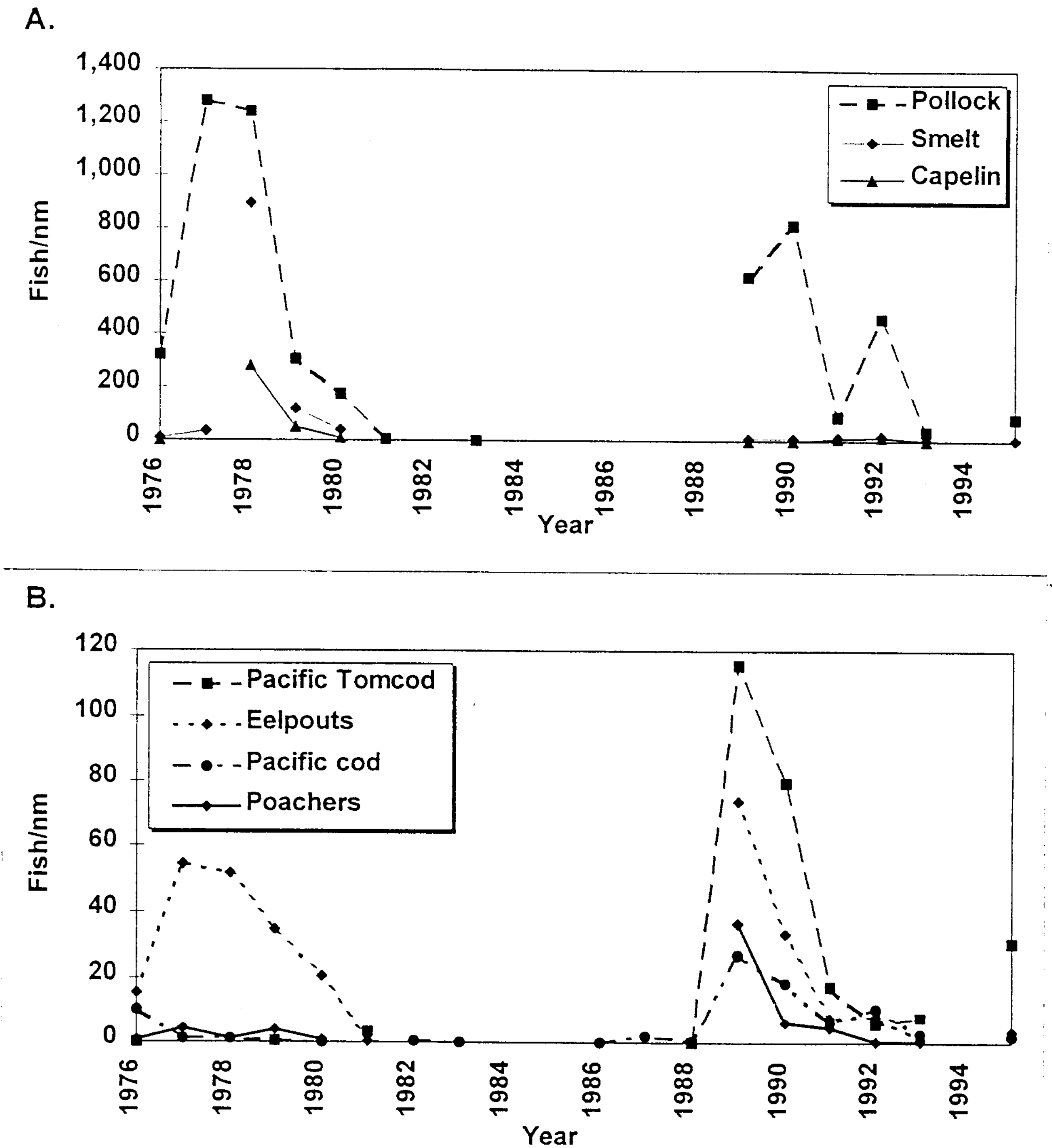

Figure 6. Mean catch of selected fish species during trawl surveys in Kachemak Bay, Alaska from 1976 to 1995.

Exxon Valdez Oil Spill
Restoration Project Annual Report

Analysis of Small-Mesh Trawl Data

Restoration Project (APEX) 96163L

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March 1997

Analysis of Small-Mesh Trawl Data

Restoration Project(APEX) 96163L
Annual Report

Study History: Restoration Project 96163L was initiated as part of the APEX project that is studying the relationship between changes in forage species composition and marine birds in the spill affected area. Large declines of apex predator populations (murres, kittiwakes, harbor seals, and Steller sea lion) have occurred in the Gulf of Alaska since the 1970s. Changes in composition and abundance of forage species may be responsible for the decline of these predator populations and their chronic low population levels. In an effort to delineate changes in forage species and a trophic regime shift, if any, over the last several decades, we have gathered together historical fishery-independent scientific survey data to address this question. This part of the annual report includes one manuscript submitted for publication from recent analysis of information and data from small-meshed tow and beach seining studies conducted in Cook Inlet and around Kodiak Island in 1976 and 1978 by the Alaska Department of Fish and Game.

Abstract: A small-mesh surface tow net and beach seine were used to sample the near-shore fishes on the west side of Kodiak and in Cook Inlet in late 1976 and 1978. Sampling was conducted from March through November, lowest catches occurring in March and November, and highest catches in May through September. The growth of sand lance (*Ammodytes hexapterus*) based on length frequencies indicated August mean size of 87 mm for age 0 and 136 mm for age 1 in the Kodiak area. Very little growth occurred between August and the following May. In Cook inlet both growth and catch rates were lower than Kodiak, with August mean size of 57mm for age 0 (age 1 average size was not available due to insufficient data). During August-September the abundance increased in inshore areas and in Cook Inlet, where growth was restricted, changes in size distribution occurred in a pattern which strongly suggested movement of the age 0 fish into near-shore waters. Catches stratified by tidal stage were not significantly different but suggested real differences exist that were not detected. Catch variability among samples were extremely high, coefficients of variation typically from 4 to 6. A few fish in spawning condition were found from August through November. Food habits from Cook Inlet showed more than 90% by weight of the food was calanoid copepods during the summer; more variety in diet was evident during different times.

Key Words: Cook Inlet, Kodiak Island, Pacific sand lance, growth, and seasonal movements.

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TITLE PAGE

Pacific Sand Lance (*Ammodytes hexapterus* Pallas) Growth, Seasonal Availability, Movements, Catch Variability, and Food in the Kodiak-Cook Inlet area of Alaska

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ABSTRACT

A small-mesh surface tow net and beach seine were used to sample the near-shore fishes on the west side of Kodiak and in Cook Inlet in 1976 and 1978. Sampling was conducted from March through November, lowest catches occurring in March and November, and highest catches in May through September. The growth of sand lance (*Ammodytes hexapterus*) based on length frequencies indicated August mean size of 87 mm for age 0 and 136 mm for age 1 in the Kodiak area. Very little growth occurred between August and the following May. In Cook Inlet both growth and catch rates were lower than Kodiak, with August mean size of age 0 of 57 mm (size of age 1 was not well documented in August in Cook Inlet). During August-September the abundance increased in inshore areas and in Cook Inlet, where growth was restricted, changes in size distribution occurred in a pattern which strongly suggested movement of the age-0 fish into the near-shore waters. Catches stratified by tidal stage were not significantly different but suggested real differences exist that were not detected. Catch variability among samples was extremely high, coefficients of variation typically from 4 to 6. A few fish in spawning condition were found from August through November. Food habits from Cook Inlet showed more than 90% by weight of the food was calanoid copepods during summer; more variety of items in the diet occurred at other times.

*Introduction

Little is known of the biology of the Pacific sand lance (*Ammodytes hexapterus* Pallas), although the species typically forms large schools (Trumble 1973) and is locally abundant in the near-shore waters of the North Pacific. Pacific sand lance are a major component of the diet of many marine birds, including tufted puffins (*Fratercula cirrhata*; Baird and Hatch 1979), horned puffins (*Fratercula corniculata*; Jones and Peterson 1979), black legged kittiwakes (*Rissa tridactyla*; Baird and Hatch 1979; Jones and Peterson 1979), glaucous winged gulls (*Larus glaucescens*; Baird and Hatch 1979), and rhinoceros auklet chicks (*Cerorhinca monocerata*; Verveer and Westrheim 1984). During winter in Kachemak Bay, Pacific sand lance were important to oldsquaw (*Clangula hyemalis*; Sanger et al. 1979; Sanger and Jones 1984) and less so to common murres (*Uria aalge*) and marbled murrelets (*Brachyramphus marmoratus*; Sanger et al. 1979). Pacific sand lance were important to Pacific cod (*Gadus macrocephalus*; Moiseev 1953; Kasahara 1961) and chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*), lingcod (*Ophiodon elongatus*), halibut (*Hippoglossus stenolepis*), and fur seals (*Callorhinus ursinus*; Hart 1973).

Trumble (1973) reviewed the sand lance family, Ammodytidae, and reported their strong association with clean sandy bottoms, probably related to their habit of burrowing. All species of sand lance live in shallow water, rarely exceeding 100 m depth. Very little information is available on seasonal distribution or migration. Kendall and Dunn (1985) reported that sand lance larvae were found in winter, spring, and summer near Kodiak, although they were most abundant in the spring, when they occurred throughout the study area.

Seasonal migration is common for Ammodytidae but has not been demonstrated in all areas (Trumble 1973). Citing Andriyashev (1954), Trumble stated that the Murman population moves into the coast beginning in mid June, where they remain until August or occasionally September, and then return to deep water for the winter. Trumble (1973) cited incomplete information from which it was deduced the North Sea sand lance migrate seasonally whereas those in the western Atlantic do not.

The purpose of this paper is to present information on the growth of sand lance, seasonal movements, seasonal availability, catch variability, spawning condition, and food in the Kodiak-Cook Inlet region of Alaska.

*Study Area

The study area included lower Cook Inlet from the Forelands south including Kachemak and Kamishak Bays and four bays on the east side of Kodiak: Izhut, Kalsin, Kiliuda, and Kaiugnak Bays (Figure 1). The Kodiak bays are more marine in character than Cook Inlet which is estuarine. In Cook Inlet the net flow consists of marine waters that enter between the Kenai Peninsula and the Barren Islands and flow north along the eastern shore. Water freshened by runoff and heavily laden with particulate matter flows south along the west side of the inlet and exits past Cape Douglas (Larrance et. al. 1977). Strong tidal currents are superimposed on the net flow. Primary productivity and chlorophyll *a* concentrations were consistently up to 2 times greater in Kachemak Bay than elsewhere in lower Cook Inlet, and primary productivity in Kamishak Bay was 10-50% that of Kachemak Bay(Larrance et al. 1977).

The ebb and flood of waters across vast intertidal deposits of silt present around the upper inlet and most of the lower inlet results in large temperature changes effected by prolonged solar heating during summer. This results in extreme fluctuations in environmental conditions, which are greatest on the west side of the inlet due to the current pattern. Near-shore water temperatures in Kamishak Bay in August 1978 ranged from 11.5^0 to 17^0 C.

*Materials and Methods

Samples for this study were collected in 1976 and 1978 as part of extensive studies of lower Cook Inlet and Kodiak. The survey of lower Cook Inlet in 1976 was designed to cover the greatest possible area once each month from June through September. In contrast, 1978 collections in Cook Inlet were designed to cover a smaller area twice each month.

In 1976, samples were taken from a pair of 5.1-m outboard skiffs. The eastern shore was accessed from the Homer boat harbor and transport by boat trailer. The western shore was reached by transporting the two skiffs on the deck of a larger vessel. Once there, two personnel in each skiff, traversed the survey area, and began collecting samples, camping nights until they rendezvoused with the larger vessel after 3-5 d.

In 1978 tow-net samples in Cook Inlet were taken using a 6.4-m outboard skiff and a 10.6-m vessel. In April the field personnel operated from Homer and in October from the Kasitsna field station. During May through September they lived in a field camp in Cottonwood Bay on the west side of the inlet.

The Kodiak field crew lived aboard and worked from a vessel, the 19.8-m M/V YANKEE CLIPPER during April through August. The R/V COMMANDO was used during November and March. A 5.7-m outboard skiff was used to pull one side of the tow net, and the larger vessel pulled the other side. The outboard was used for beach seining.

The beach seine was 47.25-m long by 3.6-m deep, was constructed of knotless nylon throughout, and was hung to float. It consisted of a rectangular center section, 10.6-m long by 3.6-m deep of 6-mm (1/4-in) ace web. amd two identical wings, tapered from the depth of the center section to 0.9-m deep at the ends, that were constructed of 6.1-m wide panels of 13-mm (1/2-in) ace webbing next to the center and 12.2-m wide panels of 38-mm (1-1/2-in) ace webbing to the ends. Ace webbing is woven, not to be confused with tied net material.

The beach was approached by a small outboard-powered boat, and the net was set within a few minutes and then immediately retrieved. The beach seine was set in an arc with each end of the net within about 3 m of the waters edge, which made escape around the ends unlikely. At nearly all locations fished the net reached bottom along its full length, preventing escape. The beach seine spanned about 30 m of beach and sampled about 370 sq m of water.

The tow net used during 1976 was 2.7 m square at the mouth and 8.2 m long. It was made of a 2.4-m forward section of 38-mm stretch mesh, a 2.7-m midsection of 13-mm stretch mesh, a 3.0-m cod end of 6-mm stretch mesh with a 3-mm (1/8-in) stretch mesh cod end liner in the last 0.6 m and a zipper on the cod end to access the catch. The net was held open vertically by spreader bars and horizontally by a towing vessel on each side. The net was pulled at the surface for 10 min at approximately 5 km/h by two 5.1-m skiffs with 70 hp outboards; each skiff was attached to the net with 20-m of cable.

The larger tow net used in 1978 was 6.1 m wide by 3.1 m deep at the mouth. It was constructed of a 4.6-m panel of 76-mm stretch mesh, a 2.2-m panel of 38-mm stretch mesh, a 2.5-m panel of 19-mm #126 web, and a 5.6-m panel of 6-mm #63 web, the last 1.2 m of which were lined with 3-mm web. The nets were deployed in a manner similar to that of the smaller tow net described above, except that one of the towing vessels was larger, 9.7 m in Cook Inlet and 19.8 m in Kodiak.

In early summer small sand lance larvae were too small to be sampled quantitatively. When larval fish were first caught in 1976 no attempt was made to identify them. During July they were first included in the catch data, and in 1978, larval sand lance were recorded throughout the study. The beach seine was spread on the beach and thoroughly examined for fish at the end of each set. Larval fish the size of sand lance were quite easily seen and recovered. When larval sand lance were caught in the tow net, often they were tangled in the meshes and only those in the cod end were readily recovered.

In 1976 in Cook Inlet, collections were made in four areas, at the same time each month. In Kachemak Bay samples were late in the month from May through September. On the west side of Cook Inlet from Cape Douglas to Chinitna Bay, samples were collected during the period of 6th to 14th of each month from June through September. Collections were made on the east side of Cook Inlet between Anchor Point and the Forelands during about 19th to 23rd from June through September. In the South Kenai area, southwest of Tutka Bay to Port Graham, collections were taken in early August and September. Length (total length in milimeters) frequencies were obtained from fish preserved in formalin for one to seven days.

In 1978, collections were taken from Kachemak Bay in April and October and from Kamishak Bay during May through September. Larval fish were routinely preserved, identified, and counted. Age-0 sand lance were usually recorded separately from large ones on catch forms. Length (total length in centimeters) frequencies were obtained from most samples of fresh fish. Stomach samples were taken from collections in Cook Inlet in 1978.

In Kodiak, samples were taken each month from April through August. Kalsin Bay was sampled from the 1st to 7th, Izhut Bay 8th to 15th, Kiliuda Bay 16th to the 23rd, and Kaiugnak Bay 24th through the end of the month. During November 1978 and March 1979 the sequence did not change but the time of month varied. A sample (selected without known bias) of fish was measured to the nearest centimeter total length at the time of capture. Unidentified larvae were routinely preserved and later sorted and recorded.

All samples collected in 1978 were classified by tidal stage using one hour before and one hour after tide change as the breaking points for low, flood, high, and ebb tide classifications. A statistical test of differences by tidal stage used a generalized linear model with binomial error and presence/absence as the dependent variable.

*Results

There were 1,449 gear sets completed in the three surveys; 437 of the sets caught sand lance, and lengths were sampled from 263 of these (Table 1). We caught 261,932 sand lance, and measured 4,676 for lengths (Table 1). Sand lance were numerically predominant in all areas except the west side of Cook Inlet in 1978, where herring were more numerous.

**Seasonality

The monthly catch rates for the tow net and beach seine (Figure 2) were highest in the Kodiak area, Kachemak Bay rates were lower, and the east and west sides of Cook Inlet had the lowest rates (Figure 2). Catch rates were low in the earliest (March and April) and latest months (November), and highest from May through September.

**Growth

The samples from Kodiak (Figure 3) contained 20-30-mm sand lance (age 0) in May, which grew about 20 mm per month to modes at 70 mm in July and 90 mm in August. A mode at 90 mm in March (age 1) progressed about 10 mm per month to 120-140 mm in July, and 130-140 mm in August and November, (note: the mode in August was hidden by the high abundance of the age-0 fish; Figure 3). If age-2 fish were present, they should have appeared at about 130-140-mm in March; there was a weak mode of the fish that progressed from that size to about 150 mm in June and was not seen later (Figure 3). Little growth occurred between August and April (Figure 3).

The samples from Cook Inlet in 1978 (Figure 4) show similar features. Age-0 sand lance 20-50 mm appeared in June and progressed to 80-90 mm by October (Figure 4). Age-1 fish, about 90-100 mm, appeared in June beach seine samples, grew for the next 2 months, but then were too infrequent to follow(Figure 4). A mode at 120 mm in May and June tow-net samples might have been age-2 fish (Figure 4). Careful examination of the July through September catches of age-0 fish (Figure 4) shows a relatively slow growth during July until the first week of August. During August and September there was a pronounced broadening of the size range of age-0 fish then a sudden shift to a much larger modal size (Figure 4). The fish in Kachemak Bay in October were about the same size as those on the west side in September (Figure 4). Monthly average sizes from the different areas indicate minimal growth between August and May (Figure 5).

The 1976 samples from Cook Inlet displayed a growth pattern similar to 1978, although several different areas were sampled (Figure 6). Kachemak Bay and South Kenai age-0 fish grew to a September size of about 73-78 mm, and those on the east and west sides grew to about 60 mm. The age-1 fish which appeared in late May in Kachemak at about 78-88 mm, grew to about 103 mm in late July and to 118-128 mm in late August. Age-1 fish from the east side appeared to be about 85 mm in late July but later growth was not clear.

**Inshore Movement

On the west side of Cook Inlet in 1978 age-0 sand lance increased in size between August and September (Figure 4), and the catch rate was substantially higher in September (Figure 2). The size mode increased from 50 mm in August to 80 mm in September, too great a change to be accounted for as growth. This suggests that the west side received an influx of larger fish (Figure 4). The west side of Cook Inlet in 1976 had neither a large increase in abundance (Figure 2) nor an increase in size of sand lance (Figure 5), indicating an influx of fish did not occur before the last samples in September that year.

In Kodiak there was neither an increase in size nor an increase in heterogeneity of sizes in August 1978 (Figure 3); however, consistent with an inshore movement there was a substantial increase in the beach seine catch rate and a decline in the tow-net catch rate (Figure 2). Catch in August was also more concentrated toward the inner portions of bays than at other times (Table 2).

Kachemak and South Kenai are essentially the inner part and outer part of the same bay. The age-0 sand lance from these areas averaged 57-58 mm in late July-early August (Figure 6). This size is consistent with 11-mm per month growth and a probable hatch date of about March 1. By one month later (late August-early September), Kachemak fish averaged 67 mm, but the South Kenai fish averaged 76 mm, much larger than expected with 11-mm per month growth (Figure 6). In late September, Kachemak fish averaged 75 mm. There was a substantial increase in catch per sample (Figure 2) in the beach seine in both the South Kenai and Kachemak areas simultaneous with the increases in size. The only likely explanation is a late August invasion of the area by larger fish, from oceanic areas, where growth was similar to that in Kodiak (Figure 6), with the larger fish first appearing in the outer part of the bay.

**Catch by Tidal Stage

Catches classified by tidal stage appeared to be different only during July and August. The trends were similar in Cook Inlet and Kodiak samples but higher Kodiak catches facilitate discerning trends. The beach seine catch rates in July and August were generally lowest on ebb and low tide and highest on flood and high stages (Table 3), whereas tow-net catch rates were higher on the ebb tide. Differences by tide stage were not statistically significant. (In an analysis by bay, tide, and gear each factor was significant but the interaction terms were also significant, masking any real effects). Both the statistical tests and the consistency suggest the differences are real, but do not establish it.

**Variability of Catch Rate

Variability of sand lance catches was typically very high. The monthly values for coefficient of variation of samples from Kodiak ranged from 2.9 to 6.4 for the beach seine and 1.8 to 5.4 for the tow net. Similar values were obtained in the Cook Inlet samples. High variability in catches per sample effected wide confidence ranges making comparisons difficult. The distributions of catch numbers per sample (Figure 7) are helpful. They convincingly show seasonality. And, the grouping of multiple catches with large values during the summer, especially in August beach seine, demonstrates repeatability in the catches.

**Spawning

Maturing ova and sperm were present in the body of larger sand lance from Kachemak Bay in September 1976. In Kodiak in 1978 maturing gametes were observed as early as late July. In late August one sample included one mature (free flowing) and two spent fish. Samples in November yielded 58 sand lance with extrudable gametes (Table 4). Mature fish were not seen at any other time of year. The 83 maturing and spawning fish captured in August and November ranged from 104 to 155 mm, and the 29 fish judged to be immature ranged from 62 to 114 mm. There were few fish between 104 and 114mm suggesting that no age-0 fish were mature and that all age-1 and older fish were mature.

**Food Habits

Sand lance from Cook Inlet were sampled for food habits during three periods in 1978. The 191 specimens had consumed 26 different taxa (Table 5). Copepods composed 43-91% by weight of the diets. Non-calanoids were eaten in April, whereas mostly calanoids were consumed from May through October. Barnacle (cirripede) nauplii composed 12% of the diet in April through mid June. Barnacle cyprids were very frequent but composed 3% or less of the diet. Larvaceans composed 23% of the diets late in the year (Figure 8). Shrimp larvae were 22% of the diet in April through mid June. Fish larvae (including herring) composed 3% of the April-mid June diet and chaetognaths (arrow worms) composed 4% of the September-October diet. Also consumed were fish eggs, cladocera, cumacea, polychaetes, diatoms, gammarid amphipods, bivalve larvae, crab larvae (6 taxa), gastropod veligers, mysids, unidentified crustacea, and adult insects.

The food during both early and late summer was much more diverse than during mid summer (mid June through August).

*Discussion

Catches of sand lance were high from May through September, but catches were largest and most frequent during August and September, especially for beach seines. In general, age-1 and older sand lance were a greater proportion of the catch early in the summer, age 0 becoming more important in July-August. The late summer increase in beach seine catch rate of age-0 sand lance was due in part to their growing to a size that could be captured, but that size was attained by the cohort in July, implying that further increase in catch rate was due to inshore movement. The interruption of studies in Kodiak between August and November precluded documenting details of the transition to low winter abundance. In Cook Inlet sand lance were still common in September though decreasingly abundant into October. The decreased abundance is probably due to the fish spending increasing amounts of time buried in the refuge of the sand. The minimal growth between August and May supports this interpretation. Fish were not captured in March in Kodiak, were rarely taken in April, and became fairly common in May. Growth of age-1 and older fish began in June, when abundance was high.

Catches in the tow net from Kodiak were a different pattern; they were mostly age 0, were highest in May, and declined through August. This is consistent with sampling at the pelagic extreme of a life history where the youngest are pelagic and dispersed, then become closely associated with shallow sandy areas.

Sand lance apparently spawn in sandy areas inside bays, especially near the outlets of rivers and creeks (Dick and Warner, 1982). The larvae would be dispersed by the currents, and as they grow, become increasingly mobile. The massive inshore migration documented here is a logical necessity to make the transition to winter residence in the refuge of sand. The larval dispersion is supported by Kendall and Dunn (1985) who found small larvae most abundant nearer shore and a bit more widely dispersed as larger juveniles. Offshore spawning or wintering areas may exist, although we have no evidence of such, and suitable offshore habitat is very limited in the Kodiak area.

The increased size of age-0 sand lance in Cook Inlet noted in September and October was probably due to larger fish moving into the area. Apparently these fish did not move back out the following summer since a decrease in size of age 1 was not observed early in summer.

The inshore migration provides an important food source to predators for a relatively short portion of the year. Many studies cite the use of sand lance during July and August as food of birds (Baird and Hatch, 1979; Jones and Peterson, 1979; Verveer and Westrheim, 1984). Moiseev (1953) states, that in Anadyrski Bay cod concentrate and feed heavily on sand lance between the middle of August and end of October when the sand lance are all over the littoral region.

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Table 1. Descriptive statistics of effort, catch of sand lance, and sampling of sand lance by gear and study from three independent studies.

Area and Gear	Number of Sets	Sets With Catch	Catch Sampled	Number Caught	Number Measured
KODIAK 1978/79					
Beach Seine	418	138	118	150,775	2,475
Tow Net	214	48	19	54,369	295
Cook Inlet 1976					
Beach Seine	241	81	14	34,432	187
Tow Net	214	76	23	16,818	318
Cook Inlet 1978					
Beach Seine	256	78	73	4,711	967
Tow Net	106	16	16	827	434
Total	1,449	437	263	261,932	4,676

Table 2. Mean number of sand lance per sample by month for the four bays sampled in Kodiak from May through November. Catches during March and April were too low to be meaningful for the purposes of this table.

	BEACH SEINE					TOW NET				
	MAY	JUN	JUL	AUG	NOV	MAY	JUN	JUL	AUG	NOV
Kalsin Bay										
Inner	0	0	25	5569	NS	2008	0	NS	0	0
Outer	0	0	0	725	0	125	0	NS	0	0
Izhut Bay										
Inner	0	10	197	4967	0	NS	35	0	350	0
Inner mid	1	4	2594	157	0	NS	300	0	1	0
Outer mid	3	0	723	0	0	NS	1000	0	0	0
Outer	NS	NS	NS	NS	NS	NS	525	0	0	0
Kiliuda Bay										
Inner	8	1	1	1	0	6	0	0	82	0
Inner mid	3	3	10	416	15	4	NS	4842	0	0
Outer mid	75	0	6	187	0	NS	NS	2765	0	0
Outer	0	16	1	188	1	NS	NS	0	0	0
Kaiugnak Bay										
Inner	230	453	0	6043	3	NS	NS	0	963	0
Outer	3	0	0	4552	0	NS	NS	0	0	0

Table 3. Catch per haul and frequency of occurrence in percent of sand lance catches from Kodiak and Cook Inlet in 1978 by gear and tidal stage.

Gear/Region	Month	TIDAL STAGE HIGH	EBB	LOW	FLOOD
		Catch Per Haul			
Beach Seine					
Kodiak	Jul	118	67	1	604
Kodiak	Aug	2930	438	1668	2425
Cook Inlet	Jul	8	4	0	13
Cook Inlet	Aug	0	3	0	4
Tow Net					
Kodiak	Jul	0	1528	0	0
Kodiak	Aug	0	148	0	93
Cook Inlet	Jul	0	20	15	0
Cook Inlet	Aug	0	0	0	0
		Percent Frequency of Occurrence(Number of Samples)			
Beach Seine					
Kodiak	Jul	33 (6)	37(19)	11 (9)	40(30)
Kodiak	Aug	45(11)	47(17)	75 (8)	67(30)
Cook Inlet	Jul	40(15)	27(15)	33 (3)	33 (6)
Cook Inlet	Aug	21(14)	57(14)	0 (2)	24(17)
Tow Net					
Kodiak	Jul	0 (4)	32(19)	0 (1)	0(14)
Kodiak	Aug	0 (7)	15(26)	0 (2)	50(14)
Cook Inlet	Jul	0 (3)	20(10)	100 (2)	12(16)
Cook Inlet	Aug	0 (3)	0(21)	0 (4)	0 (7)

Table 4. Number of fish recorded at each stage of maturity by date in Kodiak in 1978.[a]

Gonadal Stage	JULY 1-15	JULY 16-31	AUGUST 1-15	AUGUST 16-31	NOVEMBER 1-8	NOVEMBER 12-18
Maturing		1	1	18		1
Spawning				1	10	48
Spent				2		2
Inactive		6	3			

[a] The project objectives did not include documenting spawning so the methods of determining hese stages were those of the field biologists. Spawning was defined as sperm or ovulated eggs readily extruded

Table 5. Pacific sand lance (*Ammodytes hexapterus*) diet composition in percent occurrence, percent by numbers, and percent by weight by major food item and time of year from Lower Cook Inlet in 1978. April and October fish were from Kachemak Bay and others were from Kamishak Bay.[a]

Food Item	April 11 through June 15			June 16 through Aug. 31			Sep. 1 through Oct. 31		
	% Occur.	% By Number	% By Weight	% Occur.	% By Number	% By Weight	% Occur.	% By Number	% By Weight
Copepod, calanoid	78	35	43	89	93	91	84	73	68
Copepod, other	59	10	12	11	0	0	13	0	0
Cirripedia nauplii	86	34	12	37	5	2	18	1	1
Cirripedia cyprids	90	4	3	41	1	1	18	0	0
Shrimp Larvae	29	5	22	1	0	3	4	0	1
Polychaetes	32	0	0	6	0	0	20	1	1
Fish Eggs	42	1	1	0	0	0	0	0	0
Fish Larvae	7	0	3	5	0	1	0	0	0
Gastropod veligers	2	0	0	38	0	1	13	0	1
Chaetognaths	0	0	0	2	0	0	9	0	4
Larvaceans	0	0	0	1	0	0	36	25	23
Other	75	12	3	23	0	0	11	0	0
Number of Fish		59			87			45	
Number Empty		1			7			7	
Predator Size Range		66-147 mm			57-130 mm			56-100 mm	

[a] Sampling was from 12 periods (April, half-monthly from May through September, then all of October) and these have been grouped here based on periods of consistency.

*List of Figures

1. Location of areas sampled for sand lance in Cook Inlet and on the east side of the Kodiak Archipelago.

2. Number of sand lance caught per sample by month and area from four sample areas in Cook Inlet in 1976, the west side of Cook Inlet in 1978, and the Kodiak area in 1978-79. The error bar is one standard error.

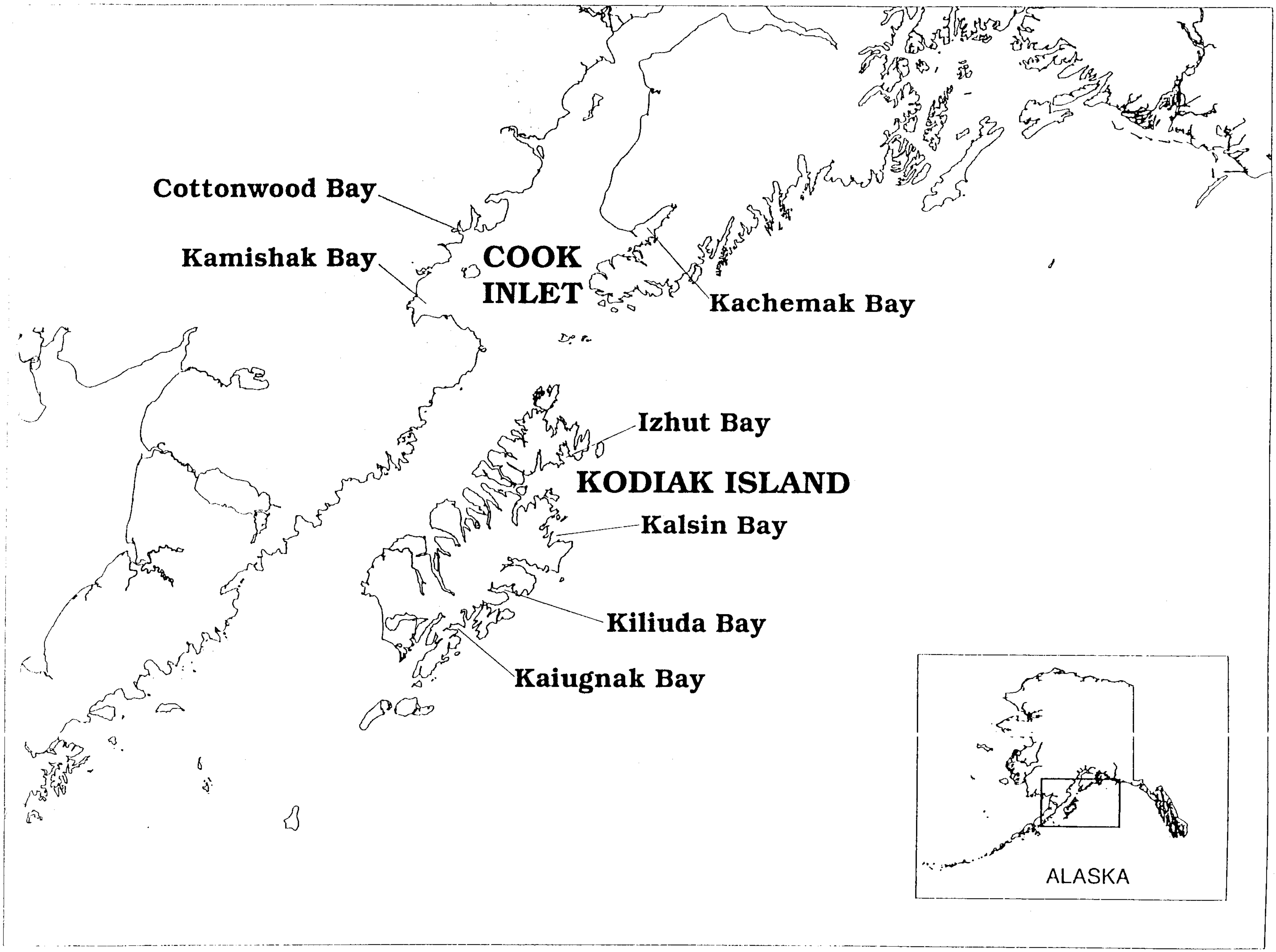
3. Monthly size-frequency distributions of sand lance from the Kodiak area in 1978-79.

4. Monthly size-frequency distributions of sand lance from Cook Inlet in 1978, by sample gear.

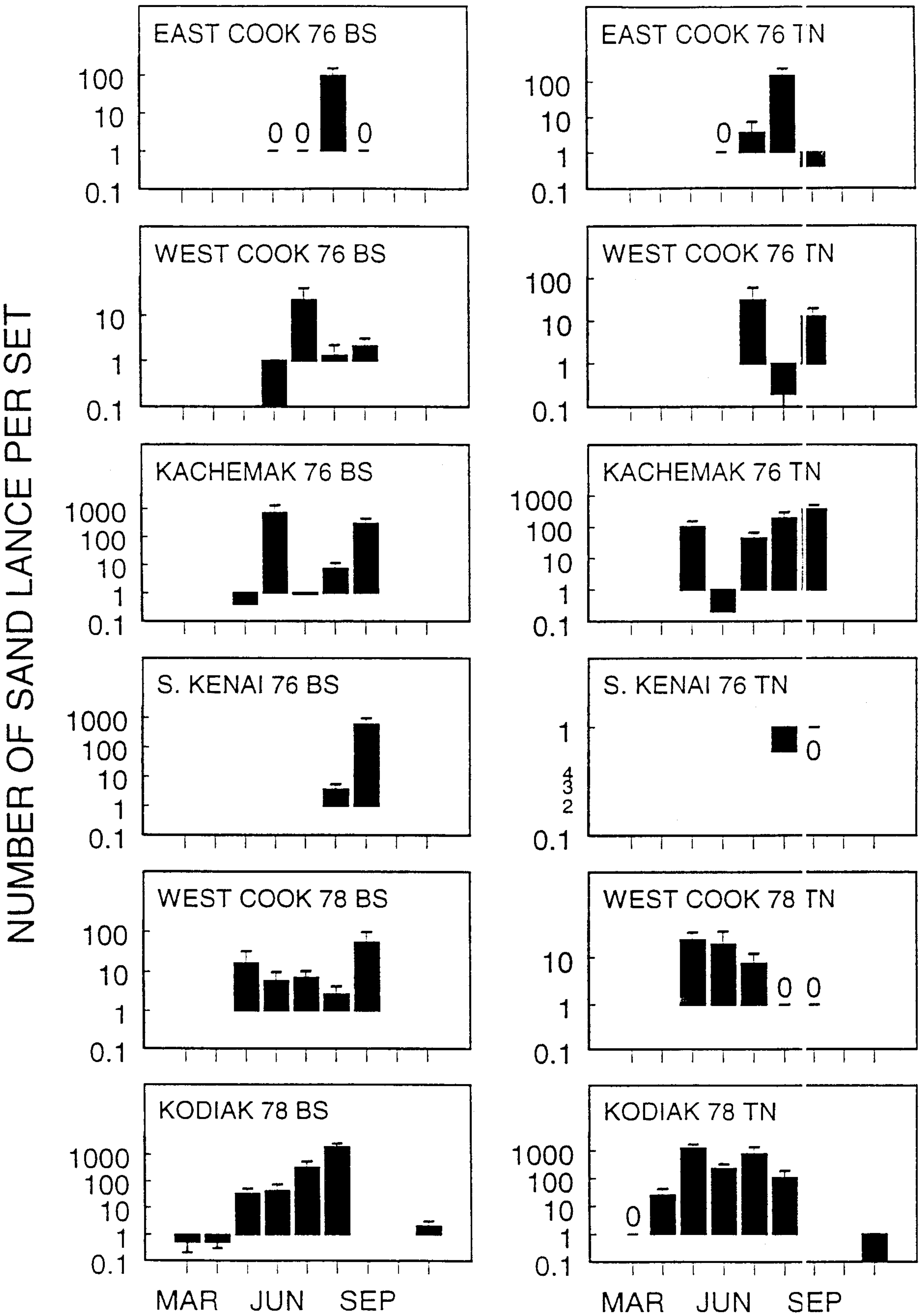
5. Average size of sand lance by month of age from Kodiak in 1978-79 and Cook Inlet in 1978. January 1 is the assumed birthday.

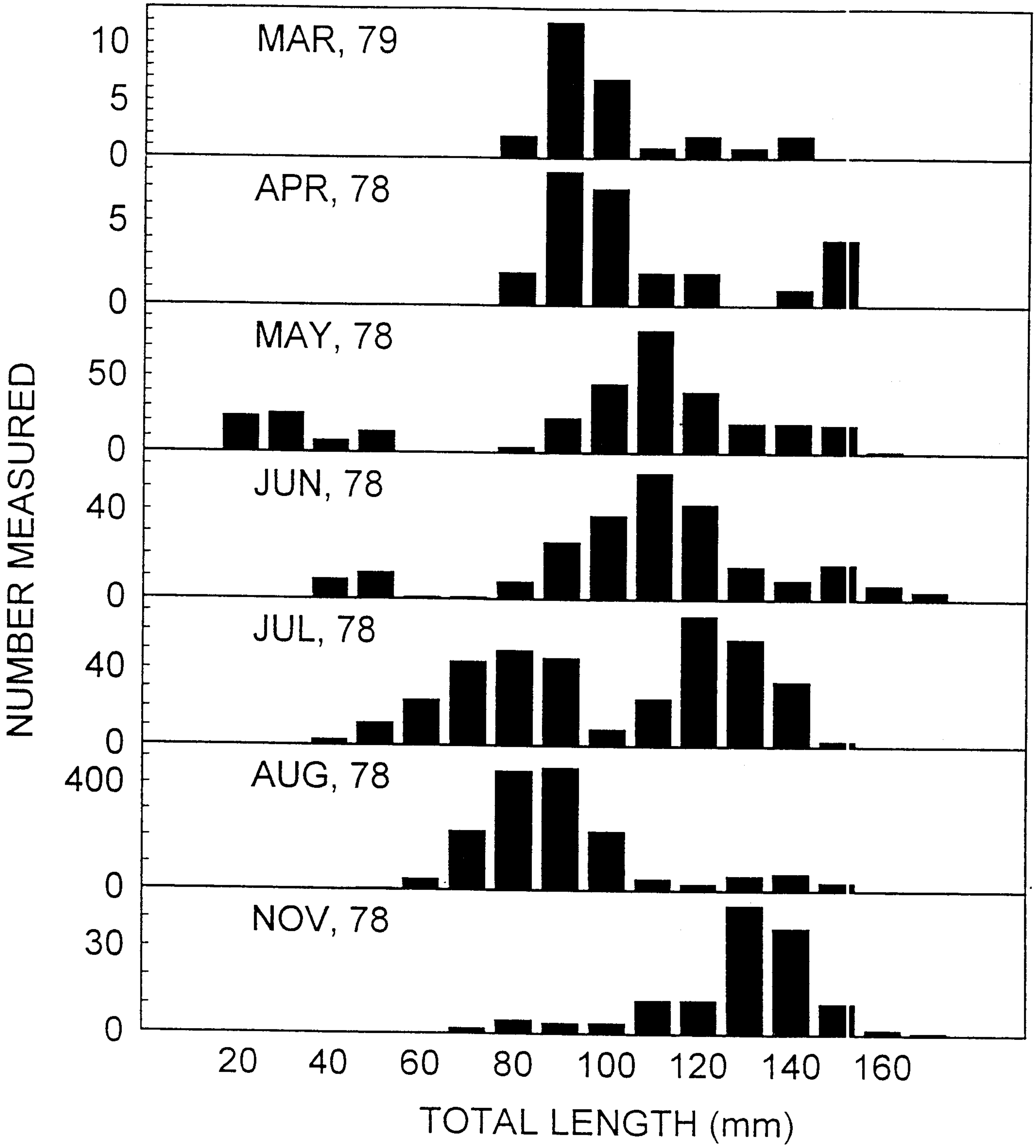
6. Weekly size-frequency distributions of sand lance from Cook Inlet in 1976 including separation by area.

7. Frequency distribution of number of beach seine sets that contained the indicated number of sand lance. Sets with zero catches were off the scale.

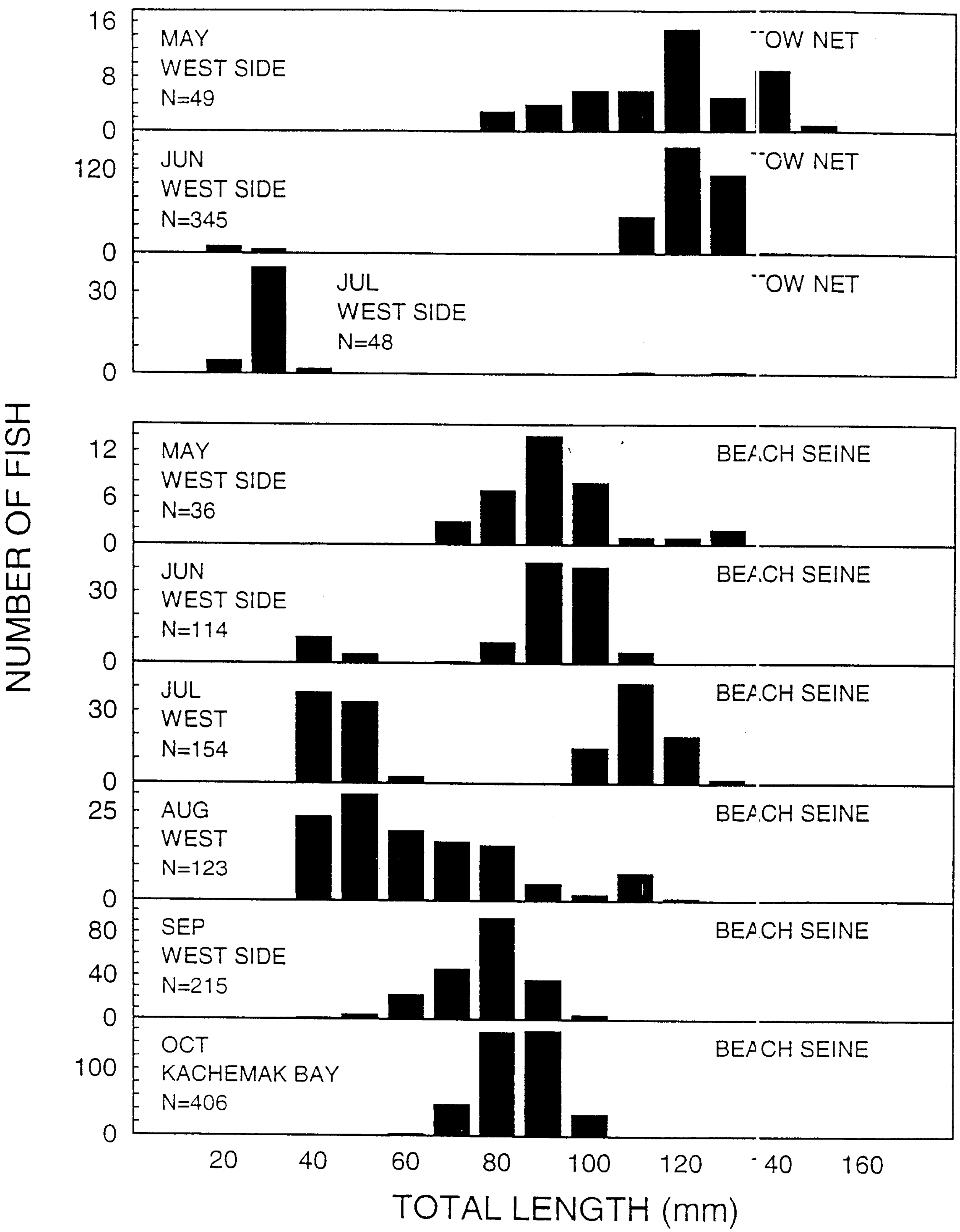


Cottonwood Bay
Kamishak Bay
COOK INLET
Kachemak Bay
Izhut Bay
KODIAK ISLAND
Kalsin Bay
Kiliuda Bay
Kaiugnak Bay
ALASKA

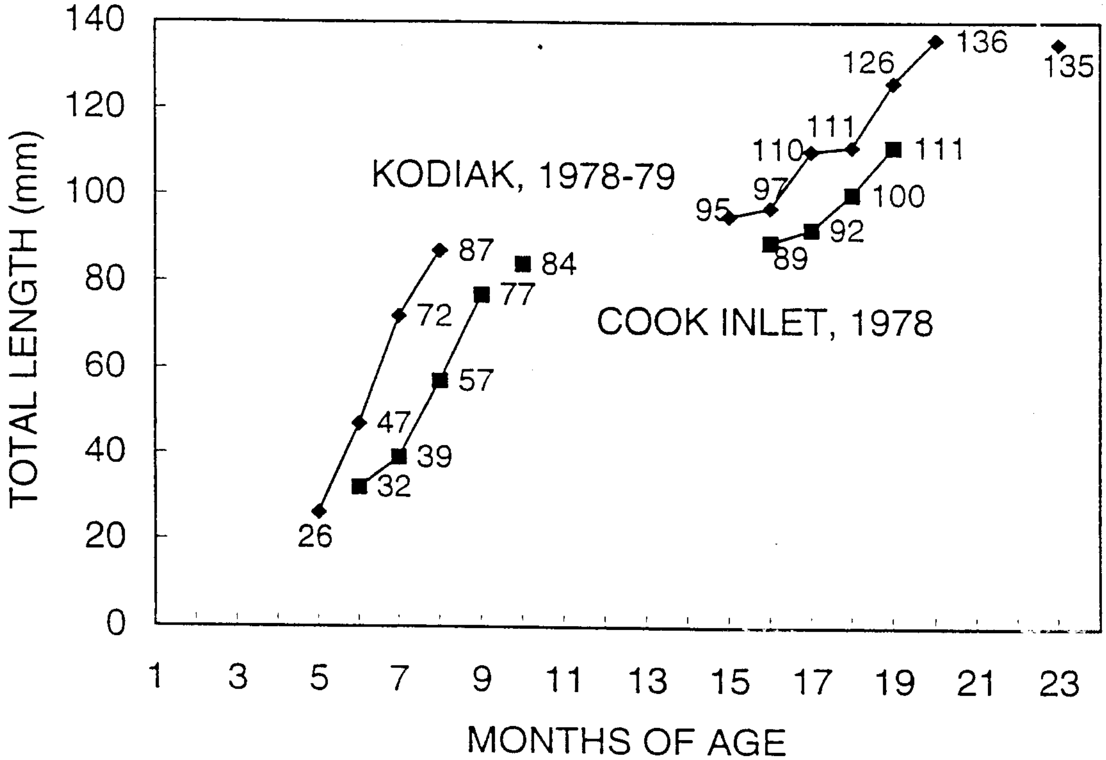

NUMBER OF SAND LANCE PER SET
EAST COOK 76 BS
EAST COOK 76 TN
WEST COOK 76 BS
WEST COOK 76 TN
KACHEMAK 76 BS
KACHEMAK 76 TN
S. KENAI 76 BS
S. KENAI 76 TN
WEST COOK 78 BS
WEST COOK 78 TN
KODIAK 78 BS
KODIAK 78 TN
MAR
JUN
SEP
MAR
JUN
SEP



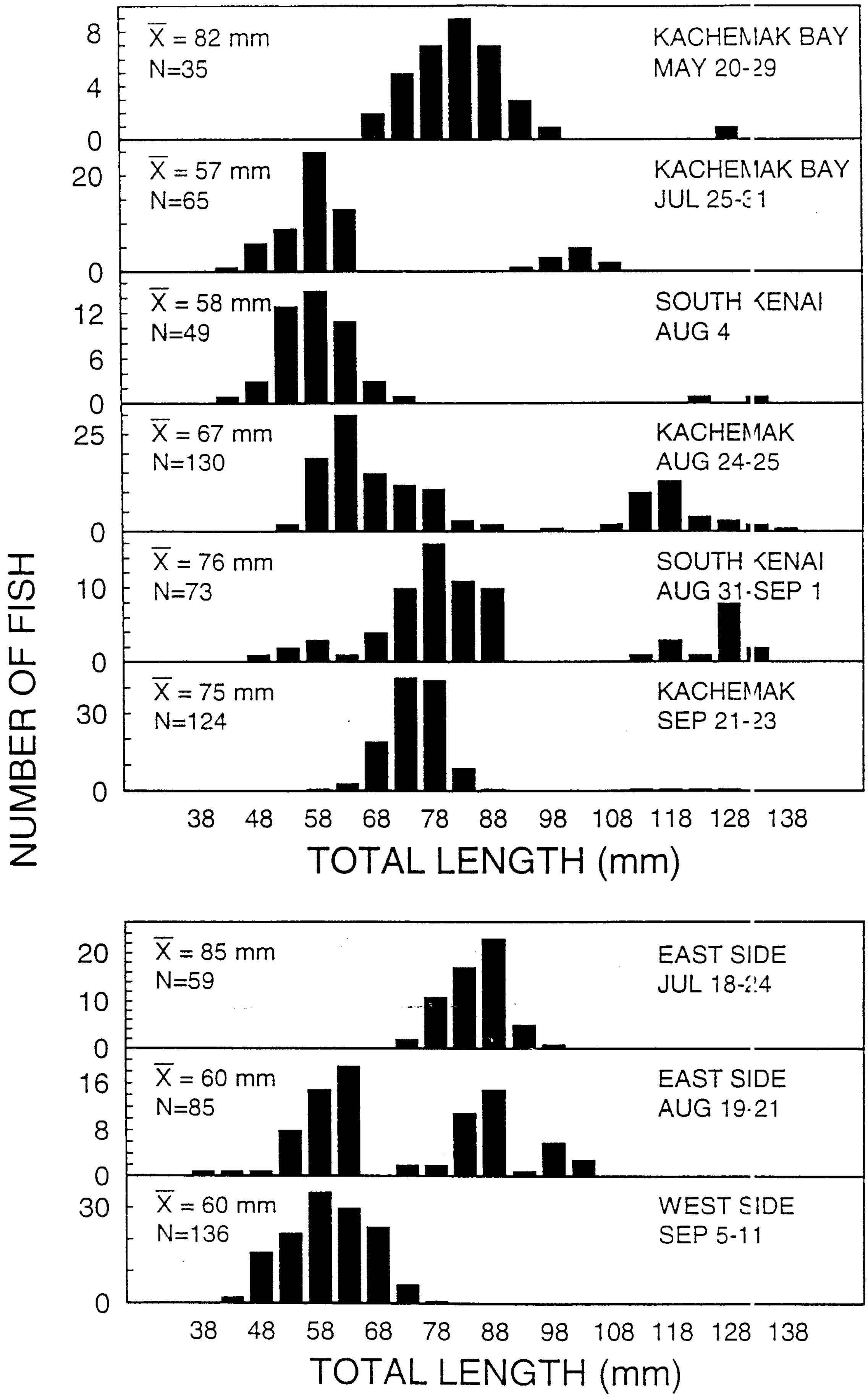
NUMBER MEASURED
MAR, 79
10
5
0
APR, 78
5
0
MAY, 78
50
0
JUN, 78
40
0
JUL, 78
40
0
AUG, 78
400
0
NOV, 78
30
0
20
40
60
80
100
120
140
160
TOTAL LENGTH (mm)



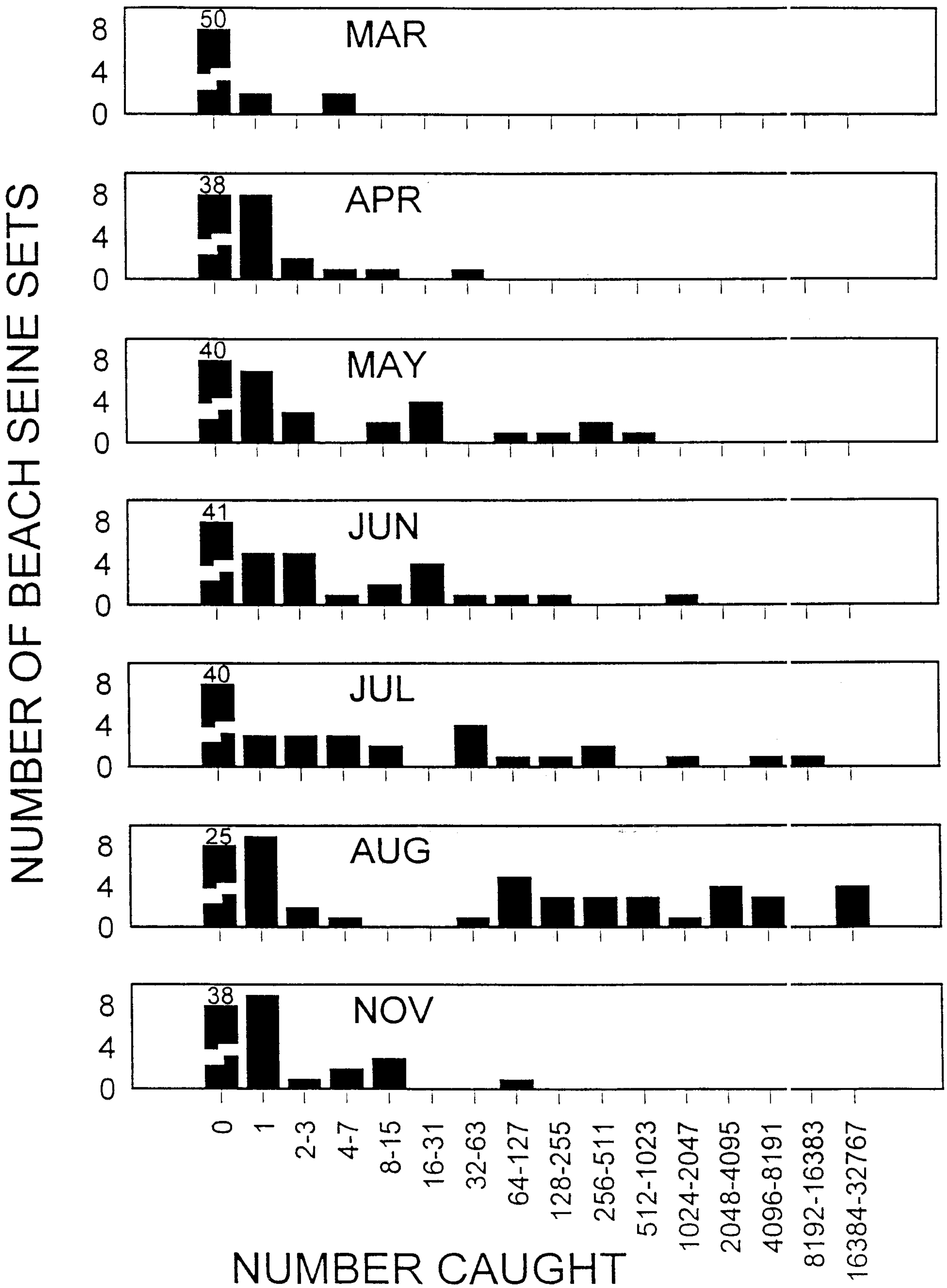
NUMBER OF FISH
MAY WEST SIDE N=49
¯¯OW NET
JUN WEST SIDE N=345
¯¯OW NET
JUL WEST SIDE N=48
¯¯OW NET
MAY WEST SIDE N=36
BEACH SEINE
JUN WEST SIDE N=114
BEACH SEINE
JUL WEST N=154
BEACH SEINE
AUG WEST N=123
BEACH SEINE
SEP WEST SIDE N=215
BEACH SEINE
OCT KACHEMAK BAY N=406
BEACH SEINE
20 40 60 80 100 120 140 160
TOTAL LENGTH (mm)



TOTAL LENGTH (mm)
MONTHS OF AGE
KODIAK, 1978-79
COOK INLET, 1978
0
20
40
60
80
100
120
140
1
3
5
7
9
11
13
15
17
19
21
23
26
47
72
87
32
39
57
77
84
95
97
110
111
126
136
135
89
92
100
111



NUMBER OF FISH
X̄ = 82 mm
N=35
KACHEMAK BAY
MAY 20-29
X̄ = 57 mm
N=65
KACHEMAK BAY
JUL 25-31
X̄ = 58 mm
N=49
SOUTH KENAI
AUG 4
X̄ = 67 mm
N=130
KACHEMAK
AUG 24-25
X̄ = 76 mm
N=73
SOUTH KENAI
AUG 31-SEP 1
X̄ = 75 mm
N=124
KACHEMAK
SEP 21-23
38 48 58 68 78 88 98 108 118 128 138
TOTAL LENGTH (mm)
X̄ = 85 mm
N=59
EAST SIDE
JUL 18-24
X̄ = 60 mm
N=85
EAST SIDE
AUG 19-21
X̄ = 60 mm
N=136
WEST SIDE
SEP 5-11
38 48 58 68 78 88 98 108 118 128 138
TOTAL LENGTH (mm)


NUMBER OF BEACH SEINE SETS
MAR
50
APR
38
MAY
40
JUN
41
JUL
40
AUG
25
NOV
38
0
4
8
0
1
2-3
4-7
8-15
16-31
32-63
64-127
128-255
256-511
512-1023
1024-2047
2048-4095
4096-8191
8192-16383
16384-32767
NUMBER CAUGHT