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Defining Habitats for Juvenile Groundfishes in Southcentral Alaska with Emphasis on Flatfishes

Volume I. Final Report

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FINAL REPORT

Defining Habitats for Juvenile Groundfishes in Southcentral Alaska, with Emphasis on Flatfishes

Volume I: Final Report

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Table of Contents

Volume I. Final Study Report

Chapter 1.

Depth and Substrate as Determinants of Distribution of Juvenile Flathead Sole (*Hippoglossoides elassodon*) and Rock Sole (*Pleuronectes bilineatus*)
by Alisa A. Abookire and Brenda L. Norcross
Published in Journal of Sea Research
(Journal's Permission Appendix II-3)

Cnapter 2.

The Effects of Seasonal Temperature and Salinity Patterns on Distribution, Abundance, **and Growth of Juvenile Flathead Sole and Rock Sole in Kachemak Bay, Alaska**
by Alisa A. Abookire and Brenda L. Norcross

Chapter 3.

Using Habitat Characteristics in the Assessment of Interannual Fluctuations in Juvenile Flatfish Abundances

by Sherri C. Dressel and Brenda L. Norcross

Chapter 4.

Influence of Spatial, Temporal and Physical Parameters on Abundance of Juvenile Groundfishes in Southcentral Alaska

by Brenda L. Norcross, Alisa A. Abookire, and Sherri C. Dressel

Contents (Volume I-Continued)

Chapter 5.

investigation of Benthos and Flatfish Diets at One Site in Kachemak Bay

by Rrenda A. Holladay and Brenda L. Norcross

Volume II. Appendices

Appendix II-1. Sample Collection Cruise Reports

LIST OF TABLES, WITH ABBREVIATED DESCRIPTIONS

Introduction

Methods

Chapter 1. Depth and substrate as determinants of distribution of juvenile flathead sole (*Hippoglossoides elassodon*) and rock sole (*Pleuronectes bilineatus*)

Chapter 2. The effects of seasonal temperature and salinity patterns on distribution, abundance and growth of juvenile flatfish in Kachemak Bay, Alaska

Chapter 3. Using habitat characteristics in the assessment of interannual fluctuations in juvenile flatfish abundances

Chapter 4. Influence of spatial, temporal and physical parameters on abundance of juvenile groundfishes in Southcentral Alaska

Chapter 5. Investigation of benthos and flatfish diets at one site in Kachemak Bay

LIST OF FIGURES, WITH ABBREVIATED DESCRIPTIONS

Introduction

Methods

Cbapter 1. Depth and substrate as determinants of distribution of juvenile flathead sole (*Hippoglossoides elassodon*) and rock sole (*Pleuronectes bilineatus*)

Cbapter 2. The effects of seasonal temperature and salinity patterns on distribution, abundance and growth of juvenile flatfish in Kachemak Bay, Alaska

Chapter 3. Using habitat characteristics in the assessment of inter-annual fluctuations in juvenile flatfish abundances

Chapter 4. Influence of spatial, temporal and physical parameters on abundance of juvenile groundfishes in Southcentral Alaska

Chapter 5. Investigation of benthos and flatfish diets at one site in Kachemak Bay

EXECUTIVE SUMMARY

Groundfishes, especially flatfishes, are of great economic importance to Alaskan commercial and sport fisheries, yet knowledge of the juvenile stages of these fishes is often incomplete. Thorough knowledge of species life history, biology and habitat requirements is necessary to assess potential environmental impacts, to assist in strategic planning by fisheries managers, members of the fishing community and industrial developers. Quality and quantity of nursery habitat are probably the most vital factors determining survival of juvenile fishes (Gibson, 1994); thus it is essential that nursery areas be identified.

Objectives of this project were (1) to identify nursery grounds for juvenile flatfishes in Kachemak Bay, lower Cook Inlet, and Chiniak Bay, Kodiak Island (Figure I-l), (2) to characterize those areas according to physical and biological parameters and (3) to develop indices of relative abundance for as many species as the data allow, on a seasonal basis for Kachemak Bay, and an annual basis for Chiniak Bay. To meet these objectives, seasonal (winter, spring and summer) surveys of juvenile groundfishes were conducted in Kachemak Bay from 1994 to 1996, and annual summer collections of juvenile groundfishes in Chiniak Bay, begun in 1991, were continued during 1995 and 1996. At each collection site, a conductivity–temperature–depth probe, sediment grab and net were deployed. Fishes were collected using a 3.05 m plumb staff beam trawl equipped with a double tickler chain 7 mm square mesh bag and 4 mm codend liner. Fishes were identified and measured, and ages of flatfishes were estimated based on total length. Catch-per-unit-effort values (CPUE) were calculated for each species based on the number of fish per 1000 m^2 area swept. These values were examined relative to the physical habitat of capture. Measured physical parameters included depth, bottom temperature and salinity, sediment grain size, organic carbon and carbonate in the sediment, and temporal relation of the fish collection to sunrise and tidal stage.

Sampling three times a year over two years in Kachemak Bay provided insight into short term interannual and seasonal variability, and allowed habitat parameters of juvenile flatfishes to be quantified in a location separate from Kodiak Island. Collections in Kachemak Bay were taken during September 1994, May and August 1995, and February, May and August 1996. Juvenile flathead sole, *Hippoglossoides elassodon*, and rock sole, *Pleuronectes bilineatus*, were the most abundant flatfishes, composing 65-85% of all flatfishes captured during any period. Year-round habitat of age-0 flathead sole was primarily from 40 to 60 m, and habitat of age-l flathead sole was primarily from 40 to 80 m. Summer habitat of ages-0 and 1 rock sole was from 10 to 30 m, and in winter age-0 rock sole moved offshore to sites as deep as 150 m. Both age classes of flathead sole were most abundant on mixed mud sediments, while age-l were also in high abundance on muddy sand sediments. Ages-O and 1 rock sole were most abundant on sand, though age-l were also found on a variety of sediments finer and coarser-grained than sand. Thus, juvenile flathead sole and rock sole had distinctive depth and sediment habitats. When habitat overlap occurred between the species, it was primarily when rock sole moved offshore in the winter.

Seasonal and interannual bottom water temperatures and salinities in Kachemak Bay from September 1994 to August 1996 were not correlated with seasonal distribution and abundance of flathead sole and rock sole. The inclusion of temperature did not improve the definition of habitat for these species from distribution models based solely on depth and sediment. The results indicated that biological factors such as food quality or quantity, which were not measured in this study, may be more important than temperature for growth of flathead sole and rock sole in Kachemak Bay.

During six years of August sampling in Chiniak Bay (1991-1996), we examined the precision of sampling design methods for estimating the distribution and abundance of four species of juvenile flatfishes. Often, fish abundance varies over space and time in response to environmental conditions (Reichert and van der Veer, 1991; Jager et al., 1993; Keefe and Able, 1994; Norcross et al., 1995, 1997). Until recently, few studies have been directed toward defining fish habitat or using habitat preference to help decrease the variability in abundance estimation (Scott, 1995). The present study investigated the use of habitat (defined here by depth and sediment) in survey design and analysis for the assessment of abundance of four particular species, i.e., flathead sole, Pacific halibut (*Hippoglossus stenolepis), yellowfin* sole (*Pleuronectes asper*) and rock sole. The survey design and analysis addressed common questions related to trawl surveys, and are thus of general interest and application. The first four years (1991-1994) determined that nursery grounds of juvenile flatfishes near Kodiak Island were defined primarily by depth, substrate and temperature (Norcross et al., 1995, 1997). Based upon 1991-1994 data, the 1995 survey was stratified by depth and substrate, with equal sample size per stratum, to estimate variability in fish abundance and cost of towing among strata. Temperature was not included in the 1995 or 1996 survey designs as this parameter could be determined only after sampling was completed. Sampling in 1996 was again stratified by depth and substrate, but sample allocation was based on the cost of towing and the variability in species abundance, as determined from 1995 sampling. Stratification by habitat parameters increased the precision of abundance estimates for age-0 flathead sole, age-0 rock sole, age-1 yellowfin sole and age-0 Pacific halibut. Setting up monitoring strata for each species in regions on the outskirts of each species' center of abundance did not provide more precise or reliable interannual monitoring estimates than stratification by habitat parameters over all regions.

Interannual variation in relative abundance over six years in Chiniak Bay was assessed for each species using three types of indices. Each index comprised the annual CPUE averaged over a particular set of tows. The difference among the indices was the selection of trawl sites that were averaged to produce the numerical index. The first index was the mean CPUE over nine sites that were sampled all six years (fixed site index). The second index was the mean CPUE over all sites sampled during the year (all site index). The third index was the mean CPUE in regions of "preferred" or occupied habitat (habitat index). The fixed site index did not reveal significant differences in abundance among years for any of the four species. This index served as a valuable reference for confirming apparent trends in abundance without the possible confounding effect of regional sampling bias. The all site index showed the most significant changes in abundance for rock sole and Pacific halibut, the species with the widest distribution (i.e., the least number of zero catches). Rock sole had an oscillating pattern of recruitment with abundances that were significantly higher in 1992 and 1994 than in the two least abundant years, 1991 and 1993. Pacific halibut increased in abundance through time, with abundances that were significantly higher in 1994 and 1995 than in 1991 or 1993. Flathead sole, which occurred in high abundance with an aggregated distribution, exhibited significant changes in annual abundance in the habitat index. According to this index, flathead sole had significantly greater abundance in 1993 than in 1991, 1995 or 1996. None of the three indices revealed significant changes in abundance for yellowfin sole, which occurred in low abundance with an aggregated distribution. All three indices exhibited an apparent decrease in yellowfin sole abundance over the six-year collection period.

Comparisons of the groundfish community compositions and abundances from collections in Kachemak and Chiniak Bays during August 1995 and August 1996 were related to physical data. Fish species composition between the two regions was similar, but there were significant differences in abundance. Depth was the most important factor governing distribution and abundance of groundfishes in these two locations. The species were divided into shallow-water and deep-water groupings. The shallow-water group (13-28 m Chiniak Bay; 26-56 m in

Kachemak Bay) included rock sole, walleye pollock (*Theragra chalcogramma*), Pacific halibut, *Myoxocephalus* spp , Pacific cod (*Gadus macrocephalus*), yellowfin sole, *Gymnocanthus* spp., sturgeon poacher *(Podothecus acipenserinus),* snake prickleback *(Lumpenus sagitta)* and sawback poacher (*Sarritor frenatus*). The shallow-water group, with the exception of sawback poacher, was found in higher numbers at Chiniak Bay. The deep-water group (44–60 m in Chiniak Bay; 57-86 m Kachemak Bay) included spinycheek starsnout (*Bathyagonus infraspinata*), shortfin eelpout *(Lycodes brevipes*), slim sculpin *(Radulinus asprellus*), spinyhead sculpin (*Dasycottus setiger),* and rex sole (*Errex zachirus*). The deep-water group was in higher or equal abundance in Kachemak Bay than in Chiniak Bay. Arrowtooth flounder (*Atherestes stomias)* was found at intermediate depths (37 m in Chiniak; 57 m in Kachemak) with higher abundances in Chiniak Bay. Other species with similar relative abundances in both locations included flathead sole, slender eelblenny (*Lumpenus fabricii*), daubed shanny (*Lumpenus maculatus*), snailfishes (Liparididae), Dover sole (*Microstomus pacificus*), *Triglops* spp., stout eelblenny *(Lumpenus medius*), and saffron cod (*Eleginus gracilis*). We concluded that physical factors affect the distribution and abundance of the juvenile groundfish species studied in these two locations. When physical parameters (i.e., depth; temperature; salinity; percents gravel, sand, mud, organic matter and carbonate) are included as covariates in a MANOVA, most differences in species abundance between locations were eliminated.

Stomach contents of five species of juvenile flatfish, i.e., arrowtooth flounder, flathead sole, Pacific halibut, yellowfin sole and rock sole, along with concurrently collected benthic fauna, were examined from one site of the Kachemak Bay September 1994 cruise. Arrowtooth flounder (N=15) consumed mysids, shrimps and rock sole. Flathead sole (N = 1) consumed only bivalves and Pacific halibut (N = 11) ate shrimps. Yellow-fin sole (N = 35) consumed bivalves, polychaete worms and brittle stars. Rock sole (N = 4) ate bivalves and amphipods. Different bivalve species were consumed by different flatfishes. Bivalvia was the dominant taxon in the benthos in terms of numbers, biomass and proportional importance. The benthos also contained gastropods, polychaetes and crustaceans. These preliminary data indicated that the diets of most flatfishes were dissimilar to the available infauna. However, these data are of liited application and should be applied with caution, as they are from a single collection.

This study provides baseline knowledge about the habitat requirements, seasonal variability and interannual variability of juvenile groundfish species in Southcentral Alaska, and establishes Chiniak and Kachemak Bays as important nursery areas for juvenile groundfishes (especially flatfishes). Such baseline knowledge is essential for the assessment of potential damage to flatfishes from habitat alteration.

ABSTRACT

Seasonal and interannual abundance and distribution of juvenile groundfishes were addressed through studies in Chiniak Bay, Kodiak Island, and Kachemak Bay, lower Cook Inlet. Sampling three times a year over two years (1994-1996) in Kachemak Bay provided insight into short term interannual variability and seasonal variability. Physical habitat parameters of the two most abundant flatfishes in Kachemak Bay, flathead sole (*Hippoglossoides elassodon*) and rock sole (*Pleuronectes bilineatus*), were quantified in a location separate from Kodiak Island. August sampling was conducted for six years (1991-1996) in Chiniak Bay. The first four years located and defined nursery grounds of juvenile flatfishes and provided the background necessary to design and test new sampling designs for abundance estimation. During 1995-1996, we used stepwise sampling strategies designed to increase the precision of abundance estimates. The interannual variability of the four most abundant flatfishes in Chiniak Bay, flathead sole, Pacific halibut (*Hippoglossus stenolepis*), yellowfin sole (*Pleuronectes asper*) and rock sole, was assessed over six years. For the two periods that Kachemak and Chiniak Bays were sampled simultaneously (August 1995 and August 1996), the groundfish community composition, distribution and abundance were compared. Depth was the most important factor related to distribution and abundance of groundfishes in these two locations. The taxonomic compositions of benthic invertebrates and flatfish diets were contrasted at one site in Kachemak Bay.

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INTRODUCTION

Identification of problem

Information on the habitat, life history and biology of individual species of fish is necessary in order to assess potential environmental impacts on fish stocks, to allow for more effective and timely management of fisheries by regulatory agencies and to assist with strategic planning by the fishing community and industrial developers, Groundfishes are of great economic importance to Alaskan commercial and sport fisheries, yet knowledge of the juvenile stages of their life histories, especially for flatfishes, is incomplete. Juvenile recruitment variability is a major cause of fluctuations in adult populations of fishes (Sissenwine, 1984; Houde, 1987). The identification of factors affecting survival of larval (van der Veer, 1986) and juvenile (Malloy and Targett, 1991) flatfishes is crucial to forecast the number of individuals of a specific year class which will survive to attain sexual maturity and join the reproductive population. Quality and quantity of nursery habitat is probably the most vital factor determining overall levels of recruitment of juvenile fishes (Gibson, 1994). Nursery habitat can be characterized by physical parameters including depth, sediment type, position in bay, temperature and salinity, and also by biological parameters such as food availability. It is essential that nursery areas be identified and protected against habitat disruption and that they be preserved to maintain the integrity of present fish stocks (Zijlstra, 1972; Gibson, 1994).

Background information on flatfishes, including preferred conditions of nursery areas

Populations of thirteen Alaskan species of flatfishes are found in the Gulf of Alaska near Kodiak Island (Rogers et al., 1986; Norcross et al., 1993, 1994). This is an unusually large number of flatfish species to be found concurrently. Pacific halibut (*Hippoglossus stenolepis*) is a prime target for the sports fishery. Commercial fisheries target rex sole (*Errex zachirus),* flathead sole (*Hippoglossoides elassodon*), Pacific halibut, Dover sole (*Microstomus pacificus*), yellow-fin sole *(Pleuronectes asper)* and rock sole *(Pleuronectes bilineatus*). Directed fisheries also exist for starry flounder (*Platichthys stellatus*) and English sole *(Pleuronectes vetulus*). By-catch includes butter sole *(Pleuronectes isolepis*), Alaska plaice *(Pleuronectes quadrituberculatus*) and sand sole *(Psettichthys melanostictus*) which are marketed secondarily. There is currently an attempt to develop a fishery for arrowtooth flounder *(Atheresthes stomias)* to be used in surimi. Additionally, Pacific sanddab *(Citharichthys sordidus*) has occasionally been captured near Kodiak (Norcross et al., 1994).

Flatfishes are bilaterally symmetrical during the pelagic larval stage. Near the end of the larval stage, one eye migrates over the top of the head so that both eyes are on one side of the fish. Following this metamorphosis, flatfishes begin a behavioral transition from the larval pelagic lifestyle to the demersal lifestyle they exhibit as juveniles and adults.

Many juvenile fishes follow predictable patterns of distribution within nursery areas. Intertidal zones, shallow coastal areas, protected bays and estuaries are vital as nursery areas for flatfishes (e.g., Tyler, 1971; Gibson, 1973; van der Veer and Bergman, 1986; Tanaka et al., 1989). Initial settlement, abundance and size distributions of juvenile flatfishes are related to depth, temperature (Gadomski and Caddell, 1991), sediment size and food availability. Initial settlement of flatfishes is also related to current velocity and salinity (Marliave, 1977). Flatfish nurseries are usually in shallow waters, often in less than 10 m (Edwards and Steele, 1968; Allen, 1988; van der Veer et al., 199 1), on substrates of silt, mud and fine to coarse sand (Poxton et al., 1982; Wyanski, 1990). Bays and estuaries are thought to serve as excellent nursery areas and ideal feeding habitat because of high insolation of the bottom, high water temperatures and the sediment types found in protected waters (Pearcy and Myers, 1974), in addition to the good supply of nutrients from land drainage (Pihl and Rosenberg, 1982). A dominant substrate of gravel or coarser materials reduces the suitability of an area to serve as a nursery (Rogers, 1985). Burying ability of juvenile flatfishes probably depends on several factors associated with sediment, such as grain size, particle compacting, cohesion and binding by activity of benthic fauna (Gibson and Robb, 1992).

The generally accepted rationale for juvenile flatfishes to inhabit a nursery area includes escape from predation, increased cover and food availability, and decreased intraspecific food competition (Toole, 1980; de Ben et al., 1990; Minami and Tanaka, 1992). A nursery may be partitioned into areas dominated by separate species or by intraspecific age groups (Edwards and Steele, 1968; Harris and Hartt, 1977; Smith et al., 1976; Zhang, 1988). Depth distribution changes with age, and may limit intraspecific and interspecific competition among flatfishes (Poxton et al., 1983). The positive correlation between mean length of fish and depth is significant for some species (Gibson, 1973). Large quantities of juvenile rock sole were taken by Harris and Hartt (1977) intertidally in the Kodiak area, with older individuals taken near the mouths of fjords. A reversal of this trend was exhibited by flathead sole; the largest of these fish were found toward the heads of Kodiak bays (Blackburn, 1979). Competitive fish species may also reduce range overlap by maintaining localized feeding territories. Intraspecific and interspecific diet diversity between groups of juvenile flatfishes near Kodiak is higher when the flatfish groups coexist at high abundances than when they coexist with low abundances (Holladay and Norcross, 1995b).

Recent models of juvenile flatfish presence and abundance near Kodiak (Norcross et al., 1995, 1997) and western Shelikof Strait, Alaska Peninsula (Norcross et al., in review) describe flatfish distribution based on environmental parameters (Table I-l). Depth and substrate are the main physical parameters defining modeled flatfish nursery areas (Norcross et al., 1995, 1997). Additional parameters examined by Norcross et al. (in review) include temperature, salinity, distance from the mouth of a bay, distance from shore and amount of enclosure of a bay. Although distributions of the most abundant flatfish species overlap, patterns of peak abundance are unique to each species.

The objectives of this study were:

(1) To identify nursery grounds for juvenile flatfishes around Kodiak Island and in Kachemak Bay (Appendix II-l).
(2) To characterize those areas according to physical and biological parameters (physical characterizations of habitat nursery areas are presented in Chapters 1, 2, 3 and 4; biological characterizations of habitat are presented in Chapter 5).
(3) To develop indices of relative abundance for as many species as the data allow, on a seasonal basis for Kachemak Bay, and an annual basis for Chiniak Bay (Chapters 1, 2, 3 and 4).

To accomplish the objectives, our main tasks were:

(1) To sample juvenile flatfishes and measure associated physical parameters in Kachemak Bay over three oceanographic seasons i.e., summer, winter and spring (1994–1996),
(2) To monitor juvenile flatfish distribution, abundance and associated physical parameters at index sites in Chiniak Bay, Kodiak Island, during August 1995 and August 1996,
(3) To conduct graphical and statistical analyses of abundance and distribution of juvenile flatfishes in Kachemak (1994-1996) and Chiniak Bays (199 l-l 996) with respect to physical variables of location within the bay, distance from shore, depth, substrate, temperature and salinity, and a temporal component of season in Kachemak Bay and year in Chiniak Bay,

(4) To compare August species composition, abundance and distribution of juvenile flatfishes in Kachemak Bay with those of juvenile flatfishes in Chiniak Bay, Kodiak,
(5) To analyze stomach contents of the most abundant flatfishes,
(6) To conduct graphical and statistical analysis of stomach contents with respect to physical variables and benthic composition.

METHODS

The general collection and sample processing procedures for all collections in Southcentral Alaska (Figure I-l) are given here. Methods of analyses for specific study components are detailed in following chapters. Six collections in Kachemak Bay (Figure I-2) and six collections in Chiniak Bay (Figure I-3) were the basis for this final report. Additionally, Izhut Bay, southern Afognak Island (Figure I-4) was examined once and the results are presented in a cruise report (Appendix 11-l) Dates, gear and samples collected for the current research are summarized (Table I-2). Specific collection procedures for cruises conducted in Chiniak Bay during 199 1 through 1994 are detailed elsewhere (Norcross et al., 1993, 1994, 1996). Detailed reports of the field collections, methods and samples collected during 1994-1996 in Kachemak Bay, 1995-1996 in Chiniak Bay and 1995 in Izhut Bay are presented here (Appendix II- 1). Collection and processing methods were similar for all locations and all cruises. All cruises were conducted during daylight hours. The gear deployed at each site included a trawl net, sediment grab and CTD (conductivity–temperature–depth recorder).

Fishes were sampled using a plumb staff beam trawl with a double tickler chain adapted from a design by Gunderson and Ellis (1986) via the addition of floats to the ends of the beam and 150 mm lengths of chain knotted to the footrope at 150 mm intervals. The very small net mesh (7 mm square) and codend liner (4 mm) retains flatfishes as small as 12 mm (Norcross et. al , 1993) Collections utilized either a 3.05 m or 3.66 m beam (Table I-2). The effective width of the tow is 0.74 multiplied by beam length (Gunderson and Ellis, 1986), i.e., 2.257 m for the 3.05 m beam and 2.707 for the 3.66 m beam. The ratio of towing line to site depth was approximately 8: 1 at sites less than 10 m, 5: 1 for depths IO-50 m and 3 : 1 at depths greater than 50 m. We endeavored to tow as slowly as possible (approximately 0.5-2.0 kts). Tow duration was usually 10 minutes. Tow time was reduced to 5 minutes where the bottom was excessively muddy. Reducing tow time expedited sorting and maximized catch ratios, since towing with a clogged net reduced fishing efficiency. Tow start and stop positions were recorded using global positioning system (GPS). These positions were used to calculate towing distance (1994-1996); distances towed in 1991-1993 were estimated as detailed later in this report. Minimum, maximum and predominant depths were recorded for each tow as read from the vessel fathometer

Fishes sampled by the trawl were identified, counted and total length (mm) was measured in the field, generally with the use of a Limnoterra digital fish measuring board (FMBIV, accuracy ± 1 mm). From collections in Kachemak Bay, a subsample of flatfishes < 200 mm was retained frozen for gut content analysis.

Fish counts were standardized to catch-per-unit-effort (CPUE) for a swept area of 1000 m^2, based on length and width of tow as described above. Ages of flatfishes were estimated separately for each cruise, using (1) total length/frequency plots of fishes produced for each cruise, (2) total length/frequency plots of fishes collected previously in the Kodiak Archipelago (Norcross et al., 1993, 1995, 1996), (3) analysis of regional differences in total lengths of fishes caught during August 1991 (Norcross et al., 1995) and (4) additional literature references (e.g., Hart, 1980). Flatfish ages could accurately be assigned as 0, 1 and ≥2 using this method. Without otolith aging, more precise estimation of ages of larger flatfish was not possible.

Substrate was collected using a 0.06 m^3 Ponar grab. Generally, one substrate sample was taken at each site. Substrate was retained frozen and shipped to Fairbanks. The proportional weights of the gravel, sand and mud fractions were obtained for all substrate samples collected using a wet and dry sieving technique (Appendix II-2). The Wentworth grade scale (Sheppard, 1973) defined grain sizes of boulder, cobble, gravel (pebble + granule), sand and mud (silt + clay). Sediment samples were sieved to determine relative percent at each Phi level of gravel and sand; the mud fraction was not partitioned into Phi levels. Results of grain size analyses were categorized after Folk (1980) (Table I-3). We employed Folk's classifications with the following exceptions. Folk's classifications of (g)sM and (g)mS (meaning less than 5% gravel) were incorporated within the categories of sM and mS for our analysis. Additionally, substrates larger than Folk had analyzed (i.e., containing cobble or boulder) were classified visually according to the Wentworth scale (Sheppard, 1973). In certain analyses, modifications were made to these classifications; exceptions are noted in text where applicable. Percentages of organic matter and carbonate present in the sediment were obtained separately for the gravel, sand and mud portions using the generally accepted method of two-step ignition loss in a muffle furnace (Appendix 11-2). Percent organic matter was calculated as weight loss on ignition at 500°C and percent carbonate was calculated as weight loss on ignition at 850°C divided by 0.44 (Dean, 1974).

A single vertical profile of salinity and temperature was recorded at each site with a portable Sea-Bird Seacat Profiler 19 Conductivity Temperature Depth profiler (CTD). This instrument is a self-contained unit which does not have a real-time readout, and the data were dumped periodically to a portable computer. The CTD was allowed to equilibrate for two minutes at 1 m depth and was then deployed until the 4 kg weight fastened below the sensors touched bottom. The CTD recorded temperature, depth and salinity at half second intervals. Data were later downloaded and processed with SeaSoft CTD software (Sea-Bird Electronics, 1992). For all sites, data collected during the 2 minute temperature equilibration of the CTD were omitted to avoid erratic temperature and salinity spikes. Raw data from the down cast of the CTD were averaged at 0.1 m intervals for sites <10 m depth and at 0.5 m intervals for deeper sites. Bottom temperature and salinity values were used for fish distribution analysis, as this project focused on groundfishes. In Kachemak Bay, vertical profiles of temperature and salinity were examined seasonally.

Illustra was used for database management of all collections (Illustra Information 'Technologies, 1995). Selected data are presented here (Appendices II-l, II-4, II-5, and II-6). Tables in the database include information about the cruise, collection site (e.g., date, time, types of gear used and data collected, depth), CTD profile, sediment, fish counts, fish CPUE and data collected from individual fish (e.g., length, age), etc.

Chapter 1. Depth and substrate as determinants of distribution of juvenile flathead sole (*Hippoglossoides* elassodon) and rock sole (*Pleuronectes bilineatus*)

by Alisa A. Abookire and Brenda L. Norcross

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Abstract

Three transects in Kachemak Bay, Alaska, were sampled in September 1994, May and August 1995, and February, May, and August 1996. Juvenile flathead *sole, Hippoglossoides elassodon,* and rock sole, *Pleuronectes bilineatus*, were the most abundant flatfishes, comprising 65-85% of all flatfishes captured at any period. Collections of fish and sediments were made at regular depth contour intervals of 10 meters. Habitat distribution was described by depth at 10 m increments and sediment percent weights of gravel, sand, and mud. Year-round habitat of flathead sole age-0 was primarily from 40 m to 60 m, and age-l habitat was primarily from 40 m to 80 m. Summer habitat of rock sole ages-0 and 1 was from 10 m to 30 m, and in winter they moved offshore to depths up to 150 m. Both age classes of flathead sole were most abundant on mixed mud sediments, while age-l were also in high abundance on muddy sand sediments. Rock sole ages-0 and 1 were most abundant on sand, though age-l were also found on a variety of sediments both finer and coarser grained than sand. Flathead sole and rock sole had distinctive depth and sediment habitats. When habitat overlap occurred between the species, it was most often due to rock sole moving offshore in the winter. Abundances were not significantly different among seasons for age-l flatfishes.

1. I Introduction

Commercially targeted flatfish species in Alaska are Pacific halibut (*Hippoglossus stenolepis*), arrowtooth flounder *(Atheresthes stomias),* flathead sole *(Hippoglossoides elassodon)*, rock sole (*Pleuronectes bilineatus*), rex sole (*Errex zachirus*), Dover sole (*Microstomus pacificus*), yellowfin sole (*Pleuronectes asper*), and starry flounder (*Platichthys stellatus*). In North Pacific federal waters the flatfish fisheries are divided into 5 groups: arrowtooth flounder, flathead sole, deep-water flatfish, rex sole, and shallow-water flatfish (including rock sole) with primary targets on rock, rex, and Dover sole (NPFMC, 1995). In 1995 the total value of flathead sole and rock sole commercial fisheries outside the three mile limit was 1.4 million and 5.3 million dollars respectively (Bret Fried, Alaska Department of Revenue, Juneau, Alaska, pers. comm). If we are to insure accurate estimates of recruitment to the fishery, we must be informed about juvenile populations and their nursery grounds. Once species specific nursery habitats are defined, it will be possible to monitor how changes in habitat might affect the juveniles of flatfish stocks, potentially causing variation in recruitment to the fishery. Specifically, oil spills threaten the nursery habitat quality, as close interaction with the sediment exposes flatfishes to oil (Moles et al., 1994, Moles and Norcross, 1995).

Sediment grain sii has an important influence on the distribution of flatfishes; individual species can distinguish between and actively select sediments based on grain size (Gibson and Robb, 1992; Walsh, 1992; Gibson, 1994; Moles and Norcross, 1995). Flatfishes have demonstrated strong preferences for specific grain sizes both in laboratory experiments which controlled for food and depth and in field studies. For example, in the laboratory, rock sole prefer sand, yellowfin sole prefer mixed mud/sand and Pacific halibut prefer mud/sand or sand (Moles and Norcross, 1995) and will remain on favored sediment even when that sediment is polluted with oil and an unoiled, less favored grain size is available (Moles et al., 1994). Additionally, field studies support the hypothesis that sediments can define flatfish habitat. In the North Sea, sandy flats are more densely populated with plaice (*Pleuronectes platessa*) than muddy areas (Berghahn, 1986; Pihl and van der Veer, 1992). Within the Irish Sea, homogeneous fine-grained sediment is an important determinant of juvenile sole (*Solea solea*) distribution, with availability of prey also playing an important role (Rogers, 1992).

Sediment selection by different age-0 flatfishes within a single nursery ground is species specific, and sediment preference is determined by more than matching the size of the fish with the grain size of the sediment (Moles and Norcross, 1995). Preference of substrate may be related to the ability of a fish to bury effectively, which is dependent on grain and fish size (Tanda, 1990). Flatfishes bury in sediment for protection from predation (Tanda, 1990; Burke et al., 1991; Rogers, 1992; Gibson, 1994) and strategic feeding (Gibson and Robb, 1992; Rogers, 1992). Sediment gram size has been related to distribution, abundance, and composition of juvenile flatfish prey (Pearcy, 1978; Fresi et al., 1983; Holladay and Norcross, 1995a). However, sediments do exist that have low densities or absence of flatfishes that select that particular sediment (Rogers, 1992), suggesting the complexity of habitats within nursery grounds. Additionally, hydrodynamics of the region and benthic organisms are related to sediment characteristics and probably affect juvenile fladish distribution (Pearcy, 1978; Gibson and Robb, 1992; Rogers, 1992).

Water depth directly influences habitat structure in the coastal areas which potentially serve as nursery grounds, and also plays an important role in determining the distribution of juvenile flatfishes (Rogers, 1992; Gibson, 1994; Norcross et al., 1995). Benthic community structure and composition (Pearcy, 1978) and diet (Holladay and Norcross, 1995a) have been r-elated to depth. Water depth is one of the most important determinants of juvenile flatfish distribution, as shallow nursery grounds (generally provide appropriate substrate, higher temperatures, lower predation risk and abundant food (Minami and Tanaka, 1992; Gibson, 1994). In bays around Kodiak Island, Alaska, rock sole age-0 are found predominantly at depths less than or equal to 50 m on sand or mud/sand substrate, and age-0 flathead sole are found predominantly at depths greater than 40 m on mud or mixed mud substrates (Norcross et al., 1995).

Lower Cook Inlet is a productive estuary which supports many commercial and sport fisheries; however, the limited research on flatfishes in this region has focused on adults (Bechtol and Yuen, 1995). Kachemak Bay is located in eastern lower Cook Inlet, and it is partially divided into inner and outer regions by Homer Spit (Figure I-5). The sediment distribution in Kachemak Bay is a result of circulation patterns which are dominated by two large gyres in the outer bay (Trasky et al., 1977). This study provides the first information about the role of lower Cook Inlet and specifically Kachemak Bay as a nursery ground for juvenile flatfishes. While we recognize there are other factors that might affect habitat of juvenile flatfishes, the objectives of this study are (1) to define year-round juvenile flathead sole and rock sole nursery areas by depth and sediment, and (2) to compare variability in abundances of flathead sole and rock sole during two springs and three summers.

7.2 Materials and methods

A pilot study to investigate the potential of Kachemak Bay as flatfish nursery grounds was conducted from September 24 to 30, 1994; at that time 16 stations were sampled. Three transects were established from May 3 to 11, 1995, when 19 stations were sampled. These initial stations were incorporated into a total of 41 permanent stations in Kachemak Bay, Alaska (Figure I-5) which were sampled from August 1 to 9, 1995, and February 24 to March 3, May 21 to 31, and August 7 to 17, 1996. These sampling periods represented oceanographic spring (May), summer (August and September), and winter (February). The three transects were chosen based on distributions and highest abundances of flatfishes from our September 1994 pilot study. The 41 permanent stations were located at 10 + 2 m depth increments on each transect on a gradually sloping bottom where depth intervals could be clearly defined. (Figure I-5). The first transect extended 7 km from the head of Kasitsna Bay (KS) with stations at depths 10, 20, 30, 40, 60, 80, and 100 m (Figure I-5). Due to steep bottom topography, we were unable to sample at 50, 70, or 90 m. The second transect extended 13 km across outer Kachemak Bay from McDonald Spit to Bluff Point (MC–BP) with stations at depths MC: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and BP: 90, 80, 70, 60, 50, 40, and 30 m (Figure I-5). Stations at BP20 and BP10 were not permanent stations due to extensive gear damage from boulders and rocks. The third transect extended 9.5 km across inner Kachemak Bay from China Poot Bay to east of Homer Spit (CP-HS) with stations at depths CP: 5, 10, 60, 80, 100, 150, and HS: 100, 90, 80, 70, 60, 50, 40, 30, 20, and 10 m (Figure I-5). Stations off China Poot Bay could not be sampled in depth increments of 10 m due to extremely steep slope. Due to the limited number of stations sampled in September 1994 and May 1995, maximum depth sampled during those periods was 70 m and 110 m, respectively.

All sampling took place from a 9.3 m aluminum Munsen skiff. Samples of fishes, vertical CTD (conductivity, temperature and depth) data, and substrate were collected from all stations. Standard tow duration was ten minutes. Minutes after high tide and minutes after sunrise were recorded at each tow. Global Positioning System (GPS) was used to determine towing distance, and a fathometer measured station depth. A 3.05 m plumbstaff beam trawl equipped with a double tickler chain (Gunderson and Ellis, 1986) was towed at all stations. The net body had 7 mm square mesh size with a 4 mm mesh codend liner. Towing direction concurred with the direction of the tide. All fishes were identified to species (Robins et al., 199 1), counted and measured to the nearest mm total length.

Sediment was collected at each station at the start of tow position with a 0.06 m3 Ponar grab which sampled the top 3-7 cm of the sediment. Samples were frozen and returned to Fairbanks for grain size analysis using a sieve/pipette procedure (Folk, 1980) which determined percentage of gravel, sand and mud following the Wentworth scale (Sheppard, 1973).

Fish data were standardized based on distance towed rather than time, as the distance towed in 10 minutes varied with sediment type and tide stage. The area towed was calculated as the effective width of net, 0.74 (Gunderson and Ellis, 1986) multiplied by the width of our trawl beam (3.05 m), multiplied by distance towed. Fish data were standardized to catch per unit effort (CPUE) for an area of 1000 m^2. Ages of flathead sole and rock sole were estimated based on length-frequency plots using 1 April as a birthdate (Appendix II-4).

Statistical analyses were performed on a combined data set containing data from all six cruises. As a dimension reduction technique, canonical discriminant analysis was used to examine presence/absence of juvenile flathead and rock sole with depth, percent sand, percent mud, temperature, salinity, tide stage, and minutes of daylight using SAS software, version G. 11 (SAS Institute Inc., 1996). A separate analysis was done for each age-class of each species. Linear combinations of the original variables were derived to produce canonical variables that summarize between-class variation in the data. The original variables were then correlated with the canonical variables to produce canonical correlation components, with the first canonical correlation accounting for the maximal multiple correlation. The (+) or (-) sign of the canonical coefficient within the canonical correlation resulted from the frequency and weight of presence and absence in the data. The two highest canonical coefficients were chosen from the first canonical correlation to account for presence/absence of flathead sole and rock sole.

Cluster analysis of stations by percent sand and mud using Euclidean distance and the average linkage method was performed using SAS. Sediment samples were not averaged over years for each station. Rather, each station was independently clustered based on the sediment grain size collected at the start of each tow. Cluster numbers were replaced with a sediment code modified from Folk's (1980) scheme.

Analysis of variance (ANOVA) followed by Bonferroni multiple comparison tests were performed at 0.05 alpha level using SAS. One factor ANOVAs by year were used to test for interannual variability in the spring and summer for age-1 flatfishes. For both age groups, a two-factor ANOVA by depth at 10 m increments, season, and the depth-season interaction was performed separately from a two factor ANOVA by sediment and sediment-season interaction and a two-factor ANOVA for sediment-depth interaction. Data did not lend themselves to a combined three-factor ANOVA due to the large number of empty cells when sediment data were combined with other variables. All CPUE data were log (X+1) transformed to correct for heterogeneity of variance (Johnson and Wichern, 1992). Significance was established at values of $p \leq 0.05$.

I.3 Results

Flathead sole and rock sole represented a large percentage of all juvenile flatfishes captured in Kachemak Bay: 77% in September 1994, 85% in May 1995, 81% in August 1995, 80% in February 1996, 65% in May 1996, and 83% in August 1996. Flathead sole age-0 were most abundant in September 1994 (N = 379), and none were caught in May 1995 or May 1996. Flathead sole age-1 were most abundant in August 1995 (N = 316). Rock sole age-0 were most abundant in August 1996 (N = 1301), and none were caught in May 1995. Rock sole age-1 were most abundant in May 1995 (N = 146) and **August 1996** (N = 144). The total number of juveniles captured for all seasons and years combined was 726 flathead sole age-0, 1261 flathead sole age-1, 1975 rock sole age-0, and 561 rock sole age-1.

Seasonal differences in abundances for flathead sole age-1 (F = 1.81, p = 0.1481, N = 197) and rock sole age-1 (F = 0.17, p = 0.9137, N = 197) were not significant. Spring abundances of flathead sole age-1 (F = 0.15, p = .7034, N = 60) and rock sole age-1 (F = 1.83, p = 0.1818, N = 60) were not significantly different between 1995 and 1996. Summer abundances of flathead sole age-1 (F = 0.6, p = 0.5495, N = 98) and rock sole age-1 (F = 0.96, p = 0.3883, N = 98) were not significantly different among years, and abundances of flathead sole age-0 (F = 9.1, p = 0.0002, N = 60) were significantly different. Summer variability for rock sole age-0 could not be rejected (F = 2.94, p = 0.0574, N = 98) at 95% significance.

The first canonical correlation assigned low coefficients to the variables temperature, salinity, tide stage, and minutes of daylight for the presence/absence of juvenile flathead sole and rock sole. For all ages of flathead and rock sole, depth and either percent sand or percent mud were assigned the highest canonical coefficients. The first canonical correlation assigned depth and sediment with the two highest canonical coefficients to explain the presence/absence of both ages of juvenile flathead sole and rock sole. Canonical variables for flathead sole scored presence higher than absence so that increased depth and high percent mud translated to presence. Depth and percent mud had equal canonical coefficients (3.670) for presence of flathead sole age-0, and depth (0.553) and percent mud (0.508) had the highest canonical coefficients for presence of flathead sole age-1 (Table I-4). Rock sole canonical variables scored absence higher than presence so that increased depth and low percent sand or high percent mud translated to absence (Table I-4). Depth (0.617) and sand (-0.518) had the highest canonical coefficients for absence of rock sole age-0 and depth (0.964) and mud (0.633) for absence of rock sole age-1 (Table I-4).

All transects had at least one station with both flathead sole and rock sole present. Of the 41 permanent stations, 24 had species overlap, and those at which this occurred more than once were: MC20, MC30, MC40, MC50, HS30, HS40, HS50, HS60, and KS80 (Figure I-5). Because physical properties such as temperature and sediment type often changed at a station between years, we considered the overlap at the total number of stations sampled. Of the 197 stations sampled over the 6 cruises, only 36 stations (18%) had both flathead and rock solo present at the same time (Table I-5). Of these 36 stations, 50% had ≥ 70% flathead sole present and 3 1% had ≥ 70% rock sole present. The remaining 7 stations (19%) had very low abundance of flatfishes (N ≤ 12 of each species) except for station HS30 in August 1996, which had 58 flathead sole and 49 rock sole. The percentage of stations with both species present was highest in winter and low in spring (Table I-5).

1.3.1 Sediment

Sediments in outer Kachemak Bay were variable with boulders and cobbles at the northern shore, shell debris further offshore, and sandy mud in the center of outer Kachemak Bay. Inner Kachemak Bay was dominated by fine-grained sediments, and the sediment distribution did not grade regularly from coarse sand to mud with increasing depth. Since the relationship between depth and sediment was different between outer and inner Kachemak Bay, a wide range of depth and sediment combinations were available within relatively close proximity. For example, at 30 m along the northern shore of outer Kachemak Bay (BP30) sediments were cobble and boulder mixed with coarse sand, whereas inner bay sediments at 30 m (HS30) were fine mud and silts (Figure I-5; Appendix II-5).

Cluster analysis of stations by percent sand and mud resulted in eight sediment clusters (Figure I-6). Sediment clusters were assigned descriptive codes for identification. Sediment clusters in order of increasing grain size were: mud and mixed mud = M, sandy mud = sM, equal parts mud and sand (mud/sand) = MS, muddy sand = mS, muddy gravelly sand = mgS, at least 90% sand = S, sandy muddy gravel = smG, and gravel = G. Cluster M had the finest grain size with > 57% mud (< 62 µ), and cluster G had the coarsest grain size with > 65% gravel (> 2 mm) (Figure T-6)

Combined over all seasons, flathead sole ages-0 and 1 were on mixed mud sediments. Although in different magnitudes, mud, sandy mud, mud/sand, and muddy sand had high abundances of flathead sole ages-0 and 1 and low abundances on sand, sandy muddy gravel, or gravel substrates (Figure I-7). Age-l were more abundant than age-0 on the coarser grain sizes of sand and gravel. Based on Bonferroni t-tests, abundances of flathead sole age-0 were significantly higher on mud than sand. Abundances of flathead sole age-l had significant differences between mud and sand, mud/sand and sand, and muddy sand and sand. Rock sole ages-0 and 1 were most abundant on sand (Figure I-7). Age-O were more concentrated on pure sand; whereas, age-l spread out to both finer and coarser grain sediments (Figure I-7). Abundances of rock sole ages 0 and 1 were each significantly higher on sand than all other sediment types.

Abundances of flathead sole age-0 (F = 3.66, p = 0.0001, N = 197), flathead sole age-l (F = 4.13, p = 0.0003, N = 197), rock sole age-0 (F = 11.62, p = 0.0001, N = 197), and rock sole age-1 (F = 7.5 1, p = 0.000 1, N = 197), were significantly different among sediment clusters. Both ages of flathead sole and rock sole were found on habitats with mud, sandy mud, mud/sand, and muddy sand. At these four shared sediment types, flathead sole were present more often than rock sole (Figure I-7). There was no significant interaction for flathead sole age-l (F = 1.27, p = 0.2284, N = 197) or rock sole age-l (F = 1.42, p = 0.1502, N = 197) between sediment clusters and season. However, flathead sole age-0 (F = 2.11, p = 0.0135, N = 197) and rock sole age-0 (F = 3.42, p = 0.0001, N = 197) each had a significant interaction effect. In August and February, flathead sole age-0 were on mud almost exclusively, and in September they were most frequently on mud/sand, and sandy mud. Rock sole age-0 selected sand almost exclusively in August and frequently in September; however, in February they selected mud more than any other sediment.

1.3.2 Depth

Flathead sole age-0 predominant depth range for all seasons combined was from 40 m to 60 m, and flathead sole age-l had high abundance at each depth increment from 40 m to 80 m (Figure I-8).

Based on Bonferroni t-tests for all seasons and sediment types combined, mean abundances of flathead sole ages-0 and 1 each had significant differences between depth pairs: 10 and 40, 50, 60. Flathead sole age-1 also had significantly different mean abundances between depth pairs: 10 and 70, 80; 50 and 20, 30, 100; and 60 and 20, 30, 100, 110, 150. Depth distribution of flathead sole age-1 was highest from 40 m to 80 m and zero or low abundances at 10 m, 20 m, 30 m, 100 m, 110 m, and 150 m (Figure I-8). Abundance of flathead sole age-1 at 90 m was not significantly different according to Bonferroni t-tests. No flathead sole were captured at depths 5 m, 10 m, or 150 m (Figure I-8).

Highest abundance of rock sole age-0 for all seasons combined was at 20 m, and for rock sole age-1 at 10 m (Figure I-8). Both ages had high abundance within the depth range of 10 m to 30 m (Figure I-8). In summer months rock sole ages-0 and 1 were found ≤ 50 m with highest abundances ≤ 30 m. Both ages of rock sole were found at depths ≥ 60 m only in February and May 1996 , with the exception of an individual age-0 rock sole captured at KS80 (Figure I-5) in August 1996 at 80 m. Rock sole age-0 were found at every depth increment from 60 m to 150 m in February and at 70 m and 80 m in May 1996 (Figure I-9). Bonferroni t-tests for all seasons and sediment types combined show that rock sole ages-0 and 1 each had significantly higher abundances at 10 m and 20 m, than at depth increments ≥ 60 m. Rock sole age-1 had high abundances at 10 4 20 m, and 30 m, but there were significantly more rock sole age-1 at 10 m than at 30 m (Figure I-8). Rock sole age-1 were found at 60 m and 90 m in February and at 60 m in May 1996. Abundances of rock sole age-1 were significantly higher at 10 m than any other depth except 20 m.

There were significant differences among 10 m depth increments for abundances of flathead sole age-0 (F = 5.71, p = 0.0001, N = 197), flathead sole age-1 (F = 5.99, p = 0.0001, N = 197), rock sole age-0 (F = 3.65, p = 0.0001, N = 197), and rock sole age-1 (F = 7.95, p = 0.0001, N = 197). There was no significant interaction between depth and season for flathead sole age-1 (F = 0.44, p = 0.9941, N = 197) and rock sole age-0 (F = 1.25, p = 0.2003, N = 197). However, this interaction was significant for flathead sole age-0 (F = 2.02, p = 0.0037, N = 197). Flathead sole age-0 were concentrated at 40 m and 50 m in September, 60 m and 110 m in August 1995, 50 m and 80 m in August 1996, 40 m and 100 m in February, and absent in May. Although September and February both had highest abundances of flathead sole age-0 at 40 m, the abundance in September was 4 times higher than the abundance in February (Figure I-9). There was also a significant season and depth interaction for rock sole age-1 (F = 2.00, p = 0.0042, N = 197). In May and August, rock sole age-1 were predominantly at 10 m, whereas they were most abundant at 30 m in September, and at 40 m in February (Figure I-8).

There was no significant interaction between depth and sediment for flathead sole age-0 (F = 0.80, p = 0.7783, N = 197) or rock sole age-0 (F = 0.84, p = 0.7247, N = 197). Flathead sole age-1 (F = 1.99, p = 0.0027, N = 197) and rock sole age-1 (F = 1.71, p = 0.0157, N = 197) each had a significant interaction effect. Flathead sole age-1 selected mud most often at all depths except 50 m and 70 m, where muddy sand was selected over mud. Rock sole age-1 was on sand most often at each depth increment ≤ 20 m, muddy sand at 30 m, and mud at 40 m, 60 m, 80 m, 90 m, and 100 m.

I.4 Discussion

Rock sole and flathead sole were the most abundant juvenile flatfishes in Kachemak Bay. A groundfish survey in October, 1989, found flathead sole was the most abundant adult flatfish in Kachemak Bay, followed by Dover sole, and rock sole (Bechtol and Yuen, 1995). Flathead sole and rock sole appear to be well adapted to the habitats within Kachemak Bay as both juveniles and as adults.

In Prince William Sound, Alaska, larval flathead sole were absent in April, most abundant in May and June, and very low in abundance in July (Norcross and Frandsen, 1996). In Kachemak Bay, flathead sole age-0 were probably absent in May during 1995 and 1996 because they were still in the larval phase. Additionally, it appears that flathead sole age-0 had not completely settled into a demersal phase by August, as abundances of flathead sole age-0 were higher in September 1994 than August 1995 and 1996. Rock sole age-0 were absent in May 1995, and in May 1996 abundance was low (N = 10). Sampling was 19 days later in May 1996, indicating that either rock sole begin to settle in mid-May in Kachemak Bay or there is interannual variability in settling time.

Juvenile flatfishes were clearly distributed according to sediment type preferences; however, flathead sole age-l and rock sole age-l were found on more sediment types than age-0 flatfishes. Flathead sole age-l were found predominantly on mixed mud sediments but also spread out to larger grain sizes like muddy sand. Similarly, rock sole age-l were found predominantly on sand but spread out to both finer and coarser grained sediments (Figure I-7). Other studies have observed that as fish size increased more sediment grain sizes were suitable for survival. Age-O juvenile flatfishes may be limited in then- ability to select certain sediment gram sizes because of their small size and the energy expenditure required for burial, whereas larger, more powerful juveniles are able to bury in coarser sediments (Gibson and Robb, 1992). Thus, as flatfishes increase in age and size they may be able to bury in a larger range of grain sizes (Moles and Norcross, 1995). In Kachemak Bay, there were very low abundances of juvenile flatfishes on coarse sediments. Similarly, there was a negative correlation between gravel and abundances of juvenile flathead sole and rock sole in bays around Kodiak Island, Alaska (Norcross et al., 1995). There appears to be an upper limit to the grain size suitable for these species.

Flathead sole and rock sole had differing habitat requirements in depth and substrate with spatial overlap limited to 7-19% of the stations in spring and summer, but rising to 5 1% of the stations in winter. Most of the habitat overlap can be explained by rock sole age-0 habitat extending offshore into deeper, muddier water in the winter (Figure I-9). Rock sole appeared to spread to sediments outside their typical range and were more adaptable than flathead sole to different sediment types. In laboratory experiments, rock sole age-0 preferred different sediments based on the density of fish. As the density of rock sole increased, they were more likely to choose mud-based sediment, although sand was still chosen more often than mud regardless of fish density (Moles and Norcross, 1995).

In addition to distinctive sediment habitats, flathead sole and rock sole had distinctive depth habitats as well. Both ages of flathead sole had high abundances from 40 m to 60 m, and rock sole had low abundances from 40 m to 60 m. Flathead sole age-l may have had a deeper predominant depth habitat than age-0 because as most juvenile flatfishes grow they gradually move farther offshore (Gibson, 1994). In the spring and summer months rock sole ages-0 and 1 were most abundant $\leq$ 30 m depth. These habitats were consistent with summer habitat models from Kodiak Island, Alaska, in which rock sole age-0 were present at depths < 28 m (Norcross et al., 1997). Much of the spatial overlap between flathead sole and rock sole occurred in winter when rock sole moved offshore to depths up to 150 m. Strong winter bathymetric movements into deeper waters were observed for juvenile ground&h in Prince William Sound, Alaska (Rogers and Rogers, 1986), and for Dover sole and rex sole off the Oregon coast (Pearcy, 1978).

The influences of depth and sediment type are often difficult to separate due to the close correlation between depth and grain size. In the majority of marine systems the relationship between current speed and sediment particle site dictates that coarse-grained sediments accumulate near slopes and in high energy areas with swift currents, sand accumulates near the coast, and fine-grained, muddy sediments accumulate in deeper areas where bottom currents are weak (Laevastu and Hela, 1970). This depth and sediment relationship exists in outer Kachemak Bay; however, inner Kachemak Bay is dominated by fine silts and mud. This range of sediments at the same depth within Kachemak Bay provided some data to differentiate between the effects of depth and sediment on juvenile flatfish distribution, Where equally high numbers of flathead sole and rock sole coexist (HS30), the depth was 30 m and the sediment type was mud; depth primarily defined habitat for rock sole, while the sediment type defined habitat for flathead sole at this station.

Both flathead sole age-1 and rock sole age-1 had significant depth and sediment interaction effects. Selection of habitat type was depth related where sand was not available at deep depths in Kachemak Bay, but mud was present at stations as shallow as 20 m; therefore, the significant interaction for rock sole age-1 may reflect sediment availability more than preference. With the present analysis, it is unclear why sediment selection changed with depth for flathead sole age- 1; additional environmental or biological factors which are related to depth, such as temperature (Pearcy, 1978) or prey distribution (Holladay and Norcross, 1995a), may explain these significant interactions. Rijnsdorp et al. (1995) identified a need for future research to develop a model which predicts presence or absence of juvenile flatfishes by measuring habitat characteristics and physical parameters of the area. This study focused on depth and substrate because they were factors which clearly defined juvenile flathead sole and rock sole habitat with low overlap; however, we recognize that other factors such as temperature, distribution of prey, predation, competition, and hydrodynamic factors play critical roles in habitat suitability (Rijnsdorp et al., 1992; Gibson, 1994).

Seasonal interannual variability for flathead sole age- 1 and rock sole age- 1 was not significant. Miller (1994) stated that mechanisms which ‘regulate’ recruitment are often density dependent and reduce interannual variability. Interannual variability among seasons in abundances of flathead sole age-1 and rock sole age-1 was not significant, suggesting that recruitment may have been regulated’ (Miller, 1994) before age-1. We tentatively suggest age-1 may be an appropriate age to monitor for recruitment predictions of these species.

Defining juvenile flatfish nursery areas is essential for management decisions relating to habitat preservation-and restoration (Burke et al., 1991). Suitable nursery areas are critical for European flatfishes *Solea solea* and *Pleuronectes platessa,* because if nursery size were reduced, numbers of juvenile flatfishes would not compensate by increasing their densities, and the total stock would be reduced (Zijlstra, 1972). It is unclear if this applies as severely to Alaskan flatfish nursery grounds; however, Zijlstra’s (1972) findings demonstrate the importance of defining and preserving juvenile habitats to maintain the integrity of current fish stocks. Once the habitats and distribution patterns of juvenile flatfishes are known, monitoring their growth, survival, and subsequent recruitment will be more accurate. This study clearly defined the seasonal distribution ofjuvenile flathead sole and rock sole by depth and sediment in Kachemak Bay.

Chapter 2. The effects of seasonal temperature and salinity patterns on distribution, abundance, and growth of juvenile flathead sole and rock sole in Kachemak Bay, Alaska

by Alisa A. Abookire and Brenda L. Norcross

Abstract

Seasonal and interannual distributions in bottom temperature and salinity in Kachemak Bay were investigated in spring, summer and winter from September 1994 to August 1996. Mean bottom temperature in August was 1.0°C higher in 1996 than 1995, and mean bottom temperature in May was approximately 15°C higher in 1996 than in 1995. Differences in bottom temperatures, but not salinities, were present among transects within the bay in May 1995, February 1996, and August 1995 and 1996. In winter, deep mixing of the water column was observed.

Distribution and abundance of flatfishes were not related to bottom water temperatures or to salinities. The seasonal offshore movement of rock sole could not be attributed to changes in bottom temperatures; thus, unmeasured factors such as winter mixing, competition, or food availability may have influenced their distribution. Temperature did not define habitats for these species in Kachemak Bay beyond previously defined models based on depth and sediment (Abookire and Norcross, 1998—Chapter 1 in this report). Differences in fish abundance were not related to seasonal or interannual temperature differences.

Mean length increases of flathead sole *(Hippoglossoides elassodon*) and rock sole (*Pleuronectes bilineatus*) from the 1334 and 1335 year-classes (YC) were compared within and between species to examine the relationship between growth rate and temperature. Among seasons, growth was greatest from spring to summer, and temperature had a positive effect on growth. However, temperature differences between years had a positive relationship with growth only for flathead sole age-1. The results indicate that other unmeasured factors such as food quality or quantity may be important for growth of flathead sole and rock sole in Kachemak Bay. To monitor year-class strength of flathead sole and rock sole, we recommend specific habitats be sampled in mid-August when abundances are high.

2.7 Introduction

Kachemak Bay is a year-round nursery area for juvenile flatfishes, and flathead sole *(Hippoglossoides elassodon)* and rock sole *(Pleuronectes bilineatus)* dominate the juvenile flatfish community (Abookire and Norcross, 1998—Chapter 1 in this report; Appendices II-1 and II-6 in this report). Parameters defining habitat have recently been established in Southcentral Alaska for several species of juvenile flatfishes (Moles and Norcross, 1995; Norcross et al., 1995, 1997; Abookire and Norcross, 1998—Chapter 1 in this report). Unlike the extensive flatfish database from the North Sea (Bolle et al., 1994), little is known about juvenile flatfishes in Alaska. Paul et al. (1992), who provided the first information on the bioenergetic requirements for flathead sole, has stated that first year minimum prey rations are from 2.2 to 6.2% bw/day at 4°C. Moles and Norcross (in review) provide the first estimate of initial growth rates of rock sole, from 0.11 to 0.14 mm/d at 10°C (Adam Moles, Auke Bay Laboratory/NMFS, pers. comm.). Both species recruit to the commercial fishery at age-4, and each has a total allowable catch of approximately 30,000 metric tons in the Gulf of Alaska (NPFMC, 1995).

Temperature, fish size, and food quality and availability are important factors determining growth of flatfishes (Deniel, 1990; van der Veer et al., 1994). Variation in growth rates is often related to temperature differences on local to global scales (Gibson, 1994; Rijnsdorp et al., 1995). When food is unlimited, temperature influences growth (Gibson, 1994), as feeding rates and mean growth rate increase with temperature (Malloy and Targett, 199 1). Growth rates of juvenile Atlantic halibut (*Hippoglossus hippoglossus*) (Hallaråker et al., 1995) and witch flounder (*Glyptocephalus cynoglossus*) (Burnett et al., 1992) are affected by temperature. Temperature preferences may also vary among age groups of the same species (Burnett et al., 1992; van der Veer et al., 1994). Compared with temperature, salinity has limited effects on growth rates (Malloy and Targett, 1991; Gibson, 1994).

Seasonal temperature changes often result in dynamic spatial distribution of juvenile flatfishes (Laevastu and Hela, 1970). Distribution ofjuvenile flatfishes within a nursery area varies with species, locality, season and year; additionally, seasonal migration between winter and summer habitats is common (Minami and Tanaka, 1992). Seasonal water temperature fluctuations may account for a difference in the regional distribution of juveniles due to individual species' physiological tolerances and preferences for temperature (Minami and Tanaka, 1992). In the Middle Atlantic Bight, juvenile summer flounder (*Paralichthys dentatus)* (Able et al., 1990) and adult Atlantic croaker (*Micropogonias undulatus*) (Norcross and Austin, 1988) are distributed in relation to temperature, and migrate offshore seasonally. Fish distribution has been strongly correlated with bottom water temperature for plaice (*Pleuronectes platessa*) (Gibson, 1973; Lockwood, 1974), witch flounder (Burnett et al., 1992), and juvenile dab (*Limanda Zimanda)* (Bolle et al., 1994). Norcross et al. (1997) found bottom temperature to be a significant factor, along with depth and substrate, in determination of flathead sole age-0 habitat near Kodiak Island, Alaska, but not for rock sole age-0.

If we are to understand and monitor recruitment variability and fluctuations in year-class strength, it is essential to first understand the environmental factors which influence growth, feeding, and survival ofjuveniles (Malloy and Targett, 1991; van der Veer et al., 1994). Mortality of juvenile fishes is generally size dependent and will decrease as fish grow; therefore, rapid growth of juveniles may reduce size-selective predation (Malloy and Targett, 1991; van der Veer et al., 1994). Because faster growing juveniles mature at a younger age, they contribute more to the reproductively viable adult population (Gibson, 1994; van der Veer et al., 1994).

Studies of juvenile flatfish habitats in Kachemak Bay indicate that flathead sole occur predominantly at depths of 40 m or greater on mixed mud substrates year-round. Rock sole are most abundant at depths of 30 m or less on sand substrates in the spring and summer, with an offshore movement in winter to depths of 150 m on mud substrates (Abookire and Norcross, 1998—Chapter 1 in this report). Because of the strong seasonal signal in rock sole habitat combined with the reality that depth and temperature are often confounded, temperature is investigated to fine-tune those models of species distribution by depth and sediment. This investigation provides baseline data for age-specific temperature ranges in Kachemak Bay, and will focus on how seasonal changes in bottom water temperature affect growth, abundance and distribution of juvenile flathead sole and rock sole. Since the water entering Kachemak Bay originates in the Gulf of Alaska and has a strong seasonal signal (Roycr, 1375; Mucnch et al., 1978), we investigate (1) temperature and oceanographic differences within Kachemak Bay and between years. The effects of bottom water temperatures on (2) distribution and (3) abundance of juvenile flathead sole and rock sole are also investigated. Because variability in abundances of age-l flathead sole and rock sole were not significantly different among seasons or years (Abookire and Norcross, 1998—Chapter 1 in this report), we hypothesize that temperature will not have a significant affect on abundance. Additionally, we investigate (4) the relationship between bottom temperatures and mean length increase to test the hypothesis that growth will be greatest from spring to summer and in years with higher bottom temperatures.

2.1.1 Study site

Cook Inlet, a large estuary in the Northern Gulf of Alaska, is about the same length as the Chesapeake Bay (Muench et al., 1978). Water circulation in lower Cook Inlet is counterclockwise as Gulf of Alaska water enters at the southeast end through Kennedy Entrance and water flows out along the west side of Cook Inlet into Shelikof Strait (Anonymous, 1977). Inflowing seawater originates in the northern Gulf of Alaska (Muench et al., 1978) and has a strong seasonal signal (Royer, 1975). Lowered salinity and higher temperatures occur during the summer due to increased freshwater input and increased insolation (Royer, 1975). In winter, thermohaline and wind mixing and decreased stratification combine with decreased insolation and cessation of freshwater input to produce lower temperatures, higher salinity, and more dense water (Royer, 1975). A localized tendency for upwelling in the central lower inlet supplies nutrient-rich, cold water from depth, and the northerly flow transports this biologically rich water mass into Kachemak Bay (Muench et al., 1978).

Kachemak Bay is located in eastern lower Cook Inlet, and it is partially divided into inner and outer regions by Homer Spit (Anonymous, 1977). Spring and summer circulation patterns in Kachemak Bay are dominated by two large surface gyres in the outer bay (Trasky et al., 1977). Kachemak Bay waters have seasonal variation in temperature, salinity, and density distribution. There is increased input of freshwater runoff and warming of the surface due to increased insolation in late spring and summer, which result in well-defined stratification of the water column (Anonymous, 1977). Such seasonal stratification combined with river input of nutrients yields extraordinarily high primary productivity (Anonymous, 1977). In the fall and winter, freshwater input is reduced to very low levels and surface cooling from winds reduces stratification. Temperature inversions also may occur as the less saline upper water becomes cooled by winter winds and becomes more dense than the more saline, warmer bottom water, resulting in strong convective mixing throughout the water column (Anonymous, 1977).

2.2 Methods

To investigate the potential of Kachemak Bay as flatfish nursery grounds, a pilot study was conducted from September 24 to 30, 1994; during that time, 16 stations were sampled. From May 3 to 11, 1995, 19 stations were sampled and transects were established. These initial stations were incorporated into a total of 4 1 permanent stations in Kachemak Bay, Alaska, (Figure I- 10) which were sampled from August 1 to 9, 1995, and February 24 to March 3, May 2 1 to 3 1, and August 7 to 17, 1996. This sampling included oceanographic spring (May), summer (August and September), and winter (February). When possible, fish trawls were taken at 10 ± 2 m depth increments on 41 permanent stations located along five transects (Figure I- 10). Sampling error between replicate tows was minimal and when replicate good tows were obtained at a station the fish numbers were averaged. The first transect extended 7 km from the head of Kasitsna Bay (KS) with stations at depths 10, 20, 30, 40, 60, 80, and 100 m (Figure I-10). The second and third transects extended 13 km across outer Kachemak Bay from McDonald Spit to Bluff Point (MC-BP) with stations at depths MC: 10, 20, 30, 40, 50, 60, 70, 80, 90,100, 110 m, and BP: 90, 80, 70, 60, 50, 40, and 30 m (Figure I-l 0). The fourth and fifth transects extended 9.5 km across inner Kachemak Bay from China Poot Bay to east of Homer Spit (CP-HS) with stations at depths CP: 5, 10, 60, 80, 100, 150, and HS: 100, 90, 80, 70, 60, 50, 40, 30, 20, and 10 m(FigureI-10).

Fish trawls and vertical collections of CTD (conductivity, temperature and depth) data were done at all stations. A 3.05 m plumbstaff beam trawl equipped with a double tickler chain (Gunderson and Ellis, 1986), net body mesh with 7 mm, and a codend liner with 4 mm mesh was towed at all stations. Fish data were standardized to catch per unit effort (CPUE) for an area of 1000 m^2. Towing procedure and calculation of CPUE are described in Abookire and Norcross (1998—Chapter 1 in this report). All fishes were identified to species, counted and measured to the nearest mm total length. Age groups -0 and - 1 were estimated with plots of length-frequency distribution using 1 April as a birth date, and growth was estimated with mean length increase between sampling periods.

Bottom temperature was measured every minute, and the average bottom temperature every 36 minutes was calculated and recorded with StowAway XT1 temperature loggers from 27 February to 12 August 1996 at stations MC20 and KS 100 (Figure I-10). Scatter plots of the StowAway data and calculation of a linear regression were done with StowAway temperature data in S-Plus (S-Plus, 1993). Temperature transects across Kachemak Bay with CTD temperature data were plotted with a minimum curvature program (Surfer, 1995). Correlation coefficients for depth and temperature were calculated in Excel (Microsoft Excel, 1994).

To test if bottom temperature or bottom salinity varied significantly within Kachemak Bay, bottom temperature and bottom salinity were each tested from February 1996, May 1995 and 1996, and August 1995 and 1996 data in one-way ANOVAs against 5 transects using SAS software, version 6.11 (SAS Institute Inc., 1996). September 1994 data were omitted from this comparison among transects because no stations were sampled on transects BP, CP, or HS. May and August interannual differences in bottom temperature and bottom salinity were tested with an ANOVA using SAS software, version 6.11 (SAS Institute Inc., 1996).

To test for bottom temperature or bottom salinity effects on the abundance of flatfishes, multivariate regressions were used with the model of CPUE equal to depth and temperature using SAS software, version 6.11 (SAS Institute Inc., 1996). A separate analysis was done for each age-class of each species. Separate regressions were performed for each season; if significant, then regressions were performed separately for that season in 1995 and 1996. No flathead sole age-0 were captured in May; therefore, analysis was not done for that species and season. To eliminate potential bias caused by depth effects on distribution, regressions were run only with data within the depth ranges established in previous analyses, $\geq$ 40 m for flathead sole and $\leq$ 30 m for rock sole (Abookire and Norcross, 1998—Chapter 1 in this report). All CPUE data were log (X+1) transformed to correct for heterogeneity of variance (Johnson and Wichem., 1992). All analysis of variance (ANOVA) tests were followed by Bonferroni multiple comparison tests using SAS software, version 6.11 (SAS Institute Inc., 1996). Significance was established at values of $p \leq 0.05$.

Two-sample f-tests were used to test for differences in mean length of age classes between years; significance was established at $p \leq 0.05$ (Microsoft Excel, 1994). To compare the change in growth across seasons, mean length increase per day (MLI/day) was calculated and used to estimate growth rates between seasons. To statistically compare MLI/day between seasons, 95% Bonferroni simultaneous confidence intervals (Johnson and Wichern, 1992) around the differences of MLI/day were estimated with 1000 iterations of the bootstrap statistic (S-Plus, 1993). If the 95% Bonferroni simultaneous confidence interval between seasons did not contain zero, then the two MLI/day values were statistically different.

2.3 *Results*

2.3.1 Temperature

Bottom temperatures were significantly higher in 1996 than 1995 in May ($F = 199.18$, $p = 0.0001$, $N = 60$) and in August ($F = 62.55$, $p = 0.0001$, $N = 82$), and were significantly different across transects in all sampling periods except May 1996 (Table I-6). From February 27 to August 12, 1996, the bottom temperature increased linearly at MC20 (20 m) from 3.28 to 10.44°C ($R^2 = 0.9703$) and at KS100 (100 m) from 2.9 to 9.76°C ($R^2 = 0.9702$) (Figure I-l 1).

Based on Bonferroni T tests, monthly bottom temperatures were significantly higher at MC20 than at KS 100 during each month from February to August 1996 (Table I-7).

2.3.1.1 KS transect

May bottom temperatures on the KS transect were significantly colder in 1995 than 1996; for example, at KS80 and KS 100 temperatures were 1.6°C higher in 1996 (Figure I-12). In August 1995 the bottom temperatures were from 0.3 to 0.8°C lower than in August 1996, but were not significantly different based on Bonferroni T tests. Additionally, KS bottom temperatures were not significantly different among stations along the transect in September 1994, August 1995, and August 1996. The water column was stratified at depths shallower than 10 m in May 1995, and in February the water column was mixed to 80 m (Figure I-12).

2.3. 1.2 MC and BP transects

Bottom temperatures were significantly higher in May 1996 than May 1995 on the MC transect For example, bottom temperature at MC 110 was 1.2°C higher in May 1996 than in 1995 (Figure I-13). Bottom temperatures on the BP transect ranged from 5 to 6°C and were not significantly different in May 1995 or May 1996 (Figure I-13). Summer bottom temperatures from 1994 to 1996 were significantly different along the MC transect, and on both MC and BP transects August 1996 bottom temperatures were higher than in August 1995. In February 1996, mixing occurred throughout the water column to 100 m at MC and 90 m at BP (Figure I-13).

2.3.7.3 CP and HS transects

Bottom temperatures in spring on the CP transect were significantly higher in May 1996 than May 1995, and bottom temperature was 2.7°C higher at CP05 and 1.3°C higher at CP80 in 1996 than in 1995 (Figure I-14). No comparison could be made for the HS transect, as it was not sampled in May 1995. Bottom temperatures in August 1995 and 1996 were not significantly different at CP, but bottom temperatures on the HS transect were higher in August 1996 than 1995. Bottom temperature was 1.1°C higher at HS60 and 0.7°C higher at HS20 in 1996 than in August 1995. In the summer of both years CP05 was the warmest station in inner Kachemak Bay at 10.1°C in 1995 and 10.3°C in 1996. In February the water column was mixed to 20 m at CP and 60 m at HS (Figure I-14).

2.3.7.4 Temperature and juvenile flatfish distribution

Offshore movements for rock sole occurred on all transects in winter. The deepest station and the corresponding bottom temperature on each transect with rock sole present in winter was KS100 (3.0°C), MC110 (2.8°C), BP90 (2.8°C), CP150 (2.1°C), and HS70 (1.2°C). In contrast to spring and summer when shallow waters had higher bottom temperatures than deeper waters, the bottom temperatures were warmer in deeper waters in winter (Table I-8). Although bottom temperatures in winter were positively correlated with depth on all transects (Table I- 8), deepest stations on a transect were not always the warmest. For example, rock sole age-0 were present at the deepest station in inner Kachemak Bay CP150, but not at the warmer station CP 100 (2.5°C).

2.3.7.5 Temperature and juvenile flatfish abundance

In May 1995, though bottom temperatures were higher at BP than at KS, MC, or CP (Table I-6), abundances of flathead sole age-l (F = 0.47, p = 0.7112, N = 13) were not significantly different across transects. While in May 1996 bottom temperatures were not significantly different among transects (Table I-6), abundances of flathead sole age-l (F = 6.77, p = 0.0009, N = 29) were significantly different with higher abundances at KS than at BP, CP, or HS transects and significantly higher abundances at MC than HS. Abundances of rock sole age-0 in May 1996 (F =

0.53, p = 0.7174, N = 18) and age-1 in May 1995 and 1996 (F = 0.87, p = 0.5074, N = 18) were not significantly different among transects.

In August 1995 and 1996 bottom temperatures were higher at the KS transect than at the other 4 transects (Table I-6). Only August abundances of rock sole age-0 (F = 7.22, p = 0.0010, N = 24) were significantly different among transects with more rock sole age-0 on MC than KS, BP, or HS transects. August abundances of flathead sole age-0 (F = 0.06, p = 0.9938, N = 58), age-1 (F = 1.03, p = 0.3990, N = 58), and rock sole age-1 (F = 1.27, p = 0.3172, N = 24) were not significantly different among transects.

In February 1996 bottom temperatures were significantly different among all transect combinations except KS and BP, with highest temperatures at MC and lowest temperatures at HS (Table I-6). The minimum bottom temperature over all seasons was in February 1996 at HS 10, with temperature 0.9°C. February abundances of flathead sole age-0 (F = 1.20, p = 0.3382, N = 27), age-1 (F = 1.63, p = 0.2031, N = 27), rock sole age-0 (F = 2.94, p = 0.1014, N = 12), and rock sole age-1 (F = 0.55, p = 0.7061, N = 12) were not significantly different among transects.

Juvenile flatfishes were present at a wide range of bottom temperatures (Table I-9). Abundances of flathead sole age-1 at depths ≥ 40 m were significantly different for bottom temperatures in August 1995 (T = -2.13, p = 0.0403), with highest abundances at 8.1 and 8.4°C. Abundances of rock sole age-0 at depths ≤ 30 m were significantly different for bottom temperatures in May 1996 (T = 2.33, p = 0.0238), September 1994 (T = -2.85, p = 0.0137), and February 1996 (T = 2.07, p = 0.0453). Abundances of rock sole age-1 at depths ≤ 30 m were significantly different for temperatures in May 1996 (T = 2.76, p = 0.0098), with highest abundance at 7.1°C.

2.3.2 Salinity

Bottom salinities were not significantly different between years in May (F = 1.91, p = 0.1761, N = 60), but were significantly higher in August 1996 than 1995 (F = 9.70, p = 0.0028, N = 82). For each sampling period, bottom salinities were not significantly different within the bay; however, in August 1996 bottom salinities could not be rejected as equal across transects (F = 2.74, p = 0.0520, N = 41). Bottom salinities in August 1996 were lowest at the CP transect, and lower at HS than BP (Table I-6).

Juvenile flatfishes were present at a range of bottom salinities from 21.8 to 32.2 (Table I-9). The test of equal abundances of flathead sole age-0 at depths ≥ 40 m among bottom salinities could not be rejected in August 1996 (T = 1.964, p = 0.0569). Abundances of rock sole age-1 at depths < 30 m were significantly affected by bottom salinities in May 1996 (T = -3.016, p = 0.0052), and in August 1996 (T = -1.948, p = 0.0589) the hypothesis that bottom salinity had no effect on abundance could not be rejected. Abundances of flathead sole age-1 and rock sole age-0 were not affected by bottom salinities in any sampling period (Table I-9).

2.3.3 Growth

Flathead sole age-0 modal length was 50 mm in September 1994, and 40 mm in August 1995 and August 1996 (Figure I-15). Mean length of flathead sole age-0 was greater in August 1995 than 1996, and greater in September 1994 than in either August 1995 or August 1996 (Table I-10).

Flathead sole age-1 modal length was 100 mm in September 1994, and 90 mm in August 1995 and August 1996 (Figure I-15). Mean length of flathead sole age-1 was less in August 1995 than 1996, and greater in September 1994 than in either August 1995 or August 1996 (Table I-10). Modal length in May 1995 was 60 mm and 70 mm in 1996 (Figure I-15); however, mean lengths were not significantly different.

Rock sole age-0 modal length was 50 mm in September 1994 and August 1995, and 30 mm in August 1996 (Figure I-16). Mean length of rock sole age-0 was greater in August 1995 than 1996, and greater in September 1994 than in either August 1995 or August 1996 (Table I- 10).

Rock sole age- 1 modal length was from 80 to 110 mm in September 1994, 120 mm in August 1995, and 110 in August 1996 (Figure I- 16). Mean length of rock sole age- 1 was significantly greater in August 1995 than 1996, and was not significantly different in September 1994 from August 1995 or August 1996 (Table I-10). Modal length in May 1995 was 60 mm and 80 mm in 1996 (Figure I-16). Mean length of rock sole age-l was significantly less in May 1995 than 1996 (Table I-10)

2.3.3.1 Mean length increase

Differences in mean length increases among seasons were compared to test the hypothesis that the most rapid growth would occur from spring to summer. For the 1994 and 1995 YCs, both flathead sole and rock sole had significantly greater growth rates from spring to summer (Tables I-l 1-12, Figures I-17-1 8). All comparisons of growth across seasons were significantly different except for mean length from summer to spring compared with summer to winter for the 1994 YC of rock sole and from summer to winter compared with winter to spring for the 1995 YC of flathead sole (Table I-12).

Mean length increases were compared between years to test the hypothesis that faster growth would occur in warmer years. From summer to summer, the 1994 and 1995 YCs of flathead sole were not significantly different (Figure I-17), whereas the 1994 YC of rock sole had a significantly higher mean length increase than the 1995 YC (Tables I-l 1-12, Figure I-18). From spring to summer the flathead sole 1994 YC had a significantly lower mean length increase than the 1995 YC (Figure I-17), whereas the rock sole 1994 YC had a significantly greater mean length increase (Tables I-l l-12, Figure I-18). From summer to spring flathead sole had no significant difference in mean length increase between YCs, whereas the rock sole 1994 YC had a lower mean length increase (Tables I- 1 l-l 2).

Mean length increases of different age groups were compared to test the hypothesis that age-0 juveniles have more rapid growth rates than age-l. From August 1995 to February 1996 age-0 flathead sole had significantly less mean length increase than age-1, and rock sole age groups had no significant difference in mean length increases. From May 1996 to August 1996, rock sole age-0 had significantly less mean length increase than age-l (Tables I- 11-12).

2.3.4 Locations with highest abundance

A total of 1987 flathead sole and 2536 rock sole ages-0 and 1 were caught at the 41 permanent stations for all seasons and years combined (Abookire and Norcross, 1998—Chapter 1 in this report). Highest numbers of flathead sole age-0 occurred at KS40, KS50, and MC50 in September 1994. Highest numbers of flathead sole age-l occurred at CP60 and MC70 in August 1995, and MC50 in September 1994. Highest numbers of rock sole age-0 occurred at MC20 in August 1996, and MC10 in September 1994, August 1995 and August 1996. Highest numbers of rock sole age-l occurred at MC10 in May 1995 and August 1996. Summer was the season with highest catches of juvenile flathead sole and rock sole.

2.4 Discussion

The results presented here show that bottom temperature varies within Kachemak Bay among seasons and years. Compared with outer Kachemak Bay, which has varying bottom temperatures between the south (MC) and north (BP) shores, the inner bay has more homogeneous temperatures between south (CP) and north (HS) shores. The HS transect is significantly colder than the other transects in winter, and in February 1996, we observed sea ice cover, which is an annual winter occurrence in inner Kachemak Bay (Anonymous, 1977).

Salinity controls distribution and movement of fishes, but it is often correlated with both Temperature and sediment. Therefore, interpretation of the role of salinity in fish distribution independent of other environmental factors is difficult (Gibson, 1994). Bottom salinities were not different between years in May. In August 1996, bottom salinities could not be statistically accepted or rejected as equal to or greater than 1995 bottom salinities. Because the only difference in fish abundance across transects in August 1996 was higher abundances of rock sole age-0 on MC than KS, BP, or HS, salinity had no clear relationship with abundance of flatfishes within Kachemak Bay. Bottom temperature was also greater in August 1996 than in 1995; Therefore, an interannual summer salinity effect is difficult to separate from temperature effects. More importantly, within-season bottom salinities were not different across transects, and in August 1996 the within-season bottom salinities could not be rejected or accepted as equal. Differences in local fish abundance were not related to bottom salinities. Therefore, in comparison with temperature, salinity exhibited slight differences within the study area and was not a significant controlling factor in growth, distribution or abundance. Malloy and Targett (199 1) state that unlike temperature, salinity did not affect spatial distribution, feeding, growth, or survival of juvenile summer flounder.

Patterns of seasonal migration are very species-specific with many possible controlling mechanisms, in addition to temperature which may affect migration on both local and regional scales (Dorel et al., 1991). Our data do not support a relationship between bottom temperature and juvenile flatfish distribution. During winter sampling, rock sole age-0 were present at all temperatures sampled (Table I-l l), and in inner Kachemak Bay they were present at the colder, deeper station (CP 150) and not at a deep, warmer station (CP 100). Rock sole age-0 displayed a winter offshore movement on all five transects and moved deeper than the maximum depth of winter mixing on all transects. Thus, rock sole may move offshore, in part, to avoid the dynamic winter mixing. Heavy winter storms which mix the water column create wave action at the bottom and stir up the sediments, which can limit the distribution of fishes (Laevastu and Hela, 1970). The winter offshore migration of *juvenile* flatfishes *(Pelotretis flavilatus, Peltorhamphus novaezeelandiae, P. tenuis,* and *P. latus) in* New Zealand was suggested to be an avoidance response to the low temperatures and increased turbulence that occur in shallow water during winter (Roper and Jiiett, 198 1). Similarly, in the Bay of Vilaine, juvenile sole *(Solea solea)* migrate offshore in winter to flee unfavorable hydrographic conditions (Dore1 et al., 199 1). Turbulence and wave action can displace fish and reduce visibility, thus reducing food intake and growth rates from levels experienced under calmer conditions (Moore and Moore, 1976; Gibson, 1994) and increasing competition for space. Such competition for space may lead to offshore movements, as laboratory experiments show that rock sole age-0 are more likely to choose mud-based sediment as their densities increase (Moles and Norcross, 995). Sampling occurred in winter in only one year, and without replicates we do not know the liming or variability of rock sole offshore movement. Additionally, we can only speculate about unmeasured mechanisms which may cause the offshore movement of rock sole, such as increased winter mixing (Roper and Jillett, 1981) and hydrodynamics (Laevastu and Hela, 1970; Dorel et al., 991).

Care must be used when interpreting environmental variables in isolation, as the nursery area is a complex system (Rogers, 1992). Although there may be significant differences in CPUE by temperature, not all stations of a given temperature have fish present. If flatfish abundance was directly related to bottom water temperature, we would expect temperature differences across transects to overlap with differences in fish abundances; however, this did not occur within Kachemak Bay. Seasonal differences in fish abundance may be more related to the life history of each species than to temperature. The annual temperature cycles may cue rock sole larvae to begin settling. For example, in May 1995 rock sole age-0 were not present; however, in May 1996, when temperatures were 1.4°C warmer, rock sole age-0 were present in low abundance. Because sampling in May 1996 was 19 days later than in 1995, time of year or higher water temperatures may cue settlement. During transport, California halibut *(Paralichthys calafornicus)* larvae delay settlement until they encounter warmer waters, which stimulate settlement (Gadomski and Caddell, 1991). In years with mild winters, juvenile summer flounder appear inshore earlier than when winters are severe, indicating that temperature is a cue for settling (Malloy and Targett, 1991).

The relationship between growth and temperature was investigated; however, because growth was estimated from seasonal mean length increase per day, bias due to migration and size-selective mortality could not be ignored. Both May and August 1996 temperatures were higher than 1995; therefore, we expected the 1995 YCs to have a greater mean length increase than the 1994 YCs. May rock sole age- 1 and August flathead sole age-l were significantly larger in 1996 than 1995, although May 1996 was sampled 19 days later than 1995, warmer spring temperatures coincided with larger fish length. These data support the hypothesis that growth is positively related to temperature. However, mean lengths of flathead sole age-O, rock sole age-0 and rock sole age-l were larger in August 1995 than 1996, contrary to that hypothesis.

Both year-classes of flathead sole and rock sole had the largest mean length increases between spring and summer. Thus, the data support the hypothesis that growth rate increases during seasons with higher temperatures. In the laboratory, growth is strongly affected by temperature for juvenile Atlantic halibut (Hallaråker et al., 1995) and turbot *(Scophthalmus maximus* L.) (Imsland et al., 1995). In the field, summer bottom temperatures are related to rapid growth for juvenile summer flounder (Able et al., 1990; Norcross and Wyanski, 1994) and sole (Dore1 et al., 1991). In fact, growth rates of summer flounder are cued by temperature and increase rapidly once temperature rises above 10°C (Malloy and Target, 199 1). Food availability for juvenile sole (Dorel et al., 1991) and photoperiod for juvenile Atlantic cod *(Gadus morhua)* (Folkvord and Otterå, 1993) are alternatives to low temperature as causes of reduced winter growth in some regions.

We investigated the relationship between mean length increase and temperature between years and expected the 1995 YCs to have greater growth rates since bottom temperatures were higher in 1996 than 1995. The rock sole 1994 YC grew less from September 1994 to May 1995, a colder period than from August 1995 to May 1996. From May to August the flathead sole 1995 YC had a greater growth rate than the 1994 YC. Since there was more growth during the warmer year, these data support the hypothesis that higher temperatures increase growth. However, from May to August the rock sole 1994 YC had a greater mean length increase than the 1995 YC, which contradicts the hypothesis. Additionally, the rock sole 1994 YC had a significantly greater mean length increase than the 1995 YC. Factors other than temperature which affect growth, such as food quality and quantity (Gibson, 1994; van der Veer et al., 1994), must therefore be considered.

Growth rates between age groups were compared to investigate the relationship between growth and age. From August to February flathead sole age-0 grew less than age-l, and rock sole age-0 growth was no different than age- 1. From May 1996 to August 1996 rock sole age- 1 grew more than the newly settled age-0 fish. These differences in growth may be explained by larval settling time, as age-l for both species grew more than age-0 during the time when age-0 were still settling into the demersal phase. Flathead sole peak spawning is from March to May in the Alaska and Pacific coast regions (Hirschberger and Smith, 1983), and they settle after May (Abookire and Norcross, 1998-Chapter 1 in this report). Rock sole spawn from February to April (Forrester, 1964; Matarese et al., 1989) and begin to settle in May (Abookire and Norcross, 1998-Chapter 1 in this report). These data do not adhere to the standard theoretical growth curve for flatfishes, which predicts that age-0 fish grow faster than age-1 (van der Veer et al., 1994). For flathead sole, this deviation from the standard growth curve may be related to a decrease in optimal temperatures as fish size and age increase (Hallaråker et al., 1995). Smaller plaice and flounder feed and grow at higher optimal temperatures than larger fish (Fonds et al., 1992).

These data are not sufficient to determine if juveniles migrated from coastal nursery grounds or if hydrological conditions enabled flatfish larvae to settle in Kachemak Bay; nevertheless, flathead sole and rock sole dominate the flatfish community within Kachemak Bay both as juveniles (Abookire and Norcross, 1998-Chapter 1 in this report; Appendices II-1 and II-6 in this report) and as adults (Rechtol and Yuen, 1995) The distributions of flathead sole and rock sole juveniles are clearly defined by depth and sediment (Abookire and Norcross, 1998-Chapter 1 in this report), and addition of the temperature variable does not further define habitat distribution within Kachemak Bay. To monitor year-class strength of flathead sole and rock sole, we recommend sampling in mid-August when abundances are high. We recommend sampling for flathead sole on the KS transect between 40 and 60 m and on the MC transect between 50 and 70 m, and for rock sole on the MC transect between 10 and 30 m. Continued sampling of juvenile flatfishes is worthwhile to continue collection of baseline data (Sharp, 1994), monitor changes in recruitment (Miller, 1994; van der Veer et al., 1994), and build on the growing knowledge of the early life history of Alaskan flatfishes.

Chapter 3. Using habitat characteristics in the assessment of interannual fluctuations in juvenile flatfish abundances

by Sherri C. Dressel and Brenda L. Norcross

Abstract

Many North Pacific fish populations are declining in abundance due to the effects of development, exploitation, pollution and other anthropogenic and natural effects. The need for effective fisheries management is stronger now than ever before. Current declines in fish stocks have resulted in a need for earlier estimates of species' year-class strength; such data would have wide-reaching benefits. A survey was developed during this study to assess relative interannual fluctuations in recruitment for four juvenile flatfish species: age-0 rock sole (Pleuronectes *bilineatus),* age-0 Pacific halibut *(Hippoglossus stenolepis),* age-0 flathead sole *(Hippoglossoides elassudon)* and age-l yellowfin sole *(Pleuronectes asper).* Six years of annual trawl data and physical parameter measurements (199 l-l 996) were collected in Chiniak Bay, Kodiak Island, to assess the distribution and abundance of juvenile flatfishes in relation to habitat characteristics. Obtaining reliable abundance indices from juvenile flatfish trawl surveys is difficult due to the tendency of juveniles to aggregate. Since the precision of survey density estimates decrease as the degree of aggregation increases, bottom trawl sampling for juvenile flatfishes often gives highly variable catches. Due to the difficulty of obtaining reliable abundance estimates, the first portion of this study was dedicated to developing and evaluating a survey design for juvenile flatfish surveys. In the second portion of the study, survey data was utilized for an assessment of interannual variability in abundance for four juvenile flatfish species.

Often, the concentration of juveniles varies over space and time in response to environmental conditions and factors. In this study, 1991-1994 sampling for fish and habitat parameter data allowed stratification of sampling by habitat characteristics in 1995 and 1996. Stratifying 1995 and 1936 sampling by the habitat parameters most closely related to each species distribution increased precision of juvenile flatfish abundance estimates. Sampling in 1996 was allocated on the outer edges of each species' geographical distribution range, defined in previous sampling with habitat parameter ranges. If the geographic distributions of these species increase and decrease in response to annual abundance changes, sampling on the outer perimeters of each species' geographical distribution range could provide an indication of population changes from regions where abundances and sampling variances are low. While sampling in these regions was hypothesized to provide abundance estimates with increased precision over sampling across all regions with a stratified (1995) or non-stratified (199 l-l 994) design an increase was not observed.

The second portion of this study was dedicated to assessing interannual variations in abundance for the four juvenile flatfish species and utilizing habitat characteristics in the analysis of all six years. Three indices were developed for each species, each index based on mean catch-per-unit-effort (number of fish per 1000 m^2) across selected sites: the first included nine fixed sites that were sampled in all six years, the second included all sites sampled in each of the six years and the third included all sites in regions of "preferred" or occupied habitat, identified specifically for each of the four species and based on depth and sediment characteristics. These indices revealed that rock sole exhibited an oscillating pattern of abundance, highest in 1992 and 1994 and lowest in 199 1 and 1993. Pacific halibut abundance was lowest in 199 1 and 1993, increasing to its highest abundance in 1994 and 1995. Flathead sole abundance showed a strong increase from 1991 to 1992, with decreasing numbers thereafter. Yellowfin sole exhibited its highest

abundance in 1991, with decreasing abundance over the following five-year period. We found that the specific index that provided the most information (i.e., the lowest error) for each species depended on both the index sample size and the individual species' geographic distribution.

3.1 Introduction

The goals of fisheries management include conserving the fish resource, controlling fisheries when overexploitation is a problem, and maximizing or optimizing the yield from the resource in terms of biological, sociological and economic perspectives (Mundy et al., 1985). Earlier estimates of species' year-class strength would have wide reaching benefits. Since early estimates would allow predictions of stock sizes years in advance of the harvest, they would provide benefits to managers, processors and participants in the fishery. Predictions of flatfish year-class strength prior to entrance to the fishery may be obtainable from juvenile flatfish surveys. This particular study focuses on the assessment of abundance of four juvenile flatfish species, age-0 rock sole *(Pleuronectes bilineatus),* age-0 Pacific halibut *(Hippoglossus stenolepis),* age-0 flathead sole *(Hippoglossoides elassodon)* and age- 1 yellowfin sole *(Pleuronectes asper).*

To develop a reliable prediction of year-class strength and reach the goals of fishery management, scientists must be able to assess population levels with a high degree of confidence. Since improperly designed data collections and sampling programs utilized to reach these goals limit how much conclusive information is gained, developing a sampling design to provide management information requires more attention than has been given in the past (Mundy et al., 1985). As a result, this paper contains two parts. The first portion focuses on survey design and the second focuses on assessing interannual variations in abundance. While this study focuses on the assessment of abundance of four juvenile flatfish species, the methods of survey design and analysis address common questions in relation to trawl surveys and are thus of general interest.

In general, the maximum precision attainable in a survey is determined by the spatial distribution of the target species (Gunderson, 1993). One of-the most important steps in developing a direct survey of abundance, therefore, is to obtain a complete understanding of the distribution of the target species. A primary difficulty with juvenile flatfish trawl surveys is the tendency of juveniles to aggregate. As the degree of aggregation increases, the precision of a density estimate will decrease (Lenarz and Adams, 1980), with the variance of catches increasing faster than the value of the mean (Forest and Minet, 198 1). As a result, bottom trawl sampling for juvenile flatfishes often gives highly variable catches making it difficult to obtain abundance indices. When assessing abundances, therefore, surveys need to be adapted to account for aggregated distributions.

Often, the concentration of juvenile flatfishes varies over space and time in response to environmental conditions and factors (Jager et al., 1993; Keefe and Able, 1994; Reichert and van der Veer, 1991, Norcross et al., 1995, 1997). In fact, habitat type and habitat quality are becoming more widely recognized as primary determinants for the distribution and survival of marine fish species (Tanda, 1990; Gadomski and Caddell, 199 1; Kramer, 199 1; Reichert and van der Veer, 1991; Gibson and Robb, 1992; Sogard, 1992; Moles et al., 1994; van der Veer et al., 1994; Moles and Norcross, 1995; Norcross et al., 1995, 1997). As habitat is a key factor in determining fish distribution, knowledge of the preferred habitat characteristics of the target species is necessary in order to design an effective survey of abundance. Until recently, however, few studies have been directed toward defining fish habitat or using habitat preference to help decrease the variability in abundance estimation (Scott, 1995). Abundance estimates derived from current surveys, which sample evenly across a variety of habitats, may be less reliable than those that could be produced if the factors responsible for the distribution were accounted for in the survey design. If habitat preferences can be determined and habitat **types quantified, sampling** stratification should be more effective, minimizing the variance in population estimates.

The juvenile flatfish survey developed in this study was a multi-step, habitat-based survey. Six years of annual trawl data and physical parameter measurements were collected in Chiniak Bay, Kodiak Island (Figure I- 1) to estimate catch-per-unit-effort (CPUE) and develop a relative index of population abundance. The survey design described in this paper had three steps, designed to make subsequent use of the information gained in prior steps of the survey. Each "step" refers to a particular combination of sampling method and sample allocation. The first step, implemented from 199 1 to 1994, incorporated non-stratified exploratory sampling. Fish abundance and physical parameter data were collected in order to identify the habitat parameters most closely related to each species' distribution. The second step in the design was implemented in 1995. Sampling was stratified by depth and substrate, the two habitat parameters selected from step one, with fixed sample allocation. Sampling in the second step was designed to obtain estimates of variability in species abundances and cost of sampling (the number of hours required to trawl and sort one tow) in each stratum. The third step was implemented in **1996.** Sampling was stratified, with strata boundaries defined in terms of depth and substrate, chosen to maximize the similarity of species abundances. The number of tows in each stratum was assigned based on the relative area in each stratum, the cost of sampling in each stratum and the variance of the four target species' abundance. Strata with low variability were chosen for each species as monitoring strata. As a result, monitoring strata for abundant species were located on the outer perimeter of the species' geographic distribution. Monitoring strata for non-abundant species incorporated larger proportions of their distribution range. The objective of this design was to determine whether integrating habitat information into survey design/analysis and allocating samples on the outskirts of each species' geographic range would provide precise estimates of relative abundance.

The analysis of interannual variability included the use of three abundance indices. The first index, the mean CPUE over nine fixed sites sampled each year, was restricted to a low sample size, but was utilized to provide annual abundance estimates with no spatial bias. The second index, the mean CPUE over all sites sampled each year, had the highest possible sample size, but included some degree of spatial bias since the location of sample sizes varied from year to year. The third index, the mean CPUE over all sites within species-specific regions of "preferred" or occupied habitat, was used to provide a measure of abundance while minimizing the effect of zero catches **in regions** of unoccupied habitat. The three indices had individual strengths and weaknesses, but were used together to more closely define the changes in juvenile flatfish recruitment over time.

3.2. Sampling methods

Sampling was conducted in Kalsin and Middle Bays, offshoots of Chiniak Bay, approximately 10 nmi from the town of Kodiak Alaska (Figure I-1). Middle Bay is approximately 8 km long, with depths of 50 m at the mouth of the bay, and an area of approximately 21 km^2. Kalsin Bay is also approximately 8 km long, reaches depths greater than 100 m at the mouth of the bay, and encompasses an area of approximately 34 km^2. The survey area for this study, which included the combined area of the two bays and the sampled region directly outside the mouths of the two bays, encompassed approximately 87 km^2 (Figure I-3).

Annual cruises were conducted in Chiniak Bay within the first two weeks of August from 199 1 to 1996. During the years of exploratory sampling, 199 1-1 994, sample sites extended into Womens and Isthmus Bays, but the indices of abundance developed in this study were restricted to inner and outer Middle and Kalsin Bays (Figure I-3). Sampling in 199 1 was conducted from 11-17 August aboard a 7.3 m skiff and from 18-19 August aboard a 24.7 m chartered trawl vessel (F/V *Big Valley*). In 1992, sampling was conducted from 9-14 August aboard the same 7.3 m skiff. Annual sampling from 1993 to 1996 was conducted as a joint effort between the Institute of Marine Science (University of Alaska Fairbanks) and the National Marine Fisheries Service (Kodiak Laboratory). All four years of sampling were conducted aboard an 8.2 m Boston Whaler owned by the Kodiak NMFS Lab. Sampling was conducted from 12-24 August 1993, 8-19 August 1994, 31 July-11 August 1995, and 1-16 August 1996.

The beam trawls used in this study were adapted from a design by Gunderson and Ellis (1986) for juvenile flatfish. In 1991, 1992 and for 7 quantitative tows in 1993, tows were made with a 3.66 m plumb staff beam trawl. In 1994, 1995, 1996 and for 32 quantitative tows in 1993, tows were made with a 3.05 m plumb staff beam trawl. Trawl nets were made of 7 mm square net mesh and a 4 mm codend liner which retained flatfishes as small as 11 mm Nets were equipped with a double tickler chain, two 40 lb. weights on the lower wings, floats on the headrope and at each end of the beam, and 6 in. lengths of chain hung from the footrope at 6 in. intervals. The towline was deployed at a 5: 1 line:depth ratio at sites less than 10 m deep and 3 : 1 ratio for depths greater than 10 m. Tows were approximately 10 minutes in duration, but varied as necessary according to factors such as sediment accumulation in the net and towpath restrictions. All tows were made during the day and primarily on a rising tide. All fish were identified to species and length measurements were taken. Fish ages were determined by length frequency analysis.

The effective sampling area of each tow was determined by multiplying the effective width of the beam trawl, 0.74 of the beam length (Gunderson and Ellis, 1986), by distance towed based on Global Positioning System (GPS) coordinates. Fish CPUE values were standardized to a 1000 m^2 tow area. For 1994, 1995 and 1996 sampling, distances were determined from GPS readings for each individual tow. Since beginning and ending GPS coordinates were not recorded in tows from the 7.3 m skiff in 1991, in 1992 or 1993, tow distances were estimated with least trimmed squares robust regression of GPS distance towed per minute data for each of the respective vessels (S-Plus, 1993). Data for the Boston Whaler (1993) were taken from Boston Whaler distances during the 1994, 1995 and 1996 cruises. Additional sampling in 1996 was conducted to determine distance statistics the 7.3 m skiff (1991 and 1992). All but two of the tows conducted from the 24.7 m trawling vessel, F/V *Big Valley* (1991), in Kalsin and Middle Bays were calculated from GPS coordinates. The remaining two tows were estimated as the average distance for a 10-minute tow conducted during that cruise.

3.3 Survey design: Methods and results

3.3.1 First step of the survey-1991 to 1994

3.3.1.1 Methods

The first step of the survey (1991-1994) incorporated extensive spatial sampling for describing juvenile flatfish distributions in relation to habitat characteristics (Norcross et al., 1995, 1997). Sites were sampled within 5 m depth increments from 0 to 10 m depth and at 10 m depth increments at greater depths. The goal was to sample over the widest range of regions and habitat characteristics possible within the constraints of bottom type suitable for trawling. At each site, a tow of 10 minutes or less was conducted and a set of physical measurements was collected. The physical measurements included depth (as read from the vessel fathometer), a sediment grab (0.06 m^3 Ponar grab) taken for grain size analysis, organic content (in 1993-1996 sampling) and carbonate content (in 1993-1996 sampling), a vertical CTD (conductivity, temperature and depth) cast for temperature and salinity measurements at depth and a record of distance from the mouth of the bay, minutes after high tide and minutes after sunrise at the time of the tow.

3.3.1.2 Results

Fish CPUE statistics were calculated for a total of 178 quantitative tows in Kalsin and Middle Bays from 1991 to 1994 (Table I-13, Figure I-19). In 1991, 50 quantitative tows were made in Kalsin and Middle Bays, 40 from a 7.3 m skiff and 10 from the 24.7 m F/V ***Big Valley.*** In 1992, 31 tows were made from the 7.3 m skiff. Sampling in 1993 and 1994 was conducted from the 8.2 m Boston Whaler, yielding 39 and 56 quantitative tows, respectively.

A comparison of fish abundances with physical characteristics was conducted by Norcross et al. (1995) in order to determine the physical characteristics most closely related to the distribution of juvenile flatfishes in bays and straits around Kodiak Island. The relationship between fish abundances and physical oceanographic data in Chiniak Bay and other bays around Kodiak Island described habitat for four of the most abundant species, age-0 rock sole, age-0 Pacific halibut, age-0 flathead sole and age-1 yellowfin sole (Norcross et al., 1995). Linear discriminant function analysis on presence or absence data was used to create habitat models for the four species (Norcross et al., 1995). Regression trees were constructed by using CPUE for each species to refine the habitat models (Norcross et al., 1997). Habitat parameters included in the statistical comparisons were depth, distance from the bay mouth, temperature, salinity, and categorical descriptions of sediment types based on Folk (1980). Two groups of habitat factors (depth/temperature and sediment composition) explained most of the observed distributions of age-0 rock sole, age-0 Pacific halibut, age-0 flathead sole and age-l yellow-fin sole (Norcross et al., 1997).

3.3.2 Second step of survey-1995

3.3.2.1 Methods

The precision of an estimated sample mean depends upon two factors: the size of the sample and the variability or heterogeneity of the population. Since the number of samples in this study was limited to those obtainable with the same amount of effort each year, the only way to increase the precision of estimates was to use sampling procedures, such as stratification, that would effectively reduce the heterogeneity of the sampled population (Sukhatme, 1963). The 1995 survey was stratified by depth and sediment, the primary habitat characteristics determined during preliminary 1991-1994 sampling. The goal of 1995 sampling was to describe the variability in abundance estimates and cost of sampling as specifically as possible across all regions of the study area. To do so, a minimum of three tows was assigned to as many strata as possible within the given amount of effort available for the survey. The resulting cost and variance estimates from each 1995 stratum were to be combined into fewer strata for the 1996 survey, based on fish distributions (as indicated by habitat types) and cost information.

In the 1995 sampling design, the survey area was divided into 10 strata based on depth and sediment (Table I-14). Depth classifications in Middle Bay were O-5 m, 5-10 m, 10-20 m, 20-30 m, 30-50 m, and greater than 50 m. Depth classifications in Kalsin Bay were O-5 m, 5-10 m, 10-20 m, 20-30 m, 30-50 m, 50-70 m, and greater than 70 m. Sediment stratification was based on percent sand in substrate. Sediment was stratified into three levels: 0–50% sand, 51–90% sand, and 91-100% sand. Ten of the most prevalent combinations of depth and sediment classifications were represented in the 1995 strata.

Three replicate tows were planned on the predominant sediment type within each depth interval, in order to establish variance estimates for each species' abundance in each strata. When the same depth and sediment classifications were present in both bays, three tows were made in each bay to account for bay differences, for a total of six tows in the strata. When available, different sites within the same strata were used. In the case where multiple trawlable sites within a particular stratum did not exist, three replicate tows were made in the same immediate location.

At each site a sediment grab was taken to visually confirm the expected sediment type, and kept for grain size analysis. Trawl and data collection methods were the same as in 1991-1994. In addition to these methods, we recorded the cost of sampling in each stratum, defined in this study as the hours needed to trawl and sort one tow.

The mean abundance and the variance for each species was calculated for each strata as

$$\bar{y} = \tfrac{1}{n}\sum_{i=1}^{n} y_i \text{ and}$$

$$s_h^2 = \tfrac{1}{n_h-1}\sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)^2.$$

In order to assess whether the chosen combinations of depth and sediment decreased the variance of abundance estimates, the variance of the mean estimators from 1995 data were compared when calculated with data stratified and when calculated without data stratified. For this analysis, the 1995 sampling was treated in one case as stratified random sampling, with the mean estimators and variances calculated as

$$\bar{y}_{st} = \tfrac{1}{N}\sum_{h=1}^{L} N_h \bar{y}_h \text{ and}$$

$$\hat{\text{var}}(\bar{y}_{st}) = \sum_{h=1}^{L} \left(\tfrac{N_h}{N}\right)^2 \left(\tfrac{N_h - n_h}{N_h}\right) \tfrac{s_h^2}{n_h},$$

with s^2 calculated as above, and in the other case as simple random sampling with the mean estimators and variances calculated as

$$\bar{y} = \tfrac{1}{n}\sum_{i=1}^{n} y_i \text{ and}$$

$$\text{var}(\bar{y}) = \left(\tfrac{N-n}{N}\right)\tfrac{s^2}{n}, \text{ with}$$

$$s^2 = \tfrac{1}{n-1}\sum_{i=1}^{n} (y_i - \bar{y})^2.$$

In order to calculate the stratified estimator, the area of each of the 1995 strata had to be assessed. To do so, the survey region was digitized and plotted in the Surfer program (Surfer, 1995). Values of percent sand were contoured over the study region for each year (199 1-1995). Due to the similarity in sand distribution over the five years of sampling and the degree of detail necessary for the area estimation, sediment data from 199 1 to 1995 were combined into a single sediment map. The method of minimum curvature was used to contour sediment values over the region and the area within each sediment-depth combination strata was calculated.

3.3.2.2 Results

A total of 38 quantitative tows was completed in 1995 sampling (Table I-15, Figure I-20). Three replicate tows were completed on the predominant sediment types within each depth interval, except KB70, for which we obtained only two tows due to time limitations (Table I-14). Based on these tows, the effectiveness of the stratification was evidenced by a general increase in precision of the mean estimators for three of the four target species (Table I-16). Overall variance of the stratified estimator was considerably lower than the non-stratified variance for rock sole, Pacific halibut and flathead sole.

Variance of the yellowfin sole non-stratified mean estimator was lower than the stratified variance, but was noticeably slight compared to the increases in precision shown by the other three species. The general decrease in variance with stratification suggests that habitat, as described by depth and sediment, was an appropriate indicator for the distributions of these target species, and is thus an appropriate stratifying parameter. The cost of sampling and the variability of species abundance in each stratum were used to design the 1996 survey.

3.3.3 The third and final step of survey-1996

3.3.3.1 Methods

Species means and variances from 1995 strata were compared with depth and sediment in order to determine strata boundaries for the 1996 survey. Strata boundaries were chosen to maximize the similarity of species abundance. Sediment was divided into three categories: 0–40% sand, 41–80% sand and 81-100% sand (Table I-17). Depth was divided into two categories: less than 30 m and greater than or equal to 30 m. Although regions greater than 30 m depth and 81–100% sand were predicted by the extrapolation of sediment values in the Surfer program, regions with those characteristics were not found in 1991-1995 sampling. As a result, that stratum was excluded from total area estimate and the remaining five strata were assumed to account for the total available sampling area in the region. The total area in the sampling region (Figure I-3), as determined using Surfer (1995), was 87.15 km^2 and each tow was standardized to 1,000 m^2 Sampling in 1996 was then distributed among these five strata (Table I-17).

Monitoring strata chosen for each species were those that composed the regions on the outer perimeters of each species' geographical distribution range (Figures I-2 l-24). Since the distributions of each species differed, the particular monitoring strata and the number of monitoring strata chosen for each species differed respectively. The distribution of samples among these strata was based on the relative area in each stratum. the cost of sampling in each stratum and the variance of the four target species' abundance. The optimum allocation equation (Thompson, 1992) was utilized to combine these factors and to estimate the relative sample sizes needed for each species in their selected strata.

$$n_h = \frac{(c - c_0) N_h \sigma_h / \sqrt{c_h}}{\sum_{k=1}^{L} N_k \sigma_k \sqrt{c_k}}$$

High sample sizes resulted for strata with high variances, large areas and low costs, while low sample sizes resulted from the opposite. It should be noted that sampling did not follow the optimum allocation design, but instead the equation was used as a reference to determine relative sample sizes in the strata chosen. All four species were weighted of equal importance when determining sample sizes.

In order to assess the effectiveness of the multi-step, habitat-based survey design in producing indices of mean abundance with high precision, data collected in 1996 under the selective stratification scheme were compared with results of the 1995 stratified sampling, and results of 1993 exploratory sampling. The 1993 sampling season was chosen to represent the years of exploratory sampling in the comparison since it was the only year from 1991 to 1994 that sampled in all habitats described by 1996 strata. It was also the year that had the sample size (n = 35) most similar to those in 1995 (n = 38) and 1996 (n = 39). While equal sample sizes were not a requirement for statistically comparing the years, the power of the comparison lest was heightened by having sample sizes as nearly equal as possible (Zar, 1996). For each species in each year, mean abundance per tow, variance of the mean and the coefficient of variation were calculated. The comparison of the three years' data was drawn not to suggest that the three sampling designs should be used or chosen individually, but to see whether the three steps that built on each other showed signs of increasing precision.

For this comparison, 1993 sampling was treated as simple random sampling and 1995 sampling was treated as stratified random sampling (see equations above). Data from 1996 were also treated as stratified random sampling, but the allocation of samples was based on the distribution of the four species (please note that none of the sampling over these years was completely random, but randomness was approximated as closely as possible within the depth, sediment, weather and logistical constraints). While the mean abundance per tow indices were calculated over the whole study area for 1993 and 1995, the mean abundance per tow index was calculated over only the selected monitoring strata for each species in 1996. The coefficient of variation was calculated for each species in each year to compare the precision of the stratification schemes. Pairwise two-tailed tests were then conducted on 1993, 1995 and 1996 fish CPUE data (Zar, 1996). In these comparisons, the logarithms of fish abundances (n + 1) were used to approximate normality in all three years.

3.3.3.2 Results

The geographic distribution of each species was closely related to depth and percent sand in substrate. Flathead sole were found in regions O-85 m in depth and with 10–100% sand (0–92% mud) in substrate, but predominantly in depths >30 m and on substrates with 0–50% sand (>35% mud). Rock sole was the most abundant flatfish species, inhabiting regions O-85 m in depth and with 0–100% sand. Rock sole were predominantly found in depths <40 m and with >20% sand in substrate. Pacific halibut were collected in regions O-85 m in depth and with 0–100% sand in substrate, predominantly in depths <30 m and with >25% sand in substrate. Yellowfin sole were collected in regions 045 m in depth (predominantly O-30 m) and with >20% sand in substrate.

Monitoring strata were chosen for each of the four species for 1996 sampling (Table I- 17). One monitoring stratum was chosen for rock sole (stratum 4), two for Pacific halibut (strata 1 and 3), four for flathead sole (strata 1, 2, 3 and 4) and all five for yellowfin sole (strata 1, 2, 3, 4 and 5). It should be noted that 1995 stratum 4 contained no yellowfin sole or Pacific halibut and stratum 5 contained no yellowfin sole, yet these strata were included as monitoring strata for these two species in 1996. Minimal-to-no additional tows were required to include these strata (no additional for stratum 4 and two additional for stratum 5) and in the event that populations of these species expanded, tows in these strata could have been important indicators of the change.

A total of 39 quantitative tows was completed in 1996, divided among the five strata (Table I- 18, Figure I-25). Stratified mean estimates and associated variances and coefficients of variation were calculated for each species across monitoring strata (Tables I- 19-20). Results from 1996 (stratified by depth and sediment with indices calculated for each species in species-specific monitoring strata) were compared with 1993 (no stratification) and 1995 (stratified by depth and sediment with the same number of samples in each strata of each bay) (Table I-20). As expected, the precision of estimates varied with the stratification and allocation method. For each of the four species, the most precise estimator was one of the stratified estimators. For flathead sole and Pacific halibut, stratified sampling with even allocation of samples (1995) gave the most precise estimator, followed by stratified sampling in selected monitoring strata (1996) and finally, sampling with no stratification (1993). Tests of flathead sole coefficients of variation showed that non-stratified sampling in 1993 and stratified sampling in 1996 had significantly larger coefficients of variation than 1995 sampling ($p < 0.05$), though not significantly different from each other. Since no Pacific halibut were caught in the 1996 selected monitoring strata, the only statistical comparison that could be drawn was between 1993 and 1995 sampling. Similar to flathead sole results, 1995 sampling yielded a significantly lower coefficient of variation than 1993 non-stratified sampling ($p < 0.05$). For yellowfin sole, stratified sampling in 1996 formed the most precise estimator, followed by stratified sampling in 1995 and, lastly, sampling with no stratification in 1993. None of the yellowfin sole coefficients of variation differed significantly. In the case of rock sole estimation, 1996 sampling was the least precise, with 1995 stratification being the most precise and sampling with no stratification ranking in between. In this case, rock sole coefficients of variation in 1993 and 1995 were both significantly lower than in 1996 ($p < 0.05$), but did not differ significantly from each other.

Since the only monitoring stratum chosen for rock sole in 1996 was stratum 4, it seemed possible that the high coefficient of variation could be related to the small sample size ($n = 7$). When the rock sole mean estimate was made over all 1996 strata, rather than the single monitoring strata, the coefficient of variation decreased from 0.65 to 0.20 (Table I-19). The 1996 coefficient of variation over all strata was higher than in 1995, but less than in 1993 and not significantly different than either (Table I-20). In this case, as with yellowfin sole, no significant differences existed among any of the three years.

Estimates of mean abundance and coefficients of variation were calculated over all 1996 strata for each species (Tables I-19-20). For flathead sole, the estimate over all strata was less precise than over the monitoring strata, but not significantly so. For Pacific halibut, the coefficient of variation over all strata provided a value for comparison with 1993 and 1995 results (Table I-20). The 1996 all strata estimate for Pacific halibut was significantly greater than in 1995 ($p < 0.05$) and was less (but not significantly less) than in 1993. Since all strata were chosen as monitoring strata for yellowfin sole, no estimations changed.

3.4 Analysis of interannual variability: Methods and results

3.4. 1 Methods

Three indices were constructed to discern interannual variations in abundance of each of the four species: a nine-site index, an all-site index and a habitat index. The nine-site index was the mean CPUE calculated over nine fixed sites. The all-site index was the mean CPUE calculated over all sites sampled each year. The habitat index was the mean CPUE calculated over all sites in a particular habitat, “type” specific to each species. The study area was divided into five habitat “types” defined by depth and by sediment characteristics (represented here by percent sand), since each of the four species were distributed in relation to particular ranges of depth and sediment characteristics (Norcross et al, 1995, 1997). The relationship between depth and sediment values in these bays and the relationship between species’ distribution and each of these physical parameters determined the five habitat types used for the habitat index. The resultant habitat types were: <30m and 0–40% sand, <30m and 41-80% sand, <30m and 81–100% sand, ≥30m and 0–40% sand, and ≥30m and 41-80% sand. The habitat type selected for each species was the habitat type with the highest proportion of non-zero trawl catches.

A Kolmogorov-Smirnov D one-sample test for normality was computed on the CPUE values for each species in each year. For the nine-site index, each species’ distribution was tested for normality across the nine sites For the all-site index, each species’ distribution was tested for normality across all sites. For the habitat index, each species’ distribution was tested for normality across all sites within the species-specific habitat type. Since the means and standard deviations of the abundances being collected were estimated from the data (the Kolmogorov-Smimov test assumes the mean and standard deviations are known, not estimated), Lilliefors probabilities were calculated along with the Kolmogorov-Smimov D statistic. For each index, overall normality was rejected if species distributions were non-normal in any one or more of the six individual sampling years. If the species CPUE values were not normally distributed, the log transform (log [x+1]) of the CPUE values was also tested for normality. Based on the results of the normality test, species' mean abundance was tested across years either with a parametric single factor analysis of variance (ANOVA), if normal, or a non-parametric analysis of variance by ranks (Kruskal-Wallis test), if non-normal. For species that showed significant differences among years (a ≤ 0.05), a Tukey HSD (honest significant difference) test for unequal sample sizes was made to determine where the differences in means existed (a ≤ 0.05). Although the underlying assumptions of population normality and homogeneity of variance are only approximated in this study, the Tukey multiple comparison test was used since it has shown to be robust with respect to departures from these assumptions (Keselman, 1976)

3.4.2 Results

The nine permanent sites were sampled at least once in all six sampling years (Figure I-26). In cases where one of the nine sites was sampled more than once in a year, CPUE values were averaged over the number of tows at that site and the averaged value was weighted as a single tow for the remainder of the nine-site analysis (Table I-21). Mean annual CPUE over the permanent sites was calculated for each species as the first indices of abundance (Figure I-27a). The CPUE values, and the log transform (i.e. log [x+1]) of the CPUE values, showed significant departures from normality for all four species, so the Kruskal-Wallis test was used to compare annual mean CPUE of rock sole, Pacific halibut, flathead sole and yellowfin sole. None of the species had statistically significant differences among years when evaluating across the nine permanent sites (a = 0.05) (Statistica, 1995).

While random sampling for the all-site index was approximated within the sampling design constraints noted for each year, annual samples still exhibited a regional bias in particular years due to weather and logistical constraints. In 1991, sampling was concentrated at the head of Kalsin and Middle Bays and, for all but nine tows that were taken from a chartered trawler, was restricted to shallow regions due to vessel limitations. In 1992 the sample size was considerably smaller than in the other five years. A number of tows were conducted in the same sites as 199 1, for continuity, and the remainder were extended into other shallow-bay regions (due to the same vessel limitations) with a higher proportion of tows on gravel sediment than in the other five years. Calm weather in 1994 allowed sampling up to 110 m depth outside the mouths of both Middle and Kalsin Bays and allowed a number of sites to be trawled in the deep outer portion of Kalsin Bay. Sampling in 1993, 1995 and 1996 was characterized by a general dispersion of sites across depths and sediments, with similar sample sizes.

Mean annual CPUE for each species was calculated over all sites as the second index of abundance (Figure I-27b). Like the permanent site data, both the CPUE values and the log transform (i.e. log [x+1]) of the CPUE values showed significant departures from normality, so the Kruskal-Wallis test was used to compare annual mean abundance of all four species. Rock sole ($p < 0.001$) and Pacific halibut ($p < 0.001$) showed significant differences in mean abundance, while flathead sole ($p = 0.168$) and yellowfin sole ($p = 0.078$) did not. Tukey pairwise comparisons were made of rock sole abundances, indicating that the 1992 mean abundance was significantly greater than in 1991 ($p < 0.001$), 1993 ($p < 0.001$) and 1995 ($p < 0.01$); however, rock sole abundance increased in 1996 and thus was not different than the high value in 1992. The 1994 mean abundance was significantly greater than the two lowest abundances, 199 1 ($p < 0.00 1$) and 1993 ($p < 0.001$). For Pacific halibut, Tukey pairwise comparisons indicated the high mean abundances in 1994 and 1995 were significantly greater than the low 199 1 ($p < 0.00 1$ for both) and 1993 ($p < 0.01$ and $p < 0.001$, respectively) abundances.

For the habitat index, the CPUE values and the log transform (i.e., log [x+1]) of the CPUE values again showed significant departures from normality for rock sole, Pacific halibut and yellowfin sole. Kruskal-Wallis non-parametric analysis of variance tests were used to determine differences in mean abundance per tow between years. Interannual trends in abundance are shown in Figure I-27c. Rock sole ($p < 0.01$) and Pacific halibut ($p < 0.0001$) showed significant differences in mean abundance, while yellowfin sole ($p = 0.182$ 1) did not (Figure I-27c). Tukey pairwise comparisons were drawn for rock sole, indicating that the 1992 mean abundance was significantly greater than in 1991 ($p < 0.05$). For Pacific halibut, Tukey pairwise comparisons indicated the mean abundance in 1994 and 1995 were significantly greater than in 1991 ($p < 0.001$ and $p < 0.01$, respectively).

Unlike the other species, flathead sole was normally distributed each year (1991, $p > 0.20$; 1992, no samples; 1993, $p > 0.20$; 1994, $p < 0.15$; 1995, $p > 0.20$; 1996, $p > 0.20$) within the chosen habitat type (> 30 m depth and 0–40% sand). As a result, mean abundance tested across years with a parametric single factor analysis of variance (ANOVA) gave significant results ($p = 0.001$) for interannual differences. Tukey pair-wise tests indicated that the flathead sole mean abundance in 1993 was significantly greater than in 1991 ($p = 0.008$) 1995 ($p = 0.022$) and 1996 ($p = 0.004$).

3.5 Discussion of survey design

Two objectives were addressed in the survey design analysis. The first was to determine whether or not stratification by habitat parameters would increase the precision of abundance indices for age-0 rock sole, age-0 Pacific halibut, age-0 flathead sole and age-l yellowfin sole. The second objective was to assess whether setting up habitat-based monitoring strata which contained regions on the outer perimeters of each species' geographical distribution range would provide more precise and reliable interannual monitoring estimates.

The results of this study indicate that stratification by habitat parameters does increase the precision of the indices of abundance (Table I-19). The comparison of 1995 data, calculated with and without stratification, shows that for rock sole, flathead sole and Pacific halibut, stratifying by habitat characteristics dramatically decreases the variability in the mean estimate. On the contrary, the yellowfin sole mean estimate was slightly less variable when calculated without stratification, but the difference is slight compared with the gains in precision for the other three species

The comparison of 1993 sampling (no stratification) with 1995 sampling (stratified by depth and sediment with the same number of samples in each stratum of each bay) and 1996 sampling (stratified by depth and sediment with indices calculated for each species in species-specific monitoring strata) yielded similar results (Table I-20). With two exceptions, the years of stratified sampling (1995 and 1996) consistently produced estimates with lower coefficients of variation than the year of sampling with no stratification (1993). The only case where sampling with stratification ranked lower than sampling with no stratification was for 1996 rock sole samples. The rock sole mean abundance calculated in 1996 was based only on stratum 4. As a result, the sample size for 1996 rock sole abundance consisted of only 7 samples, whereas rock sole samples in 1993 and 1995 had 35 and 38 samples, respectively. When the 1996 mean estimator was calculated over all strata, the coefficient of variation was 0.196, a notable increase in precision over the 0.253 no-stratification coefficient of variation (Table I-20). The other exception arose for Pacific halibut when the two strata selected as monitoring strata for halibut in 1996, strata 1 and 4, consisted of 11 tows with no halibut caught. Again, when the 1996 mean estimator was calculated for Pacific halibut over all strata, the coefficient of variation was 0.267, an improvement over the 0.324 no-stratification coefficient of variation.

Using the all-strata 1996 estimates for rock sole and Pacific halibut, statistical results follow a consistent pattern. For flathead sole and Pacific halibut, 1995 and 1996 stratified sampling surveys were more precise than the 1993 non-stratified sampling survey, but only 1995 was significantly so. For rock sole and yellowfin sole, 1995 and 1996 sampling surveys again were more precise than in 1993, but for these species none of the comparisons produced significantly different results.

In response to the two research objectives, stratification by habitat parameters does increase the precision of abundance indices for age-0 rock sole, age-0 Pacific halibut and age-0 flathead sole, while slightly decreasing the precision for age-l yellowfin sole. Setting up monitoring strata for each species on the outer edges of their geographic distribution (the 1996 method of strata selection and sample allocation) does not provide more precise and reliable interannual monitoring estimates than stratification by habitat over all regions. It is not possible to discern whether the '1996 sampling design produced less precise estimates of abundance than 1995 sampling due to the reorganization and decreased number of strata (10 strata decreased to five strata) or due to the allocation of samples within these strata. Gavaris and Smith (1987) suggest that, in general, no increase in precision will occur by dividing the sample area into more than six strata. Therefore, in this situation it is likely that the decrease in precision is due to the allocation of samples.

There are a number of reasons why the allocation may not have been successful. First, it is possible that the species' centers of abundance shift enough from year to year, despite the close association with habitat type, to make finding the perimeters of geographic distributions difficult. Similarly, the use of variances from one year to predict the sample sizes in the next may be unreliable since both within- and between-stratum variances can vary widely between years (Gunderson, 1993; Pennington and Brown, 198 1). While this may be true, it is also recognized that some gains in precision can be expected even when only rough estimates of within-stratum variance are available (Gunderson, 1993). Another explanation is that a survey design this intricate is not effective when sampling for multiple species and overlapping distributions. As noted by Lenarz and Adams (1 980), in multi-species studies it is particularly difficult to devise a sampling design based on cost, area and abundance variability.

3.6 *Discussion of interannual variability*

The results of this study stress the importance of sample size and species distribution considerations on the choice and construction of abundance monitoring indices. While the low sampling effort required for the nine-site index is favorable and abundance trends are similar to those determined in the other indices, no differences in abundance could be shown statistically. While fixed-site monitoring designs with limited samples can suggest population trends, this study indicates that it is unlikely that interannual variation in abundance can be determined with confidence. The nine-site index is valuable, however, since the fixed-site design isolates the variation in annual abundance from the spatial variation due to changing sampling locations.

Required sampling effort was high for the all-site index, but this index discerned the greatest number of annual differences for the most widely dispersed species, rock sole and Pacific halibut. It was not able to discern differences, however, for flathead sole and yellowfin sole. Flathead sole and yellowfin sole had the highest proportion of zero catches, which likely accounts for the inconclusive results. For less-abundant or more-aggregated species, therefore, calculating an index across all sites (which includes expanses of unoccupied habitat) may not successfully detect changes in abundance. While monitoring designs such as the all-site index, which require high levels of samplmg effort, are costly, interannual changes will likely be determined with confidence for widely dispersed species. For less-abundant or more-aggregated species, however, sampling across all sites may mask significant changes in abundance.

The habitat index was the only index to discern interannual changes in abundance for one of the species with the highest no-catch rates, flathead sole. While there was no sampling in flathead sole's chosen habitat type in 1992, it is reasonable to assume that the 1992 abundance was even higher than in 1993, based on the results of the other two indices. Yellowfin sole, the species with the lowest abundance over the six-year period, still did not show significant differences in annual abundance. While it is possible that no changes in abundance occurred over the six year period, this is unlikely, since all three indices show a decreasing trend over these years. The habitat index only accounts for large aggregation patterns based on habitat "preferences." It is possible that variable aggregation patterns within suitable habitat, enhanced by the low population abundance, have kept abundance changes from being detected. It is also possible that a more closely defined "habitat type" could enable detection of interannual changes for this species. For rock sole and Pacific halibut, the habitat index shows fewer significant differences among years than the all-site index The decrease in sample size is likely the reason for fewer differences.

In summary, monitoring interannual variations in abundance for multiple species may necessitate using different indices dependent upon species' distribution and abundance. Sampling across a wide range of habitats, as done for the all-site index, should allow detection of population changes for more widely dispersed species. For highly aggregated species, however, ignoring spatial patterns when using CPUE data may lead to unreliable abundance indices (Pelletier and Parma, 1994). Analyzing subsets of the same data set, when separated into "preferred" or occupied habitat types, may indicate variations in abundance for more highly aggregated species. Utilizing fixed sites that are sampled each year can provide a baseline to separate spatial and temporal variability.

Calculating multiple indices when analyzing trawl data sets, as was done in this study, is a valuable practice when trying to discern annual variations. While sampling in all regions of the study area, with randomization each year, would be theoretically ideal, weather, cost and logistical constraints are a reality when carrying out a survey. Combining the information from multiple indices can provide a deeper understanding of the underlying recruitment changes amidst the spatial variations characteristic of juvenile flatfish distributions.

Chapter 4. Influence of spatial, temporal and physical parameters on abundance of juvenile groundfishes in Southcentral Alaska

by Brenda L. Norcross, Alisa A. Abookire, and Sherri C. Dressel

Abstract

The purpose of this study was to determine if two locations, Chiniak and Kachemak Bays in Southcentral Alaska, which have some similar geologic features and some distinct physical differences, support the same relative abundance and composition of juvenile groundfish populations or if their differences can be explained by physical factors. Comparisons of physical parameters and fish species composition and abundance in two successive years revealed similar species composition but significantly different abundance between the two locations. Depth was the most important factor governing distribution and abundance of the species in these two locations. The species were divided into shallow-water and deep-water groupings. The shallow-water group (rock sole, walleye pollock, Pacific halibut, *Myoxocephalus* spp., Pacific cod, yellowfin sole, *Gymnocanthus* spp. and sturgeon poacher) was found in higher numbers in Chiniak Bay. The deep-water group (spinycheek starsnout, shortfin eelpout, slim sculpin, spinyhead sculpin and rex sole) was in higher or equal abundance in Kachemak Bay than in Chiniak Bay.

When physical parameters (i.e., depth, temperature, salinity, % gravel, % sand, % mud, organic matter and carbonate) were included as covariates in a MANOVA, most differences in abundance of species between locations were eliminated. The locations were physically similar enough to support very similar communities of groundfishes, yet different enough to support them at different levels of abundance. This may have been further complicated by factors not measured here. For example, we attributed the species distribution and abundance differences to the deeper, more open structure of Kachemak Bay compared with Chiniak Bay. However, Kachemak Bay was also more heavily used by humans than the areas studied in Chiniak Bay. The human effect is a difficult parameter to measure, but one that must be taken into consideration when assessing and safeguarding habitat.

4.1 Introduction

Southcentral Alaska has very dynamic oceanography and geology The Alaska Coastal Current (ACC) follows the coast of the Gulf of Alaska, sweeping from the northeast along the coast of Southcentral Alaska and bifurcating at Cook Inlet where it either flows north through Kennedy Entrance into Cook Inlet or flows south along the shelf east of Kodiak Island. The fast-moving ACC sweeps the Kodiak shelf and strong tidal currents move through Cook Inlet; each of these currents has significant mixing and transport effects. The entire area (Figure I-1) including Cook Inlet, Kenai Peninsula, Kodiak Island and the Alaska Peninsula is affected by frequent earthquakes and volcanoes (Sykes, 1971; Hampton et al., 1979; McCann et al., 1980; Sykes et al., 1980; Keinle et al., 1987) which contribute to sedimentation. Additionally, the ACC supplies clay mineral sediment from the Copper River, carrying it northeast (Hein et al., 1979) to lower Cook Inlet and the Kodiak shelf.

Recent research describes nursery areas of juvenile flatfishes in specific near-shore waters of Southcentral Alaska relative to sediment and other physical factors. Around Kodiak Island, nursery areas for rock sole (*Pleuronectes bilineatus*), flathead sole (*Hippoglossoides elassodon*), Pacific halibut (*Hippoglossus stenolepis*) and yellowfin sole (*Pleuronectes asper*) are defined and modeled based on depth, substrate, temperature and position within bays (Norcross et al., 1995, 1997). In lower Cook Inlet, nursery areas for rock sole and flathead sole are defined by depth and sediment type (Abookire and Norcross, 1998—Chapter 1 in this report); however, the addition of bottom temperature did not refine the definition of habitat beyond depth and sediment descriptions (Abookire, 1997). We will use simultaneous collections from these two locations to compare similarities and differences.

Chiniak and Kachemak Bays are approximately 125 nmi apart in Southcentral Alaska, and are separated by Shelikof Strait, Kennedy and Stevenson Entrances and lower Cook Inlet, Chiniak Bay, in northeast Kodiak Island, is a very large area, approximately 300 km^2, with a roughly rectangular shape (24 km wide x 15 km long). It opens to the northeast and is dominated by winds. Within Chiniak Bay are three smaller fjords, Kalsin, Middle and Womens Bays, which are offshoots to the southwest. Chiniak Bay is characterized by deep bays, rough bottom topography and strong wind-driven currents. Substrate varies with water depth, in that deeper, mid-bay areas are mud; shallower, near-shore areas within bays are sand; and near-shore areas of outer bays are generally rocky (Norcross et al., 1997). Kachemak Bay is equally large at approximately 583 km^2. However, in contrast to Chiniak Bay, Kachemak Bay is much longer and narrower (39 km wide x 62 km long), is open to the eastern side of lower Cook Inlet and is partially divided into inner and outer regions by Homer Spit. Wind-generated currents have a great impact on the outer region of Kachemak Bay, where the sediment distribution is a result of circulation patterns that are dominated by two large gyres in the outer bay (Trasky et al., 1977). Inner Kachemak Bay is dominated at all depths by fine-grained, organic-rich bottom sediments due to the calm water environment (Anonymous, 1977), and the shallow waters are predominantly mud (Abookire and Norcross, 1998—Chapter 1 in this report). Sediments in outer Kachemak Bay are more variable. Boulders and cobbles predominate near-shore, shell debris occurs further out, and the center of the bay is silt and sand (Abookire and Norcross, 1998—Chapter 1 in this report). Circulation in Kachemak Bay is dominated by tidal flow. Tides there are as high as 7.8 m, while on the east coast of Kodiak, tides are only 3.8 m.

The purpose of this study is to determine if two locations in geographical proximity, which have some similar geologic features and some distinct physical differences, support the same relative abundance and composition of juvenile groundfish populations or if their differences can be explained by physical factors. For the two locations, we compare physical parameters and fish species composition. For the two locations in two successive years we examine species abundance and the effects of physical parameters on the abundances. From the comparisons of these two areas, we determine whether a comprehensive description of fish habitat can be applied to Southcentral Alaska.

4.2 *Methods*

4.2.1 Sample collections and processing

Samples were collected concurrently in Chiniak and Kachemak Bays in 1995 and 1996. Chiniak Bay was sampled 3 1 July-10 August 1995 and 4-16 August 1996. Kachemak Bay was sampled l-9 August 1995 and 10-14 August 1996. August was chosen to maximize demersal recruitment of juvenile flatfishes, for which it was shown to be optimal (Abookire, 1997). The sampling design for these areas maximized depth and substrate combinations to study habitat for juvenile flatfishes (Norcross et al., 1995, 1997; Abookire and Norcross, 1998—Chapter 1 in this report; Dressel and Norcross, Chapter 3 in this report).

In Chiniak Bay, sampling was concentrated within and just outside of Kalsin and Middle Bays, especially in the shallow areas known to be flatfish nursery habitat (Norcross et al., 1995). In 1995, multiple samples were taken on the predominant sediment types (sand, muddy sand and sandy mud) within each 10 m depth interval, composing ten strata for a total of 38 stations and 46 collections including replicates. The objective of this design was to establish cost and variance estimates in each strata for each of the four species of flatfishes that have been studied in this area (rock sole, flathead sole, Pacific halibut and yellowfin sole). In 1996, sampling was reallocated into five strata and relative sample sizes were determined for each species in each stratum based on the relative area within the stratum, the cost of sampling and the variance of the four target species' abundance (Dressel and Norcross, Chapter 3 in this report). A similar *number* of *stations,* 3 9, were sampled during 1996, with 43 collections including replicates. Stations outside Kalsin and Middle Bays in Chiniak Bay proper could only be sampled in extremely good weather, and as a result, deep or open stations were underrepresented in relation to Kachemak Bay sampling.

In Kachemak Bay, stations were aligned in three transects crossing the outer and inner bay. The principal objective was to cover as many depth increments as possible, thus resulting in 41 stations at 10 ± 2 m depth intervals on gradually sloping bottom where depth intervals could be clearly defined (Abookire and Norcross, 1998—Chapter 1 in this report). Sites within Kachemak included depths to 150 m and most were located in open bay waters. Due to steep bottom topography, not all depth intervals could be sampled on each transect. Replicate samples were collected when the weather permitted, for a total of 49 samples in 1995 and 42 samples in 1996.

Identical sampling techniques and gear, with the exception of boats and people, were used in Chiniak and Kachemak Bays. A modified 3.05 m plumb staff beam trawl with a double tickler chain, 7 mm square mesh and 4 mm codend liner (Gunderson and Ellis, 1986) was deployed at each station from a 7.6 m Boston Whaler in Chiniak Bay and a 9.3 m aluminum Munsen skiff in Kachemak Bay. This trawl is specifically designed for juvenile bottom fishes and has been shown to be efficient for capturing flatfishes as small as 11 mm (Norcross et al., in prep.) All tows were in the direction of the tidal current for 10 minutes at approximately 50–1 00 m/s (1 .O-2.0 kts) in Chiniak and up to 150 m/s (3.0 kts) in Kachemak due to the strong tidal currents. Start and stop positions of each tow were recorded using a standard global positioning system (GPS), and tow depths were measured with a fathometer. All fishes were identified and counted in the field. Catch-per-unit-effort (CPUE) was calculated by area swept, i.e., distance towed multiplied by effective width of net (74% of beam width) (Gunderson and Ellis, 1986), and standardized to number of fish captured per 1000 m^2. All sampling was conducted during daylight hours. Total length of fishes was measured and recorded to the nearest mm using an electronic fish measuring board. Because of the trawl design, almost all fishes were small and estimated to be ages-0 and -1. Fishes that could not be identified in the field were frozen and returned to Fairbanks for positive identification. If a fish could not be identified to species, it was listed as genus and "spp." in the results. It was usually difficult to differentiate small rock greenling from kelp greenling; therefore, they are combined in a category called "rock or kelp greenling." In the ranking of species, when there was a tie in abundance the same rank number was given to both species and the following number was not used.

Also deployed at each station were a 0.06 m^3 Ponar grab to collect sediment and a conductivity-temperature-density profiler (CTD) to measure bottom temperature and salinity. On a few occasions, weather or mechanical problems prevented collection of sediment or CTD when fish were collected. In 1995, the study design in Chiniak Bay focused on securing replicate collections of fish within the same depth and sediment parameters; therefore, the number of sediment samples is less than the number of fish collections. Frozen sediment samples were taken back to Fairbanks for grain size analysis measured in Phi increments using the sieve/pipette procedure (Folk, 1980), and classified according to the Wentworth scale: mud as CO.062 mm, sand as 0.062-2.0 mm and gravel as 2.0-64.0 mm (Sheppard, 1973). Percentage organic matter content (C, CO_2, H_2O) in each sediment sample was determined by loss on ignition, i.e., the percent weight lost when burned at 500°C for 2 hr (Dean, 1974; Bengtsson and Enell, 1988). Organic matter was measured as a rough indicator of organic food available to fishes in the sediment. Similarly, percentage calcium carbonate ($CaCO_3$) was the percent lost weight when burned at 850°C for 2 hrs. The measured percent $CaCO_3$ is the amount of CO_2 lost at this temperature divided by 0.44, the fraction of CO_2 in $CaCO_3$ (Dean, 1974). Thus, the resulting amount was multiplied by 2.273 to produce the total amount of $CaCO_3$ lost from burning the sample. This amount of calcium carbonate was used to indicate the presence of organic shells (mainly mollusks) in the sediment. Data from multiple samples at a station were averaged for use in sediment classification.

4.2.2 Statistical analysis

Physical parameters, i.e., depth, bottom water temperature, bottom salinity and sediment characteristics were compared between locations and years by two-way analyses of variance (ANOVA) using Statistica (StatSoft, 1995a, 1995b). Differences between individual pairs of factors were tested using a Tukey unequal N Honest Significant Difference (HSD) test using Statistica (StatSoft, 1995). Significance values were set to $p \leq 0.01$.

Cluster analysis was used as an exploratory technique to separately examine groupings of the most abundant fishes in Chiniak and Kachemak Bays. As our objective was to compare fish at the two locations, fish from 1995 and 1996 at one location were considered together. Clustering was performed using species' abundances as variables, i.e., grouping those species that occur together in relatively equal proportions among sites (Fargo and Tyler, 199 1). Hierarchical joining was used to produce tree plots using Statistica (StatSoft, 1995). The tree clustering methods used dissimilarities, or distance between objects, when forming clusters. For this analysis, we used the most common type, Euclidean distance, which is the geometric distance in the multidimensional space. Ward's method (Ward, 1963) was chosen for the amalgamation rule. This method uses an analysis of variance approach to evaluate the distances between clusters (StatSoft, 1995) and has been used to analyze bottom fish assemblages on the western coast of the United States (Jay, 1996). As fisheries trawl catch data are non-normally distributed among hauls (Pennington, 1983; Smith, 1988; Jay, 1996), each variable was transformed by log (x + 1) to standardize catches, minimize outliers and improve distance measures. In order to maximize the number of species included in the analysis, the criterion set for inclusion in clustering was that the species composed more than 1% of the catch in at least one of the four cruises. This resulted in 27 species being included in the analysis, of which two, rex sole and saffron cod, were captured in Kachemak Bay only. The only exception to the 1% criteria was that the category *Lumpenus* spp., i.e., unidentified *Lumpenus* species, which composed 1.43% of Chiniak 1996, was not included. There were three specific species of *Lumpenus*, slender eelblenny *(L. fabricii)*, daubed shanny (*L. maculatus*) and snake prickleback *(L. sagitta)*, represented in higher percentages and we did not wish to lose information by combining all of them, yet including unidentified *Lumpenus* species confused the classification results. To increase representation of species for both locations, all three categories of *Triglops* species were combined to one category. This was done because two species were identified in Kachemak Bay, while in Chiniak Bay they were only classified to genus.

Densities of the most abundant fishes, i.e., the species categories included in the cluster analyses, were compared between locations, years with two-way ANOVAs. Their interactions were also compared. All CPUE data were log (x + 1) transformed to correct for heterogeneity of variance (Johnson and Wichern, 1992). Those species that had no significant ANOVA results, i.e., were of equal abundance across space and time, were not analyzed further. For each species with significant ANOVA results, differences between individual combinations of year and location were tested using a Tukey unequal N (HSD) test (StatSoft, 1995). This *post hoc* test was appropriate because the only a priori hypothesis was the null hypothesis, i.e., that all collections should be equal. Significance levels were set to $p \leq 0.01$. Results from these tests determined which species would be retained for further analyses.

To examine differences in species abundance between locations, those species which had statistically significant differences in some year and location combinations were further examined in relation to the physical factors that were measured with each collection. Because our purpose was to investigate the factors affecting where the fish were present, we used, for each species, only the station information, i.e., fish abundance and related physical factors, where the species was present. For each species a 2-way ANCOVA/multiple regression was conducted using year and location as independent variables and depth, temperature, salinity, % gravel, % sand, % mud, organic matter and carbonate as covariates by using ANOVA/MANOVA in Statistica (StatSoft, 1995) Multiple regression and ANOVA calculating within-cells regression with covariates are special cases of the general linear model and yield the same F value as they examine the relationship between the covariates and the dependent variable without the independent variables (StatSoft, 1995). A multiple regression of the dependent variable using standardized beta weights of each covariate was calculated. Because the percentages of the three sediment parameters add up to 100%, the beta weights and significance levels are identical for all of them; however, this did not affect the ANCOVA. A Tukey Unequal N HSD test was calculated as a *post hoc* ANCOVA test using only the stations at which the species was present and compared to the earlier results without the covariates. The Cell Means ANOVA Model (Type III) was calculated by Statistica for linear combinations of cell means as the sum of squares for different effects in design; in effect this tests the significance of partial correlations by controlling for all variables in a stepwise fashion (StatSoft, 1995). The means were examined using the effects of year, location and their interaction, using an F test. Adjusted means, computed to compensate for covariates being affected by between-groups factors, were also calculated. Significance levels were set to $p \leq 0.05$.

4.3 Results

4.3.1 Physical comparisons

For most physical parameters, differences were apparent between Chiniak Bay and Kachemak Bay (Table I-22). In Kachemak Bay, the sampling scheme took advantage of the range of depths available as evidenced by the greater mean depth and range of samples. In Chiniak Bay, the stations were in shallower waters. Perhaps reflective of these shallower depths were the warmer bottom water temperatures in Chiniak Bay. Kachemak Bay has more fresh water input than Chiniak Bay as seen in the bottom salinity values and ranges. Sediment characteristics also differed between the two locations. Chiniak Bay stations were about two-thirds sand and one-third mud with a minor amount of gravel, while Kachemak Bay stations were approximately equal in mud and sand, and had a slightly higher percentage of gravel. Mean organic matter was almost twice as high in Kachemak Bay than in Chiniak Bay, and the amount of carbonate was four times as high in Kachemak Bay samples.

Differences between years within the same location were found only for temperature and salinity (Table I-23). Whereas there was no significant difference in salinity within the same bay between years, temperature was significantly warmer in 1996 than 1995 in Chiniak and Kachemak Bays (Table I-24). Salinity was significantly different for all year and location combinations. In both locations, significant within-location temperature increases occurred between 1995 and 1996. Temperatures in Chiniak Bay in 1996 were warmer than those of Kachemak Bay both years (Tables I-22-24). However, cooler temperatures in Chiniak Bay in 1995 were not significantly different from temperatures in Kachemak Bay in either year. Mean sampling depth was significantly deeper in Kachemak than Chiniak Bay (Tables I-23-24) and may account for the temperature patterns. As expected, the between-year differences were not statistically significant for any of the five sediment parameters; i.e., bottom type was a persistent characteristic in the same location over time (Tables I-23-24). However all sediment parameters except gravel were highly significantly different between locations according to ANOVA results. Closer examination using the more conservative non-parametric Tukey HSD revealed no differences between any location and year combination for mud, nor any significant difference between Chiniak and Kachemak 1996 percentages of sand (Table I-24). Organic matter was highly significantly different between Chiniak and Kachemak Bays for both years. Carbonate content was only different between locations in 1995 (Table I-24). No interactions between location and year were significant (Table I-23).

4.3.2 Fish comparisons

A total of 33,136 fishes composed of 80 species was captured during four cruises in two years (Table I-25). Although approximately the same number of tows were made in each bay, three times as many fishes were captured in Chiniak Bay than in Kachemak Bay in both 1995 *and* 1996. The slightly longer tow distances in Kachemak Bay yielded fish densities approximately 4-6 times lower than in Chiniak Although the species composition was not identical, approximately the same number of species were captured in the same location each of the two years. The total lumber of species per tow was less in Kachemak than Chiniak Bay. The top ten most abundant species composed nearly 90% of the fish captured in Chiniak Bay each year, somewhat less (84%) in Kachemak Bay in 1995 and much less (77%) in 1996. Although one-third as many fish were saptured in Kachemak Bay, four-fifths as many species were captured (Table I-25).

Twenty species composed the top-10 most abundant species for all four cruises. Four top-10 species were common to all four cruises, and the cruises within Chiniak and Kachemak Bays each **shared seven top-10 species. Rock sole was the most abundant species in three of the four** cruises, while **being ranked third in the other cruise (Table: I-25). There were apparent outlicrs among the** top ten species. Sawback poacher *(Sarritor frenatus)* was ranked number 9 in Chiniak in 1995, was not captured in Chiniak Bay during 1996, and was ranked relatively low in Kachemak Bay. Stout eelblenny (Lumpenus *medius),* which was ranked number 8 in Kachemak Bay in 1995, was saptured in extremely low numbers in 1996, and relatively low numbers both years in Chiniak Bay. Saffron cod *(Eleginus gracilis)* which ranked fourth in Kachemak in 1996 was not collected in any of the three cruises. Most other species had similar abundance rankings within the same bay. Applying the criterion for inclusion of the most abundant species resulted in twenty-seven species, including all twenty of the top- 1 Os, being further examined by cluster analysis and 2-way ANOVA.

Four broad clusters were produced for the fish of Chiniak Bay (Figure I-28). With the exception of snake prickleback *(Lumpenus sagitta)* and sturgeon poacher *(Podothecus acipenserinus),* the first cluster on the right, was composed of species in the top nine of both years in Chiniak Bay, rock sole, Pacific halibut, Pacific cud (Gadus macrocephalus), walleye pollock *(Theragra chalcogramma), Myoxocephalus* spp. and yellowfin sole (Table I-25). The next two groupings, right to left, flathead sole, arrowtooth flounder *(Atherestes stomias),* daubed shanny *(Lumpenus maculatus),* spinycheek starsnout *(Bathyagonus infraspinata),* northern sculpin *(Icelinus borealis),* sawback poacher, *Gymnocanthus* spp., slender eelblenny *(Lumpenus fabricii)* and snailfishes (Liparididae), contained the remainder of the top IO fishes and the next most abundant species. The fourth group on the far left was all the species which have abundances <0.5%, except shortfin eelpout *(Lycodes brevipes)* which was separately linked to the rest of the group.

In contrast to Chiniak Bay, the clustering for Kachemak Bay (Figure I-29) created five groupings instead of four and divided the most abundant species into two groups, the first at the far right and a fifth at the far left. The first cluster was similar to the first cluster in Chiniak Bay in that it contained all top- *10* species with one exception, *Myoxocephalus* spp. Both first groupings contained rock sole, Pacific halibut, Pacific cod, walleye pollock, *Myoxocephalus* spp. and yellowfin sole. In Chiniak Bay halibut was linked with the rock sole-Pacific cod complex, while in Kachemak Bay it was more closely associated with the rest of the species in the group, especially yellowfin sole. The species of fifth group, shortfin eelpout, spinycheek starsnout and flathead sole, all rank within the top six of the species captured during the two cruises in Kachemak Bay. The second grouping was mainly flatfishes: arrowtooth flounder, Dover sole (*Microstomus pacificus*) and rex sole (*Errex zachirus*). Of these, only arrowtooth flounder was in a similar position in Chiniak Bay, which had no rex sole and very few Dover sole. The third grouping contained *Gymnocanthus* spp., sawback poacher and Liparididae as in the third grouping in Chiniak Bay. However, unlike Chiniak Bay, this was a rather large grouping containing six more species. Northern ronquil (*Ronquilus jordani*) and snake prickleback, which were not grouped together in Chiniak Bay, formed their own fourth group, second from the left. The most striking similarity between Chiniak and Kachemak Bay clusters was that the same species, rock sole and shortfin eelpout, were at either end of the tree plots.

Differences in abundance of fish between years (Table I-26) were found by ANOVA for three of the species examined, sawback poacher, snake prickleback and tadpole sculpin (*Psychrolutes paradoxus*). Interaction between year and location was also significant for sawback poacher, snake prickleback and also for Pacific cod. The difference in abundance of fish between the two locations, Chiniak Bay and Kachemak Bay, was significant for 19 of the 27 species examined. The other eight species, flathead sole, slender eelblenny, daubed shanny, Liparididae, Dover sole, stout eelblenny *(Lumpenus medius)* and saffron cod, showed no significant differences among locations and years and were not examined further (Table I-26).

Most species had significant differences among selected bay and year combinations, though the results of the Tukey HSD tests revealed that two species, northern sculpin and northern ronquil, had no differences (Table I-27). Although tadpole sculpin ranked exactly the same in Kachemak Bay both years (#14) the slightly higher catch in 1996 was significantly different only from the zero catch in Chiniak Bay in 1995. Because of this minor difference for this species and no difference for northern sculpin and northern ronquil, these three species were not evaluated further. Snake prickleback had significantly higher abundances in Chiniak Bay in 1996 than either Kachemak or Chiniak Bay in 1995 (Table I-27). Sawback poacher, an outlier as noted above, quite expectedly had significantly higher abundance in Chiniak in 1995 than in any of the other three collections. Although arrowtooth flounder had somewhat similar rankings in the two collections in Chiniak Bay, only the higher abundance in 1995 was significantly larger than the collection either year in Kachemak Bay (Table I-25). Six species, Pacific cod, spinycheek starsnout, shortfin eelpout, slim sculpin (*Radulinus asprellus*), spinyhead sculpin (*Dasycottus setiger)* and rex sole, had significant differences between Chiniak Bay in both years and Kachemak Bay in 1996 (Table I-27). For all but Pacific cod this was caused by higher catches in Kachemak Bay in 1996 than in any of the other three collections, whereas the catch of Pacific cod was much lower in Kachemak Ray in 1996.

Six species showed differences between locations for all time frames, but no differences within location for any time frame: rock sole, walleye pollock, Pacific halibut, *Myoxocephalus* spp., yellowfin sole and *Gymnocanthus* spp. (Table I-27). Of these, the first five species were all clustered in group 1, which contained the most abundant species, in Chiniak (Figure I-28) and Kachemak Bays (Figure I-29). *Gymnocanthus* spp., the remaining species, was included in group 3 in each bay. The only other species that had significant differences between locations for all time frames was sturgeon poacher. Like the first six, the relative rankings of this species were almost identical (Table I-25). However, unlike the other six species, the abundances of sturgeon poacher were significantly different between the two years of sampling within Chiniak Bay (Table I-27).

4.3.3 Fish and physical interactions

Most differences were eliminated and other differences were changed by incorporating the physical variables, depth, temperature, salinity, % gravel, % sand, % mud, organic matter and carbonate, in an ANCOVA test for each of the 16 species of fish which had significant differences in abundances across location and years combinations (Table I-28). Whereas previously rock sole and shortfin eelpout had been different between locations (Table I-26), their differences were eliminated by the incorporation of physical variables and replaced with differences between years. Previously, snake prickleback had significant differences for year, location and the year-location **interaction** (Table I-26). Incorporating physical covariates reduced the differences to just year and interaction (Table I-28). The only two species that still had significant differences in location, even with the incorporation of covariates, were spinycheek starsnout and slim sculpin. Without covariates, only location was different for these species; with covariates both location and year were significantly different.

In an attempt to understand the effect of the physical covariates on the ANCOVA results, multiple regressions using covariates were examined Regression coefficients were significant **for** six of the 16 species, three of which, rock sole, snake prickleback and slim sculpin, also had significant differences between years in the ANCOVA (Table I-28). Rock sole had the highest significance and also was the only fish species for which four of the covariates were significant: depth, temperature, organic matter and carbonate. For snake prickleback, the sediment parameters were significant factors, while for slim sculpin salinity and organic matter were significant. Three other species, which did not have significant ANCOVAs, had significant F values for the multiple regression. Depth was a significant covariate for Pacific cod and yellowfin sole. Pacific halibut however did not have any significant covariates. Two species, spinycheek starsnout and shortfin eelpout, that had significant ANCOVAs did not have significant regression coefficients (Table I-28). Of those, no covariates were significant for shortfin eelpout, while salinity was significant for spinycheek star-snout. Several species had significant covariates but no regression coefficients. Depth was significant for walleye pollock and *Myoxocephalus* spp. Salinity ***also*** was significant for *Myoxocephalus* spp. as well as for sturgeon poacher. Organic matter was significant for ***Gymnocanthus*** spp. and rex sole. The covariates did not explain much of the variance, as the R^2 was very low (0.12-0.39) for all species except slim sculpin (0.54). Therefore, predictive multiple regression equations based on physical factors were not developed.

To determine the effect of physical variables as covariates on the resulting differences in abundances among location and year combinations, Tukey HSD tests were carried out after the ANCOVAs. When results for the 16 species were directly compared with the previous results without the incorporation of covariates (Table I-27), twelve species no longer had significant differences (Table I-29). Snake prickleback, which previously had three significant differences, was reduced to two. Pacific halibut differences were reduced from four to three. Rock sole retained all four of its differences. The level of significance for each of these was reduced by one order of magnitude. Arrowtooth flounder increased its number of significant comparison from two to three, adding Chiniak 96-Kachemak 95.

4.4 Discussion

Chiniak Bay had a greater abundance of fish than Kachemak Bay in both years of the study. However, the dramatic differences initially suggested mostly disappeared when the effect of physical variables as covariates was considered. Thus, the difference in physical characteristics between the locations resulted in these locations supporting unequal numbers of juvenile groundfishes. A greater number of deep stations were sampled in Kachemak Bay than in Chiniak Bay. In all cases, the mean depth range for species in Kachemak Bay was deeper than for the same species in Chiniak Bay. Thus, it appears that the distribution of a fish species was affected by the selected depth range, and perhaps limited by the availability of that depth range. Depth and temperature are highly correlated (Norcross et al., 1995, in review), and the effects of one often account for the effects of the other. It is fortuitous that the interannual difference in bottom temperatures found in this study made it possible to separate the effects of these factors. Both bays had warmer bottom temperatures in 1996 than in 1995. For all species the mean temperatures at which they were collected in Kachemak Bay in 1996 was warmer than the temperatures at which they were collected in Chiniak Bay in 1995. There was no linear relationship among mean bottom water temperatures and fish abundances across the four cruises, indicating that temperature was not the prime factor affecting distribution or abundance of these species and that depth needs to be examined.

For six species, walleye pollock, *Myoxocephalus* spp., Pacific cod, yellowfin sole, *Gymnocanthus* spp., and sturgeon poacher, for which significant differences were negated by inclusion of physical covariates, and for two species that continued to have significant differences, rock sole and Pacific halibut, the abundance was higher, the number of stations at which the species was captured was higher, and the mean depth of capture was less in Chiniak than Kachemak Bay (Table I-30). One other species that still had significant differences, snake prickleback, was also captured at more stations and shallower depths in Chiniak Bay; however, while snake prickleback abundance in Chiniak Bay in 1996 was higher than in Kachemak Bay, it was lower in 1995. These nine species essentially form a shallow-water grouping. A tenth species, sawback poacher, was also characterized as a shallow-water type. Though sawback poacher was captured at a low number of stations in Kachemak Bay, it was captured at an inconsistent number of stations during the two years in Chiniak Bay (Table I-30). This shallow-water group was collected at an average depth of 26 m (13-28 m) in Chiniak Bay, which is consistent with the 24 m average depth of the stations sampled (Table I-22). However, all of them were collected at a deeper range of depths (26-56 m) in Kachemak Bay. There was a wide range of discrepancies in the depth of capture at the two locations. Rock sole were caught, on average, only 7 m deeper in Kachemak Bay, while sturgeon poacher were caught 30 m deeper (Table I-30). Though the latter is consistent with the average collection depth of 58 m in Kachemak Bay (Table I-22), the other nine species, while captured in deeper waters than in Chiniak Bay, were found in waters much shallower than average for the collection.

Conversely, five other species for which significant differences were negated by inclusion of physical covariates (spinycheek starsnout, shortfin eelpout, slim sculpin, spinyhead sculpin and rex sole) display the opposite trends; i.e., they were captured at more stations and at deeper depths in Kachemak than in Chiniak Bay (Table I-30). However only three of these, slim sculpin, spinyhead sculpin and rex sole, were captured in higher numbers in 1995 and 1996 in Kachemak Bay. The five species were captured at 44-60 m in Chiniak Bay and 57-86 m in Kachemak Bay. The only overlap was two collections for slim sculpin in which the depths were equal; otherwise, all species of the deep-water grouping were captured in deeper water in Kachemak than in Chiniak Bay, as was also found for the shallow group.

The one remaining species does not exactly fit one of the patterns of shallow-abundant-Chiniak or deep-abundant-Kachemak, but as with all the other species, their mean depth of capture was less in Chiniak Bay than in Kachemak Bay. Arrowtooth flounder was found at intermediate depths (37 m in Chiniak; 57 m in Kachemak). The average catch of arrowtooth flounder was higher in Chiniak Bay, although the number of stations at which arrowtooth flounder were captured was similar to the number in Kachemak Bay. Other groundfishes (flathead sole, slender eelblenny, daubed shanny, snailfishes, Dover sole, *Triglops* spp., stout eelblenny, and saffron cod) showed no significant differences between locations and thus were not evaluated for depth preferences.

Depth is a determinant of distribution of juvenile flatfishes around Kodiak Island and in Cook Inlet. As in the present study, rock sole are relatively shallow-water species in bays around Kodiak Island (Norcross et al., 1995, 1997) and in Kachemak Bay (Abookire and Norcross, 1998—Chapter 1 in this report). However, rock sole is a ubiquitous species and is found in deeper waters in Sitkinak Strait at the south end of Kodiak Island (Chilton, 1997) and when modeled (Norcross et al., in review). In agreement with the present findings, Pacific halibut are classified as a shallow-water species (Norcross et al., 1995, 1997; Chilton, 1997; Abookire and Norcross, 1998—Chapter 1 in this report). Likewise, yellowfin sole are found in waters < 30 m in other studies (Norcross et al., 1995, 1997, in review). Arrowtooth flounder are in deep (65 m) water in Sitkinak Strait (Chilton, 1997), perhaps indicating that they should be classed with the deep-water fish grouping here.

These proposed shallow- and deep-water groupings correspond rather closely to the results of the cluster analyses (Figures I-28-29). The first grouping on the right side for each bay was composed of shallow-water fishes while the grouping on the left side of each was deep-water fishes. This is in agreement with an analysis of community structure of juvenile demersal fishes around Kodiak Island (Muter and Norcross, in preparation). In that study the first index summarizing different aspects of community composition is related to the depth-temperature gradient. Most of the fish on the right side of our cluster analysis, rock sole, Pacific halibut, Pacific cod and *Myoxocephalus* spp. were negatively correlated with depth, while the fish on the left side, shortfin eelpout, spinycheek starsnout, rex sole and spinyhead sculpin, were positively correlated with depth.

Examining other parameters by depth grouping revealed that four of the nine species in the shallow-water group, rock sole, halibut, Pacific cod and *Gymnocanthus* spp., were collected on a higher mean percentage of sand than mud or gravel for all four cruises. Three species, pollock, yellowfin sole and snake prickleback, were found on higher or nearly equal mean percentages of sand, and two species, *Myoxocephalus* spp. and sturgeon poacher, were on higher percentages of sand for three cruises, and higher percentages of mud for one cruise.

Sediment is an important factor determining the distribution of juvenile flatfishes around Kodiak Island (Norcross et al., 1995, 1997; Chilton, 1997) in Kachemak Bay (Abookire and Norcross, 1998-Chapter 1 in this report) and on the Alaska Peninsula (Norcross et al., in review). Rock sole prefer sand and mixed sand substrates (Moles and Norcross, 1995; Norcross et al., 1995, 1997, in review; Chilton, 1997; Abookire and Norcross, 1998—Chapter 1 in this report). Although the mean percentages of sand on which rock sole were collected for these four cruises (Table I-30) differ across area and time, sand was always the sediment component with the highest percentage. Like rock sole, Pacific halibut prefer mixed sand substrates; halibut's sediment preference ranges from muddy sand in laboratory tests (Moles and Norcross, 1995) to mixed sand in field collections (Norcross et al, 1995, 1997) and coarse sand in exposed areas (Chilton, 1997). In the present study, the mean percentage of sand was higher than that of mud, and equal to or higher than the percentage of sand on which rock sole was found. Pacific cod and *Cymnocanthus* spp. were also found on higher mean percentages of sand in all four cruises, while walleye pollock, yellowfin sole and snake prickleback were on higher percentages of sand or, for one of the four cruises, on percentages approximately equal to those of mud. Yellowfin sole are found on substrates composed of sand, mud and gravel (Moles and Norcross, 1995; Norcross et al., 1995, 1997) and in this study were found on a higher mean percentage of sand in most of the cruises, with a low level of gravel in all but one cruise. Though yellowfin sole is likely to be found on muddy gravel or gravelly mud substrate (Norcross et al., 1995), their abundance was lowest in Kachemak Bay in 1995 when the mean sediment value contained a high percentage of gravel and cubonates. In Kachemak Bay in 1995, yellowfin sole had a lower abundance, distributed over a higher number of stations, than in 1996; this may be attributable to the mean depth of capture (30 m) since yellowfin sole prefer depths less than 28 m (Norcross et al., 1997).

There did not appear to be a pattern in distribution of mean sediment between these locations to account for the differences in species abundance and distribution. Only spinycheek star-snout and slim sculpin were on less sand and more mud in Chiniak Bay than in Kachemak Bay during both years. They were also collected at 2-14 times as many stations in Kachemak Bay; however, mean abundance values per station did not relate to these trends. In all other cases, there appeared to be a broad range of mean sediment values at which the fish were collected, although there were high percentages of gravel in 1995 in Kachemak Bay collection sites for rock sole, pollock, *Myoxocephalus* spp., yellowfin sole and sawback poacher. In both 1995 and 1996, there was a high percentage of gravel in sediments where Pacific cod was collected in Kachemak Bay. However, there is nothing remarkable about the percentages of gravel, sand and mud on which snake prickleback were collected to explain why sediment was significant in the multiple regression analysis. Higher carbonate values in Kachemak Bay indicate that some of the gravel substrate in that location may actually be shell hash. As organic matter is a proxy indicator of availability of food, it is incongruous that the location that consistently has lower organic matter in the sediment, Chiniak Bay, also has higher abundances of fishes.

The only other covariates that showed patterns were organic matter and carbonate. Organic matter and carbonate were consistently higher at stations in Kachemak than Chiniak Bays (Table I-22). The stations associated with the species captured in shallower water, especially in Chiniak Bay, appeared to have less organic matter, which seemed to increase in the stations associated with the fish captured in deeper water (Table I-30). The higher levels of carbonate found in Kachemak seemed to decrease with depth, but not to the low levels of Chiniak Bay.

It was helpful to specifically examine those fishes that retained some significant differences with the inclusion of covariates. Pacific halibut retained significant differences in three of four year-location combinations. The abundance of Pacific halibut in Kachemak Bay in 1995 was quite low compared with their abundance on to all other cruises. The sediment was predominantly sand, as in Sitkinak Strait (Chilton, 1997), and the percentage was well above the 35% necessary for age-0 halibut to inhabit open bays (Norcross et al., in review). However, for the Kachemak 1995 cruise, the mean depth of capture was 56 m, much deeper than the lower depth limit of 40 m for halibut around Kodiak Island (Norcross et al., 1995, 1997; Chilton, 1997). The comparatively low catches of halibut in Kachemak Bay in 1996 may be attributable to the greater mean depth of capture. Though the mean depth was shallower than the apparent acceptable range (to 40 m) for halibut, it was deep in comparison with Chiniak Bay. In Sitkinak Strait, halibut are most abundant at 20 m (Chilton, 1997), a value consistent with the shallow depths seen in Chiniak Bay. Thus it appears that depth is a governing factor in the abundance and distribution of halibut.

Arrowtooth flounder not only retained the significant differences between the high abundances in Chiniak Bay in 1995 and those of Kachemak both years, but with the inclusion of the covariates there was also a significant difference between Chiniak 1996 and Kachemak 1995. Distribution of arrowtooth flounder has been linked to sediment (Norcross et al., in review) and depth (Chilton, 1997). In this study arrowtooth flounder in Chiniak Bay were 20 m shallower than in Kachemak Bay, though the 60 m depth of Kachemak Bay is in agreement with the depth distribution of arrowtooth flounder in Sitkinak Strait (Chilton, 1997). Sitkinak Strait is an open area with a geomorphology more similar to Kachemak Bay than to Chiniak Bay; no depths between 20 and 55 m were sampled there for comparison to Chiniak Bay. Arrowtooth flounder are likely to be found on mixed substrates with less sand (Norcross et al., in review), thus the reduced percentage of sand may explain the high abundance of arrowtooth flounder in Chiniak in 1995. Less conclusive was the slightly reduced percentage of gravel in Kachemak in 1995, which may have affected the abundance of arrowtooth flounder.

The most difficult fish to explain was also the most abundant one, rock sole. It was found at almost double the density at more than twice as many stations in Chiniak Bay than Kachemak Bay. Although rock sole abundances were significantly different among all four year-location combinations, there was nothing remarkable about the values of the physical parameters to explain these differences, The mean depth of capture for rock sole in both locations was less than 28 m, as around Kodiak Island (Norcross et al., 1997). Rock sole in both locations appeared to prefer warm mean temperatures (Table I-30). Other research around Kodiak Island in 1991 and 1992 reports that rock sole inhabit waters warmer than 8.7°C (Norcross et al., 1997). Mean salinity values in this study cover a very broad range, but are consistent with rock sole being found at salinity less than 32.1 PSU (Norcross et al., 1997). Rock sole are associated with sand (Norcross et al., 1995) and muddy sand substrates (Norcross et al., 1997) around Kodiak Island, as found in Chiniak Bay and Kachemak Bay in 1336. However, the catches in Kachemak Bay in 1995 were on a high mean percentage of gravel, a substrate not usually preferred by rock sole (Norcross et al., 1995). This was coincident with the only cruise in which rock sole did not rank as the most abundant species. 'The mean carbonate content of the sediment was much lower for Chiniak Bay than for Kachemak Bay, a result which may have affected the distribution and consequent abundance of rock sole, although no previous studies have examined this parameter. Rock sole were found on sediment of lower organic content in Chiniak Bay than Kachemak Bay, which was consistent with the availability of that parameter. Rock sole were found at 82–84% of the stations sampled in Chiniak Bay and 33–40% of the stations sampled in Kachemak Bay, which may be attributable to the depth ranges of stations sampled in each location. Rock sole are rather ubiquitous in their distribution, and their depth of capture ranges tn 50, 60 (Norcross et al , 3 995, 1997, in review) or even 75 m (Chilton, 1997), readily exceeding the 18 m average found in Chiniak Bay. We hypothesize that the lack of availability of shallow waters in Kachemak Bay and the 7 m difference in average depth of capture was important in determining the broader distribution and increased abundance of rock sole in Chiniak Bay.

Examination of the abundance means, adjusted with the incorporation of the covariate effects shows that for eight species of the shallow-water group (rock sole, walleye pollock, Pacific halibut, *Myoxocephalus* spp., Pacific cod, yellowfin sole, *Gymnocanthus* spp. and sturgeon poacher) the values for the two locations were brought closer together by reducing abundances for Chiniak Bay and increasing abundances for Kachemak Bay. One of the species in the deep-water group, spinyhead sculpin, responded similarly with the values for Chiniak Bay decreasing and those for Kachemak increasing; however this resulted in the adjusted means for the two locations being farther apart. Three of the species in the deep-water group, spinycheek star-snout, shortfin eelpout and slim sculpin responded in the opposite way; i.e., the adjusted means for Chiniak increased while those for Kachemak decreased, and again the result was further separation between the mean abundances in the two locations. Snake prickleback and arrow-tooth flounder did not follow any pattern in the increase or decrease of adjusted mean in relation to location. While their numbers changed, the spread of values across locations stayed relatively constant.

We conclude that physical factors do affect the distribution and abundance of the juvenile groundfish species studied in these two locations. The locations are physically similar enough to support very similar communities of groundfishes, yet different enough that they are not supported at the same level of abundance. Depth was the most important factor governing distribution and abundance of the groundfishes in these two locations, dividing the species into shallow and deep-water groupings. Though there were interannual differences in temperature, temperature was not a prime factor affecting distribution or abundance of these fishes. This may have been further complicated by factors not measured here. For example, we attributed the differences to the deeper, more open structure of Kachemak Bay compared with Chiniak Bay;

however, Kachemak Bay is also more heavily used by humans than the areas studied in Chiniak Bay. The human effect is a difficult parameter to measure, but one that must be taken into consideration when assessing and safeguarding habitat.

Chapter 5. Investigation of benthos and flatfish diets at one site in Kachemak Bay

by Brenda A. Holladay and Brenda L. Norcross

5. I Introduction

Feeding strategy and diet are directly responsible for fish growth and consequent survival to maturity. Some researchers consider food to be the most important factor governing recruitment of juvenile fishes (e.g., Toole, 1980; Gibson, 1994). However, other researchers (Reichert and van der Veer, 199 1; van der Veer et al., 199 1; Hallaracker et al., 1995) conclude that growth of juvenile flatfishes is related to habitat characteristics and is strongly dependent upon temperature rather than possible food limitation. Depth of water is frequently related to the benthic community composition of invertebrates and vertebrates (Pearcy, 1978). A size-depth segregation of juvenile flatfishes may assist with the reduction of intra- and interspecific competition (Toole, 1980). Rogers (1992) found it more appropriate to describe the nursery area of sole (*Solea solea* L.) based on factors associated with the sediment structure rather than on the type and quantity of benthic invertebrates available. Many studies relate juvenile flatfish distribution to a preference for sediment type (e.g., Moles and Norcross, 1995; Norcross et al., 1995, 1997). Preference for a specific habitat component, such as sediment type, may be attributed to an indirect and often unmeasured link to abundance of preferred food items (Jager et al., 1993). Benthos community zonation and sediment grain size can be highly correlated with each other (e.g., Fresi et al , 1983)

Depth, sediment and temperature, three environmental factors which are linked to benthic community distribution, have been analyzed extensively relative to flathead sole and rock sole distribution and abundance in Kachemak Bay (Abookire and Norcross, 1998—Chapter 1 in this report, Chapter 2 in this report). These analyses provide a solid foundation for subsequent diet examination. Under separate funding (CMI Task Order 14278), the diets of flathead sole and rock sole, the most abundant flatfishes in Kachemak Bay, are being evaluated in relation to size of fish, distribution of fishes with respect to physical characteristics (depth, substrate), seasonality in distribution of fishes and co-occurrence of fish species.

The objectives of the present research were to examine the diets of flatfish and the benthic taxonomy from one collection in Kachemak Bay, and to establish a preliminary database of flatfish diet and benthos for this region.

5.2 Methods

Benthic fauna and the stomach contents of concurrently collected juvenile flatfishes, i.e., arrowtooth flounder, flathead sole, Pacific halibut, yellowfin sole and rock sole were examined from a single collection site during a September 1994 cruise in Kachemak Bay (CI9401). This site was consecutive station #37, located at 30 m depth along the McDonald Spit transect within Kachemak Bay (Appendix II-l : CI9401 cruise report). A profile of temperature and salinity profiles was obtained at the site with a portable CTD, and the substrate was sampled with a Ponar grab. See Appendix II- 1 for more specific collection methods. Approximately half of the substrate grab was frozen and underwent grain size analysis in the laboratory (Appendix II-2). The other half was sieved through a 1 mm screen and preserved as a benthos sample in 10% formalin, which was changed to 50% isopropyl alcohol before taxonomic laboratory analysis.

The importance of each prey taxon in the benthos was calculated using an equation similar to that of the IRI (Pinkas et al., 1971), in which the proportional importance = (N + W) * 50, where N = percent number of prey and W = percent weight. The benthos was examined to provide a biological description and an estimate of prey taxa available to flatfishes at the study site. However, the estimate of prey availability provided by benthic taxonomic analysis was of limited application, since epibenthic animals were not adequately represented in the collections by Ponar grab, and epibenthic crustaceans contribute largely to the diet of juvenile flatfishes (Toole, 1980; Holladay and Norcross, 1995b).

Diets were examined for interspecific comparison of five species of flatfishes captured at CS#37 and for comparison with the benthos. Proportional indices of relative importance (pIRI) were calculated for each predator, in which pIRI = (%N + %W) * %F, where N = number of prey, W = weight of prey and F = frequency of fish consuming the prey (Pinkas et al., 1971). The proportional importance of each taxon in the benthos was calculated as (%N + %W) *50.

Percentage similarity between the diets of each two predator species and between each predator species and the benthos was examined using a percentage overlap index calculated as follows (Renkonen, 1938, as cited in Krebs, 1989):

$$P_{xy} = \left[\sum^{n} (\text{minimum } p_{xi}, p_{yi}) \right] 100$$

where P_{xy} = percentage overlap between species x and y;
p_{xi} and p_{yi} = proportional weights of prey i in the diets of species x and y, respectively;
and n = total number of resource states.

The percentage overlap can range in value from 0 to 100%. A value of 0% indicates no dietary similarity, and a value of 100% represents complete dietary overlap in which all prey are found in equal proportions for both predators. Separate indices were calculated using resource taxa at the level of family, and also to the most specific taxonomic level possible.

5.3 Results

The physical parameters measured at CS#37 included bottom temperature (9.5°C), bottom salinity (30.3 PSU), depth of tow (31-33 m), % gravel (0), % sand (72), % mud (28) and substrate type (muddy sand). Flatfishes captured at CS#37 included arrowtooth flounder (N = 15), flathead sole (N = 15), Pacific halibut (N = 11), yellowfin sole (N = 60), rock sole (N = 101) and English sole (N = 6). A subset of those fishes smaller than 200 mm total length was retained for stomach content analysis.

Diets of all 69 fishes retained for stomach content analysis were examined (Table I-31, Figure I-30). Arrowtooth flounder (N = 15) consumed primarily mysids (81%) and to a much lesser extent shrimps (Decapoda, 9%) and rock sole (6%). Flathead sole (N = 1) consumed only bivalves (100%). Pacific halibut (N = 11) consumed shrimps (Decapoda, 94%). Yellowfin sole (N = 38) had the most varied diet, consuming bivalves (45%), polychaete worms (28%) and brittle stars (Ophiuroidea, 18%). Rock sole (N = 4) ate bivalves (67%) and amphipods (28%). Different bivalves were consumed by different flatfish species.

Bivalvia was the dominant taxon in the benthos in terms of numbers, biomass and proportional importance (55%) (Table I-32, Figure I-30). Lesser importance was attributed to gastropods (21%), polychaetes (20%) and crustaceans (Amphipoda, 3% and Cumacea, 1%).

Percentage overlap between the indices of pIRI of each two species, and between the index of pIRI of each predator species and the index of proportional importance of the benthos, was determined (Tables I-33 and I-34). We concluded that examinations of percentage overlap at the taxonomic level of family (Table I-33) constituted an artificially inflated view of the similarity between prey resources. The overlap, calculated using the most specific taxonomic level the resource could be identified to (Table I-34) was a more accurate measure of the degree to which predators are competing for the same prey species. The highest diet similarity was between yellowfin sole and the benthos (35%, Table I-34). There was very little dietary overlap between pairs of predators (O-12%, Table I-34). The largest overlap between predators at CS#37 was between arrowtooth flounder and Pacific halibut (12%, Table I-34).

5.4 Discussion

Arrowtooth flounder consumed primarily mysids in the present study as well as in studies near Kodiak Island (Norcross et al., 1993). Flathead sole, yellowfin sole and rock sole in the present study relied heavily on bivalves. Near Kodiak Island, the diets of these predators included more crustaceans (65–95%) than bivalves (0–12%) (Holladay and Norcross, 1995b). Pacific halibut in the present study consumed primarily crustaceans in the taxon Decapoda. Age-O halibut near Kodiak also consume crustaceans, but mysids and gammarid amphipods are more important than decapod shrimps near Kodiak (Holladay and Norcross, 1995a). The differences in diet between Kachemak Bay and Kodiak Island may be an artifact of the number and size of fishes examined in Kachemak Bay. For example, the age-0 halibut examined here are larger than the age-0 halibut examined in Kodiak. Holladay and Norcross (1995a) have identified an ontogenetic shift in the diet of age-0 halibut as the predator increases in size. To make an accurate comparison of diets between two regions, fish of similar size should be compared.

Diverse diet indicates opportunistic feeding (Kravitz et al., 1977), and yellowfin sole appeared to be the most opportunistic predator examined at this site. This may be an artifact of the large number of yellowfin sole in relation to the number of other flatfishes examined.

The diets of most flatfishes were dissimilar to the available infauna. The levels of diet overlap are very low compared with those found in Kodiak, where Holladay and Norcross (1995b) have noted diet overlap between groups of flathead sole, Pacific halibut, yellowfin sole and rock sole generally ranges between 30 and 50%.

These data, which represent a preliminary examination of the diets of juvenile flatfishes and benthic taxonomy in-Kachemak Bay, are from a single collection site and time; they are therefore of limited application and should be used only with caution.

DISCUSSION

Nursery habitat characterizations

Nursery habitat was identified and characterized for the numerically dominant flatfishes, i.e., ages-0 and 1 flathead sole and ages-0 and 1 rock sole in both Kachemak and Chiniak Bays, and additionally age-0 Pacific halibut and age-l yellowfin sole in Chiniak Bay. When habitats in Kachemak and Cbiniak Bays are compared with summer (August) habitats in other regions of Southcentral Alaska, there appear to be regional differences in the physical parameters which define habitats.

In Kachemak Bay, flathead sole habitat was defined primarily by depth and substrate; age-0 flathead sole were found at 40-60 m depth and age-l flathead sole were found at 40-80 m depth. Both ages of flathead sole were on mixed mud substrates in Kachemak Bay, and age-l were also Found on muddy sand. Although models of age-0 flathead sole habitat around Kodiak (Norcross et al., 1997) and the Alaska Peninsula (Norcross et al., in review) include temperature, the addition of bottom temperature to descriptions of ages-0 and 1 flathead sole habitat in Kachemak Bay did not refine the definition of habitat from descriptions based solely on depth and sediment. Depth and substrate were also used to describe flathead sole habitat in our survey for interannual abundance in Chiniak Bay. In Chiniak Bay, age-0 flathead sole were found in regions O-85 m in depth having 0–92% mud in the substrate; they were predominantly in depths >30 m and on substrates of >35% mud. Age-O flathead sole habitat in eastern Kodiak is >40 m depth, throughout bays, on mud or mixed mud substrate (Norcross et al., 1995). Around Kodiak Island, age-0 flathead sole are found primarily in temperatures less than 8.9°C on mixed mud substrates, or they are collected in warmer temperatures regardless of substrate type when depth >48 m (Norcross et al., 1997). Along the Alaska Peninsula, age-0 flathead sole distribution is modeled on temperature and sediment, and age-l flathead sole distribution is modeled only on sediment (Norcross et al., in review). Flathead sole are generally collected at 45–55 m depths, within bays, in regions of about 9°C and 75% mud content (Norcross et al., in review). In Sitkinak Strait, an exposed region near south Kodiak, depth is more important than sediment in defining distribution of ages-0 and 1 flathead sole, and the largest catches of ages-0 and 1 flathead sole in Sitkinak Strait are relatively deep (75 m and 55 m respectively) (Chilton, 1997).

Habitat of ages-0 and 1 rock sole in Kachemak Bay was defined primarily by depth and substrate. Both ages of rock sole in Kachemak Bay were in 10-30 m depths during the summer; age-0 rock sole were collected in depths to 150 m during the winter. In Kachemak Bay, both ages of rock sole were found primarily on sand; age-l rock sole were additionally on larger and finer-grained sediments. Although temperature and salinity help define habitat for age-0 rock sole around Kodiak Island (Norcross et al., 1997), these parameters were not selected in the models of ages-0 and 1 rock sole along the Alaska Peninsula (Norcross et al., in review), and did not significantly improve the definition of rock sole habitat in Kachemak Bay over models based only on depth and substrate. In Chiniak Bay, depth and substrate described age-0 rock sole habitat in our survey of interannual abundance variation. **In Chiniak Bay, age-0** rock sole inhabited regions 0–85 m in depth having 0–100% sand; they were predominantly found in depths <40 m and with >20% sand in substrate. Age-O rock sole in eastern Kodiak inhabit regions of <50 m depth, outside of or within bays, on sand or mixed sand substrates (Norcross et al., 1995). Around Kodiak Island, age-0 rock sole are found on sand or muddy sand at temp >8.7°C or at >32.1 PSU when temp <8.7°C; they are collected on other mixed sand substrates (gmS, sG, sM) when depth <28 m (Norcross et al., 1997). Along the Alaska Peninsula, age-0 rock sole habitat is modeled on depth and sediment, and age-l rock sole habitat is modeled solely on sediment; both ages of rock sole are generally collected from 20-30 m depth, near bay mouths, in regions of 10-l 1°C and approximately 70% sand content (Norcross et al., in review). In Sitkinak Strait, sediment type is more important than depth for both ages of rock sole, and the largest catches of ages-0 and 1 rock sole are on sand at 55 m and on gravelly sand at 20 m, respectively (Chilton, 1997).

Age-O Pacific halibut were not abundant in Kachemak Bay; thus habitat is described for this species only for regions near Kodiak Island and the Alaska Peninsula. Depth and substrate described age-0 Pacific halibut habitat in our survey of interannual abundance variation in Chiniak Bay In Chiniak Bay, age-0 Pacific halibut were collected in regions O-85 m in depth with O-l 00% sand; they were predominantly in depths <30 m having >25% sand in substrate. In eastern Kodiak, age-0 Pacific halibut are in depths <40 m, near or outside the mouths of bays, on mixed sand substrate (Norcross et al., 1995). Around Kodiak Island, age-0 Pacific halibut are collected at high abundances in depths <40 m, at sites more than 2.9 km outside the mouth of a bay; they are found in lesser abundances inside bays, in water >9.0°C and on substrate containing both sand and mud (Norcross et al., 1997). Along the Alaska Peninsula, age-0 Pacific halibut habitat is modeled on temperature and sediment, with age-0 Pacific halibut generally collected at 20-30 m depth, near bay mouths, in temperatures of 10-l 1°C, on substrate with approximately 70% sand content (Norcross et al., in review). Chilton (1997) reports that sediment is more important than depth to age-0 Pacific halibut in Sitkinak Strait, where the largest CPUE of age-0 Pacific halibut was in 20 m depth, on gravelly sand substrate.

Age-l yellowfin sole were abundant near Kodiak, but not in Kachemak Bay, and therefore its habitat is described only for regions near Kodiak Island and the Alaska Peninsula. In Chiniak Bay, age-l yellowfin sole habitat was described based on depth and substrate in our survey of interannual abundance variation. In Chiniak Bay, age-l yellowfin sole were collected in regions 0–45 m in depth (predominantly O-30 m) and with >20% sand in substrate. In eastern Kodiak Island, age-l yellowfin sole are in depths <40 m, in the upper reaches of bays, on mixed substrates (Norcross et al., 1995). Around Kodiak Island, age-l yellowfin sole are always in depths <28 m on mixed substrates; they are usually found within bays with the highest abundances at heads of large bays more than 32 km from the mouth (Norcross et al., 1997). Along the Alaska Peninsula, age-l yellowfin sole habitat is modeled solely on depth, and yellowfin sole are generally collected in depths of 20-30 m, within bays, on mixed sand (40–60%) and mud (35–55%) substrates. The habitat of juvenile yellowfin sole is not described for the exposed regions of Sitkinak Strait.

The biological parameters (e.g., macrobenthos, flatfish stomach contents) ofjuvenile flatfish habitat analyzed in the present study are limited to a single site, and thus can not be related to fish abundance and distribution. Results of an ongoing CMI project will help elucidate the importance of stomach contents.

Seasonal distribution and abundance of flatfishes in Kachemak Bay

Examinations of juvenile flathead sole and rock sole in Kachemak Bay provided insight into seasonal distribution and abundance, as well as species settlement and growth. Habitat of ages-0 and 1 flathead sole and age-l rock sole did not change seasonally. Age-O rock sole moved offshore from summer depths of 1 O-30 m to winter depths to 150 m. This seasonal migration of age-0 rock sole in Kachemak Bay could not be attributed to observed changes in bottom water temperature and salinity.

Abundances of age-l flathead sole and age-l rock sole in Kachemak Bay were not significantly different among spring, summer and winter or between the collection years of 1995 and 1996. Significantly more age-0 flathead sole were caught in Kachemak Bay during 1996 than 199.5, and differences in summer abundances of age-0 rock sole during 1995 and 1996 could not be rejected. Seasonal differences in abundances of age-0 flathead sole and rock sole in Kachemak

Bay were attributed primarily to time of settlement. In Prince William Sound, Alaska, the pelagic larvae of flathead sole were abundant during May and June, but very low in abundance during July (Norcross and Frandsen, 1996). In Kachemak Bay, age-0 flathead sole were probably absent from our bottom trawls in May during 1995 and 1996 because they were still in the larval phase. Additionally, it appears that age-0 flathead sole had not completely settled into a demersal phase by August, since its abundances were higher in September 1994 than August 1995 and 1996. Age-O rock sole were absent during May 1995, and in low abundance during May 1996. Sampling was 19 days later in May 1996 than 1995, indicating that either rock sole begin to settle in mid-May in Kachemak Bay or there is interannual variability in settling time.

Growth of flathead sole and rock sole was greatest from spring to summer, and was very slow during winter. Temperature differences between years (1996 was warmer than 1995) were positively correlated with growth only for age-l flathead sole. There were only slight differences in bottom salinities within the study area and salinity was not a significant controlling factor for growth or abundance. These results are in agreement with Malloy and Targett (199 1), who state that temperature, but not salinity, affects spatial distribution, feeding, growth, and survival of juvenile summer flounder.

Interannual abundance of flatfishes in Chiniak Bay

The first survey in Alaskan waters of interannual variations in year-class size of age-0 and -1 flatfish was reported here for the numerically dominant juvenile flatfishes in Chiniak Bay, i.e., age-0 flathead sole, age-0 Pacific halibut, age-l yellowfin sole and age-0 rock sole. Interannual variation in abundances of these four species were monitored over the six years (1991-1996) of collection in Chiniak Bay. Habitat characteristics were incorporated into the survey design and analysis methods for increased precision in abundance estimates. Abundance trends were species–specific and statistical significance of trends varied among the three indices used to evaluate interannual abundances.

A survey which incorporated a multi-year sampling design was used to monitor interannual variation in flatfish abundance. The sampling design included (1) exploratory sampling to identify flatfish habitat (1991-I 994), (2) sampling stratified by depth and substrate habitat parameters (1995) with fixed sample allocation to determine cost of sampling and variability in fish abundance, and (3) sampling stratified by depth and substrate, with sample allocation based on the cost of sampling and variability in fish abundance (1996). In most cases, stratification of sampling by depth and substrate (1995 and 1996) increased the precision of species abundance estimates over those of non-stratified sampling years (199 1-1994). The 1996 method of sampling on the perimeters of the species spatial habitat range, in an effort to detect changes in interannual abundances with low variability, did not increase the precision of estimates over stratified sampling with equal allocation of samples to strata.

Three indices were calculated for each species to assess interannual variations in abundance: (1) the mean abundance over nine fixed sites that were sampled in all six years, (2) the mean abundance over all sites sampled in each of the six years and (3) the mean abundance over all sites in regions of “preferred” or occupied habitat, identified specifically for each of the four species and based on depth and sediment characteristics. The index calculated over nine fixed sites did not reveal significant differences in abundance among years, but was a valuable reference to confirm trends in abundance free from the possible confounding effect of regional sampling bias. The index calculated over all sites showed the most significant changes in abundance over time for rock sole and Pacific halibut, the species with the fewest zero catches. Annual abundance of rock sole oscillated, and was lowest in 199 1 and 1993 and highest in 1992 and 1994. Pacific halibut increased in abundance over the six years, exhibiting the lowest abundances in 1991 and 1993 and highest abundances in 1994 and 1995. Thc index calculated over all sites in "preferred" habitat discerned the most significant changes in abundance for flathead sole, which had a high number of zero catches outside of preferred habitat, but exhibited high abundance and few zero catches within preferred habitat (> 30 m depth and 0–40% sand in substrate), Flathead sole increased in abundance from 1991 to 1992 and decreased in abundance thereafter. None of the three indices discerned significant changes in annual abundance for yellowfin sole, which had the most zero catches and exhibited relatively low abundances even within preferred habitat regions. Though not significant, all three indices showed an apparent decrease in abundance of yellowfin sole from 991 to 1996.

Comparison of groundfish communities in Kachemak and Chiniak Bays

Indices of relative abundance for all groundfishes caught during August 1995 and August 1996 in Kachemak and Chiniak Bays were analyzed in relation to the physical characteristics of the capture sites. Species compositions were similar but species abundances were significantly different between regions. Although interannual differences in temperature were recorded, these changes did not appear to have any effect on the abundance and distribution of fishes. Depth, which varied significantly between the two locations, explained the differential patterns in distribution and abundance. Depth at which groundfishes were collected in these two locations divided the species into shallow-water (13-28 m Chiniak Bay; 26-56 m in Kachemak Bay) and deep-water (44-60 m in Chiniak Bay; 57-86 m in Kachemak Bay) groupings. The shallow-water group included rock sole, walleye pollock, Pacific halibut, *Myoxocephalus* spp., Pacific cod, yellowfin sole, *Gymnocanthus* spp., sturgeon poacher, snake prickleback and sawback poacher. The shallow-water group, with the exception of sawback poacher, was found in higher numbers at Chiniak Bay. The deep-water group included spinycheek starsnout, shortfin eelpout, slim sculpin, spinyhead sculpin, and rex sole. The deep-water group was in higher or equal abundance in Kachemak Bay than in Chiniak Bay. These proposed shallow and deep-water species groupings are in agreement with an analysis of community structure of juvenile demersal fishes around Kodiak Island (Muter and Norcross, in preparation).

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Table I-1. Environmental parameters selected by models of juvenile flaffish presence and abundance. DistBay = distance within a bay: BayType = open, closed or intermediate aspect of the bay. A dash (-) indicates no model was attempted (after Table 4, Norcross et al., in review).

Species		**Conceptual model** (based on presence; Norcross et al., 1995)	**CART model** (based on abundance; Norcross et al., 1997)	**Resource selection model** (based on presence and abundance; Norcross et al., in review)
Arrowtooth flounder	age-0			DistBay. Sediment
	age-I			No selection
Flathead sole	age-0	Depth, Sediment	Temperature, Sediment, Depth	Temperature, Sediment
	age-I			Sediment
Pacific halibut	age-0	Depth, Sediment, DistBay	DistBay, Depth, Sediment	Temperature, Sediment
	aae-1			Bav Tvoe. Sediment
Yellowtin sole	age-0			No valid model
	age-I	Depth, Sediment, DistBay	Depth, Sediment, DistBay	Depth
Rack sole	age-0	Depth, Sediment, DistBay	Sediment, Temperature, Depth, Salinity	Depth, Sediment
	aae-I			Sediment

Table I-2. Summary of collections under present analysis. All net collections used 7 mm mesh with a 4 mm **codend.** GPS = global positioning system CTD = **conductivity–temperature–depth** recorder; x = sample collected ;. 1 = values for total sample only; ● 2 = values for gravel, sand, and mud portions; TDR = temperature depth recorder.

1

Cruise	Dates	Chief scientist	Vessel	GPS (start and end tow recorded)	Net beam (m)	CTD vertical profile	Substrate (grain size)	Substrate (% volatile matter and % carbonate)	Benthos	Additional gear
Kachemak Bay, southeast lower Cook inlet										
CI9401	24-30 Sep 94	**Norcross**	28 ft Munsen skiff	x	3.05	x	x	•1	x	none
CI9501	3-l 1 May 95	**Abookire**	**28 ft Munsen skiff**	x	3.05	x	x	•2	x	none
CI9502	l-9 **Aug 95**	Abookire	28 ft Munsen skiff	x	3.05	x	x	•2	x	**TDR** on net
CI9601	24 Feb-1 Mar 96	Abookire	28 ft Munsen skiff	x	3.05	x	x	•2	x	TDR **on** net; **Stowaway TDRs** deployed
CI9602	22-31 May 98	Abookire	28 ft Munsen skiff	x ,	3.05,	☒ 📪	☒	📪 ● 2 ,	x ,	Towed underwater video camera
CI9604	**7–19 Aug** 96	Abookire	28 ft Munsen skiff	x	3.05	x	x	*2	x	Stowaways retrieved
Chiniak Bay, northeast Kodiak Island										
KI9101	**11–17 Aug 91**	**Norcross**	**24 ft skiff, 1 outboard**	none	3.66	x	x	**none**	x	none
KI9102	**18–25** Aug 91	**Norcross**	90 ft trawler	x	3.66	x	x	**none**	x	none
KI9201	9-14 Aug 92	**Norcross**	24 ft skiff, 1 outboard	none	3.66	x	x	**none**	x	Diver/trawl comparison; additional diver stations
KI9301	**12–24 Aug 93**	**Norcross**	25 ft Boston Whaler, 2 outboards	start **only**	3.05	x	x	•1	none	**Diver/trawl** comparison
KI9403	**8–19** Aug 94	**Norcross**	25 ft Boston Whaler, 2 outboards	x	3.05	x	x	‘l	none	Diver/trawl comparison
KI9502	31 Jul-11 Aug 95	**Dressel**	25 ft Boston Whaler, 2 outboards	x	3.05	x	x	•2	none	Towed underwater video camera; TDR on net
KI9601	4-l 8 Aug 96	**Dressel**	25 ft Boston **Whaler, 2 outboards; 24 ft skiff, 1 outboard**	x	3.05	x	x	•2	**none**	Towed underwater video camera
Izhut Bay, southern Afognak Island										
KI9501	24-28 **Jul 95**	**Norcross**	22 ft skiff, 1 outboard	x	3.05	x	x	“2	none	none

Table I-3. Sediment classification by proportional grain size (after Folk 1980).

Classification	Code	% Boulder	% Cobble	% Gravel	% Sand + Mud	% Sand	% Mud
Grain size (mm)		B > 256	256> C >64	64> G >2		2 > s > 0.07	0.07 > M
Grain size (Phi)		-8 > B	-8 < C < -6	-6 < G < -1		-1 < S < 4	M > 4
Boulder	B	80< B <100	c <20	G <20			
Cobbly boulder	cB	B > C	20< c <50	G < C			
Gravelly boulder	gB	B > G	C < G	20< G <50			
Cobble	C	B=O	80< C 400	G < C			
Boulder-y cobble	bC	0< B <20	80< C 400	G < B			
Gravelly cobble	gC	B=O	C > G	G < C			
Bouldery gravel	bG	0< B <20	C < B	G > B			
Cobbly gravel	cG	B=O	0< c <50	G > C			
Gravel	G	B=O	c = o	80< G <100	20> S+M		
Muddy gravel	mG	B=O	c = o	30< G <80	70> S+M >20	S < M	M > S
Muddy sandy gravel	msG	B=O	C = 0	30< G <80	70> S+M >20	s > M	M < S
Sandy gravel	sG	B=O	c = o	30< G <80	70> S+M >20	S > 9(M)	9(M) < S
Sand	S	B=O	C = 0	0< G <5	100> S+M >95	S > 9(M)	9(M) < S
Gravelly sand	gS	B=O	c = o	5< G <30	95> S+M >70	S > 9(M)	9(M) < S
Gravelly muddy sand	gmS	B=O	c = o	5< G <30	95> S+M >70	S > M	M < S
Muddy sand	mS	B=O	c = o	0< G <5	100> S+M >95	S > M	M < S
Mud	M	B=O	c = o	0< G <5	100> S+M >95	9(S) < M	M > 9(S)
Gravelly mud	gM	B=O	c = o	5< G <30	95> S+M >70	S < M	M > S
Sandy mud	sM	-B = 0	c = o	0< G <5	1 00> S+M >95	S < M	M'S

Table I-4. First total sample canonical correlation from canonical discriminant analysis for presence and absence of all data combined.

Parameter	Flathead sole age-0	Flathead sole age-I	Rock sole age-0	Rock sole age-I
Depth	0.670	0.553	0.617	0.964
Sand	-0.428	-0.162	-0.518	-0.442
Mud	0.670	0.508	0.422	0.633
Temperature	0.319	0.231	0.264	-0.088
Salinity	-0.310	-0.089	0.305	-0.013
Tide stage	-0.322	-0.360	0.066	-0.099
Daylight	-0.081	0.053	0.391	0.201

Table I-5. Percent of stations per sampling period with both species present, neither species present, only flathead sole present, and only rock sole present.

Season	Flathead sole and Rock sole	Flathead sole only	Rock sole only	None present	Total # stations
Summer (Sep 94)	19%	38%	38%	6%	16
Spring (May 95)	0%	42%	37%	21%	19
Summer (Aug 95)	7%	54%	22%	17%	41
Winter (Feb 96)	51%	10%	28%	10%	39
Spring (May 96)	10%	46%	20%	24%	41
Summer (Aug 96)	15%	56%	22%	7%	41
All cruises	36	82	50	29	197

Table I-6. **One-way ANOVA results to test for equal bottom temperatures and bottom salinities among** transects. The greater than sign (>) denotes the transects with significantly greater bottom temperatures and bottom salinities. An asterisk (*) denotes the seasons where bottom temperatures are **significantly** different between transects ($p < 0.05$).

	Bottom Temperature						Bottom Salinity				
	N	F	p	Significant			N	F	p	Significant	
Spring											
May 95	19	6.39	0.0366	*	BP>KS BP>MC BP>CP		19	0.96	0.4794		
May96	41	1.97	0.1448				41	1.21	0.3423		
Summer											
Aug 95	**41**	**12.57**	**0.0001**	*****	KS>MC KS>BP KS>CP KS>HS		41	1.04	0.4071		
Aug 96	**41**	**13.6**	**0.0001**	*****	KS>MC KS>BP KS>CP KS>HS		41	2.74	0.052	cannot reject	CP<KS CP<MC CP<BP CP<HS HS<BP
Winter											
Feb 96	39	232	0.0001	•	MC>KS MC>BP MC>CP MC>HS KS>CP KS>HS BP>HS CP>HS		39	1.42	0.2595		

Table I-7. Mean bottom temperatures ± one standard error in 1996. Data were collected by StowAway temperature loggers at stations MC20 and KS100. N = number of data points recorded. MC20 was significantly warmer than KS100 during all months ($p < 0.0001$).

Date	N	MC20	KS100	T Stat
26–29 Feb 96	100	3.47 ± 0.01	3.03 ± 0.01	25.76
Mar 96	1240	3.78 ± 0.01	3.49 ± 0.01	68.71
Apr 96	1200	4.41 ± 0.01	4.09 ± 0.01	69.18
May 96	1240	5.77 ± 0.01	5.18 ± 0.01	94.85
Jun 96	1200	7.30 ± 0.01	6.33 ± 0.01	133.39
Jul 96	1240	6.98 ± 0.02	7.78 ± 0.01	95.86
1-14 Aug 96	643	9.73 ± 0.01	9.02 ± 0.01	74.21

Table I-8. Correlation coefficients for temperature and depth on each transect of each sampling period. A positive correlation indicates that temperature increases with depth, and a negative correlation indicates that temperature decreases with depth. A dash (-) denotes transects that were not sampled. May 1995 values are 1.00 for KS and BP transects because CTD data were available from only two stations.

Transect	Summer (Sep 94)	Spring (May 95)	Summer (Aug 95)	Winter (Feb 96)	Spring (May 96)	Summer (Aug 96)
KS	-0.44	+1.00	-0.95	+0.58	-0.34	-0.66
MC	+0.26	-0.88	-0.88	+0.04	-0.61	-0.60
BP	-	+1.00	-0.44	+0.63	-0.99	-0.72
CP	-	-0.92	-0.67	+0.74	-0.79	-0.75
HS	-	-	-0.59	+0.89	-0.41	-0.90

Table I-9. Bottom temperature (“C) and salinity (PSU) ranges with presence of fish for each season and year. A dash (-) denotes no fish were caught; ** denotes a significant ($p \leq 0.05$) bottom temperature effect on fish abundance; and * denotes a significant ($p \leq 0.05$) bottom salinity effect on fish abundance. Bottom temperature and salinity sampling ranges and means ± one standard deviation are presented.

		Summer	Spring	Summer	Winter	Spring	Summer
		Sep 94	May 95	Aug 95	Feb 96	May 96	Aug 96
Flathead sole age-0	Temp.	959.7		7.8-8.8	1.O-3.6		8.7-9.6
	Salinity	30.3-30.8	-	31 .0-31.4	21.8-31.9	-	31.3-31.6
Flathead sole age-l	Temp.	9.5-9.7	3.9-4.2	7.9-9.8 **	1 .o-3.5	5.0-5.8	8.7-9.6
	Salinity	30.3-30.8	31.7-31.8	31 .o-31.4	21.8-31.9	31.8-32.0	31 J-31.6
Rock sole age-0	Temp.	9.2-9.8 **	-	9.3-l 0.1	0.9-3.6 **	5.7-6.9 **	9.2-l 0.3
	Salinity	30.3-30.7	-	28.4-31.3	21.8-31.9	31 .o-31.9	29.3-31.7
Rock sole age-l	Temp.	9.2-9.7	4.1-4.6	8.2-l 0.1	1 .o-3.5	5.0-7.1 **	9.2-l 0.3
	Salinity	30.3-30.6	31.4-31.8	28.4-31.3	31.4-31.9	30.8-32.2 *	29.3-31.6
Temperature sampling range		9.2-9.8	3.8-4.7	7.8-l 0.1	0.9-3.6	5.0-7.1	8.6-l 0.3
Temperature mean ± SD		9.6 ± 0.1	4.2 ± 0.3	8.7 ± 0.7	2.3 ± 0.8	5.6 ± 0.5	9.6 ± 2.7
Salinity sampling range		30.3-30.8	30.4-33.8	28.4-31.4	21.8-31.9	30.8-32.2	29.0-31.6
Salinity mean ± SD		30.6 ± 0.2	31.7 ± 0.6	31.2 ± 0.5	31.2 ± 2.0	31.9 ± 0.3	31.4 + 0.4

Table I-10. Interannual differences in mean length of **flathead** sole and rock sole. No age-0 **flathead** sole or rock sole were captured in **May 1995.**

Year A	Year B	**Flathead** sole age-0		**Flathead** sole age-I		Rock sole age-0		Rock sole age-I	
		P	**df**	P	**df**	P	-	P	**df**
Spring									
May 95	**May 96**	-	-	**0.9935**	**349**	-	-	**< 0.0001**	183
Summer									
Sep 94	**Aug 95**	< 0.0001	311	< 0.0001	444	0.0004	566	0.2983	143
Sep 94	Aug 96	< 0.0001	415	< 0.0001	233	< 0.0001	832	0.1068	176
Aug 95	Aug 96	0.0001	178	< 0.0001	117	< 0.0001	490	0.0007	117

Table I-11. Mean total length (mm) + one standard deviation for the 1994, 1995, and 1996 year classes (mean length increase between sampling periods, in mm), and the rate (mm/day) of length increase per day.

1994 Year class	**Sept 94 age-0**		**May 95 age-I**		**Aug 95 age-I**		**Feb 96 age-I**
Flathead sole	40.9 ± 4.5	(20.3)	61.2 ± 7.0	(21.8)	**83.0** ± 11.1	(24.5)	107.5 ± 20.8
mm/day		0.09		0.24		0.12	
Rock sole	**48.0 ± 8.8**	(13.7)	61.7 ± **10.2**	(49.6)	**111**.3 ± 13.	(6.8)	118.1 ± **16.9**
mm/day		0.06		0.55		0.03	
1995 Year class	**Aug 95 age-0**		**Feb 96 age-0**		**May 96 age-I**		**Aug 96 age-I**
Flathead sole	**36.2 ± 4.4**	(15.7)	51.9 ± **7.2**	(9.3)	61.2 ± 7.8	(27.3)	**88.5** ± 15.2
mm/day		0.08		0.11		0.35	
Rock sole	**45.0** ± 5.5	(14.3)	**59.3 ± 8.5**	(14)	73.3 ± 8.0	(29.7)	**103.0** ± 2.7
mm/day		0.07		**0.16**		**0.38**	
1996 Year class	**May 96 age-0**		**Aug 96 age-0**				
Flathead sole	none		33.1 t4.3				
mm/day							
Rock sole	16.6 ± 2.1	(14.3)	30.9 ± 5.5				
mm/day		0.18					

Table l-12. Differences in mean length increase per day with 95% upper and lower confidence interval limits as estimated with the bootstrap statistic. The symbol ** denotes 95% confidence intervals which do not contain zero, denoting that the time periods tested are significantly different from each other. See Table l-l 1 for actual means (mm) and mean length increase per day (mm/day).

	Lower 95% confidence limit	Mean (mm/day)	Upper 95% confidence limit
Seasonal scale			
1994 YC	Sept 94 age-0 May 95 age-l	vs.	Aug 95 age-l Feb 96 age-l
Flathead sole	0.01	0.03	0.05 **
Rock sole	-0.08	-0.03	0.01
1994 YC	May 95 age-l Aug 95 age-l	vs.	Aug 95 age-l Feb 96 age-l
Flathead sole	0.09	0.12	0.16 **
Rock sole	0.45	0.52	0.59 **
1994 YC	Sept 94 age-0 May 95 age-l	vs.	May 95 age-l Aug 95 age-l
Flathead sole	0.13	0.15	0.18 **
Rock sole	0.43	0.49	0.55 **
1995 YC	Aug 95 age-0 Feb 96 age-0		May 96 age-l Aug 96 age-l
Flathead sole	0.24	0.27	0.31 **
Rock sole	0.25	0.31	0.36 **
1995 YC	Aug 95 age-0 Feb 96 age-0	vs.	Feb 96 age-0 May 96 age-l
Flathead sole	-0.01	0.03	0.06
Rock sole	0.05	0.09	0.13 **
1995 YC	Feb 96 age-0 May 96 age-l	vs.	May 96 age-l Aug 96 age-l
Flathead sole	0.18	0.24	0.28 **
Rock sole	0.16	0.22	0.28 **
Interannual scale			
	May 95 age-l Aug 95 age-l	vs.	May 96 age-l Aug 96 age-l
Flathead sole	0.06	0.10	0.15 **
Rock sole	0.10	0.18	0.28 **
	Sept 94 age-0 May 95 age-l	vs.	Aug 95 age-0 May 96 age-l
Flathead sole	-0.02	-0.01	0.01
Rock sole	0.02	0.04	0.05 • ☒
	Sept 94 age-0 Aug 95 age-l	vs.	Aug 95 age-0 Aug 96 age-l
Flathead sole	-0.01	0.01	0.02
Rock sole	-0.07	-0.05	-0.03 **
Age-0 vs. age-l			
	Aug 95 age-l Feb 96 age-l	vs.	Aug 95 age-0 Feb 96 age-0
Flathead sole	-0.07	-0.04	-0.02 **
Rock sole	-0.01	0.04	0.08
	May 96 age-l Aug 96 age-l	vs.	May 96 age-0 Aug 96 age-0
Rock sole	-0.26	-0.20	-0.14 **

Table 1-13. Catch-per-unit-effort (numberoffish per 1000 m^2) values from 1991-1994 sampling in Kalsin and Middle Bays. The station code identifies the specific tow; i.e., 912100103 indicates year = 1991, region = 2 (Kodiak), cruise number = 1 in that region during 1991, the consecutive station number = 001, and the tow number = 03 at that station during that cruise.

Station code	Rock sole	Pacific halibut	**Flathead** sole	Yellowfin sole
1991				
912100103	130.7	0.0	0.0	8.2
912100202	99.6	16.3	0.0	13.1
912100502	6.5	0.0	0.0	6.5
912100602	0.0	0.0	0.0	0.0
912100701	166.6	4.9	0.0	45.7
912100802	49.0	1.6	0.0	62.1
912100901	18.0	8.2	0.0	35.9
912101001	63.7	16.3	0.0	34.3
912101101	1.6	0.0	0.0	0.0
912101201	0.0	0.0	0.0	0.0
912101302	13.1	4.9	0.0	18.0
912101401	104.5	11.4	0.0	132.3
912101501	49.0	4.7	4.7	51.3
912101601	39.2	3.3	0.0	6.5
912101701	14.7	3.3	0.0	0.0
912101801	39.2	6.5	0.0	6.5
912101901	57.2	4.9	0.0	50.6
912102001	0.0	0.0	0.0	0.0
912102101	0.0	0.0	0.0	0.0
912102201	27.8	49.0	0.0	1.6
912102301	96.4	6.5	0.0	9.8
912102401	18.0	0.0	0.0	4.9
912102501	88.2	0.0	0.0	26.1
912102601	4.9	0.0	0.0	0.0
912102701	0.0	0.0	0.0	0.0
912102801	84.9	3.3	0.0	29.4
912102901	80.0	11.4	0.0	8.2
912103001	39.2	0.0	3.3	52.3
912103101	7.3	0.0	3.6	43.6
912103201	88.2	9.8	0.0	75.1
912103301	13.1	0.0	0.0	1.6
912103401	65.3	3.3	0.0	0.0
912103501	47.0	0.0	0.0	0.0
912103601	156.8	6.5	0.0	0.0
912103701	0.0	0.0	0.0	0.0
912103801	116.0	1.6	1.6	19.6
912103901	68.6	0.0	0.0	40.8
912104001	0.0	12.3	0.0	0.0
912104101	0.0	0.0	0.0	0.0
912104201	52.3	0.0	4.9	3.3
912200101	0.0	0.0	7.9	0.0
912200102	0.0	0.0	26.2	0.0

Table l-13. Continued.

Station code	Rock sole	Pacific halibut	Flathead sole	Yellowfin sole
912200201	14.4	0.0	0.0	0.0
912200301	2.0	0.0	3.3	0.0
912200401	1.3	0.0	28.8	7.2
912200501	70.0	0.0	0.0	3.9
912200601	0.0	0.0	3.9	0.0
912200701	0.0	0.0	0.7	0.0
912200802	2.6	0.0	0.0	0.7
912200902	0.7	0.0	12.4	0.0
1992				
922100101	1.6	0.0	0.0	0.0
922100201	0.0	0.0	0.0	0.0
922100301	0.0	0.0	0.0	0.0
922100401	0.0	3.3	19.6	0.0
922100501	3.3	0.0	0.0	0.0
922100602	0.0	0.0	481.9	0.0
922100701	0.0	0.0	1.6	0.0
922100702	4.9	1.6	0.0	0.0
922100703	0.0	0.0	0.0	0.0
922100801	150.3	9.8	0.0	1.6
922100802	80.0	3.3	0.0	3.3
922100803	161.7	16.3	0.0	1.6
922100804	179.7	6.5	0.0	3.3
922100901	307.1	26.1	29.4	6.5
922101001	124.1	21.2	0.0	0.0
922101201	316.9	14.7	3.3	16.3
922101301	26.1	4.9	0.0	3.3
922101401	165.0	18.0	0.0	4.9
922101402	227.1	3.3	0.0	4.9
922101403	253.2	8.2	0.0	1.6
922101404	238.5	16.3	0.0	4.9
922101501	300.6	0.0	0.0	0.0
922101601	107.8	0.0	0.0	0.0
922101702	650.1	49.0	0.0	4.9
922101801	463.9	37.6	0.0	6.5
922101802	387.1	27.8	1.6	40.8
922101803	385.5	35.9	3.3	55.5
922101804	405.1	49.0	0.0	52.3
922101901	11.4	0.0	0.0	0.0
922101902	276.1	1.6	0.0	0.0
922101903	13.1	0.0	0.0	0.0
922101904	0.0	0.0	0.0	0.0
922102101	19.6	18.0	0.0	0.0
1993				
932100201	0.0	1.5	0.0	9.0
932100302	0.0	0.7	0.7	0.7
932100401	0.0	0.7	0.0	0.0

Table I-13. Continued.

Station code	Rock sole	Pacific halibut	Flathead sole	Yellowfin sole
932100501	0.0	0.0	0.0	0.0
932100601	2.2	0.7	0.0	6.7
932100701	0.0	0.0	0.0	0.0
932100801	0.0	0.0	23.2	0.0
932100901	0.0	0.0	0.7	0.0
932101101	39.6	0.0	0.0	0.7
932101201	2.2	0.0	2.2	0.0
932101301	0.0	0.0	48.5	0.0
932101401	0.0	0.0	1.5	0.0
932101502	0.0	0.0	0.0	0.0
932101601	81.4	44.8	0.0	6.0
932101701	0.0	4.5	0.0	0.0
932101901	67.2	10.5	0.0	48.5
932102001	0.7	0.0	0.0	0.7
932102101	14.9	0.0	0.0	0.0
932102201	26.1	0.7	0.0	1.5
932102301	23.9	0.0	3.0	1.5
932102401	0.0	0.0	124.0	0.0
932102501	0.0	0.0	103.8	0.0
932102601	1.5	0.0	77.7	0.0
932102701	20.2	9.7	0.0	1.5
932102702	0.0	2.2	0.0	0.0
932102703	18.1	4.4	0.0	0.0
932102801	31.8	8.7	0.0	4.4
932102802	9.3	4.4	0.0	0.0
932102803	40.3	17.2	0.0	1.5
932102804	6.7	12.0	0.0	0.0
932102901	108.3	6.7	0.0	3.7
932102902	206.1	6.0	0.0	12.7
932102903	89.7	1.2	0.0	0.0
932102904	147.0	6.8	2.5	26.2
932103001	23.7	1.9	0.0	0.6
932103002	18.7	0.6	0.0	0.0
932103003	44.8	1.5	0.0	0.0
932103004	22.4	0.0	0.0	0.0
1994				
942300101	0.0	12.8	0.0	0.0
942300201	4.9	8.1	0.0	0.0
942300301	0.0	7.6	0.0	0.0
942300401	4.4	5.9	0.5	0.0
942300501	128.2	39.9	0.0	1.2
942300601	66.1	10.2	0.0	0.0
942300602	115.1	32.5	0.0	0.0
942300603	215.3	47.6	0.0	5.0
942300604	101.6	30.5	0.0	5.1
942300605	170.2	25.0	0.0	2.5

Table I-13. Continued.

Station code	Rock sole	Pacific halibut	Flathead sole	Yellowfin sole
942300606	142.3	35.6	0.0	5.1
942300607	177.7	42.6	0.0	5.0
942300608	127.0	27.9	0.0	5.1
942300609	82.4	17.3	0.0	2.2
942300610	31.3	10.4	0.0	0.0
942300611	91.8	18.8	0.0	0.0
942300612	166.9	26.0	0.0	6.5
942300613	158.2	23.8	0.0	4.3
942300614	141.8	16.7	0.0	2.1
942300701	62.2	15.6	0.0	0.0
942300801	71.5	20.6	0.0	0.9
942300901	147.0	20.8	0.0	0.0
942301004	90.4	2.7	5.5	0.0
942301101	4.3	0.0	30.3	1.4
942301202	565.5	42.5	0.0	8.9
942301203	364.6	38.7	0.0	22.1
942301204	261.5	20.1	0.0	0.0
942301206	348.7	33.5	0.0	4.5
942301207	615.9	58.0	0.0	24.9
942301208	303.8	49.7	2.8	30.4
942301209	460.4	29.1	0.0	4.5
942301210	433.6	40.2	0.0	0.0
942301211	207.1	22.1	0.0	41.4
942301212	395.0	44.2	0.0	19.3
942301213	540.9	55.9	0.0	8.9
942301214	453.7	33.5	0.0	0.0
942301215	342.5	44.3	0.0	24.9
942301301	1.2	0.0	0.0	0.0
942301303	5.4	0.0	0.0	0.0
942301403	0.0	0.0	0.0	0.0
942301501	0.0	0.0	0.0	0.0
942301601	0.0	0.0	21.4	0.0
942301701	53.0	1.6	0.0	0.0
942301801	370.5	12.3	0.0	0.9
942301901	0.7	0.0	9.2	0.0
942302001	0.0	0.0	1.9	0.0
942302101	0.0	0.0	8.8	0.0
942302401	0.0	0.0	0.7	0.0
942302501	1.0	0.0	21.6	0.0
942302502	0.0	0.0	5.9	0.0
942302601	0.0	0.0	98.8	0.0
942302602	0.0	0.0	18.3	0.0
942302701	57.4	0.0	0.0	0.0
942302901	1.4	4.3	0.0	0.0
942303001	27.6	0.0	5.5	0.0

Table I-14. 1995 stratum classification by depth and sediment parameters, and 1995 allocation of samples among strata. Stratum codes denote bay (KM = Kalsin and Middle Bays, KB = Kalsin Bay, MB = Middle Bay) and depth range (0 = 0–5 m, 5 = 5–10 m, 10 = 10-20 m, 20 = 20-30 m on high sand sediment, 22 = 20-30 m on low sand sediment, 30 = 30–50 m, 50 = 50-70 m, 70 = 70 m and deeper). The asterisk (*) denotes a region of variable sediments; its sediment classification is based on 1991-1995 measurements.

1995 stratum	Bay	Depth (m)	Sediment (% sand)	Number of 1995 tows
KM0	Middle Bay	0–5	91–100	3
	Kalsin Bay	0–5	91–100	3
KM5	Middle Bay	5–10	91–100*	3
	Kalsin Bay	5–10	91–100	3
KM10	Middle Bay	10–20	51–90	3
	Kalsin Bay	10–20	51–90	3
MB20	Middle Bay	20–30	90–100	3
KB20	Kalsin Bay	20–30	51–90	3
KB22	Kalsin Bay	20–30	0–50	3
KB30	Kalsin Bay	30–40	0–50	3
MB50	Middle Bay	50–60	50–90	3
KB50	Kalsin Bay	50–60	0–50	3
KB70	Kalsin Bay	70–80	0–50	2
Total				**38**

Table I-15. Catch-per-unit-effort (number of fish per 1000 m^2) values from 1995 sampling in Kalsin and Middle Bays with associated depth and sediment measurements and stratum classification (see Table I-14 for definition of 1995 stratum classification by depth and sediment parameters). The station code identifies the specific tow; i.e., 952200101 indicates year = 1995, region = 2 (Kodiak), cruise number = 2 in that region during 1995, the consecutive station number = 001, and the tow number = 01 at that station during that cruise.

Station code	**Predominant depth (m)**	**% sand in** substrate	**1995** stratum	**CPUE** rock sole	**CPUE Pacific halibut**	**CPUE flathead** sole	**CPUE yellowfin sole**
952200101	2	94	KB0	43.7	5.2	0.0	0.0
952200201	2	99	KB0	82.9	3.8	0.0	13.6
952200301	3	96	KB0	240.9	60.2	0.0	5.8
952200401	6	97	KB5	141.7	55.7	0.0	3.4
952200402	7	97	KB5	148.8	71.3	0.0	11.4
952200403	7	97	KB5	112.6	53.0	0.0	4.4
952200501	5	75	MB5	1.5	28.9	0.0	0.7
952200601	8	29	MB5	5.1	20.5	0.0	0.0
952200701	7	91	MB5	5.2	20.8	0.0	0.0
952200801	3	98	MB0	12.6	34.7	0.0	0.8
952200802	3	98	MB0	59.8	29.5	0.0	3.3
952200803	3	98	MB0	22.0	42.3	0.0	0.8
952200901	13	69	KB10	260.7	101.2	0.0	20.9
952200902	13	66	KB10	69.4	32.4	0.0	0.0
952201001	12	52	KB10	114.8	34.4	0.0	5.1
952201801	23	64	KB20	40.4	0.0	0.0	4.8
952201901	23	70	KB20	11.1	8.9	0.0	7.8
952202001	22	53	KB20	87.7	2.5	3.7	46.9
952202101	67	11	KB70	0.0	0.0	16.7	0.0
952202102	68	11	KB70	0.0	0.0	14.6	0.0
952202201	12	65	MB10	11.0	20.2	3.7	0.0
952202202	13	65	MB10	155.3	71.6	0.0	13.7
952202203	11	65	MB10	99.9	36.2	0.0	1.7
952202301	**52**	**53**	**MB50**	**0.0**	**0.0**	**57.4**	**0.0**
952202302	55	53	MB50	0.0	0.0	13.1	0.0
952202304	53	53	MB50	2.9	0.0	54.8	0.0
952202401	24	97	MB20	359.4	44.1	0.0	0.0
952202402	24	97	MB20	360.0	46.4	0.0	0.0
952202403	25	97	MB20	247.1	17.0	**1.3**	0.0
952202501	**54**	**18**	KB50	0.0	0.0	35.2	0.0
952202502	57	18	KB50	2.2	0.0	20.8	0.0
952202503	53	18	KB50	0.0	0.0	9.5	0.0
952202601	**32**	**23**	**KB30**	**0.0**	**0.0**	**26.1**	**0.0**
952202603	33	23	KB30	0.0	0.0	11.3	0.0
952202604	34	23	KB30	0.9	0.0	6.6	0.0
952202701	24	29	KB22	43.6	5.4	12.7	7.3
952202702	27	29	KB22	7.8	1.9	7.8	0.0
952202703	27	29	KB22	0.0	0.0	1.3	0.0

Table I-16. 1995 mean catch-per-unit-effort (number of fish per 1000 m^2) and associated variances with and without stratification.

			Mean CPUE				Variance			
Bay	Depth	% Sand	Rock sole	Pacific halibut	Flathead sole	Yellowfin sole	Rack sole	Pacific halibut	Flathead sole	Yellowfin sole
Stratification by depth and sediment										
Kalsin and Middle	0-5 m	90-100%	56.9	24.3	0.0	3.6	1346.3	211.2	0.0	21.4
Kalsin	5-10 m	90-100%	134.4	60.0	0.0	6.4	245.5	65.0	0.0	12.9
Middle	5–10 m	50–90%	3.2	20.5	0.0	0.2	3.0	59.8	0.0	0.1
Kalsin and Middle	10-20 m	50–90%	57.1	22.9	0.2	3.5	2426.1	327.2	0.2	19.6
Kalsin and Middle	20-30 m	50–90%	92.1	9.9	0.4	5.0	5229.7	88.2	0.5	70.7
Kalsin	20-30 m	0–50%	5.7	0.8	2.4	0.8	39.9	0.6	2.4	1.3
Kalsin	30-50 m	0–50%	0.2	0.0	7.4	0.0	0.1	0.0	16.3	0.0
Middle	> 30 m	50–90%	0.5	0.0	20.9	0.0	0.5	0.0	103.0	0.0
Kalsin	50-70 m	0–50%	0.2	0.0	7.3	0.0	0.1	0.0	12.2	0.0
Kalsin	> 70 m	0–50%	0.0	0.0	7.8	0.0	0.0	0.0	0.3	0.0
Stratification		Overall	39.0	13.6	2.3	2.3	49.3	4.0	0.2	0.7
No stratification		Overall	43.9	15.4	3.5	2.5	89.4	10.3	1.2	0.6

Table I-17. 1996 stratum classification by depth and sediment parameters, species to be monitored within respective stratum and allocation of samples among strata.

1996 stratum	Species to monitor	Bay	Depth (m)	Sediment (% sand)	Number of 1996 tows
1	Pacific halibut flathead sole yellowfin sole	Kalsin and Middle	< 30	0-40	4
2	flathead sole yellowfin sole	Kalsin and Middle	< 30	41-80	13
3	flathead sole yellowfin sole	Kalsin and Middle	< 30	81-100	13
4	rock sole Pacific halibut flathead sole yellowfin sole	Kalsin and Middle	> 30	0-40	7
5	yellowfin sole	Kalsin and Middle	> 30	41-80	2
All strata					**39**

Table I-18. Catch-per-unit-effort (number of fish per 1000 m^2) values from 1996 sampling in Kalsin and Middle Bays with associated depth and sediment measurements and stratum classification (see Table I-I 7 for definition of 1996 stratum classification by depth and sediment parameters). The station code identifies the specific tow; i.e., 962100102 indicates year = **1996**, region = **2** (Kodiak), cruise number = **1** in that region during 1996, the consecutive station number = 001, and the tow number = 02 at that station during that cruise.

Station code	Predominant depth (m)	% sand in substrate	1996 stratum	CPUE rock sole	CPUE Pacific halibut	CPUE flathead sole	CPUE yellowfin sole
962100102	3	97	3	197.6	7.3	0.0	16.0
962100201	3	99	3	56.5	2.3	0.0	7.7
962100301	4	99	3	29.3	9.5	0.0	5.6
962100401	5	98	3	35.2	7.8	0.0	6.3
962100501	5	98	3	131.8	13.7	0.0	0.0
962100601	68	14	4	0.0	0.0	3.7	0.0
962100701	56	21	4	0.0	0.0	5.3	0.0
962100702	57	22	4	0.0	0.0	5.7	0.0
962100802	36	20	4	138.4	0.0	0.0	0.0
962100803	36	20	4	112.4	0.0	9.7	0.0
962102101	54	60	5	20.8	0.0	0.0	0.0
962102103	57	43	5	0.0	0.0	6.7	0.0
962102201	27	93	3	125.8	28.7	0.0	0.0
962102402	7	99	3	254.4	29.7	0.0	0.0
962102502	13	68	2	0.0	1.6	0.0	0.0
962102601	3	85	3	6.4	18.3	0.0	0.8
962102701	76	15	4	0.0	0.0	6.4	0.0
962102702	75	15	4	0.0	0.0	3.4	0.0
962102801	14	86	3	164.4	63.2	0.0	1.6
962102901	7	99	3	22.3	15.8	0.0	0.0
962103001	27	30	1	468.2	0.0	2.6	4.0
962103002	27	33	1	394.2	0.0	6.3	2.5
962103003	27	32	1	125.0	0.0	1.4	0.0
962103005	28	32	1	429.0	0.0	6.1	2.4
962103201	18	76	2	165.8	0.0	0.0	24.2
962103301	23	96	3	126.9	20.4	0.0	11.7
962103401	14	65	2	201.5	33.8	0.0	29.2
962103601	7	99	3	61.3	4.7	0.0	5.5
962103701	12	62	2	23.5	10.7	0.0	0.0
962103802	14	44	2	41.6	0.0	0.0	0.0
962103902	4	99	3	17.4	73.6	0.0	1.9
962104001	8	85	2	9.2	36.1	0.0	0.0
962104002	8	85	2	16.9	20.3	0.0	0.8
962104003	7	77	2	5.1	36.5	0.0	0.0
962104301	25	72	2	144.4	0.0	11.5	0.0
982104401	20	40	2	205.9	0.0	11.2	2.5
962104501	16	71	2	40.3	0.7	0.0	23.4
962104601	15	51	2	25.3	10.1	0.0	5.1
982104701	21	41	2	442.8	8.9	0.0	30.6

Table I-19. Mean catch-per-unit-effort (number of fish per 1000 m^2), variance and coefficient of variation (CV) statistics for 1996 data in Kalsin and Middle Bays across the selected monitoring strata for each species and across all strata. A dash (-) denotes where abundance was 0 and therefore CV could not be calculated.

1996 stratum	Bay	Depth	% Sand	Rock sole Mean	Rock sole Variance	Rock sole CV	Pacific halibut Mean	Pacific halibut Variance	Pacific halibut CV	Flathead sole Mean	Flathead sole Variance	Flathead sole CV	Yellowfin sole Mean	Yellowfin sole Variance	Yellowfin sole CV
Depth and sediment stratification -selected strata															
1	Kalsin and Middle	0-30m	0–39%				0.0	0.0		4.1	61	0.60	2.2	2.7	0.74
2	Kalsin and Middle	0–30m	40–79%							1.7	181	2.44	8.9	160.6	1.42
3	Kalsin and Middle	0–30m	80–100%							0.0	OD	-	4.4	25.7	1.16
4	Kalsin and Middle	>30m	0–39%	35.8	3500.4	1.72	0.0	0.0	-	4.9	9D	0.61	0.0	0.0	-
5	Kalsin and Middle	>30m	40–79%										0.0	0.0	-
Depth and sediment stratification -all strata															
1	Kalsin and Middle	0–30m	0–39%	354.1	24248.4	0.44	0.0	0.0	-	4.1	61	0.60	2.2	2.7	0.74
2	Kalsin and Middle	0-30m	40–79%	101.7	16486.3	1.26	12.2	212.6	1.19	1.7	181	2.44	8.9	160.6	1.42
3	Kalsin and Middle	0–30m	ao-100%	94.6	6146.2	0.83	22.7	486.9	0.97	0.0	03	-	4.4	25.7	1.16
4	Kalsin and Middle	>30m	0–39%	35.8	3800.4	1.72	0.0	0.0	-	4.9	9.1	0.61	0.0	0.0	-
5	Kalsin and Middle	>30m	40–79%	10.4	215.9	1.41	0.0	0.0	-	3.3	223	1.41	0.0	0.0	-
elected strata overall				36.8	641.9	0.65	**0.0**	0.0	-	2.1	0.7	0.39	**5.5**	3.7	0.35
All strata overall				**112.6**	**466.9**	**0.20**	6.4	**5.1**	0.27	2.4	0.3	0.40	**5.5**	3.7	**0.35**

Table I-20. Coefficients of variation (CV) calculated from three consecutive sampling schemes (1996 CV are calculated over selected strata and over all strata). A dash (-) denotes where abundance was 0 and CV could not be calculated.

Year	Stratification method	Rock sole	Pacific halibut	Flathead sole	Yellowfin sole
1993	Nonstratified exploratory sampling	0.253	0.324	0.457	0.445
1995	Stratified by depth and sediment, fixed allocation of samples	0.180	0.146	0.205	0.354
1996	Stratified by depth and sediment, samples from selected strata	0.650		0.390	0.350
1996	Stratified by depth and sediment, samples from all strata	0.196	0.267	0.399	0.350

Table I-21. Catch-per-unit-effort (number of fish per 1000 m^2) values from nine permanent sites sampled 1991–1996.

Year	Permanent site #	Rock sole	Pacific halibut	Flathead sole	Yellowfin sole
1991	1	1.6	0.0	0.0	0.0
1991	2	80.9	8.2	0.0	91.5
1991	3	116.0	1.6	1.6	19.6
1991	4	0.0	0.0	23.3	0.0
1991	5	130.7	0.0	0.0	8.2
1991	6	99.6	16.3	0.0	13.1
1991	7	0.0	0.0	0.0	0.0
1991	8	166.6	4.9	0.0	45.7
1991	9	133.2	0.0	0.0	7.5
1992	1	1.6	0.5	0.5	0.0
1992	2	139.2	11.4	0.0	2.0
1992	3	307.1	26.1	29.4	6.5
1992	4	0.0	0.0	481.9	0.0
1992	5	107.8	0.0	0.0	0.0
1992	6	26.1	4.9	0.0	3.3
1992	7	220.9	11.4	0.0	4.1
1992	8	410.4	37.6	1.2	38.8
1992	9	650.1	49.0	0.0	4.9
1993	1	81.4	44.8	0.0	6.0
1993	2	18.1	8.4	0.0	1.0
1993	3	39.6	0.0	0.0	0.7
1993	4	0.0	0.0	48.5	0.0
1993	5	26.1	0.7	0.0	1.5
1993	6	14.9	0.0	0.0	0.0
1993	7	27.4	1.0	0.0	0.2
1993	8	137.8	5.2	0.6	10.6
1993	9	2.2	0.7	0.0	6.7
1994	1	0.0	7.6	0.0	0.0
1994	2	2.4	10.4	0.0	0.0
1994	3	128.2	39.9	0.0	1.2
1994	4	0.0	0.0	8.8	0.0
1994	5	62.2	15.6	0.0	0.0
1994	6	71.5	20.6	0.0	0.9
1994	7	127.7	26.1	0.0	3.1
1994	8	404.1	38.9	0.2	16.3
1994	9	57.4	0.0	0.0	0.0
1995	1	31.5	35.5	0.0	1.6
1995	2	3.9	23.4	0.0	0.2
1995	3	322.2	35.8	0.4	0.0
1995	4	1.0	0.0	41.7	0.0
1995	5	43.7	5.2	0.0	0.0
1995	6	82.9	3.8	0.0	13.6
1995	7	134.4	60.0	0.0	6.4
1995	8	165.1	66.8	0.0	10.5
1995	9	40.4	0.0	0.0	4.8
1996	1	17.4	73.6	0.0	1.9
1996	2	10.4	31.0	0.0	0.3
1996	3	125.8	28.7	0.0	0.0
1996	4	10.4	0.0	3.3	0.0
1996	5	197.6	7.3	0.0	16.0
1996	6	42.9	5.9	0.0	6.6
1996	7	126.9	20.4	0.0	11.7
1996	8	201.5	33.8	0.0	29.2
1996	9	165.8	0.0	0.0	24.2

Table I-22. Summary of physical characteristics measured at the two sample sites for two years. Standard deviation (sd) is presented in parentheses..

	Chiniak 95	Chiniak 96	Kachemak 95	Kachemak 96
N Depth (from fish tows)	46	43	49	42
Mean Depth (m) (sd)	**23.9 (18.8)**	**24.3 (20.5)**	**59.9 (34.9)**	**56.7 (33.1)**
Depth Range (m)	1.7-68.0	**2.5-76.0**	**4.0-147.0**	**4.0-142.0**
N CTD Casts	39	34	45	42
Mean Temperature (°C) (sd)	8.99 (1.1)	**10.03 (0.7)**	**8.59 (0.8)**	**9.22 (0.4)**
Temperature Range (°C)	**7.34-11.38**	**8.41-11.64**	**6.96-10.06**	**8.62-10.32**
Mean Salinity (PSU) (sd)	31.84 (0.6)	**32.07 (0.1)**	**31.16 (0.5)**	**31.41 (0.5)**
Salinity Range (PSU)	**30.22-32.73**	**31.59-32.31**	**28.36-31.39**	**29.04-31.63**
N Sediment Samples	27	38	45	41
(Mean %Gravel (sd)	2.79 (9.1)	**4.09 (15.9)**	**9.23 (19.9)**	**7.45 (15.9)**
%Gravel Range	**0.0-44.46**	**0.0-95.77**	**0.0-80.45**	0.0-64.71
Mean %Sand (sd)	**69.67 (28.6)**	**63.44 (31.6)**	**45.38 (28.5)**	**46.28 (29.6)**
%Sand Range	10.71-99.55	3.84-99.35	3.63-99.01	7.13-99.15
Mean %Mud (sd)	**27.54 (29.1)**	**32.47 (31.4)**	**49.25 (32.0)**	45.85 (31.1)
%Mud Range	0.04-89.25	0.39-86.33	0.01-96.29	0.16-92.41
Mean %Organic Matter (sd)	2.61 (1.01)	**2.85 (0.97)**	**4.37 (1.53)**	**4.32 (1.56)**
%Organic Matter Range	**1.27-4.02**	**0.76-5.52**	**1.22-7.83**	**1.26-8.80**
Mean % Carbonate (sd)	**2.86 (3.74)**	**2.21 (1.41)**	**8.54 (10.86)**	**10.02 (13.37)**
%Carbonate Range	**0.78-20.68**	0.48-7.49	1.21-50.55	1.21-50.55

Table I-23. Results of two-way ANOVAs comparing physical characteristics among locations (Chiniak Bay, Kodiak Island and Kachemak Bay, Lower Cook Inlet) and years (1995 and 1996). F values are presented for location, year and the year-location interaction, with the level of significance indicated.

Factor	Year	Location	Location x Year
Depth	0.11	**67.50”**	**0.19**
Temperature	**45.70”**	**23.51”**	**3.02**
Salinity	10.29*	82.52***	**0.05**
Gravel	0.01	**3.34**	**0.33**
Sand	0.01	31.19***	**1.37**
Mud	**0.02**	**11.77”**	**0.41**
Organic carbon	**0.17**	53.20***	**0.45**
Carbonate	**0.07**	19.05***	**0.47**
	* $p < 0.01$	** $p < 0.001$	*** $p < 0.0001$

Table I-24. Results of Tukey unequal N HSD test for physical factors found to be significantly different in two-way ANOVAs; p values from all combinations of location (Ch = Chiniak Bay, Ka = Kachemak Bay) and year (95, 96).

Factor	Ch95 - Ch96	Ka95 - Ka96	Ch 95 - Ka 95	Ch96 - Ka96	Ch95 - Ka96	Ch96 - Ka95
Depth	1.000	0.953	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Temperature	**< 0.0001**	**< 0.01**	0.127	< 0.0001	0.534	**< 0.0001**
Salinity	0.200	0.600	**< 0.0001**	**< 0.0001**	**< 0.001**	**< 0.0001**
Sand	0.867	0.858	**< 0.01**	0.056	**< 0.01**	**< 0.01**
Mud	0.937	0.961	0.051	0.218	0.133	0.075
Organic matter	0.910	0.997	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**
Carbonate	0.994	0.889	0.112	< 0.01	0.024	0.016

Table I-25. Rank, total CPUE and percentage contribution of each species of fish caught in each of the four cruises. Summary statistics are for each cruise as a whole; sd denotes standard deviation.

		Chiniak 95			Chiniak 96			Kachemak 95			Kachemak 96		
Scientific Name	Common Name	Rank	Count	Catch%	Rank	Count	Catch%	Rank	Count	Catch%	Rank	Count	Catch%
Pleuronectes *bilineata*	Rock sole	1	5824.9	41.27%	1	5409.8	36.19%	3	523.5	12.84%	1	1402.5	28.58%
Theragra chalcogramma	Walleye pollock	2	1959.3	13.88%	2	1841.2	12.32%	4	312.3	7.66%	6	190.1	3.87%
Hippoglossoides elassodon	Flathead sole	3	1197.41	8.48%	5	638.6	4.27%	2	573.0	14.06%	3	456.2	9.30%
Hippoglossus stenolepis	Pacific halibut	4	1150.8	8.15%	8	481.2	3.22%	10	72.4	1.78%	9	139.1	2.83%
Myoxocephalus spp.	*Myoxocephalus* spp.	5	842.9	5.97%	7	555.9	3.72%	12	61.5	1.51%	15	74.2	1.51%
Gadus macrocewhalus	Pacific cod	6	734.3	5.20%	4	1353.0	9.05%	1	1283.8	31.49%	25	30.7	0.63%
Atherestes stomias	Arrowtooth flounder	7	360.91	2.56%	11	244.7	1.64%	16	47.2	1.16%	12	97.8	1.99%
Pleuronectes asper	Yellowfin sole	6	232.2	1.64%	9	279.5	1.87%	13	57.7	1.41%	11	108.5	2.21%
Sarritor frenatus	Sawback poacher	9	175.0	1.24%		0.0		36	2.9	0.15%	31	9.4	0.19%
Gymnocanthus spp.	*Gymnocanthus* spp.	10	131.7	0.93%	13	196.6	1.32%	29	10.6	0.26%	39	3.3	0.07%
Lumpenus fabricii	Slender eelblenny	11	129.1	0.91%	6	558.0	3.73%	31	5.9	1.93%	7	189.1	3.85%
Lumpenus maculatus	Daubed shanny	12	125.61	0.89%	15	165.7	1.11%	9	78.5	1.93%	10	113.9	2.32%
Microgadus proximus	Pacific tomcod	13	108.41	0.77%	48	2.3	0.02%	39	2.2	0.05%		0.0	
Liwarididae	Snailfishes	14	106.0	0.75%	23	48.2	0.32%	17	37.7	0.92%	17	69.3	1.41%
Podothecus acipenserinus	Sturgeon poacher	15	103.01	0.73%	14	170.8	1.14%	32	5.2	0.13%	38	3.7	0.08%
Lumpenus sagitta	Snake prickleback	16	102.91	0.73%	3	1641.1	10.98%	20	27.0	0.66%	21	48.2	0.98%
Icelinus borealis	Northern sculpin	17	79.81	0.57%	10	277.61	1.86%	22	23.51	0.58%	22	40.11	0.82%
Bathyagonus infraswinata	Spinycheek starsnout	18	77.01	0.55%	18	86.3	0.58%	5	179.51	4.40%	5	282.0	5.75%
Bathymaster signatus	Searcher	19	72.21	0.51%	37	8.9	0.03%	24	16.6	0.41%	26	16.0	0.33%
Microstomus pacificus	Dover sole	20	64.7	0.46%	27	27.2	0.18%	15	49.5	1.21%	19	58.3	1.19%
Lumpenus spp.	*Lumpenus* spp	21	53.8	0.38%	12	213.9	1.43%	26	13.2	0.32%	32	8.0	0.16%
Pleuronectes vetulus	English sole	22	53.7	0.38%	17	96.2	0.64%	44	1.3	0.03%		0.0	
Pleuronectes quadrituberculatus	Alaska plaice	23	48.5	0.34%	25	30.6	0.21%		0.0			0.0	
Hexagrammos stelleri	White-spotted greenling	24	44.9	0.32%	24	41.1	0.27%	23	20.6	0.51%	29	13.2	0.27%
Pleuronectes isolepis	Butter sole	25	44.8	0.32%	21	52.7	0.35%		0.0		44	1.5	0.03%
Triglops spp.	*Triglops* spp.	26	44.4	0.26%		0.0			0.0			0.0	
Gymnocanthus galeatus	Armorhead sculpin	27	36.4	0.23%	28	26.3	0.18%		0.0			0.0	
Lycodes breviwes	Shortfin eelpout	28	32.5	0.23%	16	154.0	1.03%	6	162.8	3.99%	2	478.6	9.75%
Psychrolutes sigalutes	Soft sculpin	29	21.81	0.15%		0.0			0.0			0.0	
Hexagrammos octogrammus	Masked greenling	30	16.3	0.12%	30	17.5	0.12%		0.0			0.0	
Lumpenus medius	Stout eelblenny	31	13.0	0.09%	26	28.21	0.19%	8	93.3	2.29%	42	2.0	0.04%
Psettichthys melanostictus	Sand sole	32	12.2	0.09%	42	7.01	0.05%		0.01			0.0	
Hemilepidotus iordani	Yellow irish lord	33	11.4	0.08%	34	11.8	0.03%	45	1.0	0.03%	35	5.1	0.10%
Pallasina barbata	Tubenose poacher	34	10.51	0.07%	42	7.0	0.05%		0.01		36	4.11	0.08%

Table I-25. Continued.

		Chinlak 95			Chiniak 96			Kachemak 95			Kachemak 96		
Scientific Name	**Common Name**	**Rank**	**Count**	**Catch%**	**Rank**	**Count**	**Catch%**	**Rank**	**Count**	**Catch%**	**Rank**	**Count**	**Catch%**
Radulinus asprellus	Slim sculpin	35	9.9	0.07%	47	2.7	0.02%	11	70.9	1.74%	6	159.7	3.26%
Platichthys stellatus	Starry flounder	36	6.4	0.06%	36	9.3	0.06%	39	2.5	0.06%		0.0	
Ammodytes hexapterus	Pacific sand lance	37	8.3	0.06%	20	81.2	0.54%	28	11.2	0.28%		0.0	
~ *Enophrys lucesi*	Leister sculpin	38	6.6	0.05%	37	9.1	0.06%		0.0			0.0	
Dasycottus setiger	Spinyhead sculpin	39	6.3	0.04%	34	11.2	0.07%	18	33.4	0.82%	16	73.6	1.50%
Cottidae	Sculpins	40	5.5	0.04%	33	12.4	0.08%		0.0		45	0.9	
Hemilepidotus spp.	Irish lords	40	5.5	0.04%		0.0			0.0			0.0	
Enophrys spp.	*Enophrys* spp.	42	5.2	0.03%		0.0			0.0			0.0	
Aspidophoroides bartoni	Aleutian alligatorfish	43	4.2	0.03%		0.0			0.0		30	10.8	0.22%
Pholis laeta	Crescent gunnel	44	3.8	0.03%	39	8.1	0.05%		0.0		27	15.8	0.32%
Trichodon trichodon	Pacific sandfish	45	3.6	0.03%	52	1.2	0.01%		0.0			0.0	
Sitchaeus punctatus	Arctic shanny	46	3.3	0.02%	30	23.3	0.16%	36	3.0	0.07%	34	7.0	0.14%
Hexagrammos spp.	Rock OR kelp greenling	47	3.1	0.02%	40	7.7	0.05%		0.0		28	15.4	0.31%
Nautichthys pribilovius	Eyeshade sculpin	48	2.5	0.02%	44	5.3	0.04%		0.0		33	7.4	0.15%
Leptocottus armatus	Pacific staghorn sculpin	49	2.1	0.01%	55	0.8	0.01%		0.0			0.0	
Mallotus villosus	Capelin	50	2.0	0.01%		0.0			0.0			0.0	
Gadidae	Cods	51	1.8	0.01%		0.0			0.0			0.0	
Blepsias cirrhosus	Silverspotted sculpin	52	1.7	0.01%	46	3.1	0.02%		0.0			0.7	
Enophrys bison	Buffalo sculpin	53	1.4	0.01%		0.0			0.0			0.0	
Ronquilus jordani	Northern ronquil	54	1.3	0.01%		0.0		7	132.6	3.25%	12	97.8	1.99%
Scorpaenidae	Rocktishes	54	1.3	0.01%		0.0		35	3.5	0.09%	24	43.4	0.68%
Occella verrucosa	Warty poacher	54	1.3	0.01%		0.0			0.0			0.0	
Bathymasteridae	Ronquils	54	1.3	0.01%		0.0			0.0			0.0	
Raja binoculeta	Big skate	58	1.2	0.01%	53	1.1	0.01%		0.0			0.0	
Poroclinus rothrocki	Whitebarred priikleback	59	0.8	0.01%	50	1.3	0.01%	25	14.2	0.35%	23	45.2	0.92%
Ophiodon elongatus	Lingcod	60	0.7	0.01%	42	7.2	0.05%	38	2.6	0.06%		0.0	
Triglops pingeli	Ribbed sculpin		0.0		23	50.3	0.34%	19	30.4	0.74%	20	56.0	1.14%
Psychrolutes peradoxus	Tadpole sculpin		0.0		30	17.5	0.12%	14	51.7	1.27%	14	80.6	1.64%
Myoxocephalus polyacanthocephalus	Great sculpin		0.0		32	12.8	0.09%		0.0			0.0	
Triglops macellus	Roughspine sculpin		0.0		44	3.3	0.02%		0.0		40'	3.2	0.06%
Zaprora sinenus	Prowfish		0.0		49	2.2	0.01%	48	0.3	0.01%		0.0	
Hemilepidotus hemilepidotus	Red irish lord		0.0		50	1.3	0.01%		0.0		37	7.6	0.16%
Anoplagonus inermis	Smooth alligatorfish		0.0		53	1.1	0.01%	34	3.6	0.09%		0.0	
Anoplarchus insignis	Slender cockscomb		0.0		57	0.6	0.00%		0.0			0.0	
Errex zachirus	Rex sole		0.0			0.0		21	24.5	0.60%	18	63.4	1.29%
Lycodes palearis	Wattled eelpout		0.0			0.0		27	12.3	0.00%	43	1.6	0.03%

Table I-25. Continued.

		Chiniak 95			Chiniak 96			Kachemak 95			Kachemak 96		
Scientific Name	**Common Name**	**Rank**	**Count**	**Catch%**	**Rank**	**Count**	**Catch%**	**Rank**	**Count**	**Catch%**	**Rank**	**Count**	**Catch%**
Raja rhina	Longnose skate		0.0			0.0		32	5.0	0.12%	41	2.1	0.04%
Lumpenella longirostris	Longsnout prickleback		0.0			0.0		30	6.1	0.15%		0.0	
Nautichthys oculofasciatus	Sailfin sculpin		0.0			0.0		41	1.9	0.05%		0.0	
Icelus spp.	*Icelus* spp.		0.0			0.0		42	1.7	0.04%		0.0	
Hemitripterus bolini	Bigmouth sculpin		0.0			0.0		43	1.5	0.04%		0.0	
Pholis spp.	*Pholis* spp.		0.0			0.0		45	1.0	0.02%		0.0	
Unidentified flatfish	Unidentified flatfish		0.0			0.0		47	0.6	0.01%		0.0	
Eleginus gracilis	Saffron cod		0.0			0.0			0.0		4	364.7	7.43%
Cryptacanthodes aleutensis	Dwarf wrymouth		0.0			0.0			0.0		46	0.5	0.01%
Liparis spp.	*Lipsris* spp.		0.0			0.0			0.0		47	0.4	0.01%
Tow summary													
number of samples			46			43			49			42	
total distance towed			176011			202021			306811			231071	
average distance towed			383			470			626			550	
sd distance towed			120			239			342			263	
actual no. fish caught			11654			13502			3428			4552	
Fish density summary													
adjusted no. fish (CPUE)			14115.6			14946.9			4076.5			4906.8	
average # fish/tow			306.9			341.3			83.2			116.8	
sd fish/tow			236.1			267.1			146.7			185.1	
minimum # fish/tow			21.7			59.9			1.8			7.3	
maximum # fish/tow			1029.2			1017.3			836.5			1153.3	
# fish/1000 m^2 over total tow distance			355.31			324.91			58.91			94.1	
Species summary													
total number			60			57			48			47	
average # species/tow			13			15			8			10	
sd species/tow			3.2			3.2			3.3			3.0	
minimum species/tow			7			9			2			4	
maximum species/tow			20			20			15			17	
% abundance of top-10 species				89.33%			89.87%			83.69%			76.95%

Table I-26. Results of two-way ANOVAs comparing fish abundances among locations (Chiniak Bay, Kodiak island and Kachemak Bay, lower Cook Inlet) and years (1995 and 1996). *F* values for location, year and their interaction with the level of significance indicated. Fishes are in order of decreasing abundance.

Fish	Year	Location	Location x Year
Rock sole	2.11	103.20"	0.14
Walleye pollock	0.02	37.26"	1.52
Flathead sole	0.06	0.13	0.52
Pacific halibut	2.40	59.37"	4.29
Myoxocephalus spp.	0.01	61.67"	0.01
Pacific cod	0.94	27.52"	8.05*
Arrowtooth flounder	0.70	15.31"	2.51
Yellowfin sole	0.21	28.74"	0.62
Sawback poacher	22.45"	19.46"	35.38"
Gymnocanthus spp.	0.06	37.71"	0.09
Slender eelblenny	0.03	0.21	0.28
Daubed shanny	0.21	1.00	0.02
Snailfishes	0.03	1.42	2.96
Sturgeon poacher	6.15	79.83***	6.57
Snake prickleback	14.30"	26.25"	14.73"
Northern sculpin	2.31	8.03*	0.04
Spinycheek starsnout	1.57	15.38"	3.94
Dover sole	2.59	2.86	0.66
Triglops spp.	0.35	1.23	0.15
Shortfin eelpout	6.47	19.67"	0.62
Stout eelblenny	0.97	0.14	2.76
Slim sculpin	0.09	21.45"	2.54
Spinyhead sculpin	4.95	16.11"	1.93
Northern ronquil	0.02	18.43"	0.01
Tadpole sculpin	6.85*	9.83*	0.01
Rex sole	2.11	21.44"	2.11
Saffron cod	6.44	6.44	6.44
	* $p < 0.01$	** $p < 0.001$	*** $p < 0.0001$

Table I-27. Results of Tukey unequal N HSD test for fish abundances found to be significantly different in two-way ANOVAs; p values from all combinations of location (Ch = Chiniak Bay, Ka = Kachemak Bay) and year (95 96). Fishes are in order of decreasing abundance.

Fish	ChS5 - Ch96	Ka95 - Ka96	Ch 95 - Ka 95	ChS6 - Ka96	Ch95 - Ka96	Ch96 - Ka95
Rock sole	0.584	0.884	<0.0001	<0.0001	~0.0001	~0.0001
Walleye pollock	0.781	0.876	<0.0001	co.01	<0.001	<0.001
Pacific halibut	0.059	0.985	<0.0001	<0.001	~0.0001	<0.001
Myoxocephalus spp.	0.999	1.000	<0.0001	<0.0001	~0.0001	~0.0001
Pacific cod	0.568	0.045	0.31	<0.0001	<0.001	0.016
Arrowtooth flounder	0.337	0.956	<0.001	0.381	co.01	0.143
Yellowfin sole	0.822	0.996	co.01	<0.001	co.01	<0.001
Sawback poacher	<0.0001	0.841	<0.0001	0.719	~0.0001	0.996
Gymnocanthus spp.	0.981	1.000	<0.001	<0.0001	<0.001	~0.0001
Sturgeon poacher	co.01	1.000	<0.0001	<0.0001	~0.0001	~0.0001
Snake prickleback	<0.0001	1.000	0.794	<0.0001	0.795	~0.0001
Northern sculpin	0.801	0.638	0.129	0.275	0.805	0.014
Spinycheek starsnout	0.957	0.118	0.509	<0.001	co.01	0.251
Shortfin eelpout	0.618	0.102	0.045	co.01	<0.0001	0.557
Slim sculpin	0.974	0.292	0.13	<0.001	<0.001	0.056
Spinyhead sculpin	0.938	0.064	0.237	<0.01	~0.001	0.602
Northern ronquil	0.999	1.000	0.012	0.016	0.023	0.011
Tadpole sculpin	0.279	0.265	0.118	0.131	<0.001	0.984
Rex sole	1.000	0.191	0.104	co.001	~0.001	0.123

Table I-28. Results of two-way **ANCOVAs,** using physical variables (depth, temperature, salinity, % gravel, % sand, % mud, organic matter, carbonate) as covariates, comparing fish abundances between locations (Chiniak Bay and Kachemak Bay) and years (I 995 and 1996). Number of stations used for calculations includes only stations where the species was collected. *F* values for location, year and their interaction with the level of significance are indicated. Multiple regression results from same data, including variables that are significant parameters. D = depth, T = temperature, S = salinity, Sed = sediment (% gravel, % sand, % mud), 0 = organic matter, C = carbonate. Dashes (-) denote comparisons that could not be made because the species was not collected in at a particular location and time.

		ANCOVA *F* Value			Multiple Regression		
Fish	**# Stations**	**Year**	**Location**	**Loc x Year**	***F* Value**	**R^2**	**Variable**
Rock sole	110	**4.26***	**I.99**	**I.39**	4.66’“’	0.28	D, T, 0, C
Walleye pollock	96	1.41	**I.55**	0.17	**I.34**	0.12	D
Pacific halibut	82	I.49	0.21	**I.73**	**2.53***	**0.23**	▪
Myoxocephalus spp.	93	0.68	0.88	0.00	**I.88**	0.16	D, S
Pacific cod	84	2.39	0.01	**I.42**	**2.63***	0.24	D
Arrowtooth flounder	77	0.27	2.71	0.38	1.81	0.19	▪
Yellowfin sole	84	0.26	0.9	0.1 I	**2.92****	**0.26**	D
Sawback poacher	37	0.01	0.01		0.78	0.23	▪
Gymnocanthus spp.	48	0.06	2.13	**0.01**	**1.32**	0.25	0
Sturgeon poacher	67	0.28	0.2	1.78	**I.79**	**0.22**	**S**
Snake prickleback	76	**9.01****	**I.86**	**7.40****	**2.86****	0.28	Sed
Spinycheek starsnout	83	**6.06***	**5.04***	**I.09**	11.43	10.15	▪
Shortfin eelpout	50	4.95”	I.82	0.01	Io.97	**0.18**	S, 0
Slim sculpin	38	**5.85***	**7.73***	3.54	**3.28***	**0.54**	-
Spinyhead sculpin	47	0.08	3.69	0.45	0.88	0.19	0
Rex sole	32	0.61			**I.29**	0.39	
				I < 0.05	** p < 0.01	****p < 0.0001	

Table I-29. Results of Tukey unequal N HSD test using physical variables (depth, temperature, salinity, % gravel, % sand, % mud, organic matter, carbonate) as covariates, comparing fish abundances among locations (Chiniak Bay, Kodiak Island and Kachemak Bay, Lower Cook **Inlet)** and years (1995 and 1996). Only those stations where the species was present are included in analysis. Dashes (-) denote comparisons that could not be made because the species was not collected at a particular location and time.

Fish	**Ch95 - Ch96**	**Ka95 - Ka96**	**Ch 95 - Ka 95**	**Ch96 - Ka96**	**Ch95 - Ka96**	**Ch96 - Ka95**
Rock sole	0.522	0.739	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Walleye pollock	0.999	1.000	0.119	0.048	0.064	0.095
Pacific halibut	0.041	0.631	**<0.001**	0.102	**<0.001**	**<0.01**
Myoxocephalus spp.	0.988	0.981	0.195	0.583	0.277	0.471
Pacific cod	0.924	0.550	0.499	0.091	0.171	0.211
Arrowtooth flounder	0.942	0.858	**<0.001**	0.019	**<0.01**	**<0.01**
Yellowfin sole	0.998	0.936	0.669	0.968	0.984	0.595
Sawback poacher	-	0.981	0.993	-	0.417	-
Gymnocanthus spp.	0.971	0.764	0.991	0.210	0.297	0.971
Sturgeon poacher	0.570	0.976	0.31	0.039	0.149	0.100
Snake prickleback	**<0.001**	0.987	0.854	0.010	0.727	**<0.001**
Spinycheek starsnout	0.800	0.076	0.861	0.999	0.777	0.421
Shortfin eelpout	0.611	0.045	0.991	0.952	0.825	0.154
Slim sculpin	0.996	0.058	0.948	0.866	0.224	1.000
Spinyhead sculpin	1.000	0.864	0.969	0.864	0.814	0.935
Rex sole		0.559				0.000

Table I-30. For the stations at which the species were found (# stations) in each of the four cruises, **LOG** mean number of fish, LOG mean number of fish adjusted for the covariates, and mean values for each of the physical variable used as covariates. Species which retained significant differences in abundance between cruises when physical variables were included as covariates are marked with an asterisk (*)

Year	Location	# Stations	Log #Fish	Log Adjusted #Fish	Depth	Temperature	Salinity	% Gravel	% Sand	% Mud	Organic	Carbonate
***Rock sole**												
1995	Chiniak	38	1.775	1.358	18.1	9.15	31.84	3.59	49.93	46.49	2.58	2.19
1996	Chiniak	36	1.953	1.849	17.9	10.15	32.06	4.53	71.10	24.37	2.60	2.21
1995	Kachemak	16	0.919	1.196	25.3	9.23	30.96	25.69	42.02	32.29	4.25	16.06
1996	Kachemak	17	1.124	1.367	26.8	9.52	31.35	0.76	55.61	43.63	3.73	16.18
Walleye pollock												
1995	Chiniak	34	1.281	0.992	25.9	8.70	32.04	4.41	45.77	49.82	3.01	1.88
1996	Chiniak	26	1.308	1.353	30.1	9.93	32.07	4.70	52.63	42.67	3.08	2.13
1995	Kachemak	14	0.674	0.701	37.3	8.96	31.18	15.85	52.74	31.42	4.06	14.23
1996	Kachemak	18	0.703	0.921	49.8	9.32	31.43	4.45	56.22	39.33	3.45	11.93
***Pacific halibut**												
1995	Chiniak	31	1.434	1.210	13.4	9.33	31.79	2.80	55.89	41.32	2.36	2.78
1996	Chiniak	26	1.119	0.774	12.8	10.29	32.06	6.13	81.94	11.92	2.36	2.27
1995	Kachemak	12	0.504	0.906	55.7	8.65	31.27	0.69	70.12	29.19	3.81	6.91
1996	Kachemak	11	0.713	0.881	31.5	9.47	31.32	1.04	49.42	49.53	3.12	19.27
***Myoxocephalus* spp.**												
1995	Chiniak	36	0.964	0.742	18.3	9.14	31.85	3.73	49.67	46.59	2.70	2.48
1996	Chiniak	33	0.925	0.605	20.5	10.10	32.07	4.82	51.81	33.37	2.89	2.06
1995	Kachemak	14	0.566	0.943	38.1	8.74	30.80	17.03	30.36	52.61	4.75	8.39
1996	Kachemak	10	0.648	0.814	33.2	9.36	31.22	1.05	52.10	46.85	4.05	7.77
Pacific cod												
1995	Chiniak	26	1.220	1.053	14.6	9.17	31.90	4.21	54.25	41.54	2.29	2.43
1996	Chiniak	28	1.317	0.918	13.0	10.27	32.07	5.67	80.15	14.19	2.37	2.08
1995	Kachemak	24	0.967	1.297	41.6	8.86	31.04	17.50	45.02	37.48	4.22	11.72
1996	Kachemak	6	0.525	0.759	48.0	9.29	31.50	20.78	66.34	12.88	4.51	19.50

Table I-30. Continued.

Year	Location	#Stations	Log #Fish	Log Adjusted #Fish	Depth	Temperature	Salinity	% Gravel	% Sand	% Mud	Organic	Carbonate
***Arrowtooth flounder**												
1995	Chiniak	24	1.067	1.019	36.2	8.28	32.06	6.27	31.84	61.90	3.22	1.84
1996	Chiniak	17	0.994	1.034	39.1	9.56	32.07	6.25	44.71	49.03	3.29	2.44
1995	Kachemak	18	0.488	0.467	58.7	8.64	31.27	4.92	47.46	47.61	4.28	9.52
1996	Kachemak	16	0.592	0.621	56.5	9.24	31.55	8.56	45.98	45.46	3.87	9.92
Yellowfin sole												
1995	Chiniak	29	0.772	0.577	18.4	9.22	31.77	4.47	53.73	41.80	2.78	1.88
1996	Chiniak	30	0.790	0.689	23.9	9.98	32.07	0.57	59.59	39.84	3.08	1.74
1995	Kachemak	14	0.598	0.781	30.1	9.12	31.14	15.60	48.00	36.41	4.42	13.43
1996	Kachemak	9	0.706	0.819	27.2	9.36	31.48	0.93	45.26	53.82	4.00	9.78
Sawback poacher												
1995	Chiniak	25	0.729	-	20.2	8.45	31.94	3.67	53.20	43.12	2.45	2.18
1996	Chiniak	0	0.000		-	-	-	-	-	-	-	-
1995	Kachemak	1	0.593	-	30.0	8.82	31.32	38.59	39.21	22.20	3.30	39.43
1996	Kachemak	6	0.399	-	52.8	9.21	31.51	7.28	33.03	59.69	4.27	7.16
Gymnocanthus **spp.**												
1995	Chiniak	20	0.744	0.284	15.2	9.15	31.88	5.55	61.99	32.46	2.21	3.17
1996	Chiniak	19	0.801	0.381	12.3	10.33	32.08	2.37	79.55	18.07	2.56	2.19
1995	Kachemak	2	0.630	0.854	35.5	8.69	31.24	0.98	57.93	41.09	3.81	2.12
1996	Kachemak	4	0.250	0.905	39.0	9.41	31.51	0.18	72.40	27.42	3.82	25.72
Sturgeon poacher												
1995	Chiniak	25	0.605	0.365	25.3	8.66	32.04	5.45	37.35	57.19	2.84	1.82
1996	Chiniak	31	0.712	0.446	21.2	10.06	32.06	0.90	68.25	30.85	2.81	1.90
1995	Kachemak	5	0.298	0.626	56.2	8.80	31.30	2.32	55.72	41.96	4.06	8.80
1996	Kachemak	5	0.225	0.403	56.0	9.05	31.51	0.16	74.38	25.46	4.30	5.01
*Snake prickleback												
1995	Chiniak	23	0.592	0.641	20.7	8.91	32.01	3.66	47.58	48.76	2.84	2.81
1996	Chiniak	27	1.406	1.520	18.6	10.26	32.06	4.98	67.09	27.93	2.57	2.09
1995	Kachemak	9	0.726	0.604	42.8	8.76	31.26	7.62	43.31	49.07	4.47	12.37
1996	Kachemak	10	0.790	0.749	28.4	9.46	31.48	0.17	81.19	18.64	4.13	20.82

Table I-30. Continued,

Year	Location	# Stations	Log #Fish	Log Adjusted #Fish	Depth	Temperature	Salinity	% Gravel	% Sand	% Mud	Organic	Carbonate
Spinycheek starsnout												
1995	Chiniak	15	0.710	1.012	44.1	8.09	32.14	4.74	29.95	65.31	3.73	1.74
1996	Chiniak	9	0.878	1.256	52.7	9.13	32.10	1.06	27.37	71.57	4.27	2.52
1995	Kachemak	31	0.594	0.124	73.0	8.41	31.29	1.56	46.84	51.61	4.14	6.15
1996	Kachemak	30	0.850	0.640	67.5	9.11	31.54	9.98	55.44	34.58	4.50	7.33
Shortfin eelpout												
1995	Chiniak	3	0.878	0.893	64.0	7.68	32.07	4.88	65.33	29.80	4.74	1.39
1996	Chiniak	6	1.332	1.550	59.8	8.86	32.10	0.09	30.53	69.38	4.45	2.20
1995	Kachemak	20	0.769	0.558	85.8	7.97	31.23	1.10	22.85	76.05	5.10	4.01
1996	Kachemak	20	1.194	1.173	80.7	8.98	31.43	7.02	59.24	33.74	5.07	6.24
Slim sculpin												
1995	Chiniak	4	0.471	1.205	51.8	7.68	32.14	0.70	23.10	76.20	3.29	2.70
1996	Chiniak	1	0.563	1.491	57.0	9.42	32.06	0.06	42.95	56.99	3.55	2.34
1995	Kachemak	15	0.584	-0.678	56.5	8.64	31.29	4.77	57.38	37.85	3.77	9.40
1996	Kachemak	14	0.887	0.487	64.1	9.17	31.58	12.29	56.58	31.14	3.92	8.31
Spinyhead sculpin												
1995	Chiniak	4	0.387	0.009	61.8	7.60	32.10	3.77	50.93	45.30	4.39	1.48
1996	Chiniak	7	0.388	0.047	59.4	8.92	32.10	0.11	23.08	76.81	4.58	2.15
1995	Kachemak	13	0.476	0.958	80.9	8.13	31.27	0.90	35.18	63.92	4.36	4.48
1996	Kachemak	19	0.561	0.798	74.4	9.05	31.50	13.14	56.77	30.10	4.82	7.68
Rex sole												
1995	Kachemak	11	0.412	0.301	62.9	8.57	31.26	0.69	54.86	44.45	4.05	6.14
1996	Kachemak	15	0.496	0.607	59.1	9.18	31.56	9.90	58.40	31.71	3.95	6.80

Table I-31. Proportional IRI of the prey taxa consumed by predator species at Cl9401 CS#37. Rows of summation data are in bold font.

	Arrowtooth flounder	Flathead sole	Pacific halibut	Yellowfin sole	Rock sole
N fish examined (empty)	**15(0)**	**2(1)**	**11(0)**	**38(3)**	**4(0)**
Total length (mm) of fish ± stdev	**68.1±14.6**	**217.5±6.4**	**75.2±9.1**	**87.1±8.5**	**220.3±23.5**
Total N prey	51	6	77	205	26
Total weight prey (mg)	466	265	347	1940	1036
Total prey taxa	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Total Protista (Foraminiferida)				0.3	
Total Polychaeta	**1.1**		0.6	28.2	**5.1**
Polychaete fragments	1.1		0.6	3.2	3.1
Unid. Scaleworm				0.2	
Stemaspis scutata				24.7	
Lumbrineris sp.					2.0
Total Bivalvia		**100.0**		45.3	67.1
Unid. Bivalve siphons				3.1	44.8
Unid. Bivalve				1.3	
Mya sp.					22.3
Nucula tenuis				0.2	
Nuculana fossa				0.1	
Yoldia sp.				co.1	
Yoldia scissura ta		81.8		0.2	
Serripes groenlandicus				18.2	
Siliqua sp.				0.4	
Lucinoma annulata				0.3	
Adontorhyna cyclia				co.1	
Axinopsida spp.		18.2			
Clinocardium sp.				0.3	
Veneroida				0.1	
Lyonsia sp.				20.8	
Total Copepoda (Calanoid)				**1.7**	
Total Mysidae	80.5		3.7	0.3	
Unid. Mysidae	55.2		3.7	0.1	
Acanthomysis spp.	25.3			0.2	
Total Cumacea				0.6	
Unid. Cumacea				0.3	
Diastylis alaskensis				0.4	
Total Amphipada	3.7		1.3	2.2	27.7
Unid. Amphipoda	3.1		0.4	1.5	0.9
Protomediae sp.				0.4	26.8
Byblis sp.	0.6		0.8	0.1	
Monoculodes sp.				0.2	
Total Decapoda	8.7		**94.5**	3.1	
Crangonidae	3.1		**1.0**	0.5	
Hippolytidae	5.6		**93.2**	0.1	
Hermit crab (Paguridae)			0.3	2.5	
Crab fragments				co.1	
Total Bryozoa (fragments)				0.2	
Total Ophiuridae				18.3	
Unid. Ophiuridae				co.1	
Ophiura sp.				18.3	
Total Teleostei (Rock sole)	6.0				

Table I-33. Similarity between the taxonomic compositions of predator diets and benthic fauna; these calculations consider prey taxa at the level of family.

	Flathead sole	Pacific halibut	Yellowfin sole	Rock sole	Benthos
Arrowtooth flounder	0.0	14.2	6.7	4.8	3.8
Flathead sole		0.0	45.3	67.1	55.0
Pacific halibut			5.3	1.8	1.8
Yellowfin sole				52.6	67.9
Rock sole					62.8

Table I-34. Similarity between the taxonomic compositions of predator diets and benthic fauna; these calculations consider prey taxa at the lowest taxonomic level (species level whenever possible).

	Flathead sole	Pacific halibut	Yellowfin sole	Rock sole	Benthos
Arrowtooth flounder	0.0	11.9	3.5	2.0	1.7
Flathead sole		0.0	0.2	0.0	10.7
Pacific halibut			2.1	1.0	1.0
Yellowfin sole				7.5	35.4
Rock sole					16.2

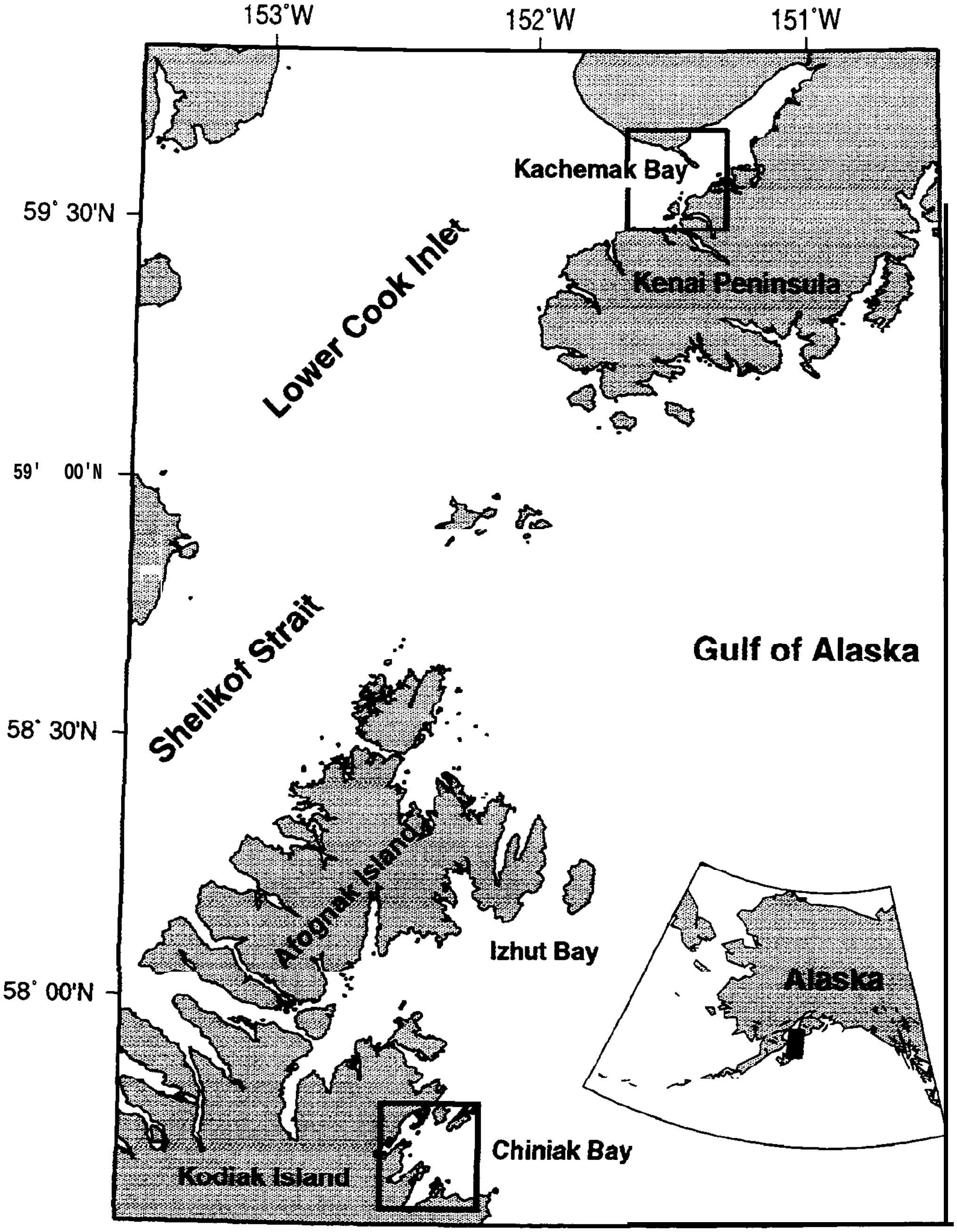


Figure I-l. Collections for present research were from Kachemak Bay in lower Cook Inlet, Izhut Bay on south Afognak Island and Chiniak Bay on northeast Kodiak Island.

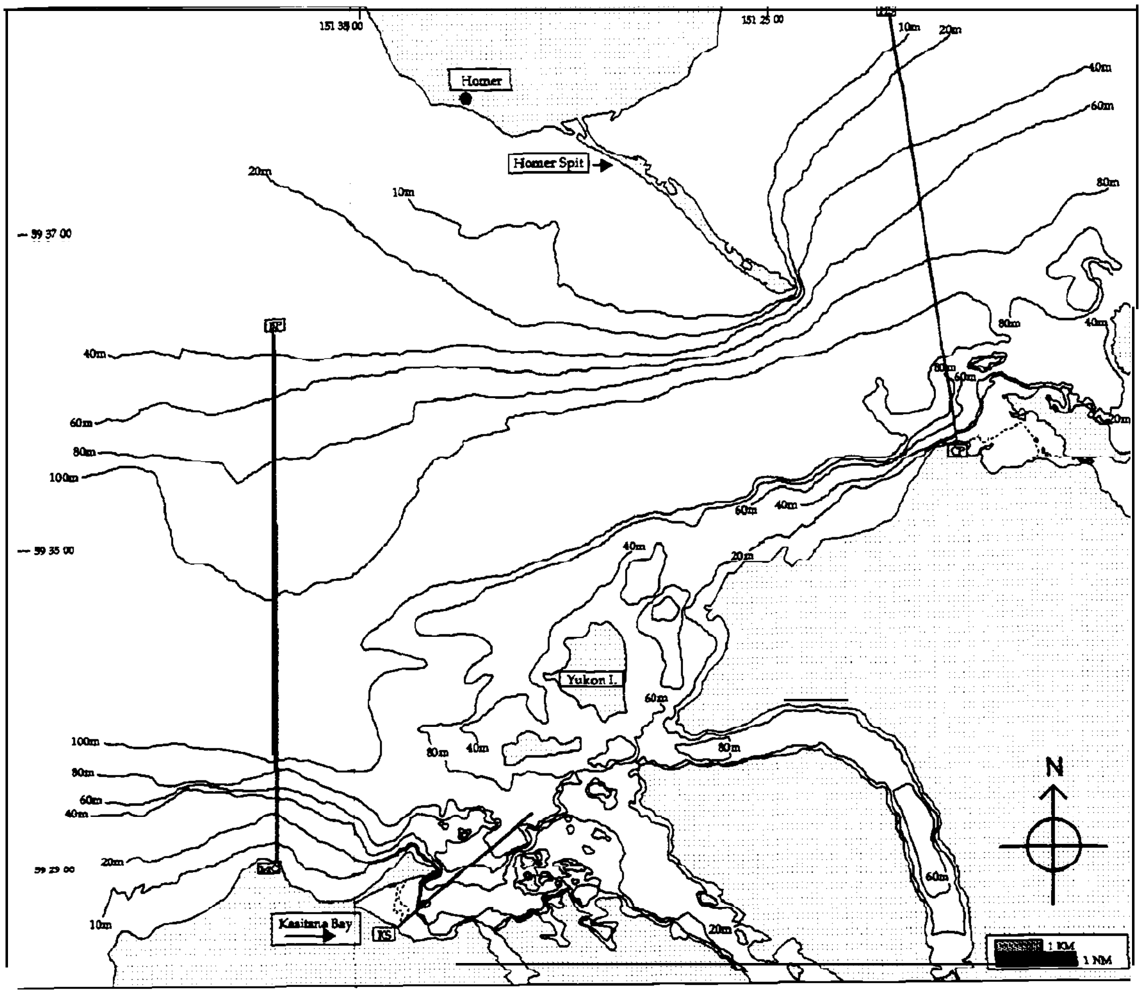


Figure I-2. Depth contours and permanent transects sampled in Kachemak Bay (1994- 1996).

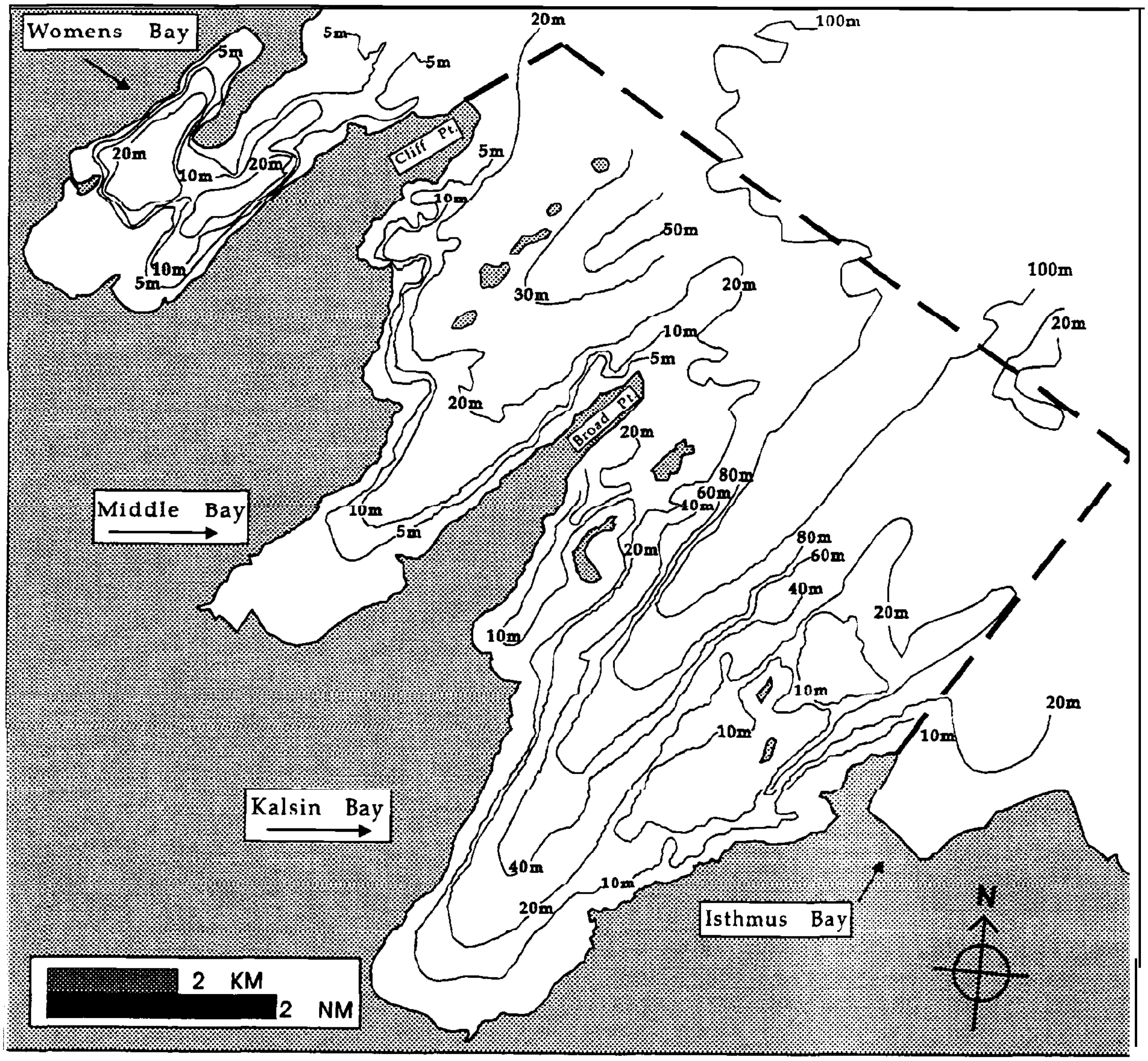


Figure I-3. Depth contours of Womens, Middle, Kalsin and Isthmus Bays sampled within Chiniak Bay, Kodiak Island (1991-1996). The dashed line defines the Middle and Kalsin Bay survey region (Dressel and Norcross, Chapter 3 in this report).

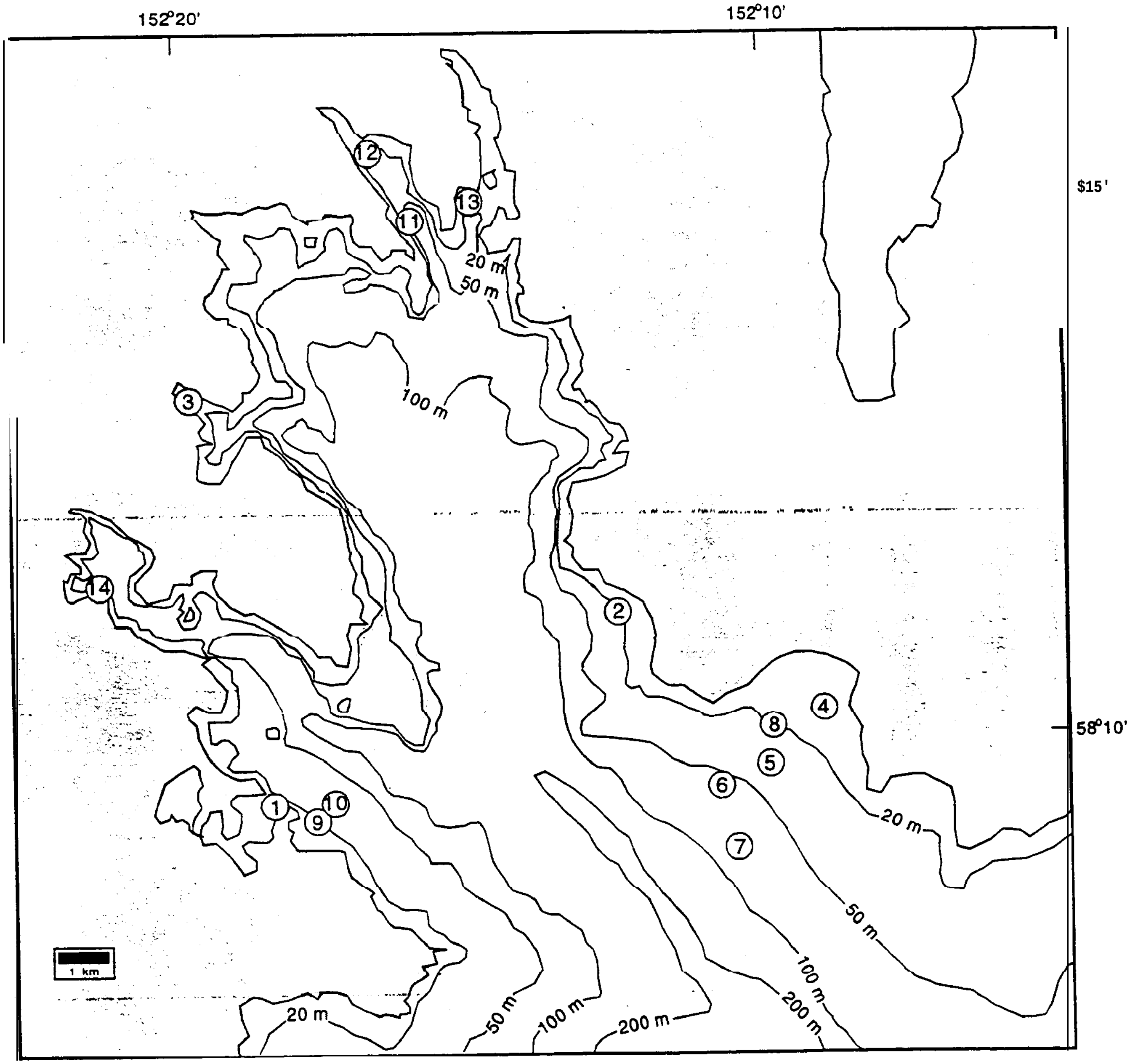


Figure I-4. Depth contours and consecutive station sites examined in Izhut Bay, Afognak Island (1995).

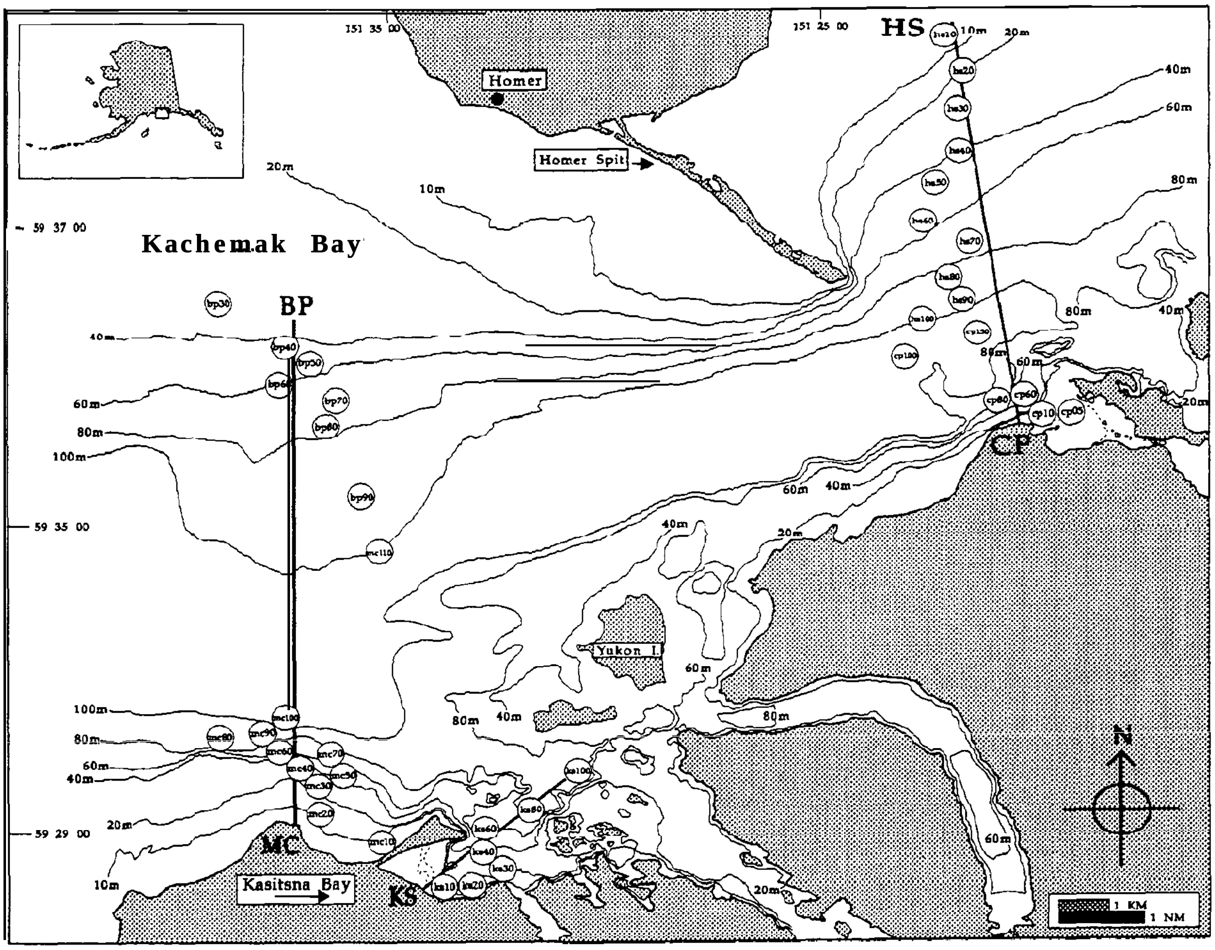
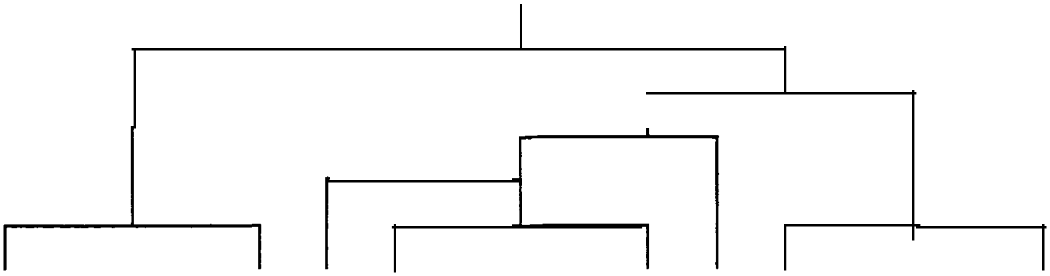


Figure I-5. Depth contours and permanent transects and stations sampled in Kachemak Bay (19944996).



Cluster	1	2	3	4	5	6	7	8
Sediment	M	sM	MS	mS	mgS	S	smG	G
N of stations	69	29	19	39	10	21	7	3
min%M	57.3	42.34	18.51	1.33	1.14	0.06	19.11	0.01
max%M	95.36	65.63	42.1	30.35	32.64	8.97	35.62	7.68
min%S	435	31.53	51.38	69.56	47.63	90.92	21.59	19.53
max%S	42.67	54.08	67.55	88.34	63.32	99.37	39.95	28.3
Description	mud and mixed mud	sandy mud	mud/sand	muddy sand	mixed sand	>90% sand	>25% gravel	>65% gravel

Figure **I-6. Cluster analysis with eight station separations by percent mud and sand for all data** combined. Below the cluster is a list of cluster code, frequency of stations, minimum and maximum percentages of mud and sand. Sediment clusters are in order of increasing grain size. Descriptions explain the composition within each cluster, and codes are assigned based on a modified Folk (1980) scale.

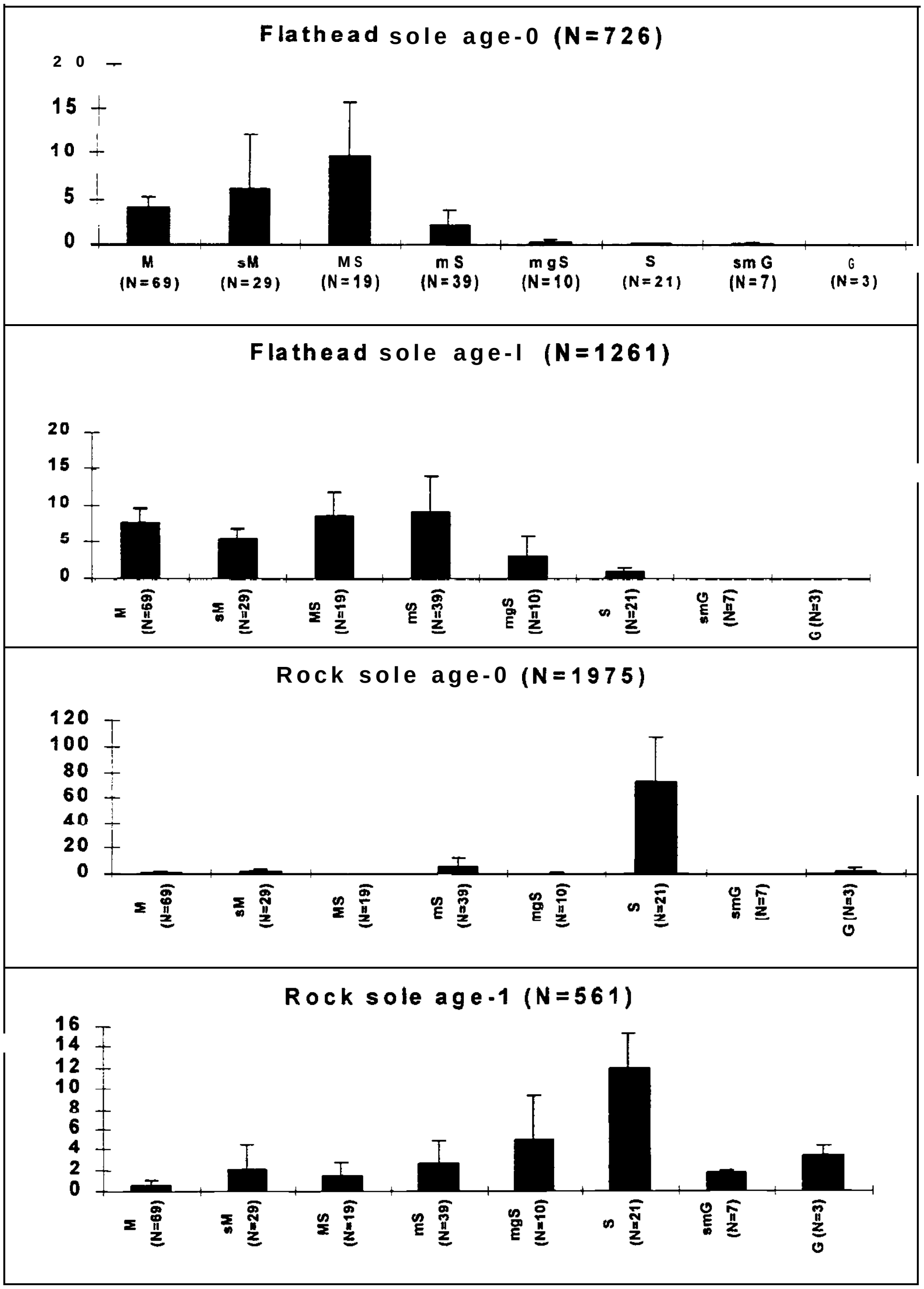
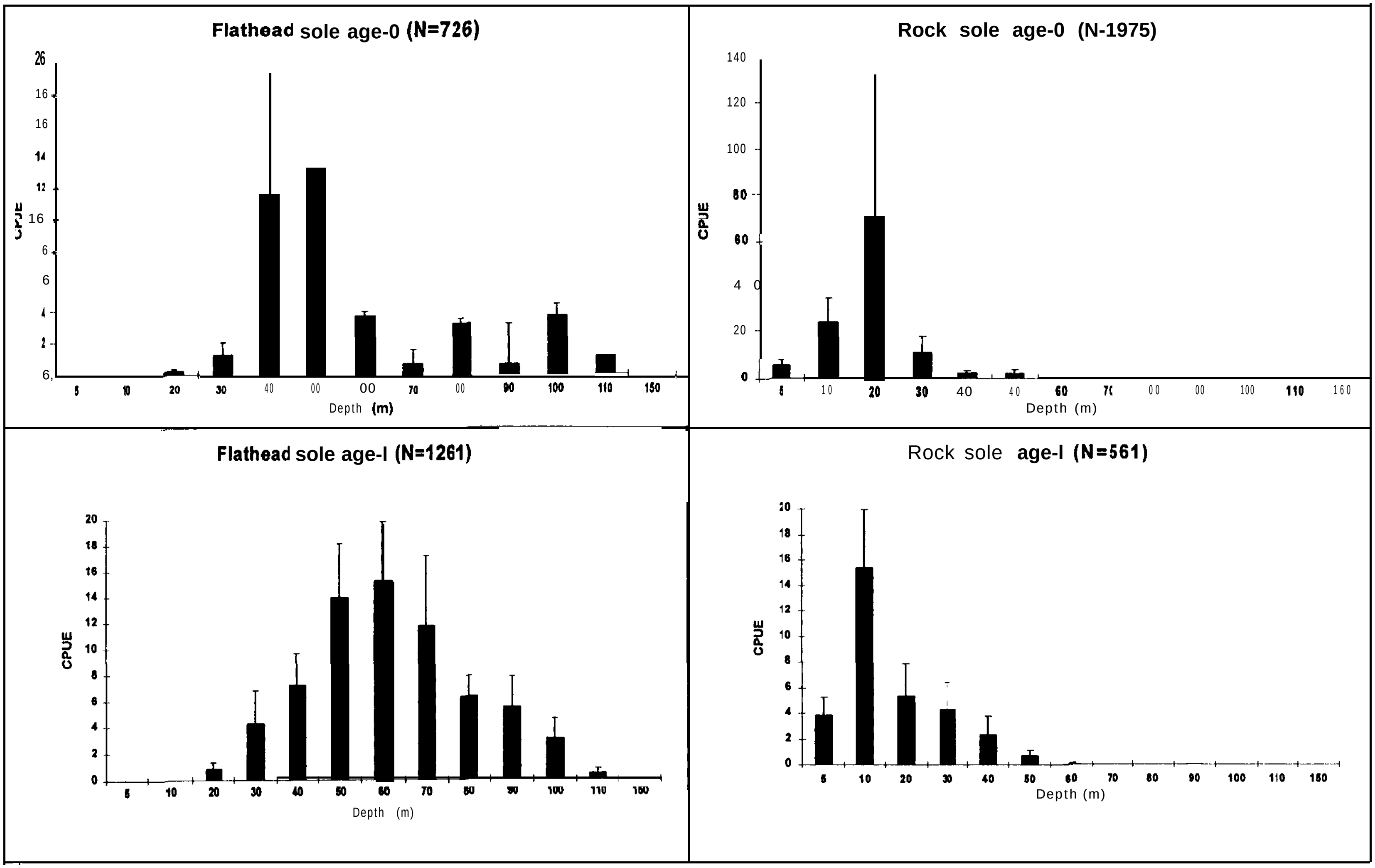


Figure I-7. Mean CPUE/1000 m^2 of flathead sole and rock sole by eight sediment clusters for all seasons and years combined. Standard error bars are shown above the mean. Sediments on the x-axis are listed in order of increasing mean grain size.


Flathead sole age-0 (N=726)

Rock sole age-0 (N-1975)

Flathead sole age-I (N=1261)

Rock sole age-I (N=561)

Figure I-8. Mean CPUE/1000 m^2 of flathead sole and rock sole by 10 m depth increments for all seasons and years combined. Standard error bars are shown above the mean.

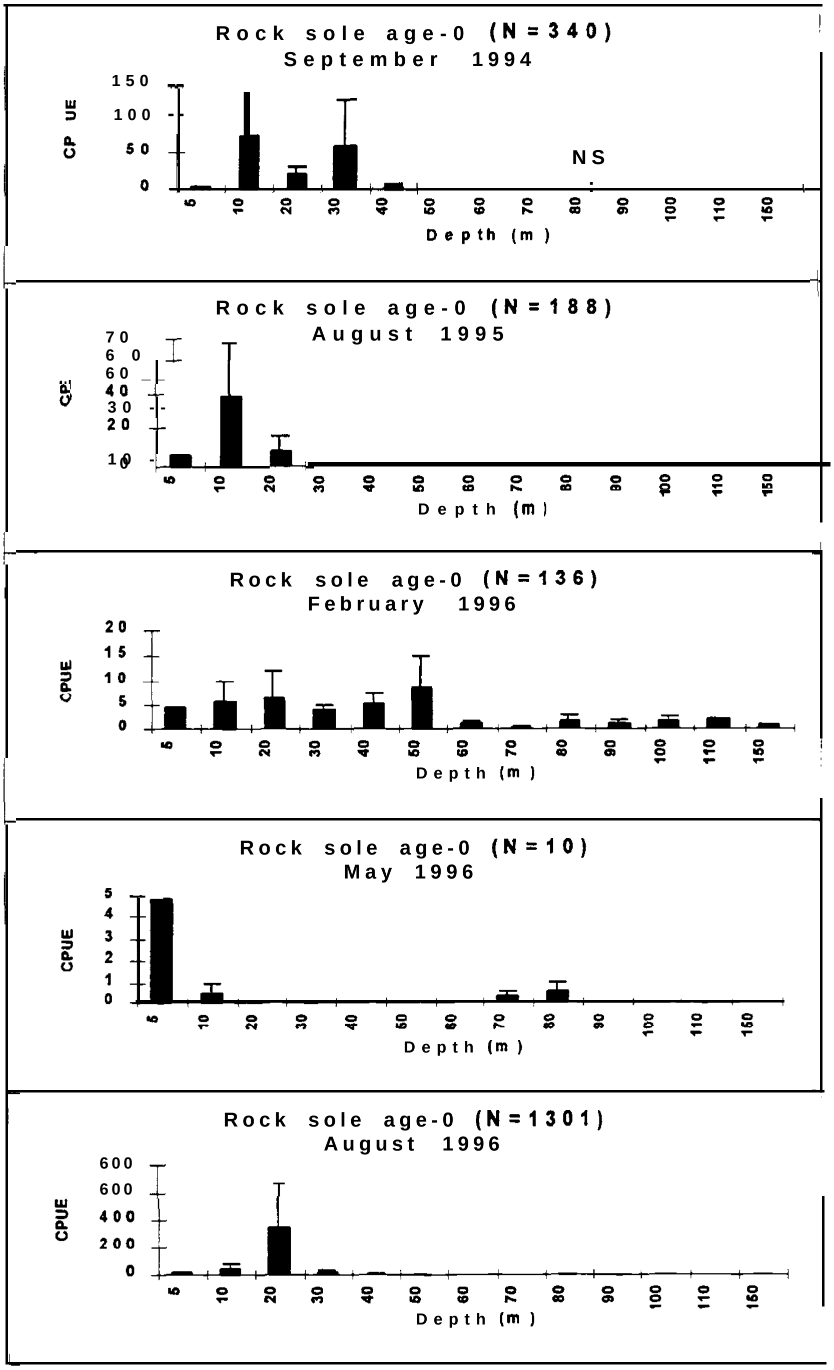


Figure I-9. Distribution of rock sole age-0 by 10 m depth increments and seasons (N = total number rock sole age-0 caught that season). Standard error bars are shown above the mean, and are absent at stations which were sampled only once. Stations deeper than 70 m were not sampled (NS) in September 1994. No rock sole age-0 were caught in May 1995.

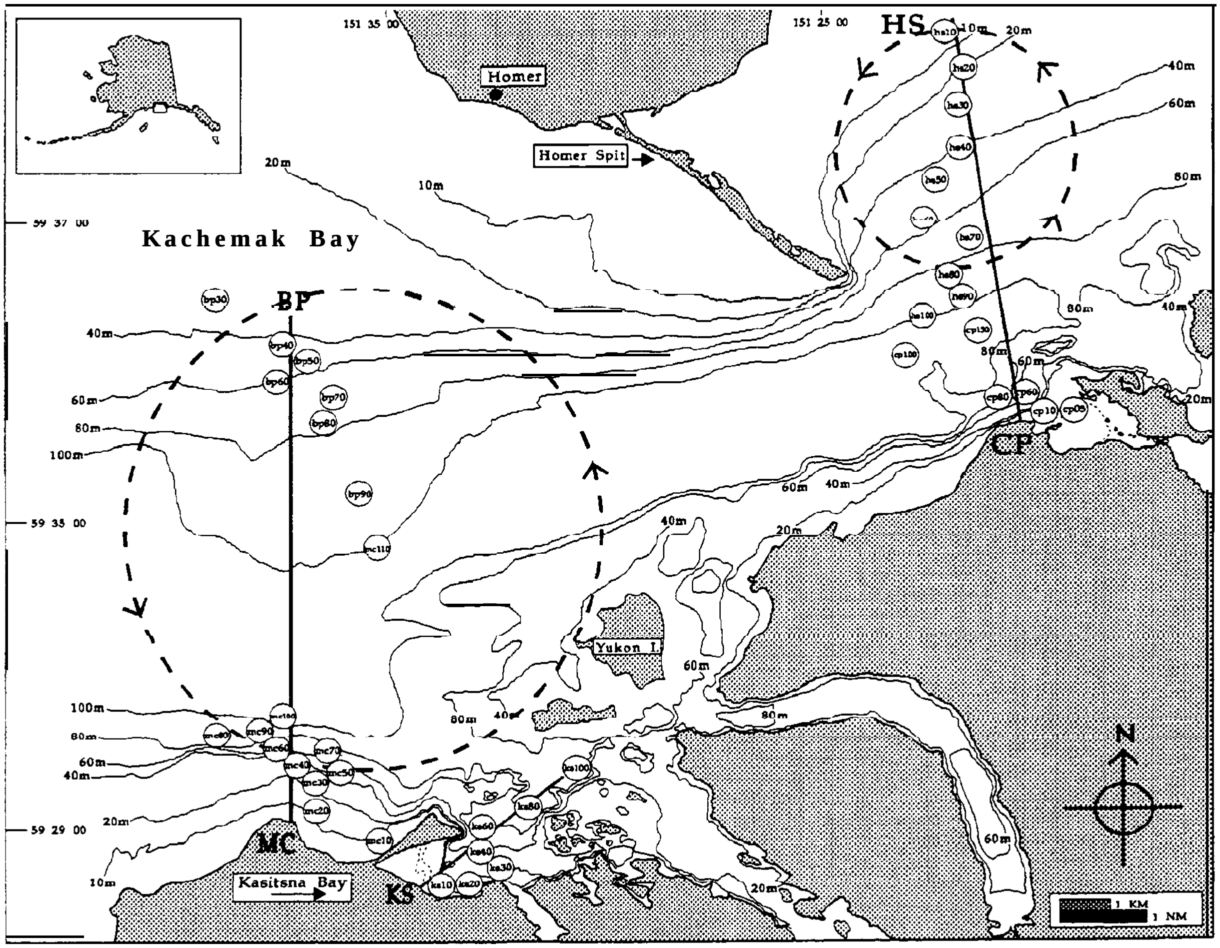


Figure I-10. Permanent stations and transects sampled in Kachemak Bay, Alaska. Surface gyres taken from Trasky et al. (1977).

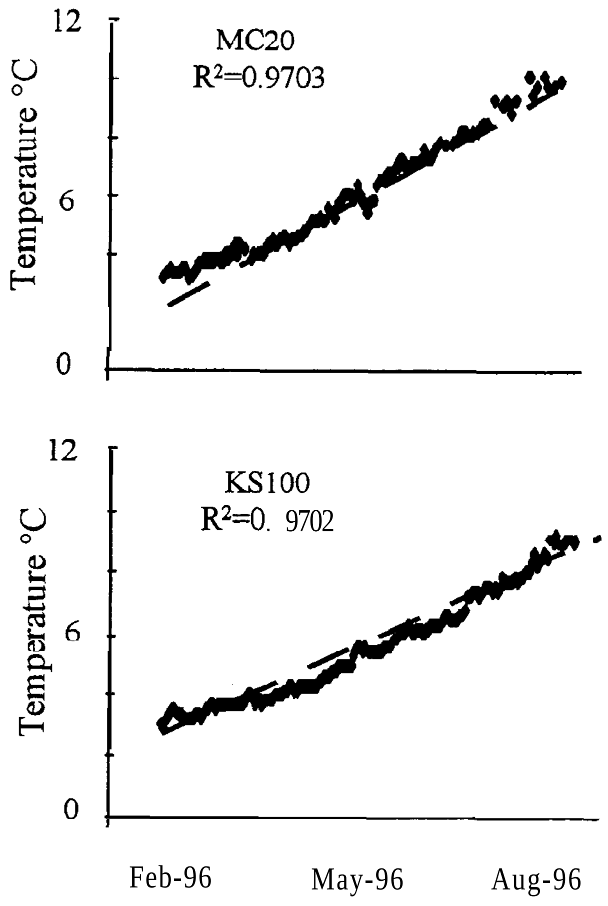


Figure I-l 1. Bottom temperature ("C) at stations MC20 and KS 100. Linear regression is a dashed line. Data were measured continuously from 27 February to 12 August 1996 using StowAway temperature loggers.

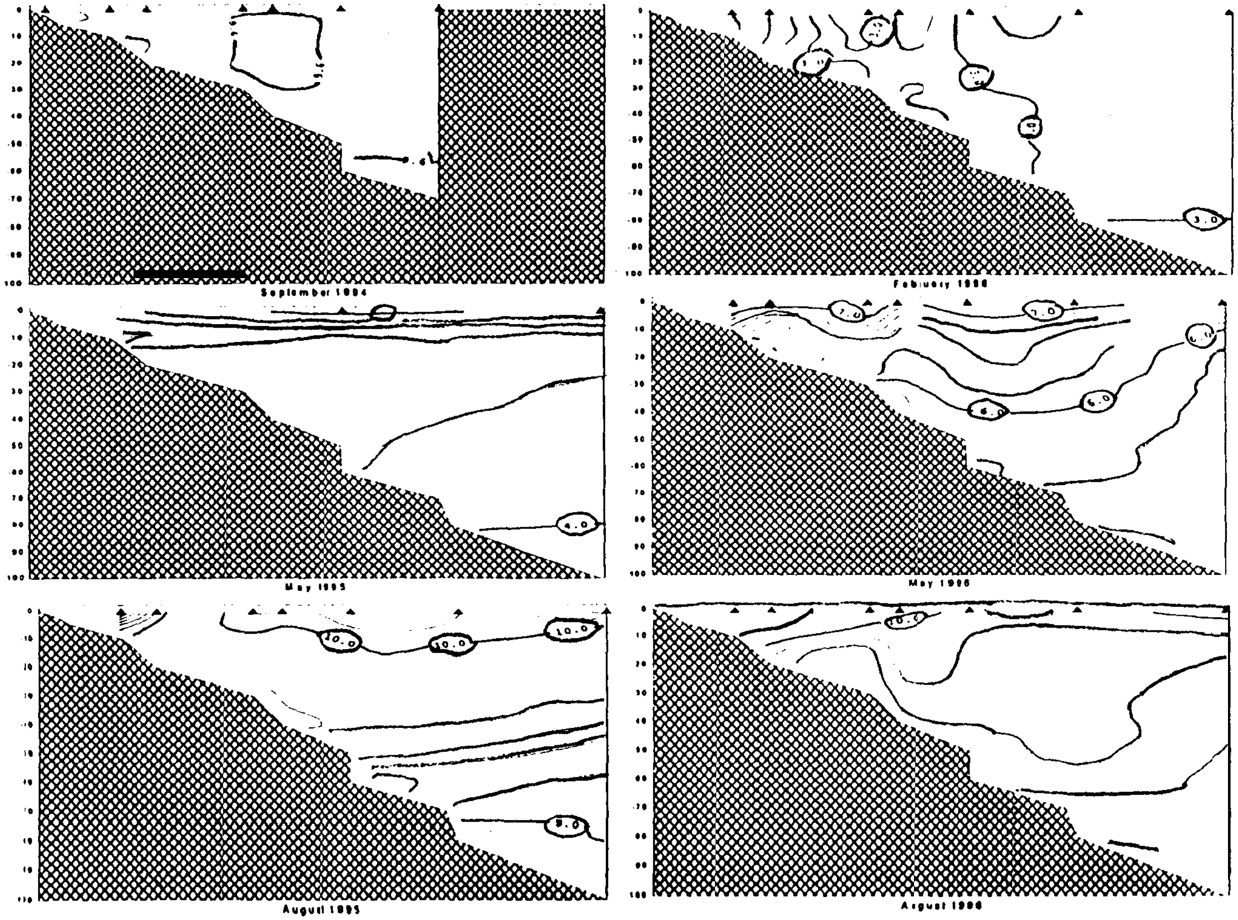


Figure I-12. Temperature profiles from KS10 to KS100. In September 1994, the deepest station was at 70 m. Total distance along the x-axis is 5.5 km, and triangles mark stations with CTD data. Integers of temperature value are circled, and other isotherms are in increments of 0.2°C.

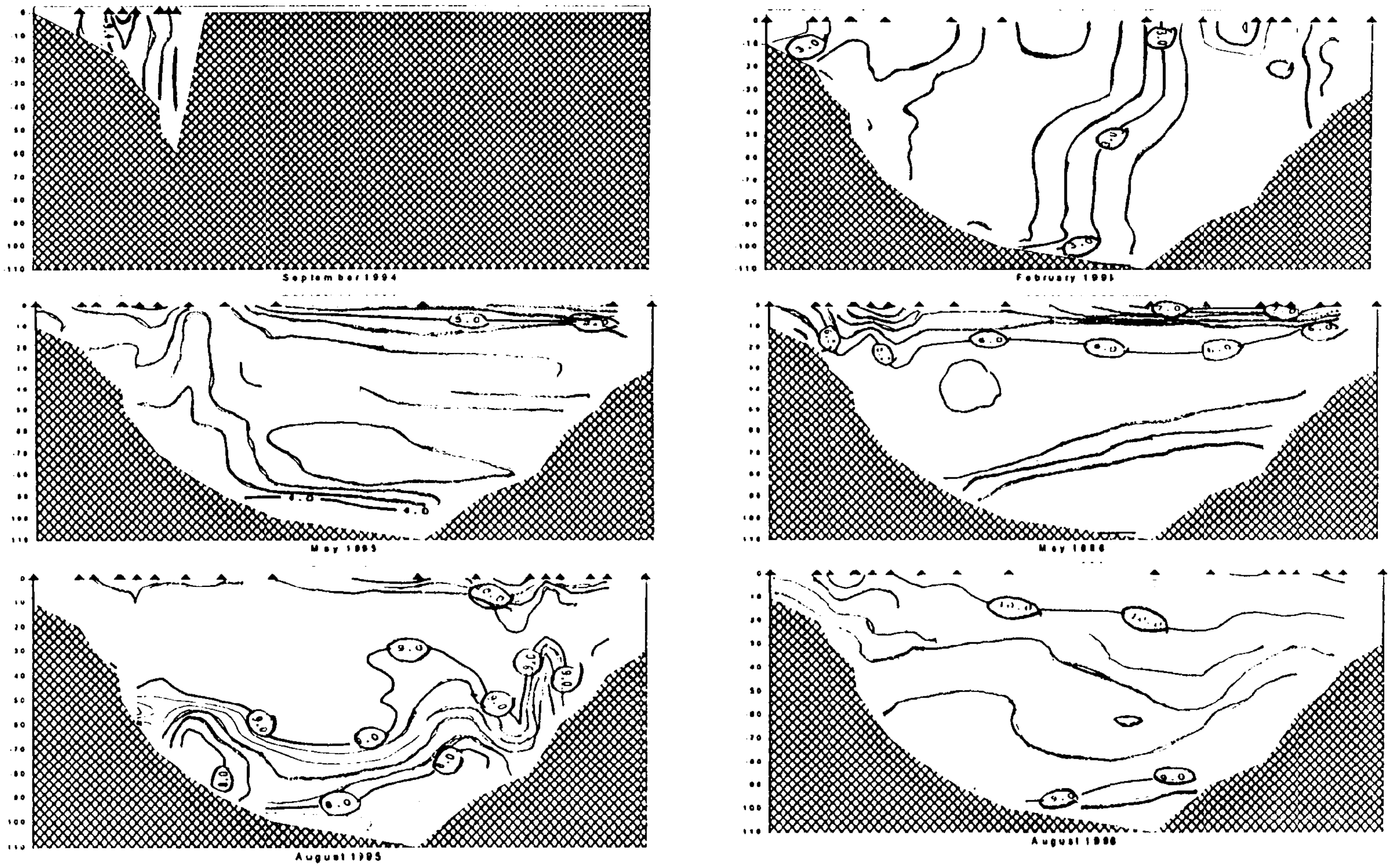


Figure I- 13. Temperature profiles from MC 10 to BP30. In September 1994, the deepest station was at 70 m. Total distance along the x-axis is 2 1.6 km, and triangles mark stations with CTD data. Integers of temperature value are circled, and other isotherms are in increments of 0.2°C.

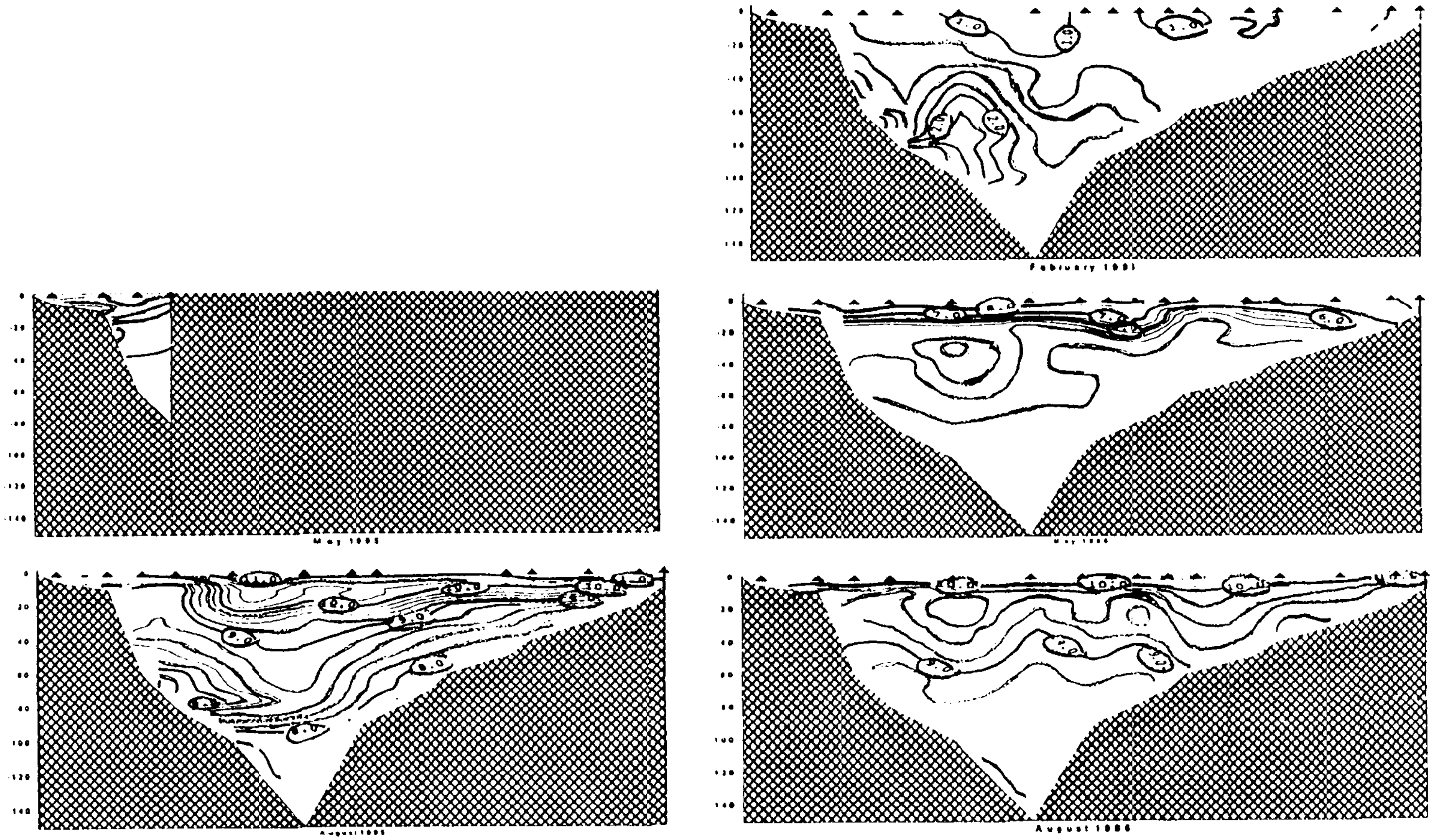


Figure I-14. Temperature profiles from CP05 to HS10. These transects were not sampled in September 1994, and the deepest station sampled in May 1995 was at 80 m on the CP transect. Total distance along the x-axis is 15.5 km, and triangles mark stations with CTD data. Integers of temperature value are circled, and other isotherms are in increments of 0.2°C.

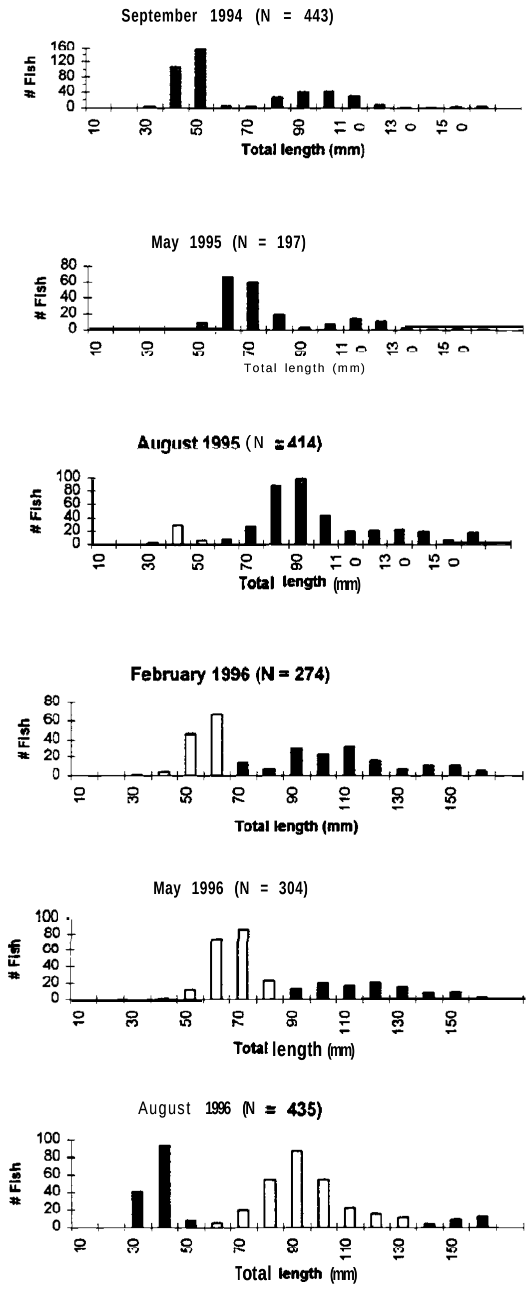


Figure I-15. Flathead sole length frequency histograms ≤160 mm total length. N = number of fish plotted. The 1994 year class is shaded gray, the 1995 year class is white, and in the final two plots the 1996 year class is black.

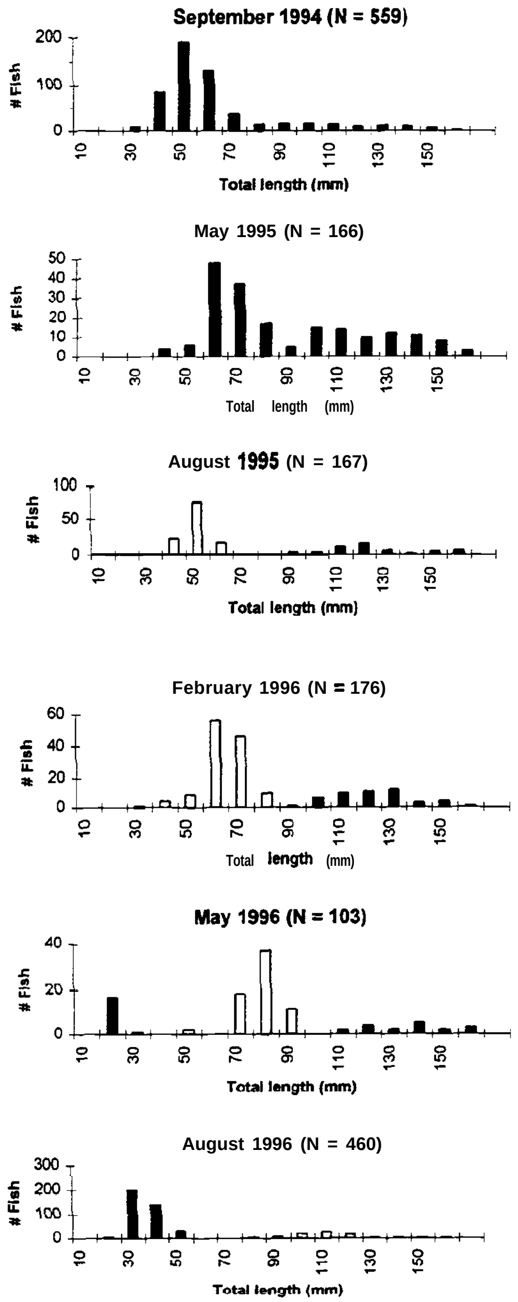


Figure I-16. Rock sole length frequency histograms ≤ 160 mm total length. N = total number of fish plotted. The 1994 year-class is shaded grey, the 1995 year-class is white, and in the final two graphs the 1996 year-class is black.

Figure I-17. **Flathead** sole growth

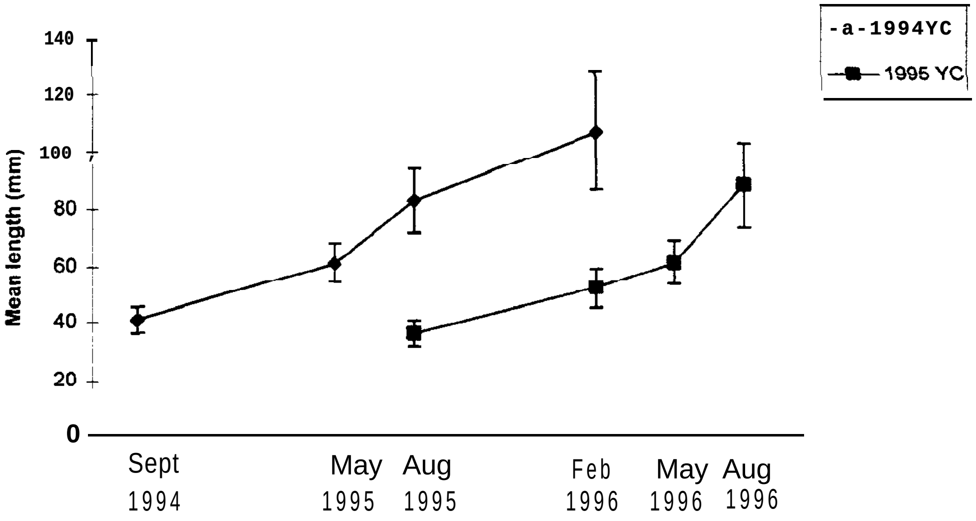


Figure I-18. Rock sole growth

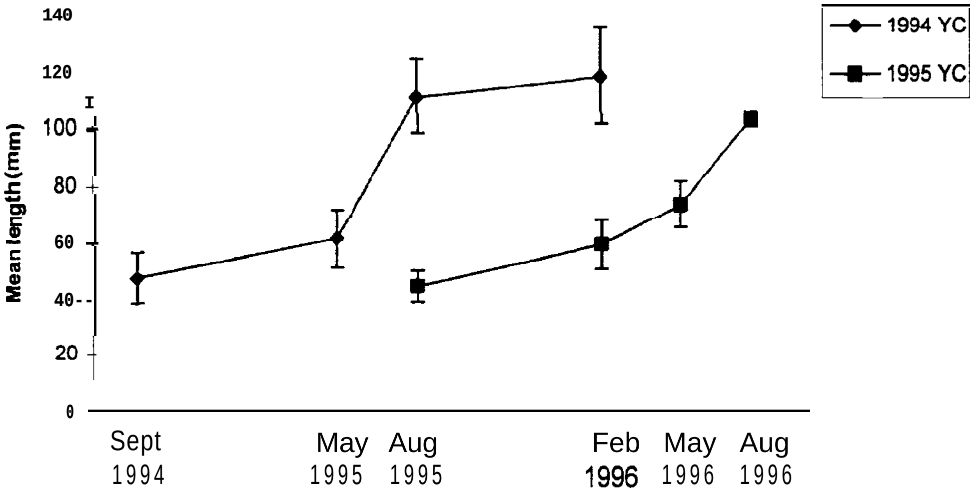


Figure I-17 (flathead sole) and Figure I-18 (rock sole).

Mean total length (mm) ± one standard deviation at each sampling period.

YC = year class.

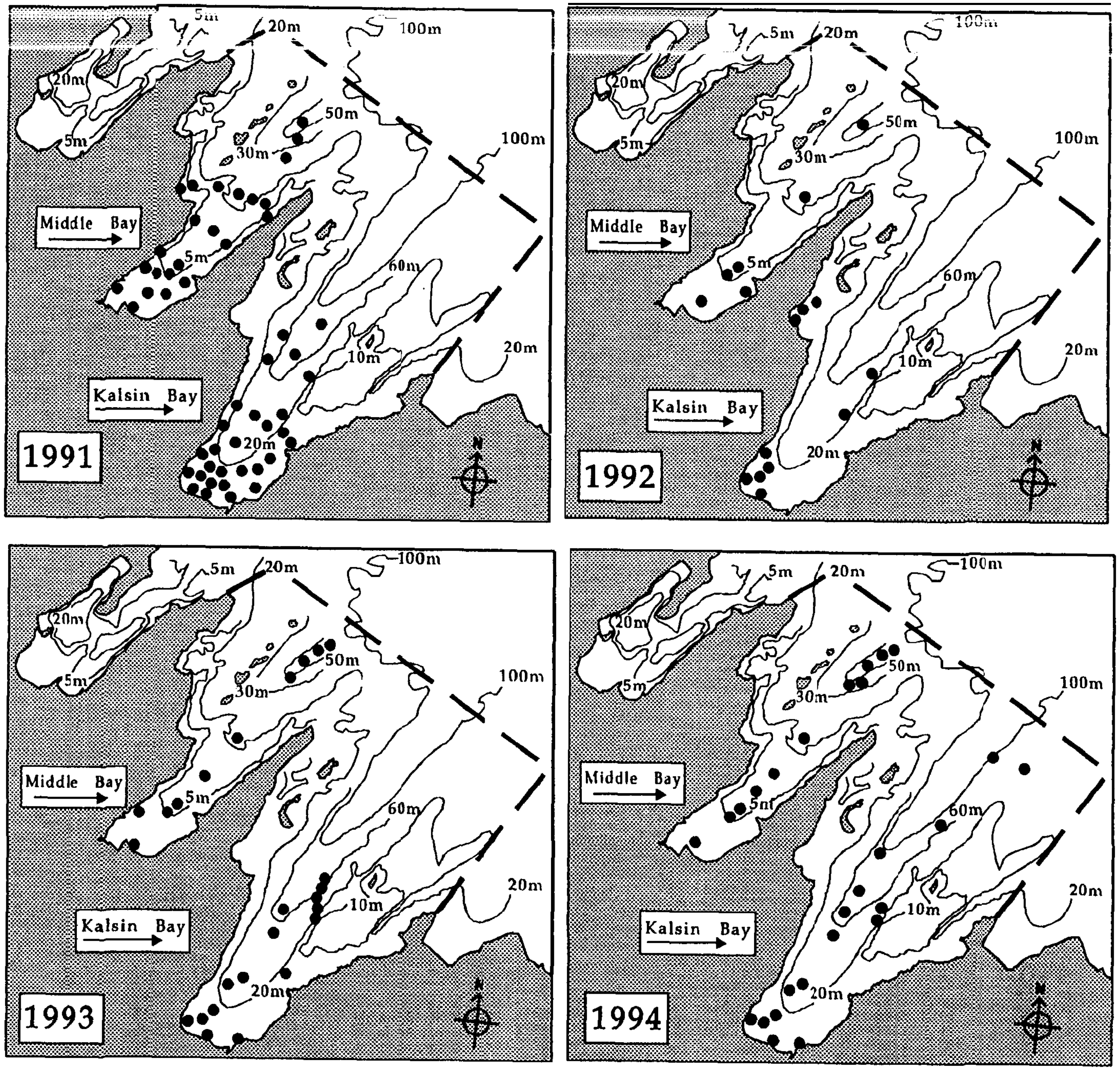


Figure I-19. Sample site locations in Kalsin and Middle Bays from 1991 to 1994.

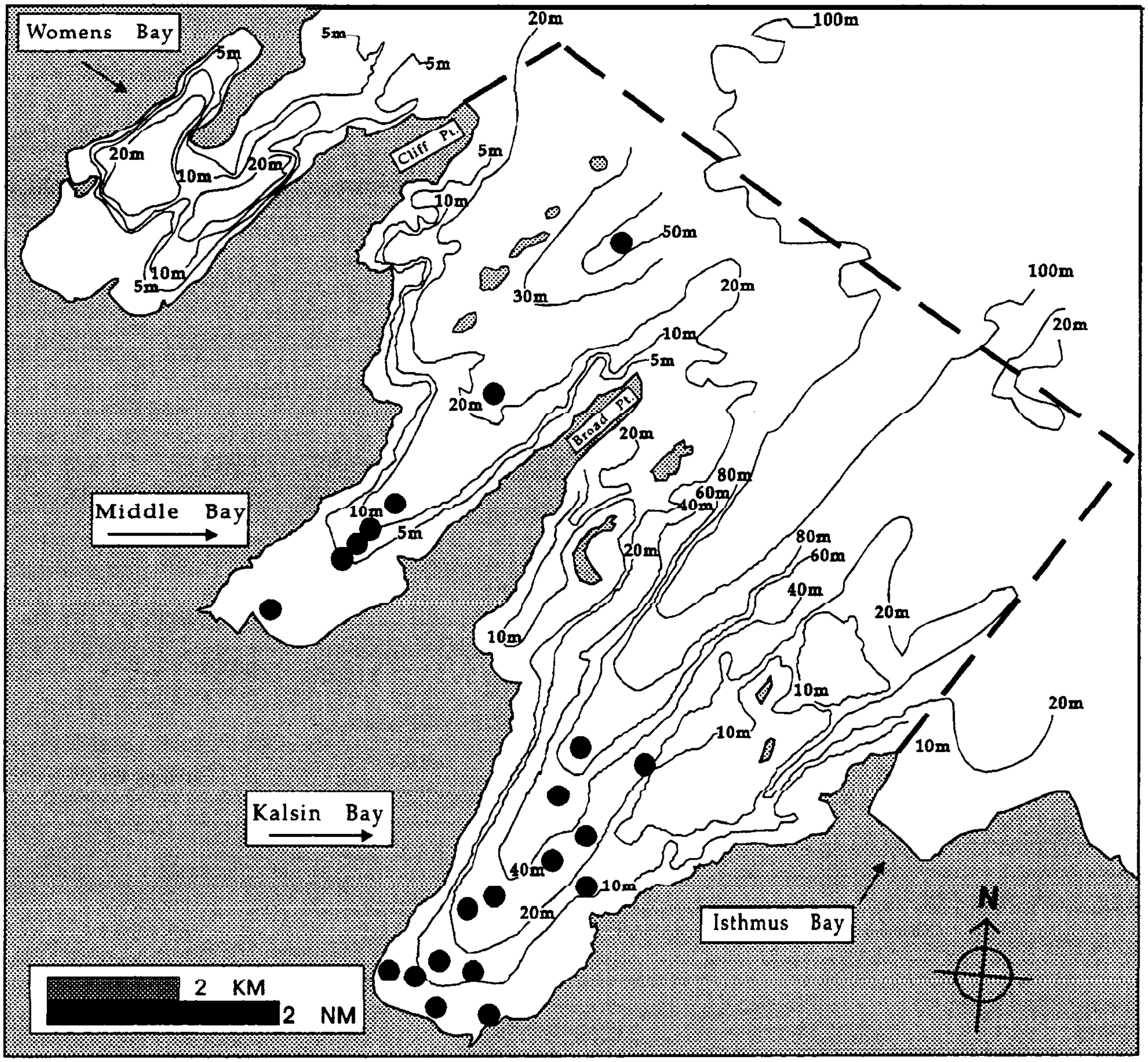


Figure I-20. Sample site locations in Kalsin and Middle Bays in 1995.

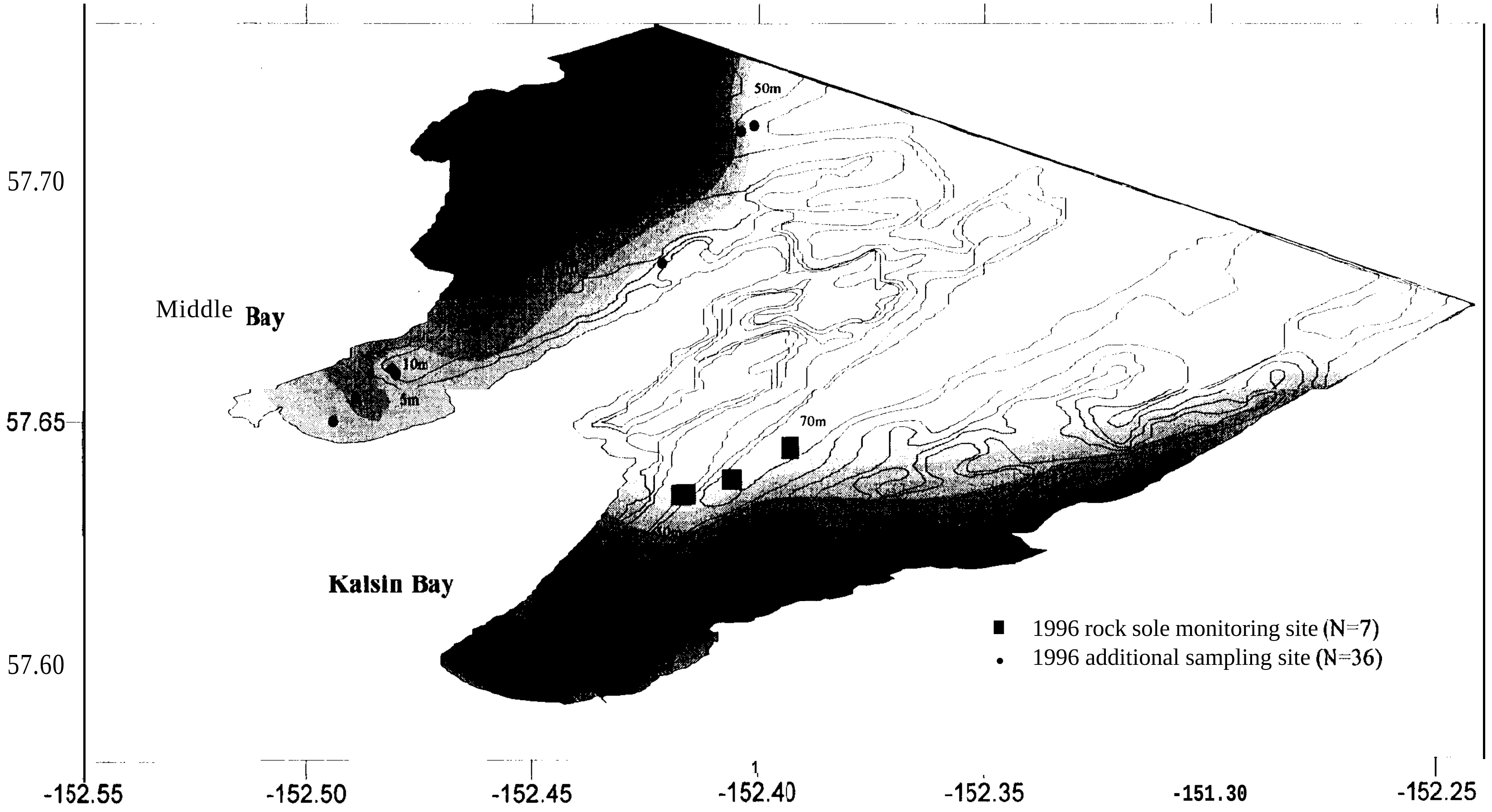


Figure I-2 1. Rock sole 1996 distribution and monitoring sites. Dark lines indicate depth contours. Shaded contours indicate relative fish density on a logarithmic scale (darker shading indicates denser fish distribution).

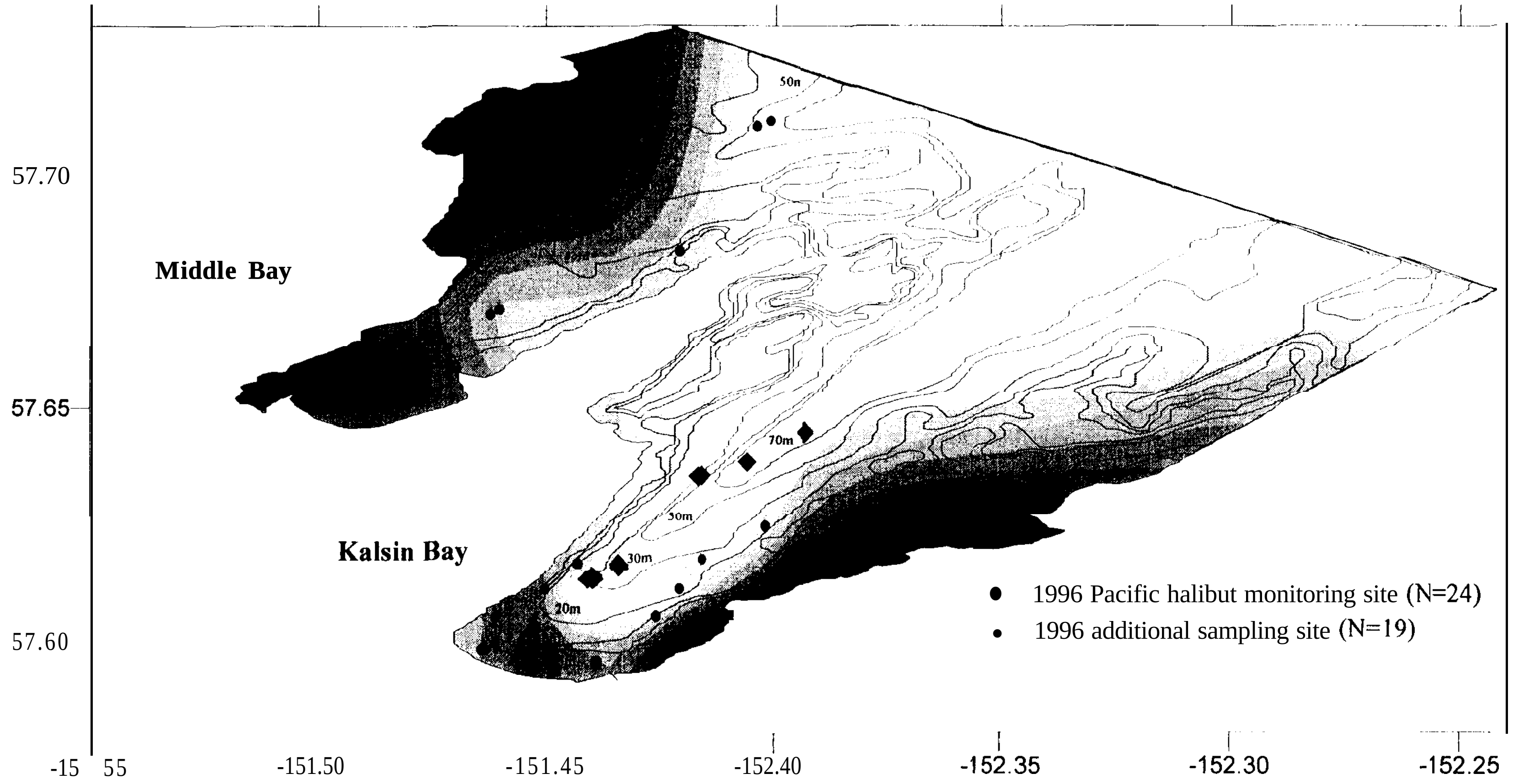


Figure I-22. Pacific halibut 1996 distribution and monitoring sites. Dark lines indicate depth contours. Shaded contours indicate relative fish density on a logarithmic scale (darker shading indicates denser fish distribution).

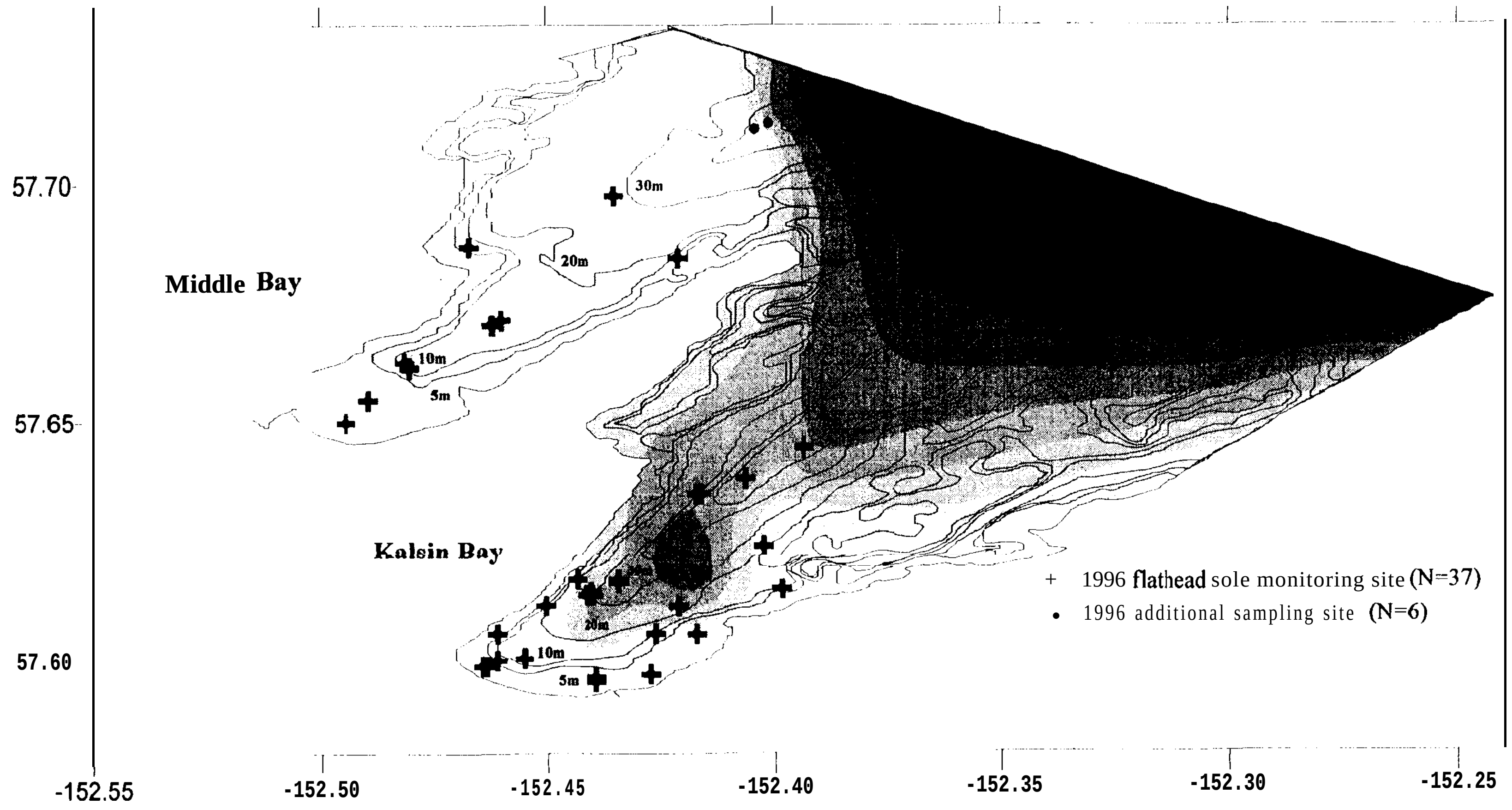


Figure I-23. Flathead sole 1996 distribution and monitoring sites. Dark lines indicate depth contours. Shaded contours indicate relative fish density on a logarithmic scale(darker shading indicates denser fish distribution).

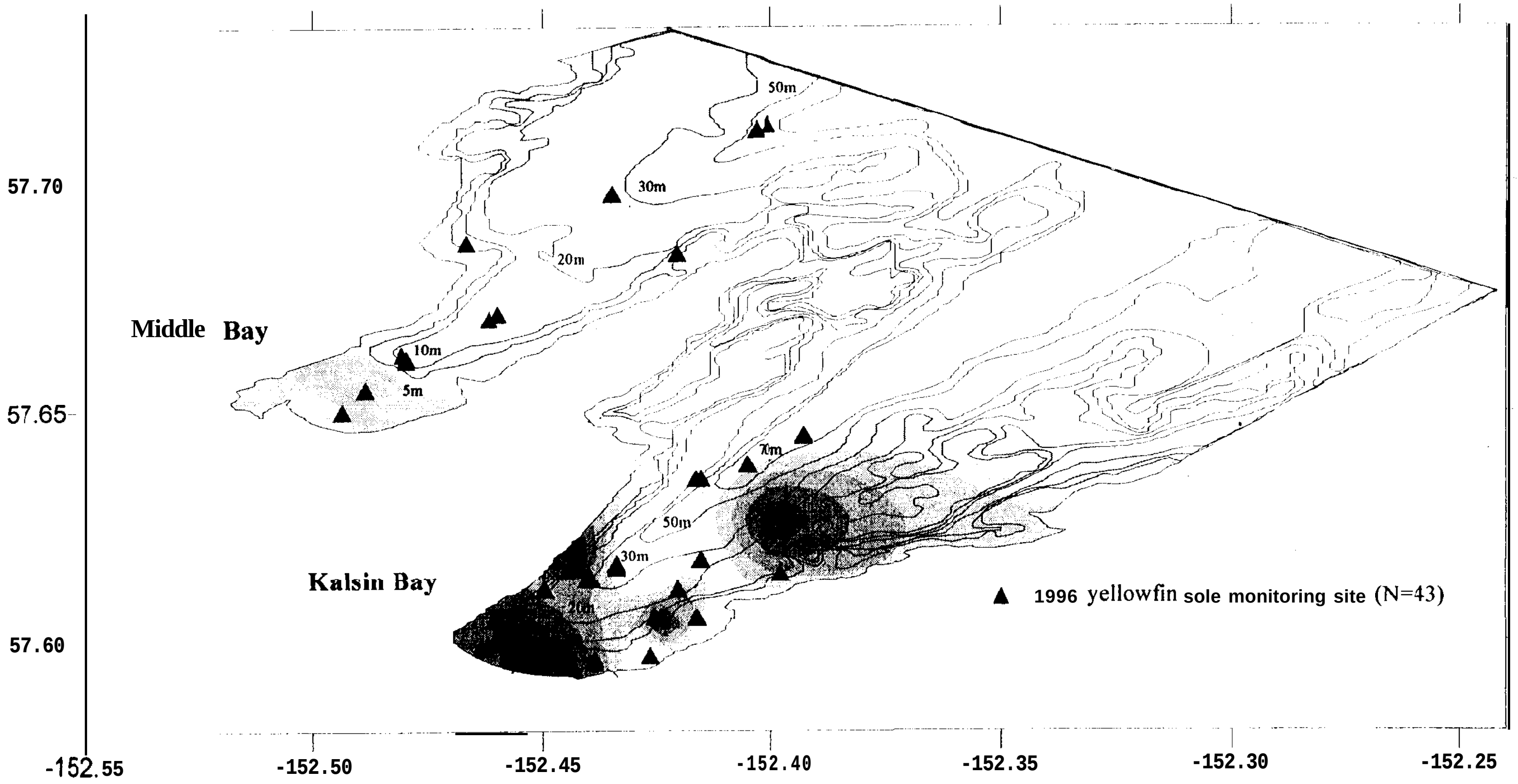


Figure I-24. Yellowfin sole 1996 distribution and monitoring sites. Dark lines indicate depth contours. Shaded contours indicate relative fish density on a logarithmic scale (darker shading indicates denser fish distribution).

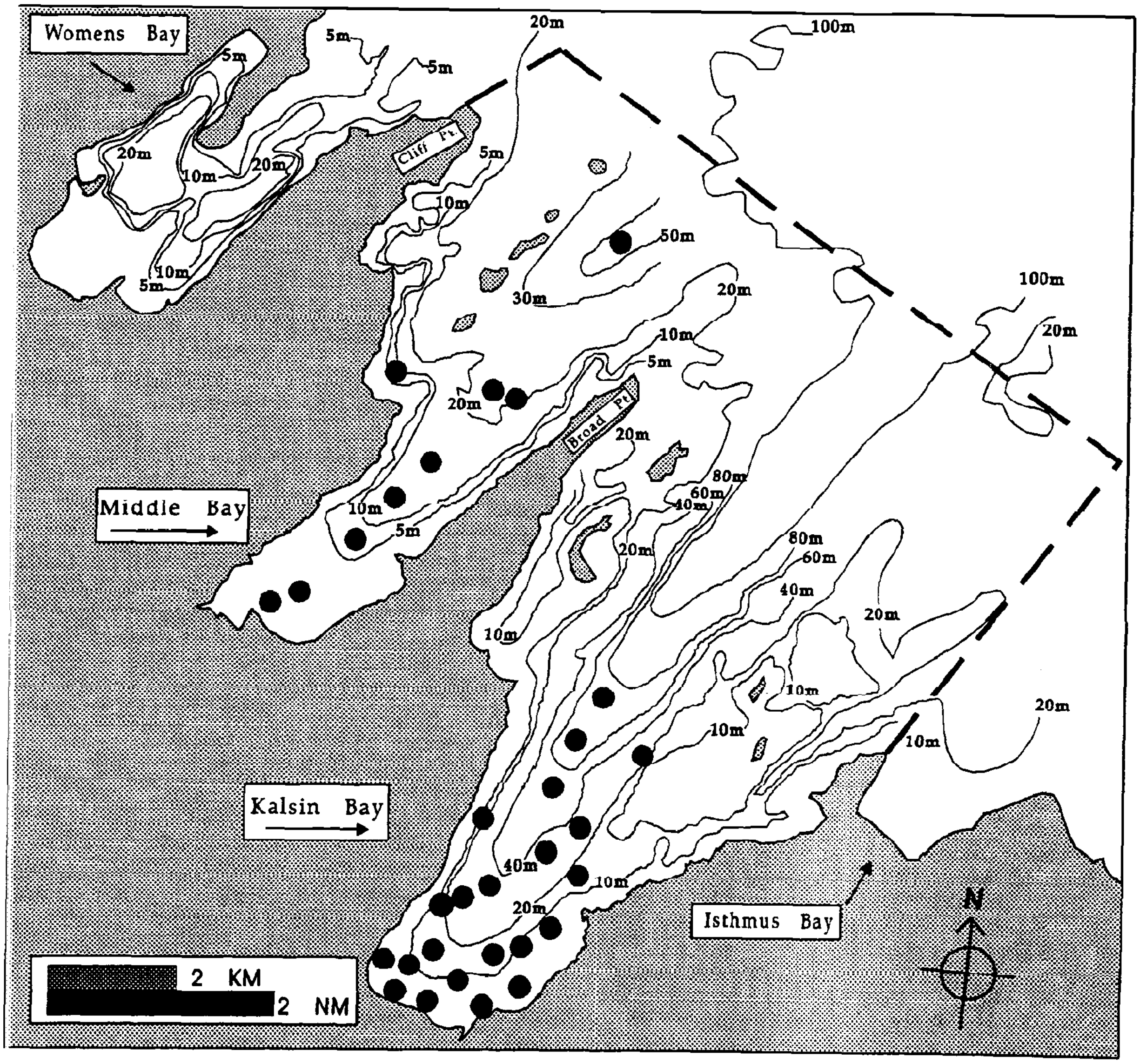


Figure I-25. Sample site locations in Kalsin and Middle Bays in 1996.

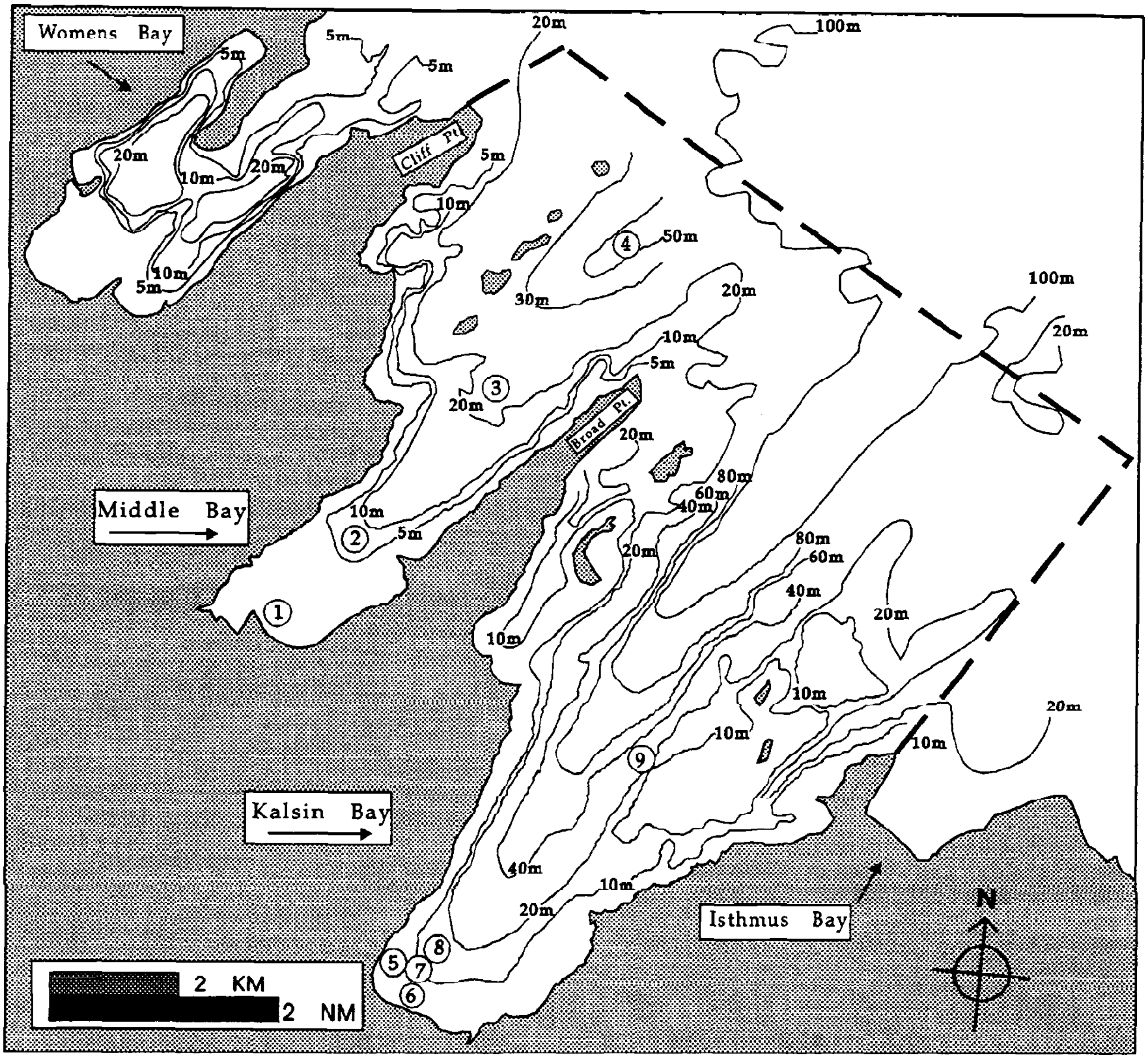
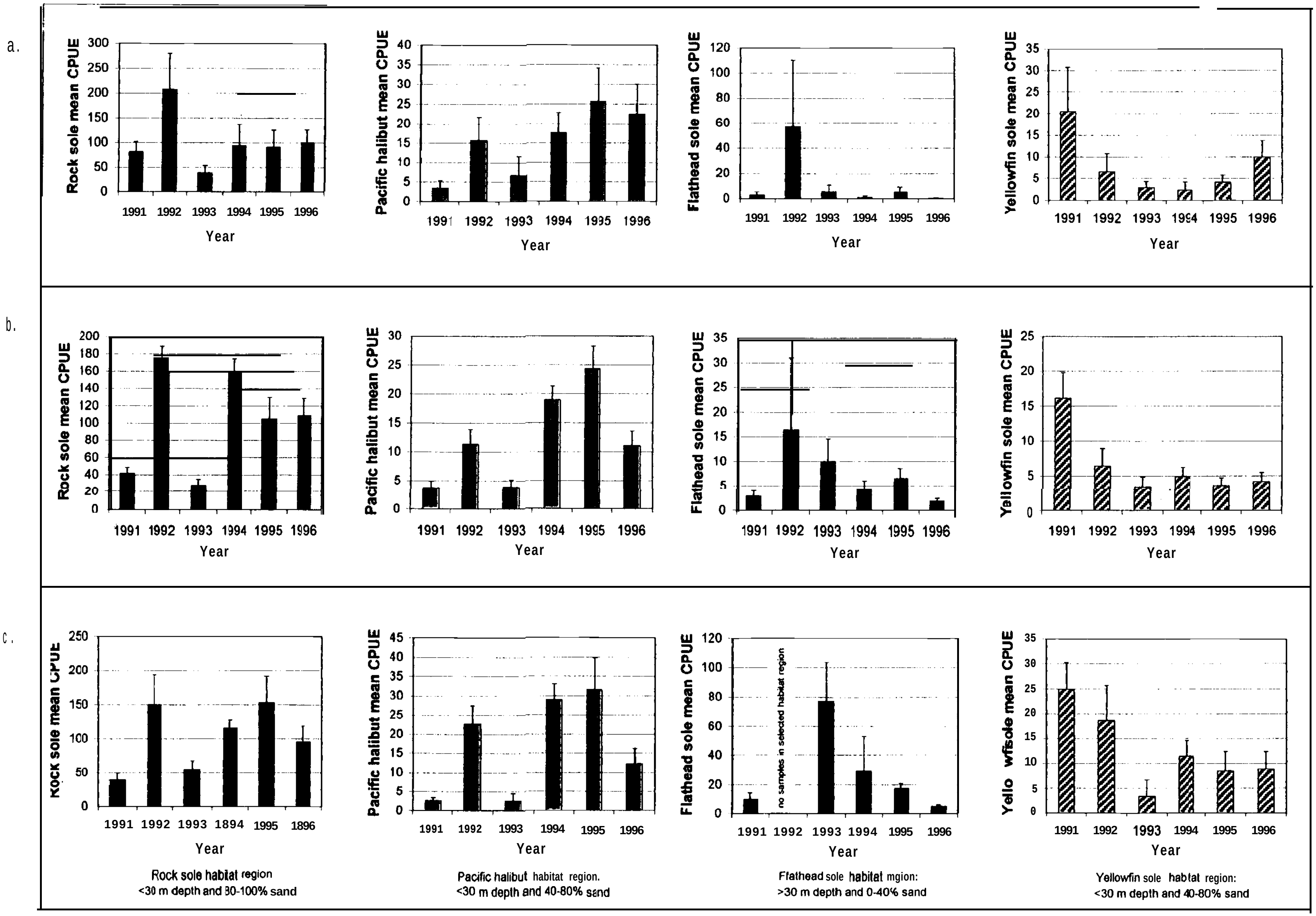


Figure I-26. Nine permanent sample site locations in Kalsin and Middle Bays, 1991-1996.



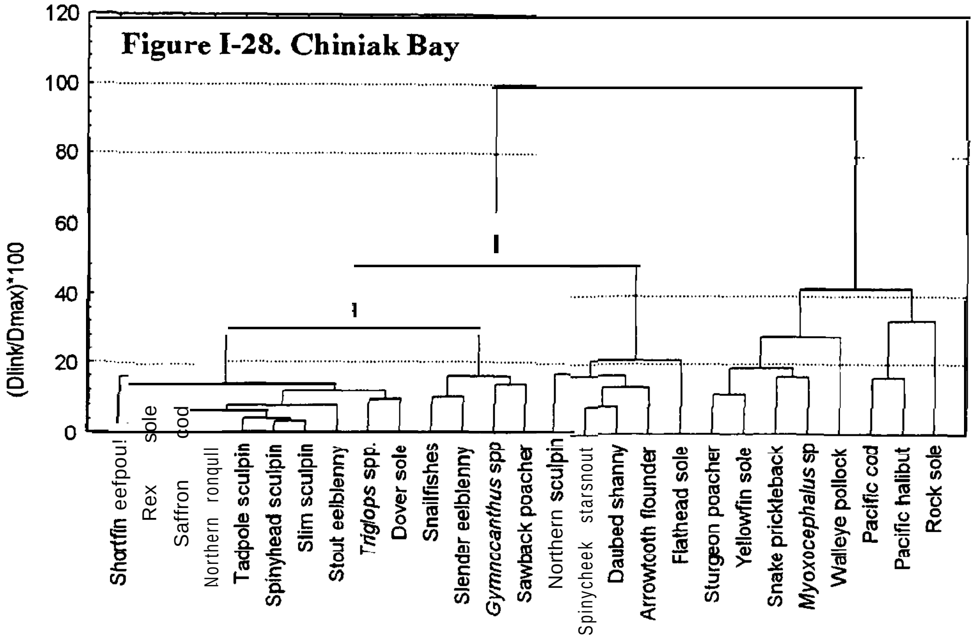
Rock sole habitat region
<30 m depth and 30-100% sand

Pacific halibut habitat region.
<30 m depth and 40-80% sand

Flathead sole habitat region:
>30 m depth and 0-40% sand

Yellowfin sole habitat region:
<30 m depth and 40-80% sand

Figure I-27. Mean annual CPUE (number of fish per 1000 m^2) with standard error bars for rock sole, Pacific halibut, flathead sole and yellowfin sole over (a) the nine permanent sites, (b) all sites and (c) all sites in the habitat selected to monitor the individual species.



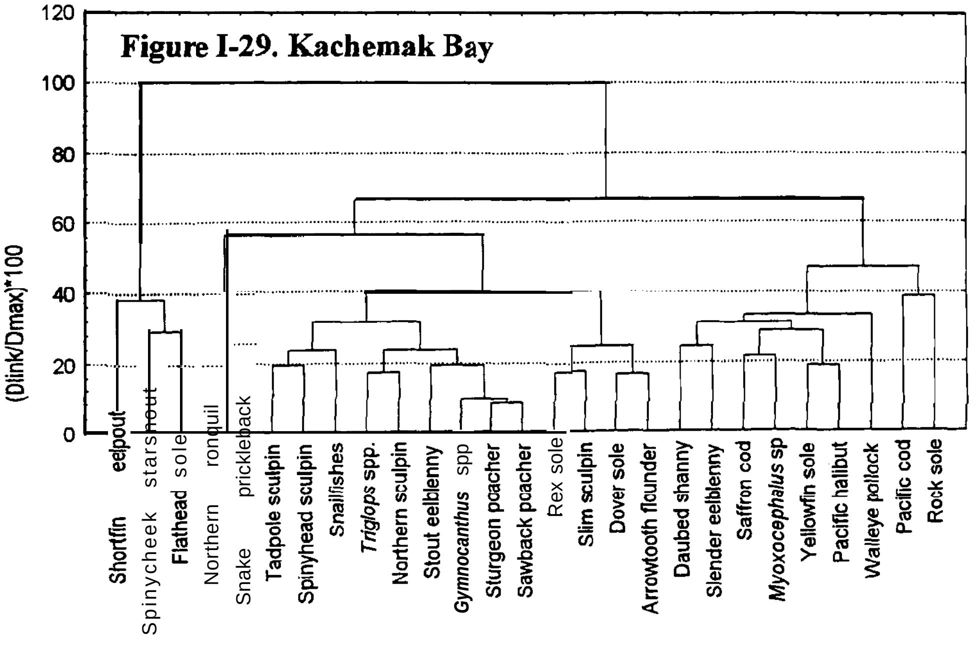


Figure I-28 (Chiniak Bay) and Figure I-29 (Kachemak Bay). Tree diagrams for 27 variables, Ward's method using Euclidean distances.

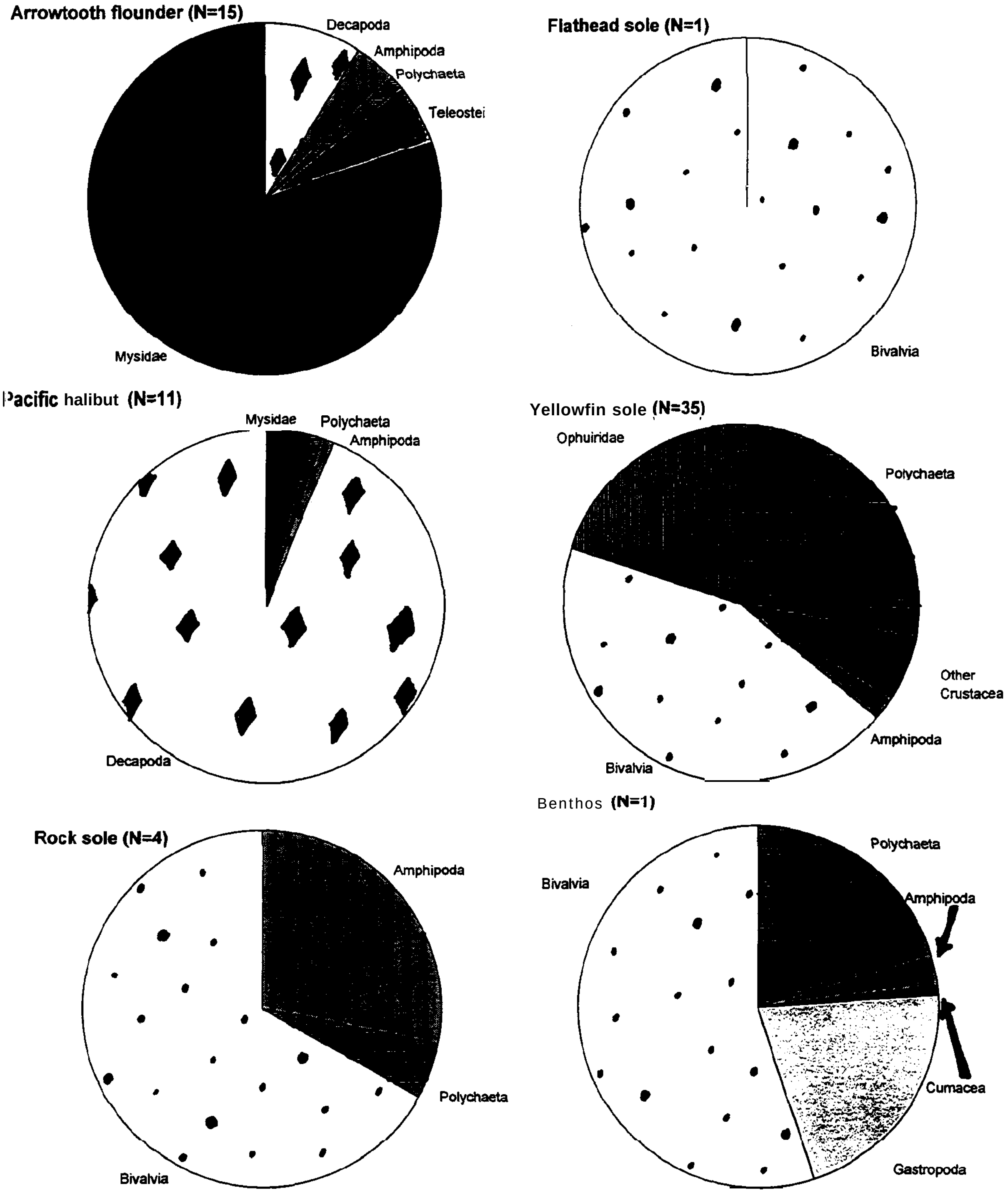


Figure i-30. Proportional importance of taxa within juvenile flatfish diets and within the benthos, at CI9401 CS#37.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of thr Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resourcea; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parka and historical places; and providing for tha enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and far people who live in island territories undar U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS). collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the Offshore Minerals Management Program administers the OCS cornpetitiva leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS Royalty Management Program meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its rasponsibilitiss through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic