PREY BIOMASS ABUNDANCE, DISTRIBUTION, AND AVAILABILITY TO THE ENDANGERED STELLER SEA LION (*EUMETOPIAS JUBATUS*) POPULATION AT UGAMAK ISLAND, ALASKA, 1995-99.

by

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ABSTRACT

Prey biomass abundance, distribution, and availability to the endangered Steller sea lion (*Eumetopias jubatus*) population at Ugamak Island, Alaska, 1995-99.

Kathryn Chumbley

A 70% overall decline in the number of Steller sea lions (*Eumetopias jubatus*) has occurred throughout most of Alaska since the 1970s. Data collected from population abundance surveys conducted since 1990 indicate that the decline continued in the Gulf of Alaska and Aleutian Islands at about 5% per year through 2000. Ugamak Island (54^{o} 12.45 N, 164^{o} 46.6 W), formerly the largest Steller sea lion rookery site in Alaska, is located in the eastern Aleutian Islands in Unimak Pass. The western stock of Steller sea lions (west of 144° W) was listed as endangered under the Endangered Species Act in 1997 and includes Ugamak Island. Seasonal and geographical changes in prey resource distribution, abundance, and availability to young foraging Steller sea lions is one of the potential causes of the population decline in the endangered western stock of Steller sea lions.

The National Marine Mammal Laboratory in conjunction with the Alaska Maritime National Wildlife Refuge and the University of Alaska, Fairbanks conducted hydroacoustic and trawl surveys within the 20 nm critical habitat area surrounding Ugamak Island, AK from 1995 through 1999 during summer and winter seasons to assess a relative index of prey resource biomass available to Steller sea lions. Reseach associated with this thesis included cruise participation, hydroacoustic data analysis, and survey variance estimation using geostatistical analysis software, Estimation of Variance (EVA), to increase accuracy of survey variance estimates. Estimates of relative biomass collected during prey assessment surveys ranged from 23.8 kg/m^2 to 331.08 kg/m^2 during summer surveys and 300.81 kg/m^2 to 1930.88 kg/m^2 during winter surveys. Survey variance ranged from 17.4 to 52.1% for summer surveys and 19.0 to 39.4% for winter surveys. Bottom trawls, mid-water trawls, and longline surveys were also conducted within the Ugamak Island study area.

Prey survey results show that Steller sea lion prey species, as well as species important to those prey, were present with the 20 nm fishery management area surrounding Ugamak Island. Results also show that prey species diversity is higher in the Ugamak Island area than in other surveyed areas. Bottom trawls conducted during summer months were predominately composed of walleye pollock (*Theragra chalcogramma*), Pacific halibut (*Hippoglossus stenoepis*), rock sole (*Lepidopsetta spp.*), and sculpins (Cottidae). No bottom trawls were conducted during winter months. Mid-water trawls were conducted on an opportunistic basis during summer and winter months and species caught included walleye pollock, gadids, sandlance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), hexagramids, euphausiids and other invertebrates. Longline surveys were conducted during summer and winter months in areas unsuitable for bottom

trawling. Stomach contents collected from Pacific halibut and Pacific cod (*Gadus macrocephalus*) on longline surveys were composed of gadids, small schooling fishes, demersal fish, cephalopods, crustaceans, mollusks and benthic invertebrates.

Ongoing satellite telemetry and foraging research shows that Ugamak Island is an important diving and potential foraging habitat for young Steller sea lions and that most of the satellite tagged sea lions stayed close to the island (within 20 nm) and dove to depths ranging between 0 and 50 meters of water. The results of the satellite telemetry research demonstrate that the nearshore marine environment around Ugamak Island is an important and potentially critical part of the habitat of foraging young Steller sea lions. Results from this study provide baseline data needed to explore the relationships between biomass density changes and the effects on endangered Steller sea lions foraging at Ugamak Island, Alaska.

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INTRODUCTION

Identification of the Problem

Marine life in the North Pacific Ocean has undergone major changes in population dynamics in recent decades. While walleye pollock (*Theragra chalcogramma*) and salmon (*Oncorhynchus* spp.) populations have increased dramatically, stocks of crab and Pacific herring (*Clupea pallasii*) have declined. From 1950 to 1995, a period witnessed by an explosive growth and change in fisheries resources, a concurrent marked decline in Alaskan Steller sea lion (*Eumetopias jubatus*) populations occurred in Alaska (Merrick et al. 1987, Alverson 1992). During the same time period, some marine mammal populations increased, while others declined. These changes are most evident in the western Gulf of Alaska and the eastern Bering Sea where the Steller sea lion population has undergone a dramatic decline. The National Marine Fisheries Service (NMFS), following analysis of population abundance data, estimated over a 75% decrease in numbers of Steller sea lions in these areas since the late 1970s (Loughlin et al. 1992; Loughlin and York 2000). Genetic evidence suggests that the Alaskan Steller sea lion population consists of a western stock (which has declined) and an eastern stock (which has increased over the past two decades to about the same size as the current western stock) (Bickham et al. 1996; Loughlin 1997). The NMFS listed Steller sea lions as threatened under the Endangered Species Act (ESA) in 1990. Results from genetics studies prompted the NMFS to relist the western stock as endangered and the eastern stock as threatened under the Endangered Species Act (ESA) in 1997.

One of the prominent hypothesized causes for the population decline in Steller sea lions is that available food resources (i.e., species abundance and composition of forage fishes) have changed, and specifically that this change is affecting nursing females with pups on the rookeries (Merrick, et al. 1987;

Merrick et al. 1995). Steller sea lion food habits research has been of interest for several years (Sea Grant 1993). Since that time there is even more interest in comparing the western versus eastern sea lion stocks and determining effects of food availability on both. Some diet studies show a strong positive correlation between differences in Steller sea lion diet diversity by area and the degree of population decline in those areas while other studies do not show a correlation between diet diversity and population decline (Merrick et al 1997, Sinclair and Zeppelin 2002, Wynne et al. 2005). Merrick et al. (1997) report in the 1990's that as diet diversity decreased Steller sea lion populations decreased, suggesting that Steller sea lions require a variety of prey species for survival (Merrick et al 1997; Sinclair and Zeppelin 2002). However, recent studies in the Kodiak area show that the sea lion population decline is continuing in that area even though diet diversity is high (Wynne et al. 2005).

Steller sea lions eat a variety of fish and invertebrates, including species of primary and secondary importance to Alaskan commercial fisheries. Sea lion prey species that are targets of prime commercial fisheries in Alaskan waters, include walleye pollock, Atka mackerel (*Pleurogrammus monopterygius*), Pacific cod (*Gadus macrocephalus*), flatfishes (Pleuronectidae), rockfishes (*Sebastes* spp.), shrimps (Pandalidae), Pacific herring, and salmon. Other prey of pinnipeds include those that are also the prey of the commercially harvested groundfish species. These prey include capelin (*Mallotus villosus*), Pacific sandlance (*Ammodytes hexapterus*), eulachon (*Thaleichthys pacificus*) and cephalopods. Pinnipeds are opportunistic feeders and thus tend to eat whatever is most abundant and accessible. Their diets are based more on availability of prey than preference for a specific food item (Pitcher 1980; Pitcher 1981; Kajimura 1985; Merrick et al. 1997; Sinclair and Zeppelin 2002). Utilization of a given prey item may differ among individuals due to age or reproductive status (Frost and Lowry 1986). This and the variability in prey abundance results in seasonal, annual, and regional dietary differences among individuals of the same species. The potential for competition between commercial fisheries and marine mammals exists if increased seasonal or age-specific energetic demands of marine mammals coincide with temporal and spatial scarcity of prey resulting from removal by commercial fisheries (Mueter and Norcross 1998).

Commercial fisheries have been affected by the listing of Steller sea lions under the ESA despite the fact that the extent to which commercial fishery harvests influence pinniped populations is unknown (Lavigne 1982; Swartzman and Haar 1983; Harwood and Croxall 1988; Loughlin and Merrick 1989; Alverson 1992; NMFS 1992). Until adequate fisheries data are available, uncertainty about interactions between fisheries and marine mammals forces resource managers to be conservative in their management plans and policies, erring on the side of the declining and endangered marine mammal populations. NMFS has implemented conservation measures to encourage Steller sea lion recovery, including time and area restrictions for potentially competitive fisheries. NMFS has also established 3, 10, and 20 nautical mile (nm) management zones around sea lion rookeries and haul-outs because commercially important species such as walleye pollock and Atka mackerel were found in sea lion stomachs during diet studies conducted in the Gulf of Alaska and Bering Sea. While more primary prey availability is important, the need for seasonal availability of primary prey in the right locations is a vital component for foraging juvenile and adult female Steller sea lions.

The relationships between prey fish abundance, harvest, and impacts on pinniped populations are not well defined. However, nutritional stress in Steller sea lions has been correlated with large commercial walleye pollock harvests (Calkins and Goodwin 1988; Lowry et al. 1989). Sea Grant (1993) reported that the importance of walleye pollock in the diet of Steller sea lions may be biased in that it is an assessment based on stomach contents of sea lions from the late 1970's and early 1980's when there was an explosive increase of walleye pollock in the Gulf of Alaska (Pitcher 1981). Abundance of walleye pollock not only increased in the diets of Steller sea lions, but also precipitated the increase in commercial fishing effort. When there was no commercial fishery for walleye pollock in the 1950's, there were also no walleye pollock in sea lion diets (Mathiesen et al. 1962; Thorsteinson and Lensink 1962; Fiscus and Baines 1966). In the central and eastern Aleutian Islands (west of Ugamak Island) the diet of sea lions is dominated by Atka mackerel, the most abundant prey in the area. Changes in Stelller sea lion diet between the early 1970's and the 1990's reflect the nature of sea lions as opportunistic feeders and may be more indicative of the availability of prey rather than an indicator of sea lion feeding preferences.

Measures to establish buffer zones around Steller sea lion rookeries, in conjunction with the research emphasis on walleye pollock and Atka mackerel, tend to obscure the significance of other known pinniped prey such as flatfishes, Pacific herring, cod, salmon, capelin, Pacific sandlance, and cephalopods. Interdecadal changes in pinniped consumption of these species, as well as walleye pollock and Atka mackerel, are reflected in the stomach contents of Steller sea lions. Steller sea lions around Kodiak Island consumed mainly small forage fishes such as capelin, with cephalopods as a secondary food source, between 1973 and 1978 (Pitcher 1981). From 1985 to 1986, sea lion diets included no capelin but were dominated by walleye pollock, octopus and flatfishes (Calkins and Goodwin 1988, Merrick and Calkins, 1996).

Although demersal fish availability was poorly understood, it was a significant component of juvenile Steller sea lion diets in the Gulf of Alaska in 1985-86 (Calkins and Goodwin 1988, Merrick and Calkins 1996). Changes in the species composition of the juvenile groundfish community may have been reflected in sea lion diets when walleye pollock replaced capelin as the major species in the diet. A groundfish community dominated by gadids and flatfishes coincided with a marked decline in a shrimp dominated crustacean community which occurred in the nearshore zones around Kodiak Island in the late 1970's (Anderson and Piatt 1999). The decline in shrimp occurred concurrently with a decline in capelin and other forage fishes. This decline has been demonstrated to affect commercial fish species in the eastern North Pacific Ocean (Hollowed and Wooster 1995) and some researchers indicate that the change may have been part of the regime shift that occurred in the Gulf of Alaska during the late 1970's (Royer 1989, Ebbesmeyer et al. 1991, Trenberth and Hurrell 1994). Other researchers show that pollock population abundance is naturally highly cyclic, that forage fish species likely were not the dominate prey species in the fish community and that shifts in abundance were likely not affected by a regime shift (Fritz and Hinckley 2005).

The extent and causes of the changes in prey availability and their effects on Steller sea lion populations and the nearshore marine ecosystem are unknown. Mortality of juvenile pinnipeds due to decreased availability of suitable food is hypothesized as a cause of the Steller sea lion population decline (Loughlin and Merrick 1989; Sea Grant 1993; Merrick 1995) as is a decrease in natality (Holmes and York, 2003). To test this hypothesis NMFS and USFWS initiated a study to assess the availability of small fishes, which are the principal prey of juvenile Steller sea lions. Prey assessment surveys were conducted in cooperation with the U.S. Fish and Wildlife Service (USFWS) Aleutian Maritime National Wildlife Refuge (AMNWR), the Biological Research Division of the U.S. Geological Survey (USGS), and the University of Alaska Fairbanks, Alaska (UAF) under the auspices of a cooperative research group named Seabird, Marine Mammal, Oceanographic Coordinated Investigations (SMMOCI). Surveys of fish species availability were conducted in conjunction with NMFS/NMML (National Marine

Mammal Lab) population abundance surveys of Steller sea lions at major rookeries in the Gulf of Alaska. The emphasis of the study was on small prey species abundance near sea lion rookeries in concurrence with the theory that poor survival of sea lion pups is causing the decline in the population, and that juvenile survival may be less successful because of reduced availability of forage fish.

SMMOCI surveys were initiated as a 5 year pilot study to investigate functional response on sea lion rookeries and seabird colonies related to changes in the nearshore marine ecosystem (V. Byrd, pers. comm., USFWS/AMNWR). Summer surveys were initiated due to a concern about nutritional health and stress on adult female sea lions during the breeding season, nutritional health and stress on breeding seabirds, and how these factors may contribute to the declines in each population. Vessel cost and availability was also a factor in the decision to conduct summer surveys. Winter surveys were conducted to assess prey resources available to young sea lions during their first year of foraging, resource availability to the general population of Steller sea lions during winter, as well as resource abundance and availability differences between seasons.

The main objectives of this study were:

1. To assess distribution and abundance of juvenile and subadult life stages of commercially important fishes which serve as potential prey for Steller sea lions within the 20 nm critical habitat area surrounding Ugamak Island.
2. To determine distribution and abundance of non-commercially important species of fish which serve as potential prey for Steller sea lions within the 20 nm critical habitat area surrounding Ugamak Island.

3. To determine interannual fluctuations in availability of commercially and non-commercially important demersal fishes around sea lion rookeries.

4. To utilize geostatistical methods to increase accuracy of hydroacoustic survey variance estimation.

Description of the Study Area

Ugamak Island (54° 12.45 N, 164° 46.6 W) was formerly one of the largest Steller sea lion rookeries in the world. Ugamak Island lies near the western edge of Unimak Pass in the Fox Islands area of the eastern Aleutian Islands (EAI), at the downstream end of the Alaska Coastal Current (Fig. 1). The pass is broad, about 18 km at its most narrow spot, and is relatively shallow (mostly <100 m). The island is subject to oceanographic influences from water masses of both the Gulf of Alaska (GOA) and the Bering Sea. Water flow in Unimak Pass is largely governed by tidal processes which may push GOA water north or Bering Sea shelf break water south through Unimak Pass and adjacent passes (Kinder and Schumacher 1981, Schumacher et al. 1982, Hood 1986). Warm, low-salinity Alaska Coastal Current water hugs the coast of Unimak Island and winds around into the Bering Sea without crossing the passes. Waters around Ugamak Island and nearby Aiktak Island are well-mixed by tidal upwelling in the passes (Haney et al. 1991). They are characterized by temperatures and salinities that are intermediate between shelf break water and GOA waters, and have weak vertical property gradients (Haney et al. 1991).

Euphausiids, particularly, *Thysanoessa inermis*, completely dominate the biomass of zooplankton and form large, dense aggregations in passes and straits in the study area (Troy et al. 1991). Shelf species of forage fish, such as capelin and sandlance, are relatively scarce perhaps in part because shelf habitat around the islands is rather limited. Troy et al. (1991) found that in tidally mixed water around the islands, juvenile pollock (age 0+) overwhelmingly dominate (99.7%)

in trawl catches during fall. Farther offshore in GOA water, lanternfishes (Myctophidae) are the most abundant species of forage fish (Troy et al. 1991).

The Steller sea lion rookeries at Ugamak Island are located in small bays on the southeast and northeast ends of the island. The water is relatively shallow near the rookery, and then drops off to about 50 m with some deeper areas of up to 150 m, within 5 miles of the rookery. Moderate to strong tidal currents, with an average maximum flow of 1.3 to 4 knots, and small tidal ranges of about 0.5 m are typical in the Ugamak Island area. The waters surrounding Ugamak Island are characterized by very rough bottom topography (Mueter and Norcross 1998).

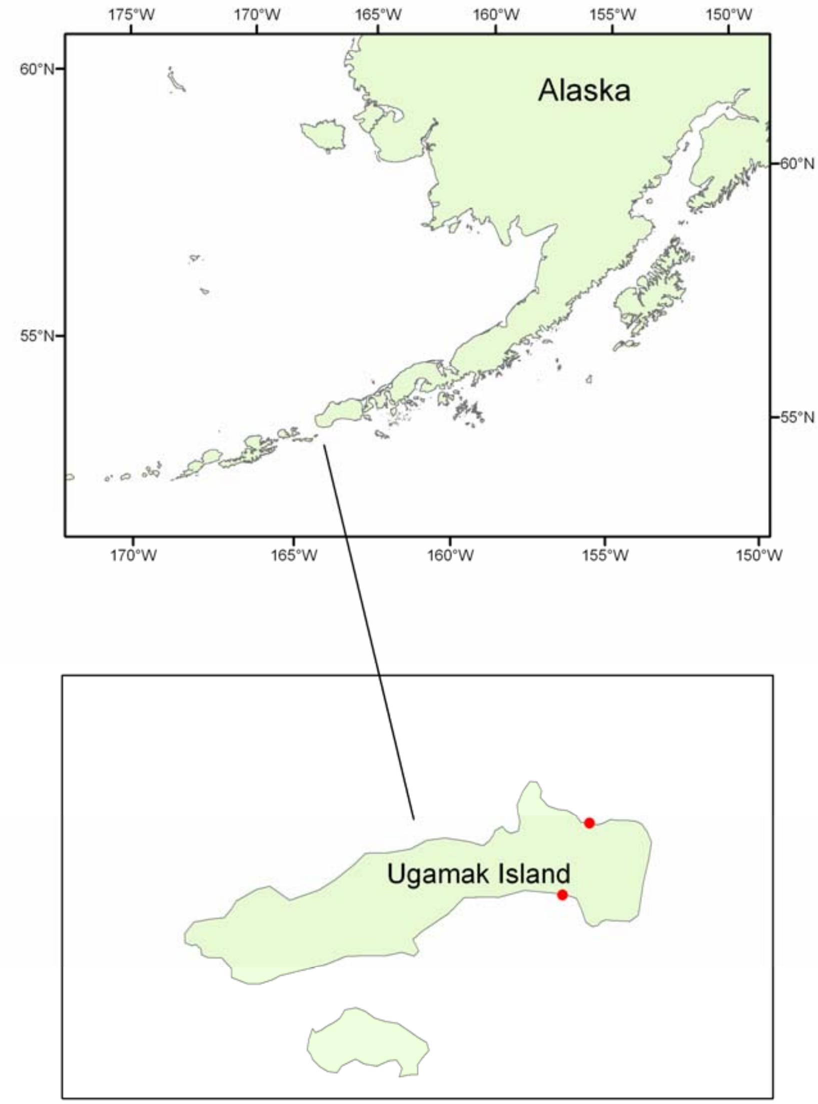


Fig. 1. Map of Alaska and Ugamak Island Steller sea lion rookery sites.
Prey Assessment Surveys at Ugamak Island

The main objective of the SMMOCI surveys was to describe the nearshore marine ecosystem including assessing potential prey biomass available to Steller sea lions and seabirds in the vicinity of sea lion rookeries and haulouts and seabird colonies. Research conducted at Ugamak Island as a part of the SMMOCI surveys includes hydroacoustic line transects, mid-water and bottom trawl surveys, marine mammal and seabird line transect surveys, and collection of oceanographic data (temperature and salinity).

From 1995-99 the National Marine Mammal Laboratory's (NMML) Alaska Ecosystem Program conducted SMMOCI prey assessment survey research onboard the USFWS vessel *M/V Tiglax* during both the Steller sea lion breeding (June-July) and non-breeding seasons (March) in Alaska in the regions from the Kenai peninsula to the western Aleutian Islands. SMMOCI surveys were conducted during June-July 1995-98 and March 1997-99. Many sites were surveyed including Marmot, Sugarloaf, Chowiet, Atkins, Kasatochi, Kiska, Buldir, Agattu, and Ugamak islands as well as Cape Sarichef and the Unimak Pass area. Additional surveys were conducted by USFWS at Buldir, Kasatochi, and Aiktak islands as well as by USGS in the Barren islands, however, only surveys from Ugamak Island are reported in this thesis.

The nearshore marine components of the study include: (1) biomass estimates of potential seabird and marine mammal prey within 20 nm of the breeding areas, (2) identification of common prey in the area, (3) assessing oceanographic characteristics of water masses nearby, (4) characterizing bottom fauna, (5) recording the feeding distribution of birds and marine mammals, and (6) assessing food web relationships by analyzing stomach contents of fish and birds (Byrd et al. 1997).

This thesis will focus on relative biomass indices from hydroacoustic transects, variance estimation from hydroacoustic transect surveys, and trawl and longline surveys from Ugamak Island during SMMOCI studies. Ugamak Island study objectives were to:

- Describe the nearshore marine ecosystem including assessing relative biomass indices within the 10-20 nm fishery management area surrounding the Ugamak Island.
- Determine interannual and seasonal fluctuations in relative biomass surrounding the Ugamak Island Steller sea lion rookery.
- Utilize geostatistical methods to better estimate variance in hydroacoustic survey biomass at Ugamak Island.

METHODS

Hydroacoustic prey assessment surveys

The USFWS vessel, *M/V Tiglax*, was used on all surveys conducted during this study. Hydroacoustic data were collected along a series of parallel transects within 20 nm radius of Ugamak Island to estimate the distribution and relative biomass index of potential prey resources (Fig. 2).

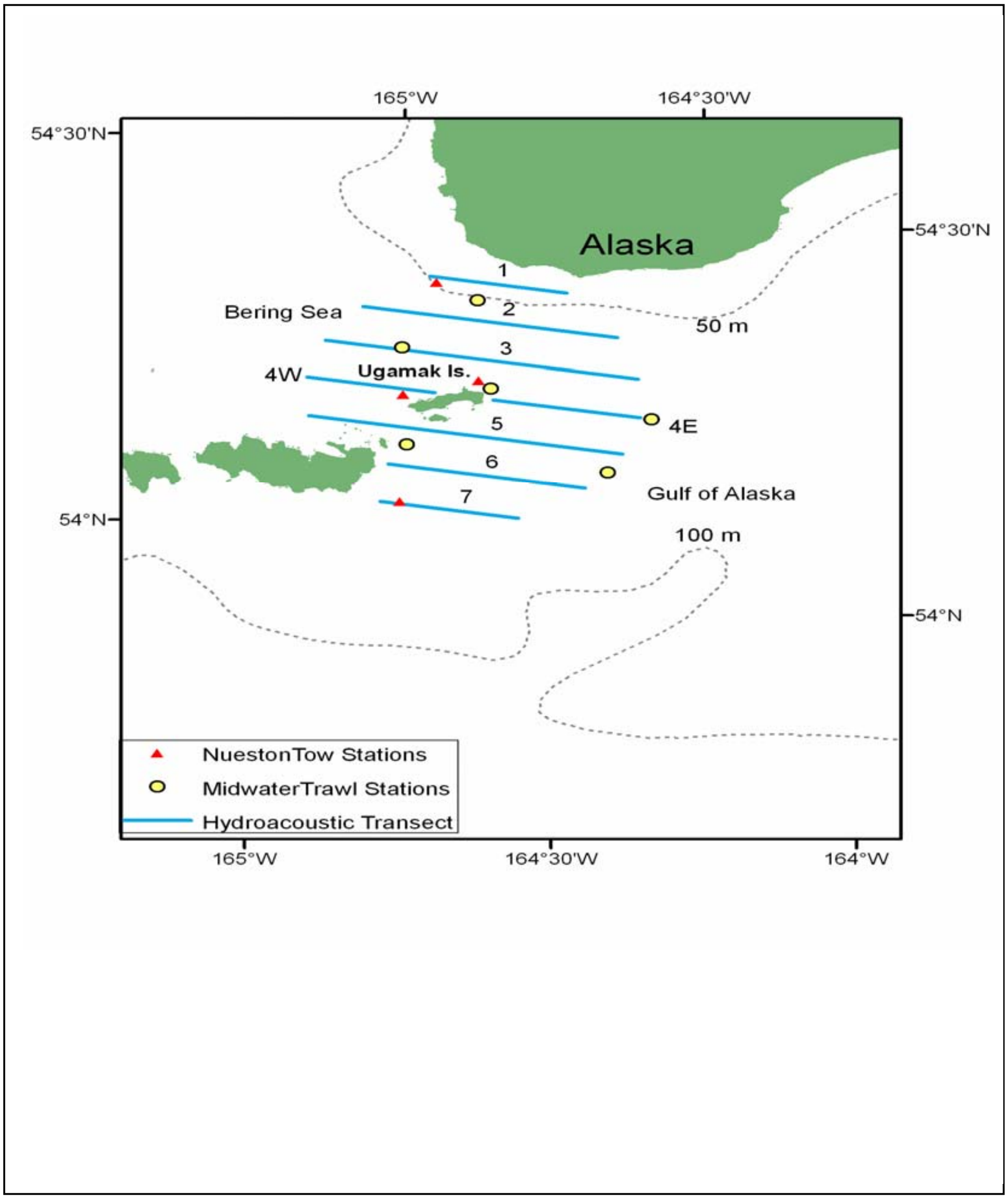


Fig. 2. Map of hydroacoustic transects, midwater trawl stations, and nekton tow stations at Ugamak Island, Alaska, 1995-99.

The vessel operated at 10 knots (kts) during hydroacoustic transects. Data were collected using the vessel's BioSonics 102 hydroacoustic system, with hull mounted (4 m deep) 38 and 120 kHz transducers operated in a multiplexing (alternating between transducers) mode (BioSonics 1994). The system was run in multiplexing mode to obtain separate estimates of total biomass (large and small targets) using the 120 kHz transducer and estimates of large target biomass using the 38 kHz transducer. All data were echo integrated in real time using BioSonics Echo Signal Processing (ESP) software running on the ships' computer. Transects were standardized, such that subsequent surveys covered the same areas and bathymetry. All transect legs (7) were surveyed once during daylight hours. Additionally, the central transects (3) were also surveyed at night, on an opportunistic basis, for a total of 10 transect lines equaling approximately 160 km of transects per survey. However, night transects were less consistent than daylight transects and are not used in the analysis.

Acoustically derived relative biomass estimation

Targets Per Unit Surface Area (TPUSA) were integrated by the ESP software program using the reports from the Run Table (RE output table) and values were reported in kg/m^2**.** The RE table contains all the integration report information collected by ESP on a per depth stratum and per report basis. Each report listed in this file includes individual depth stratum results and contains calculated values for relative biomass density collected at 1 minute intervals along each transect. Transect lengths ranged from 8 nm (Transect 1) to 18.7 nm (Transects 3 and 5). Data collected from the 120 kHz transducer was used in the analysis as it provided a better index of relative biomass density available to all predators. Relative biomass density is an estimate of the amount of acoustically detected biomass encountered during transect survey for all species ranging from zooplankton to fish. Relative biomass estimated by the 120 kHz transducer ranged from zooplankton species to fish species but were not discernable to species. In order to differentiate between species extensive trawling would be required to verify and identify prey to species.

Data were analyzed post-survey using additional ESP software and EXCEL. Analysis of data provided average bottom depth, TPUSA (kg/m^2) and mean relative biomass density. TPUSA provided a relative index of biomass by averaging the biomass density (kg/m^2) of each sample obtained from each one minute time segment from each depth strata sampled on each transect for all transects on a survey.

Relative biomass density values were then graphed for each depth strata in order to detect areas where the bottom may have been integrated, as well as other data anomalies. Integrated bottom signal and other anomalous data were edited by hand since the ESP program did not have the capability to edit them automatically (J. Piatt, USGS, pers. comm.). Sources of anomalous data can include surface bubbles extending below the depth of the transducer or poor weather conditions caused by winds or sea state resulting in pitching and rolling of the ship.

After anomalous data points were removed the edited survey data were analyzed to detect the horizontal location of concentrations of relative biomass density geographically in the survey area. For each transect, edited data were averaged by depth strata to obtain a single data point to represent seasonal and annual variability within the study area by depth strata, transect, year and season.

To represent annual and seasonal vertical relative biomass density distribution in the survey area data were averaged by depth strata across all transects. These average data were then summed to obtain an average relative biomass density for each survey year and season. These summed data were then divided by the depth strata midpoints (e.g. 5m, 10m, 15m, etc.) to obtain a weighted average relative biomass density data for each survey year and season. Weighted average relative biomass densities were graphed to compare vertical variability between years and seasons.

Estimation Variance Analysis (EVA)

Ecological analysis generally includes investigations of the dispersion and patterns associated between species at different places and times- patterns that reflect spatial dependence rather than independence (Pielou 1977). Both Ricklefs (1973) definition of ecology as “the study of the natural environment, particularly the interrelationships between organisms and their surroundings” and that of McNaughton and Wolf (1973) - “the scientific study of the relationships”, imply spatial and temporal dependence (Rossi et al. 1992). The concepts of spatial and temporal dependence or continuity should be readily apparent to the ecologist. Examples of these concepts include vegetation species and densities that are generally different on north-facing vs. south-facing slopes, increased density of grasshoppers during hot, dry periods, and plants in greenhouse experiments that are routinely rotated to eliminate micro climatic and micro environmental effects. Additionally, distance from a major seed, a predator, or an herbivore source or temporal features of a system such as diel trends in temperature, radiation, salinity, or thermocline can affect a species distribution and behavior (Robertson 1987).

Interpolation of data is key to ecological field studies. Ecologists who infer mean values for particular variables within a given experiment or time increment implicitly interpolate values for all points not measured. If assumptions regarding sampling independence and normality are met then parametric statistics provide optimal estimates of variance around unbiased means. These variance estimates, based on normally distributed data, are widely used to describe attributes of experiments and to test hypotheses about ecological processes (Robertson 1987). However, assumptions about sample independence are difficult to meet in ecological field studies due to autocorrelation of sampled data points: samples collected close to one another are often more similar to one another than are samples collected farther away, whether in space or time (Robertson 1987).

Because of the prevalence of autocorrelated data in field studies, estimates of variance around interpolated points may differ substantially from overall population variance. As a result imprecise estimates of sample values within the unit sampled and a biased estimate of treatment effects in experimental systems can occur (Trangmar et al. 1985, Sokal and Rohlf 1981).   The recent development of regionalized variable theory, for applications in geology (Matheron 1971, Journel and Huijbregts 1978, Krige 1981) and soil science (Burgess and Webster 1980a) provides an elegant means for describing autocorrelation in data, and a means to use this autocorrelation information to derive precise, unbiased estimates of sample values within the sampling unit. These estimates incorporate the detailed spatial patterns with known variance for each interpolated point. Spatial variability in particular has long been difficult to quantify in ecologically meaningful ways and the development of this theory is of considerable interest to ecologists (Robertson 1987).

In recent years there has been increased attention on the design of acoustic surveys and estimates of survey variance. Two approaches which have been commonly adopted are: (1) a stratified random sample design relying on classical statistics for variance estimation (Jolly and Hampton 1990) and (2) a systematic sampling design using a grid of parallel transects and employing techniques commonly used in geology from a field of statistics known as "geostatistics" (Petitgas 1993). The first approach is design-based requiring data from a random sample of transects. The second approach is a statistical model-based approach that assumes a non-random model of spatial structure (Petitgas 1993). Many practitioners of acoustic survey assessment acknowledge the statistical validity of the random sampling approach, but prefer to employ a grid of parallel transects at a fixed intertransect distance knowing that the abundance estimate will be more precise. The problem with this approach is that classical statistics do not provide an estimator for the variance in a systematic survey (Williamson and Traynor 1996).

The theory of geostatistics offers a solution to this problem. Geostatistics is a branch of applied statistics that focuses on the detection, modeling, and estimation of spatial patterns. The theory makes use of the observed spatial structure evident in the correlations in the sampled data and incorporates this structure into the calculation of variance, which is a two step process: (1) defining the degree of autocorrelation (or similarity between neighboring data points) among the measured data points, and (2) interpolating values between measured points based on the degree of autocorrelation encountered. Autocorrelation is evaluated by means of the semi-variance statistic $\gamma(h) = 1/2N(h) \sum^{N(h)}_{I=1} [z(x_i) - z(x_{i+h})]^2$ where $z(x_i)$ is the measured sample value at point x_i, $z(x_{i+h})$ is the sample point value at point x_{i+h}, and N(h) is the total number of sample point contrasts or couples for the interval in question. The resulting plot of γ(h) vs. all **h**'s evaluated is termed the semi-variogram; the shape of this plot describes the degree of autocorrelation present (Robertson 1987).

The one dimensional (1D) procedure proves to be very appropriate for acoustic surveys performed along regularly spaced parallel transects (Petitgas 1993). In echo integration surveys of pelagic marine biomass, the measured backscattered acoustic energy is summed over all individual samples made through the water column and averaged along unit distances of the ship's course.

Thus, the structural information present on an echogram is not used when performing biomass estimation (Petitgas and Levenez 1996). Since it is common that dense targets will constitute a large percentage of the biomass, survey reliability largely depends on encountering a sufficient number of these targets (Petitgas and Levenez 1996). If the researcher is primarily interested in global estimation (i.e. survey abundance and its variance), Petitgas (1993) recommends the use of the transitive method in 1D. Since acoustically sampled data are serially correlated along each transect, the information from the transect can be represented by a single point or cumulate. A cumulate is defined as the product of the average acoustic return multiplied by the length of the transect. A matrix of the transect data in two dimensions now becomes a set of n transect cumulates in 1D (Williamson and Traynor 1996). The 1D transitive method models patchiness of biomass and spatial structure to calculate sample variance. This method is not generally well known, but is excepted by fisheries acousticians as valid. The 1D transitive method was used to calculate survey variance for all of the Ugamak Island survey transects during this study.

Transitive theory in One Dimension (1D)

The transitive theory in one dimension (1D) was applied to the Ugamak Island survey data using the Estimation Variance (EVA) software provided by Petitgas and Prampart (1993). EVA software provides a mechanism to characterize data structure and to estimate variance (Williamson and Traynor 1996). The 1D theory was developed to assess total quantity present over an area by sampling on a regular grid pattern. In general, the origin of the grid is not determined by the variable values to be surveyed. As described in systematic sampling design of Cochran (1977), the origin of the grid may be considered randomly and uniformly located within the survey area (Petitgas 1993). In the transitive theory, a fixed spatial distribution showing a fixed total quantity is sampled by a grid of random origin (Petitgas 1993). The transects are oriented parallel to the y-axis of the grid and traverse the entire width of the grid area. Hydroacoustic data systematically collected along parallel transects are continuously sampled, therefore, the data can be cumulated without making an error on the value of the cumulates (Petitgas 1993) .

Backscattered acoustic data from the Ugamak Island surveys were analyzed from edited relative biomass density output tables of the BioSonics Echo Signal Processing (ESP) program. Each transect was summed by depth strata then totaled to give a cumulate relative biomass density over all depth strata for each transect. Each cumulate value represents a unit of relative biomass per transect line and the data set is considered to be one dimensional. Using EVA, an estimate of total relative biomass, Q, is obtained by multiplying the sum of the cumulates by the intertransect distance (Petitgas 1993). Seven daytime transects were conducted at Ugamak Island during most survey years and the inter-transect distance was equal to 3 nm. The quantity to estimate is $Q = \int_{-\infty}^{+\infty} q(x)dx$. It is estimated by the discrete summation:

$$Q^* = a \sum^{7}_{k=1} q\,(x_0 + ka)$$

where x_0 is the (random) origin of the grid and where a is the inter-transect distance.

Covariograms

The transitive 1D covariogram is a type of non-centered covariance that is used as a tool to describe the spatial structure of the population of interest (Petitgas and Prampart 1993, Williamson and Traynor 1996). To calculate an estimation variance of the relative biomass density (Q), a model is fitted to the covariogram of the raw data. The models available in the EVA software to fit a covariogram are the exponential, spherical, Gaussian, and triangular with a nugget effect optional in each selection. The shape of the covariogram describes the degree of autocorrelation in the data in 1D. A model was then fit to the covariogram of the transect cumulate data for each Ugamak Island survey.

Given f(x) to represent relative biomass density for transect location x, the total abundance $Q = \int f(x)dx$. Its estimator is:

$$Q^* (x_0) = a \sum f(x_{0 +} ia)$$

where a is the distance between transects and x_0 is the random starting point. The covariogram function is defined as $g(h) = \int f(x)\, f(x + h)dx$. The experimental covariogram value at lag k is calculated by summing all non-zero products f(x) f (x +ka), i.e. all transect cumulates k intertransect distances apart. Note that the behavior of g(h) is both a function of the values f(x) and the number of non-zero products f(x)f(x +ka).

As described in Williamson and Traynor (1996), the Ugamak Island data were best fit using a spherical or exponential model or some combination of the two. Guidelines followed in fitting a model to the raw covariogram values included:

1. If a single model provided the best fit, the sill was set to the raw covariogram value at lag 0 and the range was set equal to the width of the survey area.
2. If a combination of models best fit the data, the sum of the sills was set equal to the 0 lag covariogram value and the range for one of the models matched the field length.
3. For some data sets, the range in the second model was set to roughly coincide

with the size of any aggregates discernible within the field; for others, the range was selected to provide the best fit.

4. In choosing model parameters, emphasis was placed on fitting the first few lags as closely as possible (Williamson & Traynor 1996).

EVA variance estimates compared to random sample variance estimates

The variance of such estimation writes simply in 1D:

$$\sigma_Q^2 = a \sum_{n=-\infty}^{+\infty} g(na) - \int_{-\infty}^{+\infty} g(h)\, dh,$$

where g(h) is the transitive covariogram model of the cumulates (Petitgas 1993).

Relative estimation error is defined as:

$$\sigma_Q \div Q$$

Confidence intervals using EVA are derived as ± 2 x the relative estimation error.

For comparison purposes, (relative) confidence intervals were also estimated using classical random sample methods for each Ugamak Island survey.

$$((\sigma/m) \div \sqrt{nb}\,) \times 2$$

where m equals mean values of the cumulates and b equals the number of transects.

Trawl surveys

Midwater and bottom trawls, as well as long line surveys, were conducted during SMMOCI survey years at Ugamak Island from 1995-98. These surveys assessed the types of potential prey within the foraging range of Steller sea lions and seabirds, in the midwater and bottom portions of the Ugamak Island nearshore marine habitat.

Midwater Trawls and Neuston Tows

Midwater Trawls

Both midwater trawls and neuston tow sampling were conducted by NMML during SMMOCI hydroacoustic surveys near Ugamak Island between 1995 and 1999. Midwater trawls were conducted on an opportunistic basis in conjunction with hydroacoustic survey transects. When echo sign of potential prey was detected along transects the midwater trawl was deployed to verify potential prey species. Additionally, the trawl was deployed during periods of no detected echo signal return to verify that no potential prey species were present.

A total of 5 opportunistic midwater trawls and 4 Neuston surface tows were conducted to verify echo sign encountered near the Ugamak Island Steller sea lion rookery. When acoustic echo sign was evident during transects, and reachable by the trawl sampling gear, the transect was paused and the trawl was deployed. During 1995-96 a 2 m Isaac Kidd midwater trawl (IKMT) was towed for 15-30 minutes at 2-3 knots (Byrd et al. 1997) (Fig. 3). From 1997 to 1998 a modified midwater herring trawl was used to sample echo sign and was towed for approximately 15 minutes at the same speed (Fig. 4). The herring trawl net design consisted of a 30 ft. wide mouth opening, 1/8 inch (3.2 mm) codend mesh, and a double warp headrope. A netsounder system was placed on the trawl headrope for the duration of the tow to indicate the depth and configuration of the net, and in order to fish the net through the layer of potential prey species. Tows were limited to 15 minutes in duration at equilibrium (depth of the target layer) in order to identify the target signal return and assess species composition. Tows were also deployed using both the IKMT and the herring trawl, and when no targets were encountered in order to ground truth acoustic echo signal return accuracy. Midwater trawls were only utilized to verify acoustic echo sign during transects and not designed to serve as a quantitative midwater prey assessment survey tool.

During occasions when echo signal was detected near the surface, when large aggregations of seabirds were seen feeding at the surface, or when the seas were too rough for trawling, a Neuston plankton net, measuring 30 cm by 49 cm, was deployed (Fig. 5). Neuston tows were deployed at Ugamak Island during summer 1998 and winter 1997 and 1999. The net was deployed vertically off the starboard side of the vessel using a small winch and towed at a speed of 2-3 kts. for a period of 15 minutes. Samples collected from midwater trawls and neuston tows were identified to the lowest taxonomic level possible, counted, measured, and preserved for later identification if unidentified in the field.

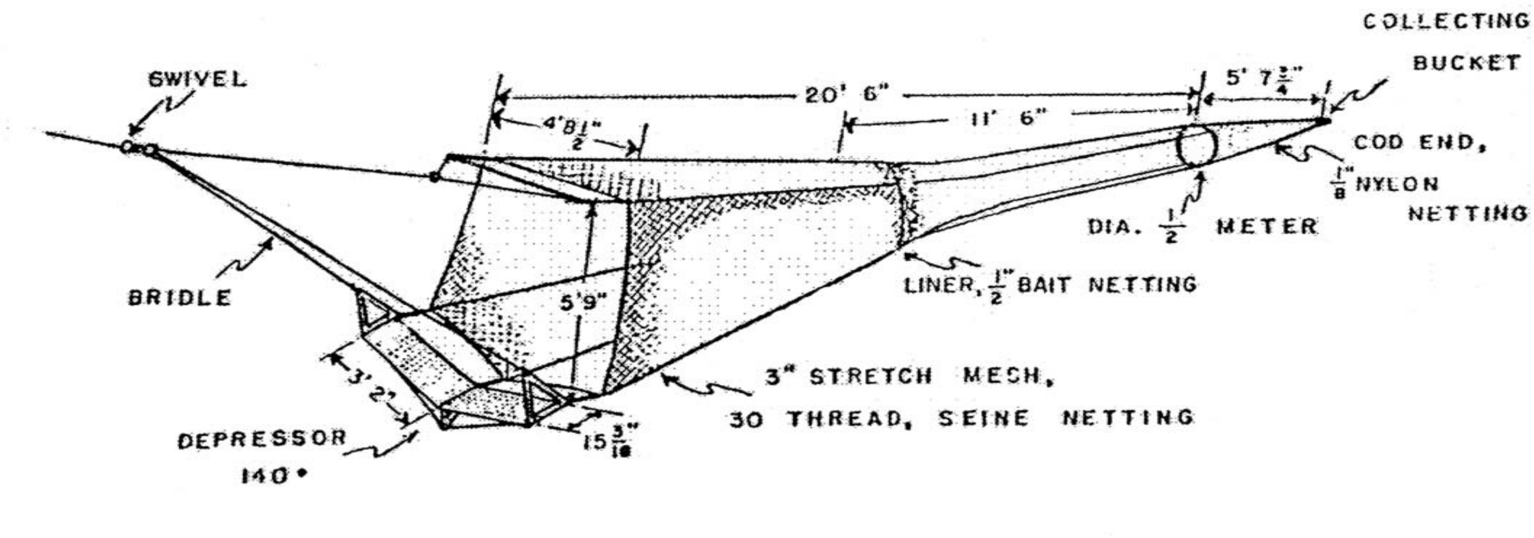


Fig. 3. Modified Issacs-Kidd Midwater Trawl

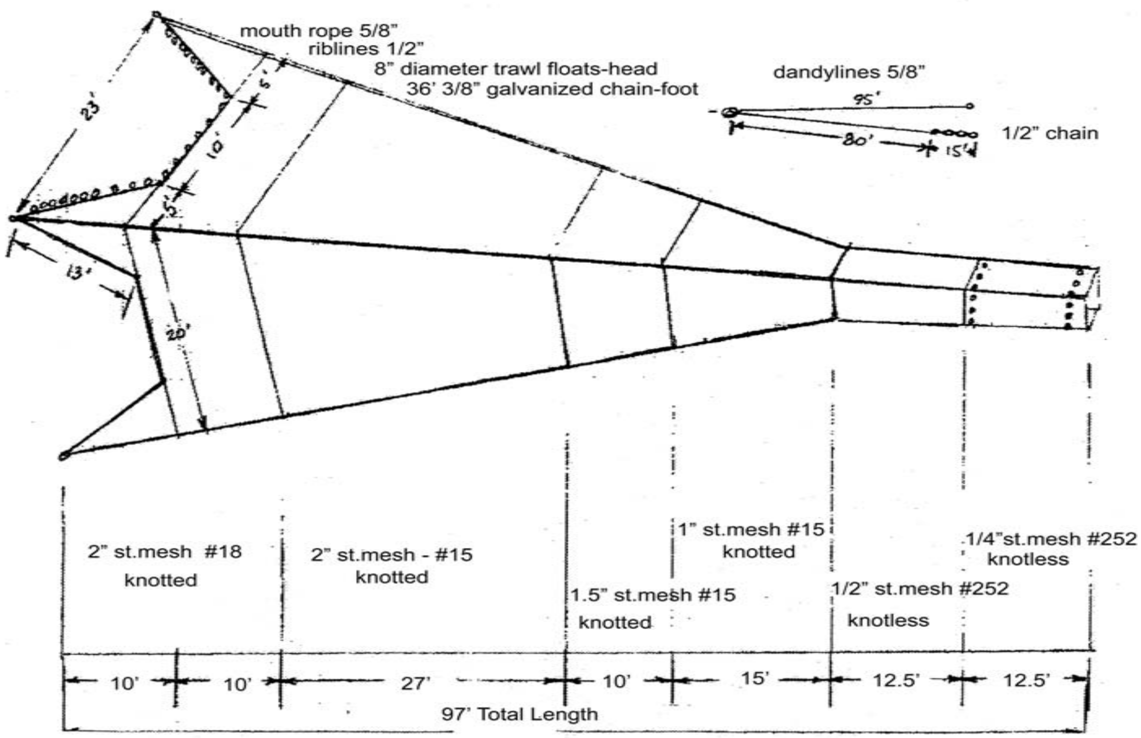
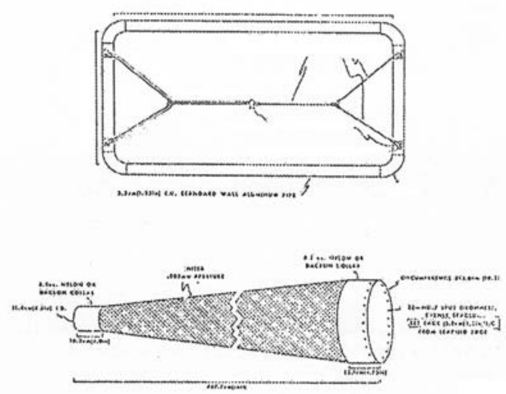


Fig. 4. Modified Herring Trawl

Neuston Net

Neuston nets are used for sampling organisms at the upper few centimeters of the water. This net uses a 1.0 m x 0.5 m aluminum frame with a net that fits loosely to the frame.



Neuston Sampler

Neuston sampler used during Ugamak Is. surveys included fins for stabilization at the surface of the water.

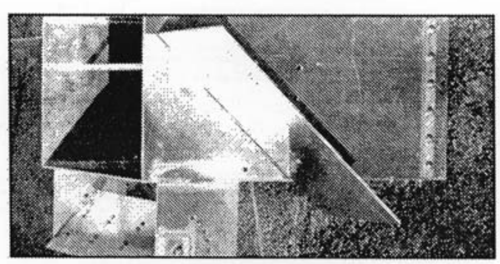


Fig. 5. Neuston Net

Bottom Trawls

A series of bottom trawls were conducted by University of Alaska Fairbanks (UAF) researchers during June-July 1995-98 SMMOCI surveys at Ugamak Island (Fig. 6). The surveys targeted small demersal fishes within the foraging range of the Ugamak Island Steller sea lion rookery. Bottom trawls were conducted from the M/V Tiglax, but separately from the hydroacoustic surveys, at depth-stratified stations radiating out from Ugamak Island. Juvenile and subadult stages of demersal fishes were the primary target species of the bottom trawl net. Sampling followed a random sampling design incorporating 3 depth strata. The depth strata chosen were based on previous study results and were designated as 10-40 m, 40-70 m and over 70 m (Norcross et al. 1995a). Bottom trawl survey methods are fully described in Holladay et al. 2000, Mueter and Norcross 1998, and Norcross et al. 1995a.

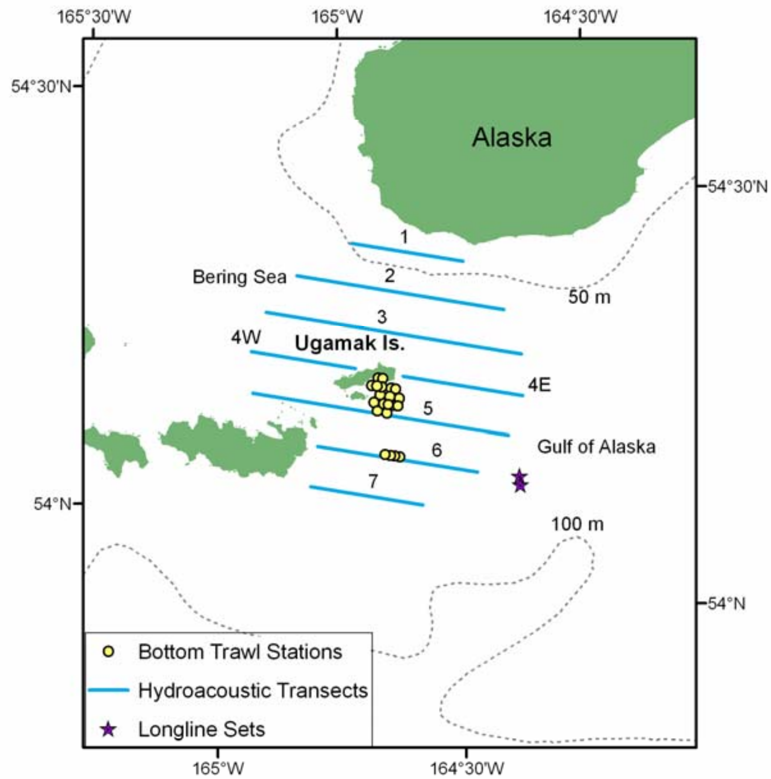


Fig. 6. Bottom trawls, longline sets and hydroacoustic transects at Ugamak Island, AK 1995-99.

Longline Surveys

Many areas surrounding the SMMOCI study locations were not surveyed with bottom trawls due to rough bottom substrate, including areas surrounding Ugamak Island. Due to the amount of untrawlable area, longline surveys were initiated in 1996 to sample large predatory bottom fishes. Bottom fish predator species were used as a sampling mechanism to assess prey fish species abundance occurring near the bottom in the areas that exhibited undesirable trawl substrate. Stomach contents of opportunistic bottom predators were assumed to reflect the abundance of common prey species available to foraging Steller sea lions in the same location (Fahrig et al. 1993, Mueter and Norcross 1998).

Longline surveys were conducted near Ugamak Island sea lion rookery during June-July 1996-98 and during March 1997-98 (Fig. 6). A single skate 100 hook herring baited longline was used to sample hard bottom rocky substrates where it was difficult to tow a small bottom trawl. The skate was deployed about 4 km from the rookery, sets ranged from 32 m to 62 m in depth, and 80% of sets were allowed to sample for less than 3 hours to prevent digestion of predator fish stomach contents.

Predatory fish caught by longline were identified to species, measured, weighed, and sexed. The mouth and gills of each predator were checked for signs of regurgitation of prey contents. If regurgitation was evident the stomach from the predator was not collected. Stomachs were excised, placed in a cloth bag with a sample identification label which included vessel name, cruise number, haul location, haul number, date, predator species name, predator length and weight, and collectors initials. Stomach samples were preserved in 10% buffered formaldehyde solution for later laboratory analysis.

Diet composition of predatory fish

Traditional dietary analysis methods include estimation of volume or weight, counts, and frequency of occurrence of individual prey items (Cortes 1977; Hyslop 1980). Analysis of fish stomachs from longline surveys were conducted by the Institute of Marine Sciences, University of Alaska Fairbanks (UAF) in summer 1996-97 and by the Resource Ecology and Fisheries Management (REFM) division of NMFS at the Alaska Fisheries Science Center (AFSC) in Seattle, Washington in winter 1997 and during both winter and summer 1998. No longline surveys were conducted in winter 1999 due to very poor weather conditions and time constraints. Pacific halibut (*Hippoglossus stenoepis*) and Pacific cod (*Gadus macrocephalus*) stomach samples were analyzed for diet composition at Ugamak Island. Stomach contents at the time of capture were considered to be representative of the diet composition of the bottom predator species in the sampling area.

Prior to laboratory processing, the formalin was neutralized from each collection of stomach samples, then rinsed in freshwater. An estimated stomach fullness to the nearest 10% (volume) was determined for each stomach sample prior to removing all stomach contents for identification. All prey items were removed from the stomachs, blotted on paper towels to remove excess moisture, and weighed (0.01 g resolution) to obtain total stomach content weight. Wet weights (0.01 g resolution) were recorded for individual fish and crab species while percent volume was estimated for other species. Prey items were counted and identified to the lowest possible taxonomic level. Prey items occurred in different stages of digestion and were identified based on remaining hard parts including shells, bones, scales, and fish otoliths. Prey taxa were placed into the following grouped categories for analysis (Mueter and Norcross 1998, Holladay et al. 2000):

(1) Cephalopods: octopus and squid
(2) Crustacea: barnacles (*Balanus spp.*), Amphipoda, Isopoda, Mysidacea, shrimp, decorator crab (*Oregonia gracilis*), Pygmy cancer crab (*Cancer oregonensis*), lyre crab (*Hyas lyratus*), hermit crab (Paguridae), and unidentified decapods
(3) Other benthic invertebrates: unidentified tunicates; unidentified gastropods and bivalves; bryozoans; ribbon worms; polychaetes; brittle stars; sea urchins; and invertebrate fragments
(4) Gadidae: walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*) and unidentified gadids
(5) Small schooling fishes: Pacific herring (*Clupea pallasii*); Pacific sandlance (*Ammodytes hexapterus*) and capelin (*Mallotus villosus*)
(6) Pleuronectidae: flathead sole (*Hippoglossoides elassodon*), rock sole (*Lepidopsetta spp.*), butter sole (*Pleuronectes isolepis*), and unidentified flatfishes
(7) other demersal fishes: rockfishes (Scorpaenidae), pricklebacks (*Lumpenus* spp.) unidentified poachers (Agonidae), skates (Rajidae), sculpins (Cottidae) including *Triglops* spp., northern sculpin (*Icelinus borealis*), yellow Irish Lord (*Hemilepidotus jordani*), and unidentified sculpins.
(8) Unidentified fishes: This category could possibly include members of other fish categories.
(9) Seabird: crested auklet (*Aethia cristatella*).

In a comparative review of fish stomach contents analysis methods, Hyslop (1980) found that recording the number of stomachs containing one or more individuals in each food category as a percentage of all stomachs, commonly referred to as frequency of occurrence, was the simplest method. Even though frequency of occurrence gives little indication of the relative amount of each food category, it does present a qualitative assessment of population-wide food habits (Hyslop 1980; Cortés 1977). Frequency of occurrence of each prey category was used to measure relative importance of prey in the diet of a predator species at the rookery, and is defined as:

# of stomachs in which prey was found ÷ Total # of stomachs

where the number of stomachs in which prey was found for a stomach collection sample event is divided by the total number of stomachs collected during the same sampling event. The frequency of occurrence approach considers only presence-absence of a prey taxon and is not an estimation of the number or weight of prey species consumed.

The indices used above were meant as simple descriptors of diet composition and were assumed to reflect prey availability of commonly consumed prey groups near the rookery. Rigorous statistical comparisons of diet composition or prey availability among rookeries was not possible because the variance of the estimators was not known (Mueter and Norcross 1998; Holladay et al. 2000).

RESULTS

Acoustically derived relative biomass estimation at Ugamak Island

The relative biomass densities reported during Ugamak Island hydroacoustic prey assessment surveys should be considered to be a relative index of midwater biomass, rather than an absolute estimate.

Mean relative biomass densities were calculated for Ugamak Island for summers 1995-98 (Fig. 7) and winters 1997-99 (Fig. 8) (Table 1). Average relative biomass densities were calculated annually and seasonally for each transect by depth strata. Geographic distribution of relative biomass density during summer surveys was the highest in 1995 on Transect 7 (.0354 kg/m^2) and lowest on Transect 5 (.0003 kg/m^2) in 1996 (Fig. 7). During winter surveys geographic distribution of relative biomass density was much higher than summer relative density with the highest density on Transect 4 (.1750 kg/m^2) in 1999. The lowest relative density during winter occurred on Transect 5 (.00009 kg/m^2) in 1998 (Fig 12). Transect 1 was not surveyed during winter 1999.

Vertical distribution of relative biomass density at Ugamak Island during summer surveys ranged from 16 m in 1996 to 32 m in 1995. During winter surveys vertical distribution
of relative biomass density ranged from 37 m in 1997 to 44 m in 1999 (Fig. 9). Although vertical distribution of relative biomass was located deeper in the water column during winter surveys than during summer surveys it was still within the average diving range of young Steller sea lions at Ugamak Island (0-50 m) (Fadely et al. 2005).

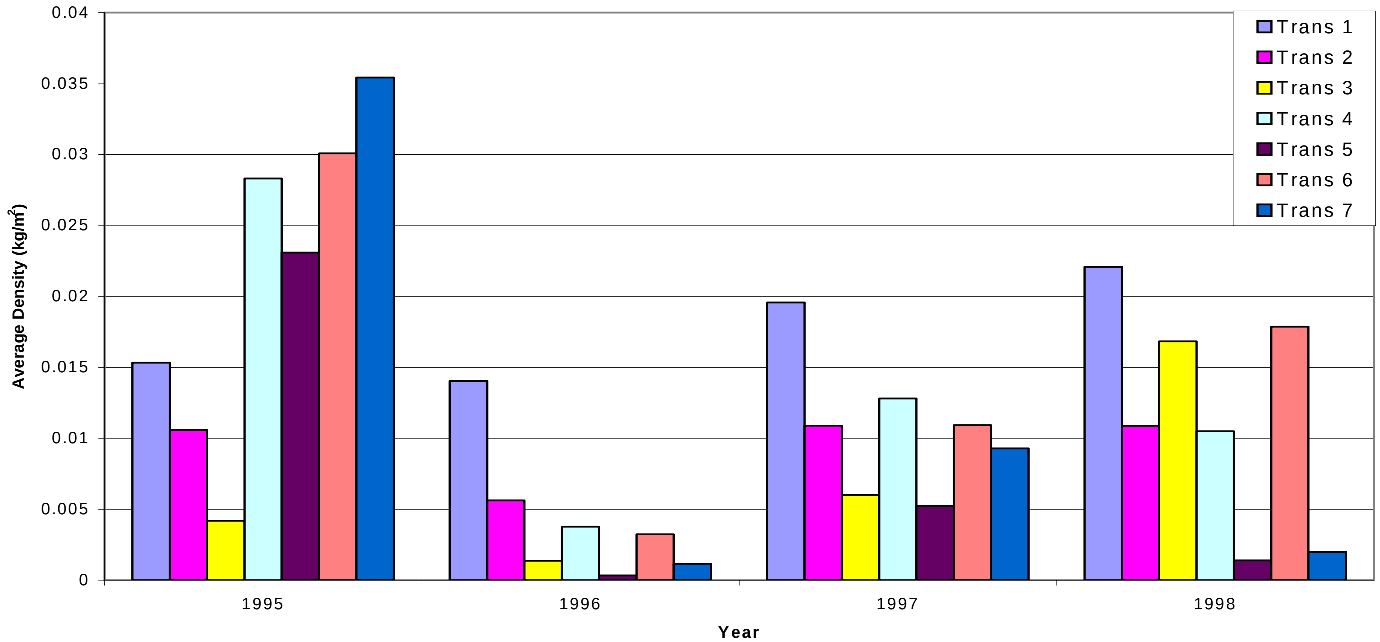


Fig. 7. Summary of Relative Biomass Density by Hydroacoustic Transect and Year Ugamak Island, Alaska, Summer 1995-98.

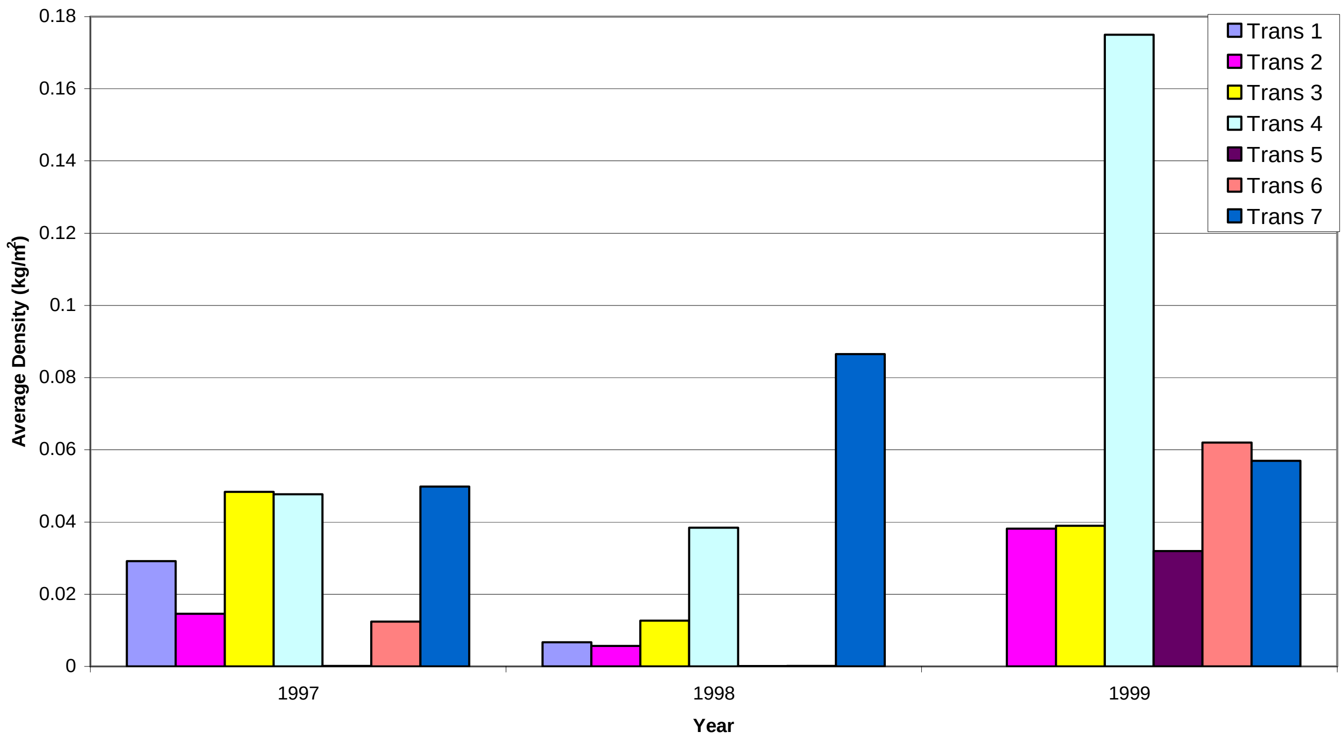


Fig. 8. Summary of Relative Biomass Density by Hydroacoustic Transect and Year Ugamak Island, Alaska, Winter 1997-99**.**

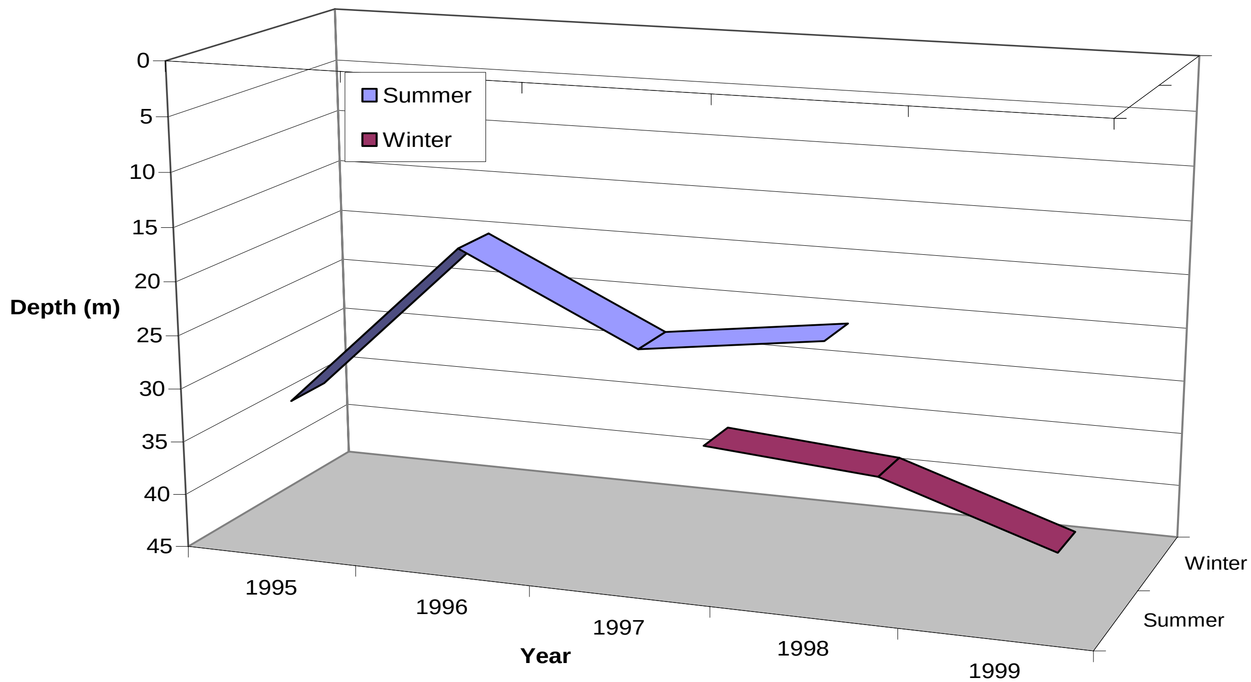


Fig. 9. Vertical Distribution of Biomass Density at Ugamak Island, AK 1995-99

Estimation Variance Analysis (EVA)

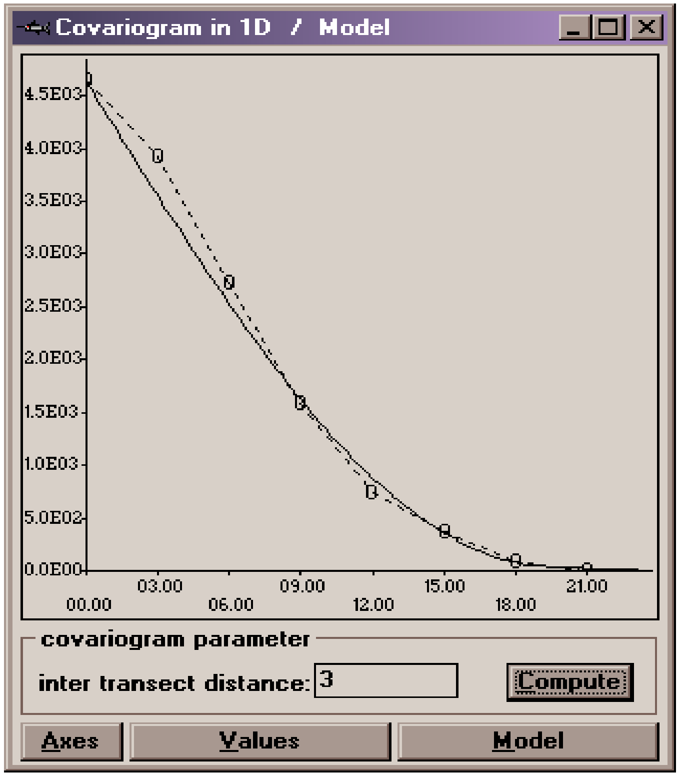
For each survey, estimates of relative biomass density (Q) and relative estimation error (σ_Q/Q^*) were calculated (Table 1). Relative biomass density was highest during winters 1997 and 1999 and lowest during summer 1996. Relative estimation errors were highest during summer 1998 and winters 1997 and 1998, and about the same during summers 1995, 1996, and 1997 and winter 1999 (Table 1). The Ugamak Island survey variance estimates using EVA ranged from 17.4 to 52.1% for summer surveys and 19.0 to 39.4% for winter surveys (Table 2). Classical random statistical sampling estimates showed dramatic differences from the EVA results. Summer surveys ranged from 49 to 112% while winter surveys ranged from 46 to 108% (Table 2).

Cumulate values were calculated for each survey transect by summing the voltage returns in each depth strata then calculating a total voltage return (Q) for each transect (Table 1). A histogram of the transect cumulates was graphed for each survey and a model was fitted to the raw covariogram values. Raw covariogram values are influenced by the amount of relative biomass present, which varies interannually and interseasonally. The shape of the covariogram plot describes the degree of autocorrelation in the data in 1D. A curved line on the covariogram indicates patchiness in the distribution of relative biomass whereas a straight line indicates a more uniform distribution in relative biomass. Covariogram models of relative biomass estimates during summers 1995 and 1998 show more sharply curved lines, indicating a more patchy relative biomass distribution than those of summers 1996 and 1997 (Fig. 7). During winters 1997 and 1998 the covariogram models show sharper curved lines and thus more patchy relative biomass distribution than during winter 1999 (Fig. 8). The covariogram model for summer 1997 shows the most uniform distribution of relative biomass of all of the Ugamak Island surveys during summer or winter (Figs. 6 and 7).

Histograms from transect cumulate data show that during summer 1995 relative biomass was higher on transects 4, 5, and 6 than on other transects; in summer 1996 relative biomass was higher in transects 1, 2 and 4; in summer 1997 relative biomass was higher in transects 2 and 3; in summer 1998 relative biomass was higher in transect 4 (Fig. 9).

During winter surveys transect cumulate data show that during winter 1997 relative biomass was higher on transects 3 and 4; in winter 1998 relative biomass was higher on transects 3, 4 and 7; in winter 1999 relative biomass was higher on transect 3 but more uniformly distributed throughout the survey area than in previous winter surveys (Fig. 10).

Ugamak – Summer 1995



Ugamak – Summer 1996

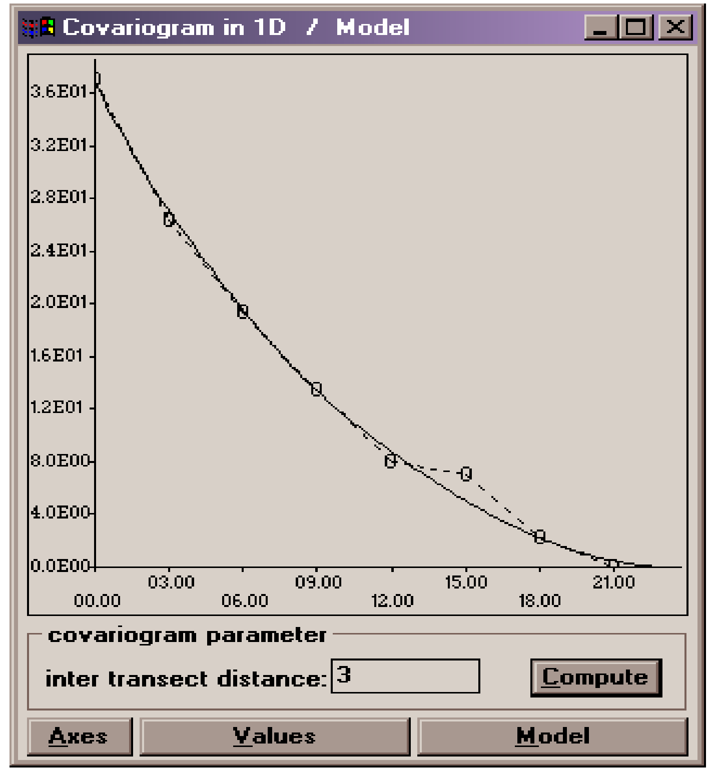
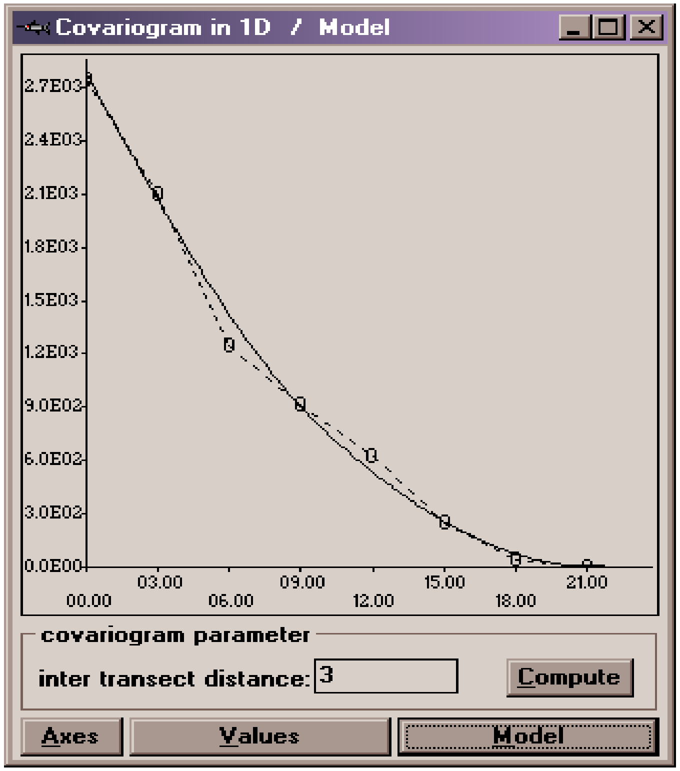


Fig. 10. Survey Variance Estimation Covariograms, Summer 1995-98, Ugamak Island, Alaska

Ugamak – Summer 1997



Ugamak – Summer 1998

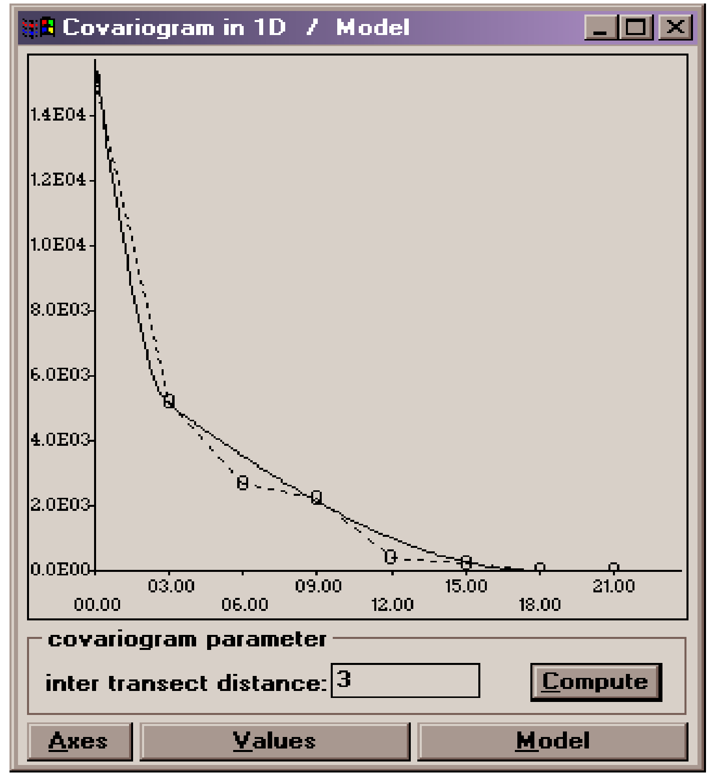


Fig. 10. Survey Variance Estimation Covariograms, Summer 1995-98, Ugamak Island, Alaska

Ugamak – Winter 1997 Ugamak – Winter 1998 Ugamak – Winter 1999

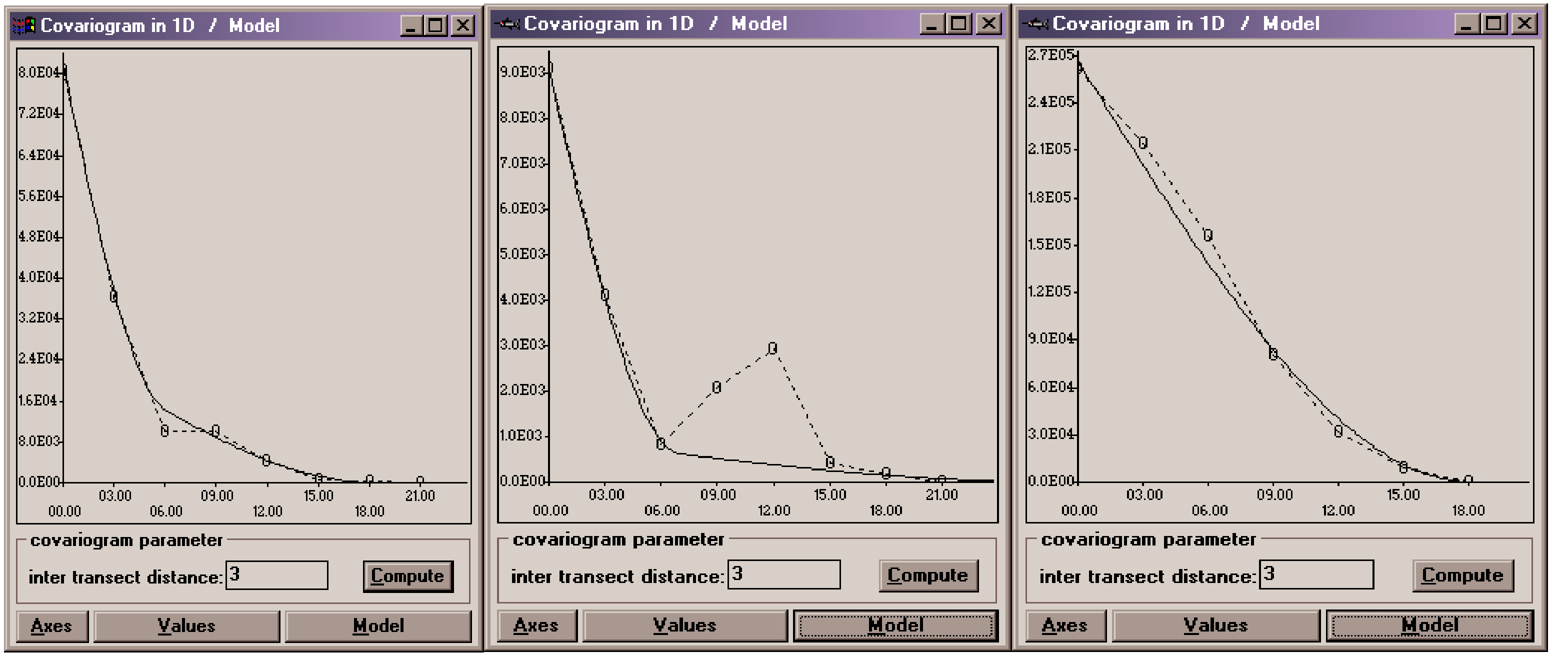
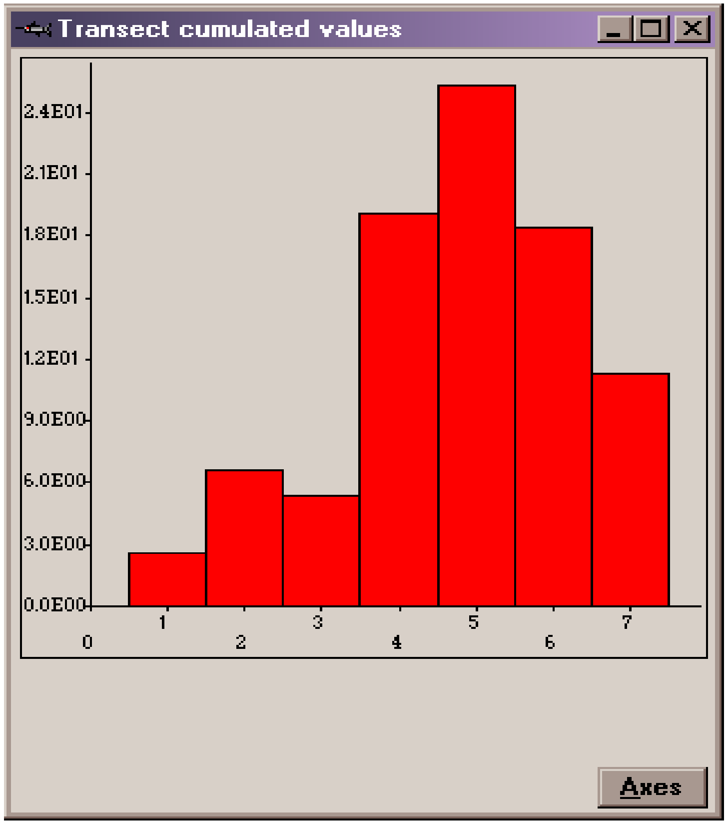


Fig. 11. Survey Variance Estimation Covariograms, Winter 1997-99, Ugamak Island, Alaska

Ugamak – Summer 1995



Ugamak – Summer 1996

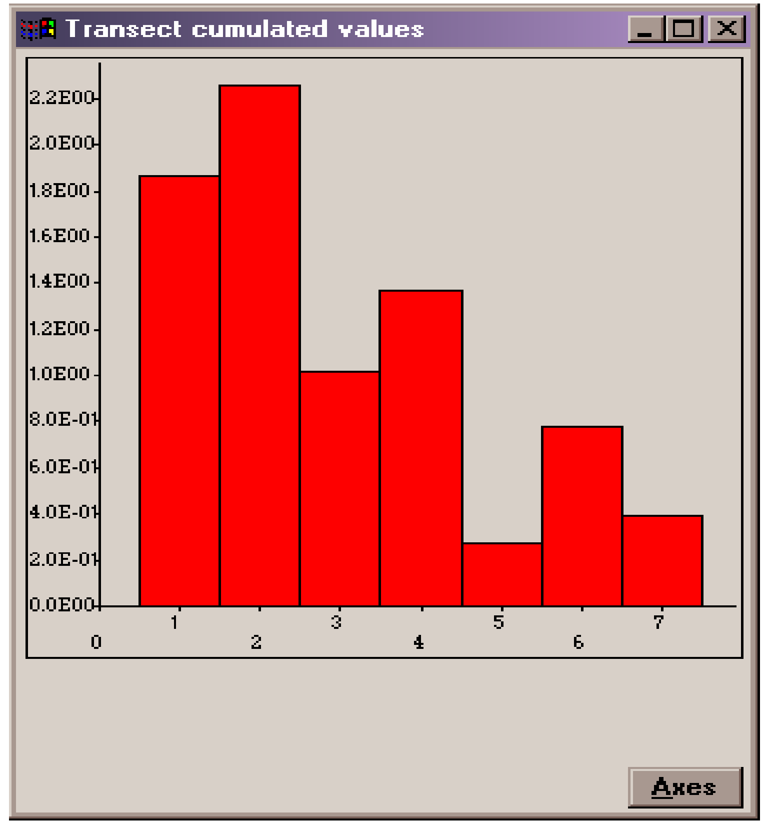
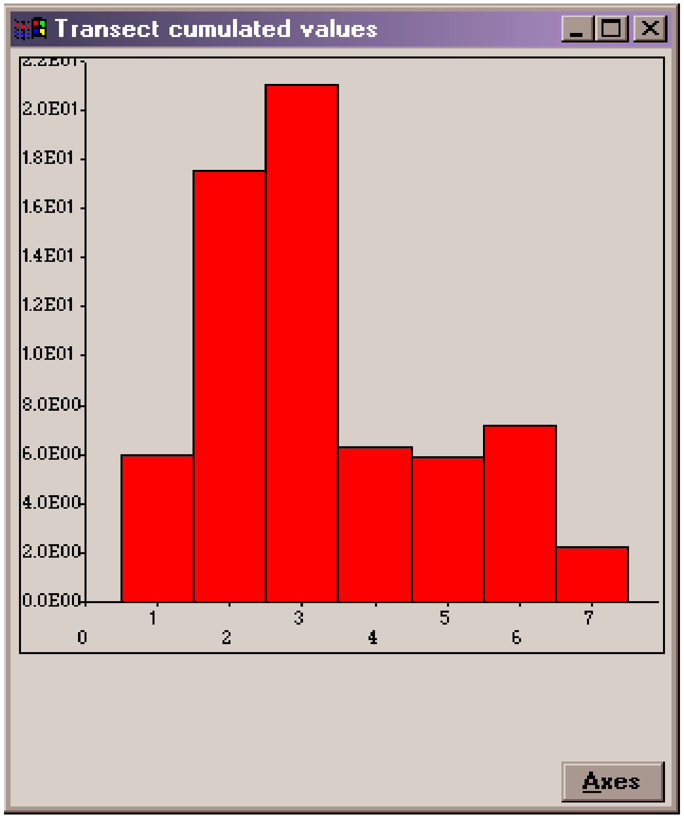


Fig.12. Hydroacoustic Transect Cumulates, Summer 1995-98, Ugamak Island, Alaska

Ugamak – Summer 1997



Ugamak – Summer 1998

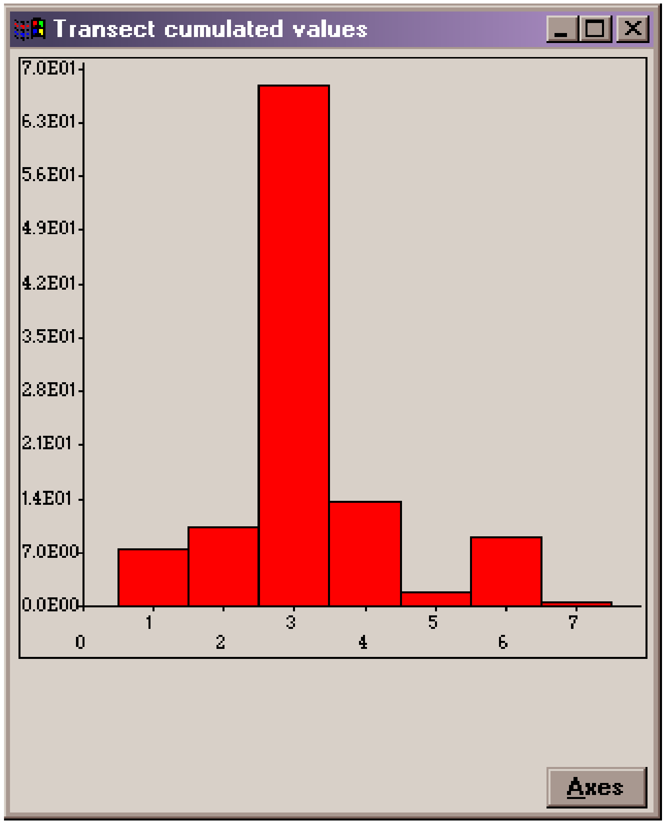


Fig 12. Hydroacoustic Transect Cumulates, Summer 1995-98, Ugamak Island, Alaska

Ugamak – Winter 1997 Ugamak – Winter 1998 Ugamak – Winter 1999

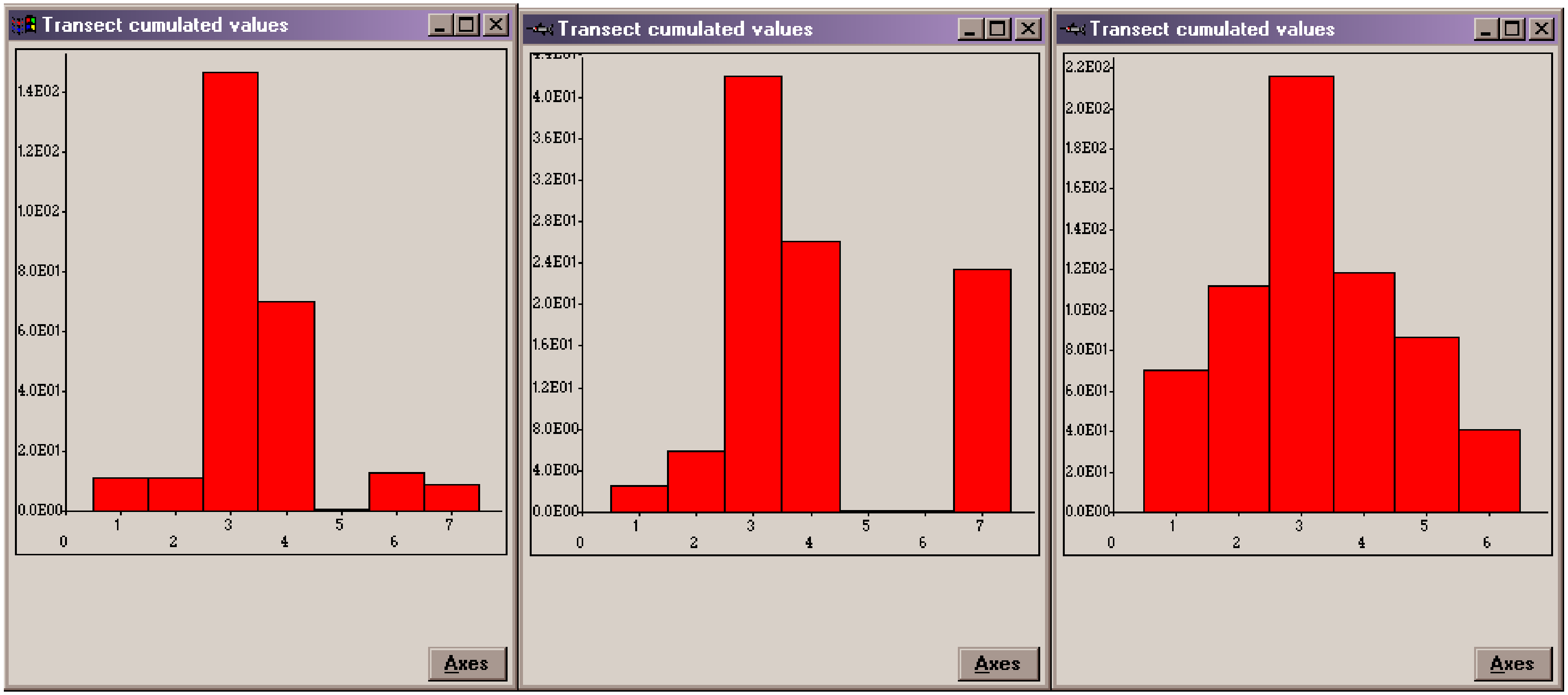


Fig. 13. Hydroacoustic Transect Cumulates, Winter 1997-99, Ugamak Island, Alaska

Table 1. Estimates of relative biomass density (Q) and relative estimation error by season and year at Ugamak Island,AK, summer 1995-1999.

Survey Year	Season	Spacing (nm)	Number of Transects	Q	Relative est. error
1995	summer	3	7	265.66	.0873
1996	summer	3	7	23.87	.0097
1997	summer	3	7	197.94	.0953
1998	summer	3	7	331.08	.2607
1997	winter	3	7	783.85	.1969
1998	winter	3	7	300.81	.1680
1999	winter	3	6	1930.88	.0924

Table 2. Survey variance using EVA and random variance estimates during surveys at Ugamak Island, AK, Summer and Winter 1995-99.
("----" indicates no survey).

	Summer		Winter	
Year	EVA	Random Variance Est.	Random EVA	Variance Est.
1995	17.4%	50%	------	------
1996	19.46%	49%	------	------
1997	19.1%	56%	39.4%	108%
1998	52.1%	112%	34.0%	86%
1999	------	-------	19.0%	46%

Trawl surveys

Midwater trawl surveys

In summer 1995 infrequent echo sign was seen on hydroacoustic survey transects at Ugamak Island, particularly during the day, with the exception of what was believed to be occasional patches of Pacific herring (*Clupea pallasii*) and capelin (*Mallotus villosus*). Pacific herring was identified at the surface twice during survey transects. During night transects, the scattered day time echo sign coalesced to form long bands or layers which were rarely seen on the vessel's 50 kHz sounder, suggesting that the return echo signal was either from zooplankton or fishes without a swim bladder. Unfortunately, trawling during these transects was not conducted due to insufficient wire on the net reel to reach the target species layer which was located near the bottom. Past experience from other midwater tows at other locations indicated that the echo sign was probably from 0-aged fish (usually gadids) or euphausiids. The only other significant echo sign believed to be something other than zooplankton was observed outside of the Ugamak Island study area at the southeast corner of the Chowiet Island study area. Very strong sign was seen at the bottom (>150 m) on both the BioSonics 120 kHz system and ship's 50 kHz system. An attempt was made to sample this layer, however, was unsuccessful due to the depth of the echo sign layer and the amount of wire on the net reel. Tows made in the same area by the NOAA ship RV Miller Freeman in April 1995 found a similar aggregation of fish and identified it as age-1 and age-2 walleye pollock (*Theragra chalcogramma*).

In summer 1995-96 the Isaacs Kidd Midwater trawl (IKMT) was used during midwater trawl sampling. In the summer 1996 well defined midwater layers were seen at Ugamak Island. As in 1995, significant midwater fish sign was seen at Ugamak during the day, and was believed to be due to occasional patches of Pacific herring (*Clupea pallasii*) and capelin (*Mallotus villosus*). However, no midwater tows were conducted at Ugamak Island in 1996 due to the depth of the target species layer and the limitations of the wire on the net reel (Table 3)

Table 3. Midwater and neuston trawls at Ugamak Island, AK, summer and winter 1995-99.

Cruise	Haul #	Haul Date	Begin Lat/Long	End Lat/Long	Location	Net	Species	Common Name	# Fish
95-1	MT6	7/15/1995	54 08.70N 164 52.6W	54 10.50N 164 54.60W	Avatanak/Ugamak	IKMT	*Theragra chalcogramma*	Walleye pollock	
							Ammodytes hexapterus	juvenile sandlance	1
								Euphausiids	
								Calanus copepods	
								Amphipod	
								Crab zoea	
95-1	MT7	7/17/1995	54 16.16N 164 55.20W	54 17.42N 164 57.08W	Ugamak	IKMT		Gadids, age 0 & 1	
97-1	M03	3/8/1997	54 13.85N 164 45.44W	54 45.65N 164 45.11W	Ugamak	HerringTrawl	*Hexagrammos sp.*	*Hexagrammos sp.*	1
								Euphausiids	
97-1	M04	3/10/1997	54 20.58N 164 48.71W	54 20.60N 164 50.59W	Ugamak	HerringTrawl	*Triplops forficata*		2
97-1	N02	3/8/1997	54 14.13N 164 46.86W	54 14.13N 164 47.42W	Ugamak	Neuston	*Hexagrammos sp.*	*Hexagrammos sp.*	12
97-1	N03	3/10/1997	54 21.68N 164 53.18W	54 21.68N 164 51.93W	Ugamak	Neuston	*Hexagrammos sp.*	*Hexagrammos sp.*	1
97-2	M01	7/11/1997	54 08.43N 164.32.00W	54 07.67N 164 32.68W	Ugamak	HerringTrawl	*Ammodytes hexapterus*	juvenile sandlance	1
								larval flatfish	
								Larval gadids	
								Euphausiids	1
98-1	M01	3/20/1998	54 13.00N 164 28.80W	54 12.67N 164 30.06W	Ugamak	HerringTrawl	*Mallotus villosus*	larval capelin	15
98-2	N02	7/8/1998	54 4.07N 164 52.07W	54 04.37N 164 53.78W	Ugamak	Neuston		Larval fish	1
								Pteropods,Amphipods	
99-1	N01	3/21/1999	54 12.84N 164 54.04W	54 12.73N 164 55.15W	Ugamak	Neuston	*Ammodytes hexapterus*	Larval sandlance	15

During 1997-99 surveys the modified midwater herring trawl was introduced and enabled sampling of older aged fishes as well as age-0 gadids, euphausiids, and jellyfish that were captured using the IKMT net. In summer 1997, one midwater trawl was made with the herring trawl at Ugamak Island to identify echo sign observed in the upper 30 m. The catch from this tow included larval gadids, flatfish, Pacific sandlance, capelin, euphausiids, and jellyfish. Larval fishes obtained were frozen for later identification in the laboratory. During the summer 1998 cruise one midwater tow, two neuston surface tows and one vertical plankton tow were conducted to verify echo sign. Indication of echo sign at Cape Sarichef, northwest of Ugamak at the entrance to the Bering Sea, prompted a midwater tow at 50 m depth. Samples collected from this tow included very large jellyfish and 0-age walleye pollock. One neuston tow was conducted at Ugamak Island to verify echo sign near the surface and produced a catch of pteropods, amphipods, and larval fishes. Otherwise relatively little echo sign was seen during Ugamak Island survey transects (2) (Table 3).

Ugamak Island surveys were expanded to include winter survey transects during February/March 1997-99. During the winter 1997 survey at Ugamak Island two midwater trawls were made with the modified herring trawl and one with a neuston net. The midwater trawls caught a variety of fish, including adult walleye pollock, hexagramid fish species, as well as euphausiids and a few jelly fish.

Winter 1998 surveys rarely indicated strong echo sign during the day and on few occasions at night. Night time transects at Ugamak revealed faint, scattered echo sign of zooplankton and fish after 1-2 am. A tow with the herring trawl on a layer of widely scattered stronger echo sign revealed a catch composition of adult walleye pollock, larval capelin, and euphausiids.

The winter 1999 survey once again was characterized by sparse echo sign during the day and on few occasions at night. Night time transects at Ugamak showed faint scattered echo sign mostly likely that of zooplankton and small fish.

A Neuston tow on a vertical layer of strong echo sign at Ugamak showed it was composed of larval Pacific sandlance and worms (Fig. 2) (Table 3). Very rough weather prevented midwater trawling during the 1999 survey.

Neuston Tows

Neuston plankton tows were conducted at Ugamak Island during summer 1998 due to large concentrations of feeding seabirds on the surface of the water and on acoustic signal return of prey concentration near the surface. Species caught during this tow included pteropods, larval fish and amphipods. During winter 1997 the neuston tows were made to identify the echo sign being fed upon by murres and auklets. Catches were generally composed of juvenile hexagramid fishes, euphausiids, and copepods. During winter 1999 very rough weather conditions prevented midwater trawling and instead a Neuston tow was made to verify echo sign with the catch composed of larval Pacific sandlance (Fig. 2) (Table 3).

All larval fish samples collected from tows were either identified in the field or by fisheries scientists at the University of Alaska Fairbanks (UAF), or NMFS Recruitment Processes Program of the Alaska Fishery Science Center in Seattle, Washington.

Longline Surveys

Diet composition of predatory fish

Large predatory groundfish, such as Pacific cod and Pacific halibut were utilized as sampling tools in untrawlable areas around Ugamak Island during surveys. Stomach contents of these groundfish predators were assumed to reflect the abundance of common prey species in the vicinity of Ugamak Island.

Generally, each longline set caught between 0 and 34 fish (Table 4). Fishes, particularly gadids and osmerids, were a major component of Pacific halibut diets near the rookery at Ugamak Island in 1996, with 79% frequency of occurrence. In summer 1996, 5 Pacific halibut and 16 Pacific cod were caught at Ugamak Island by longline surveys. The Pacific halibut caught averaged 131 cm in length (range 116-138 cm). Pacific cod sampled by longline averaged 65 cm in length (range 56-70 cm). Proportionally more Pacific cod contained prey than did Pacific halibut and both consumed demersal and pelagic prey species (Holladay et al. 2000). In summer 1996 Pacific cod at Ugamak Island consumed a relatively large frequency of occurrence of crustacea (81%), other demersal fish (50%), and small schooling fish (50%), followed by mollusks (44%), other invertebrates (31%) and flatfish (6%) (Fig. 14). Pacific halibut consumed other demersal fish (80%), gadids (40%), cephalopods (20%) and mollusks (20%) during summer 1996 (Fig. 15) (Table 5).

In summer 1997 stomach samples were collected from 17 Pacific halibut and 6 Pacific cod at Ugamak Island during longline surveys. Two additional halibut were caught during the same time frame by baited hook and line and one additional cod was caught by beam trawl at Ugamak. The Pacific cod averaged 67 cm in size (range 58.5-75 cm) with no empty stomachs reported. Pacific cod from this collection consumed crustacea (100%), mollusks (57%), small schooling fish (43%), benthic invertebrates (42%), other demersal fish (28%) and

Table 4. Longline set log at Ugamak Island, AK, 1995-98.

Tow	Date	Time	Area	Beginning Lat. (N)	Long. (W)	Lat. (N)	Ending Long. (W)	Dur. (min)	Depth (m) min.	Depth (m) max	Pred.Sp.	#Stomachs
LL-1	6/27/95	3:30	Ugamak	54 11.64	164 49.08	--	--	480	32		Empty	0
	6/30/96	4:30	Ugamak	54 07.20	164 28.80	54 07.20	164 28.20	120	40		Empty	0
L01	3/10/97	6:10	Ugamak	54 07.20	164 28.80	54 07.20	164 28.20	140	40	60	Halibut	1
											Pcod	8
L1	7/11/97	5:40	Ugamak	54 06.60	164 28.50	54 06.60	164 28.19	120	49		Halibut	1
											Pcod	8
LL2	3/20/98	17:15	Ugamak	54 43.80	164 28.20	54 36.00	164 28.80	120	42	62	Halibut	4
											Pcod	10

Table 5. Frequency of occurrence of prey in the diets of Pacific halibut and Pacific cod at Ugamak Island, Alaska from 1995-98

Date	Predator	N	N Empty	Length range (cm) (mean)	Cephalopod	Crustacea	Mollusca	Other benthic invert	Gadidae	Sm. school fish	Pleuronectidae	Other demersal fish	Unid. fish
6/1996	P. Cod	16	0	56 - 70 (65)	0%	81%	44%	31%	19%	50%	6%	50%	0%
6/1996	P. halibut	5	1	116 - 138 (131)	0%	20%	20%	0%	40%	0%	0%	80%	0%
3/1997	P. halibut	1	1	(98)	0%	0%	0%	0%	0%	0%	0%	0%	0%
3/1997	P. Cod	8	1	52 -75 (68)	0%	85%	14%	71%	0%	28%	14%	42%	14%
6/1997	P. Cod	7	0	58.5 - 75 (67)	14%	100%	57%	42%	0%	43%	0%	28%	28%
6/1997	P. halibut	23	4	69 - 160.5 (112)	9%	13%	0%	13%	35%	13%	0%	0%	17%
3/1998	P. halibut	4	2	94 - 149 (118)	0%	0%	0%	0%	50%	0%	50%	0%	0%

Date	Predator	N	N Empty	Length range (cm) (mean)	Cephalopod	Crustacea	Mollusca	Other benthic invert	Gadidae	Sm. school fish	Pleuronectidae	Other demersal fish	Unid. fish
3/1998	P. Cod	10	0	53 - 76 (61)	10%	40%	10%	20%	20%	10%	0%	50%	20%
6/1998	P. halibut	22	12	69 - 125 (96)	10%	10%	0%	10%	80%	10%	0%	10%	10%
6/1998	P. Cod	3	0	46 - 57 (52)	67%	99%	0%	67%	0%	0%	0%	33%	0%

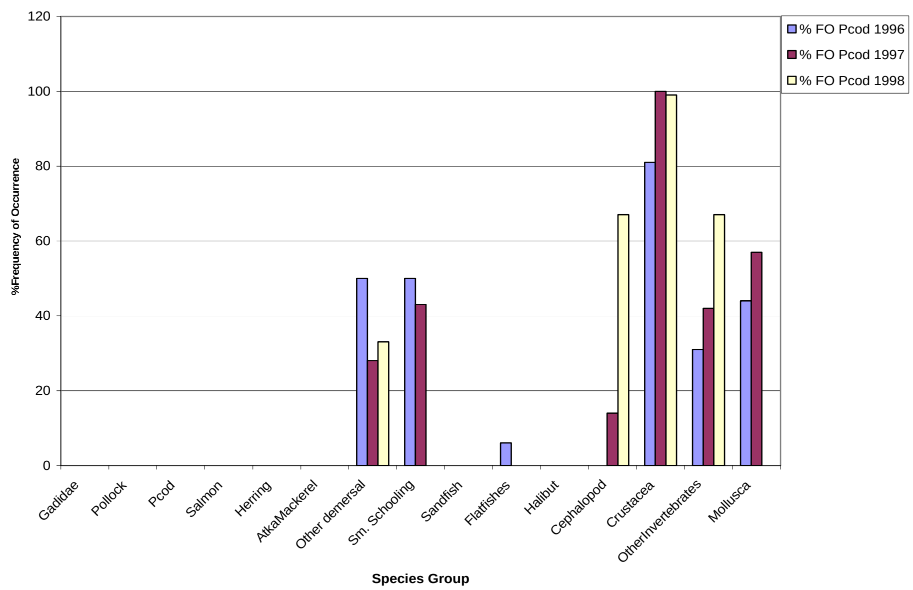
cephalopods (14%) (Fig. 14). Pacific halibut averaged 112 cm in size (range 69-160 cm) with 4 empty stomachs reported. Pacific halibut contained proportionally more prey than Pacific cod and consumed gadids (35%), small schooling fish (13%), crustacea (13%), other benthic invertebrates (13%), and cephalopods (9%) (Fig. 15) (Table 5).

During summer 1998 stomach samples were collected from 22 Pacific halibut and 3 Pacific cod at Ugamak Island during longline surveys. The Pacific cod averaged 52 cm in size (range 46-57 cm) with no empty stomachs reported. Pacific cod at Ugamak Island consumed a relatively large frequency of occurrence of crustacea (81%), other invertebrates (67%), cephalopods (67%), and other demersal fish (33%) (Fig. 14). Pacific halibut averaged 96 cm in size (range 69-125 cm) with 12 empty stomachs reported during summer 1998. Pacific halibut consumed gadids (80%), small schooling fish (10%), other demersal fish (10%), cephalopods (10%), crustaceans (10%) and other invertebrates (10%) (Fig. 15) (Table 5).

Longline surveys during winter 1997 collected stomach samples from 1 Pacific halibut and 8 Pacific cod at Ugamak Island. The Pacific cod averaged 68 cm in size (range 52 -75 cm) with 1 empty stomach reported. Pacific cod consumed a relatively large frequency of occurrence of crustacea (85%), followed by other invertebrates (71%), other demersal fish (42%), small schooling fish (28%), flatfish (14%), and mollusks (14%) (Fig. 16). The one Pacific halibut caught during winter 1997 measured 98 cm in length had an empty stomach (Fig. 17) (Table 5).

During winter 1998 stomach samples were collected from 4 Pacific halibut and 10 Pacific cod at Ugamak Island during longline surveys. The Pacific cod averaged 61 cm in size (range 53 - 76 cm) with no empty stomachs reported.

(A)



(B)

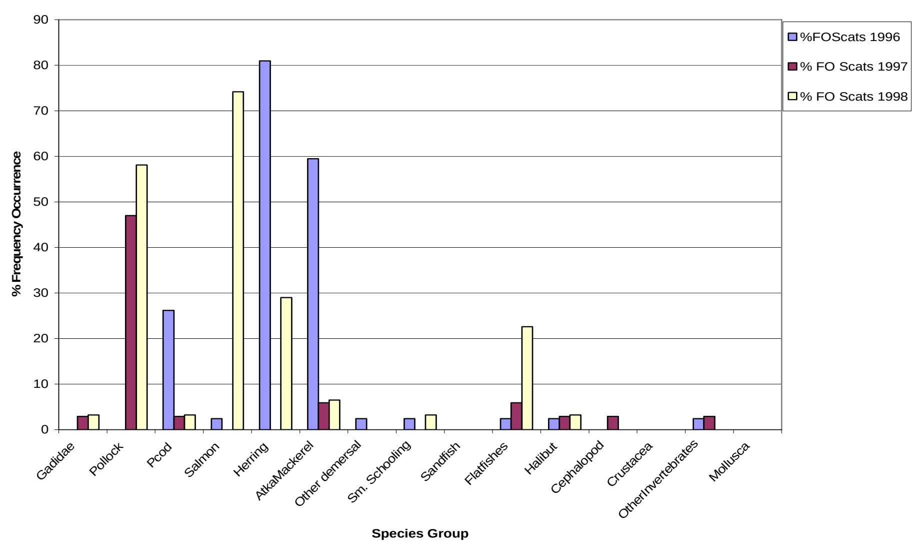
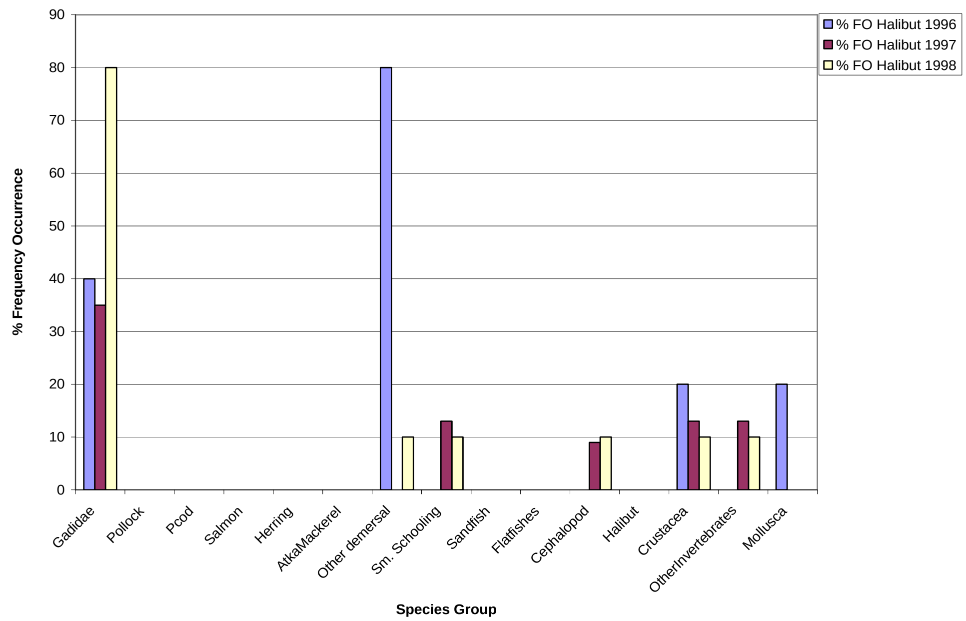


Fig. 14. Pacific Cod stomach contents from longline surveys (A) and Steller sea lion scat samples (B) Summer 1996-98 at Ugamak Island, Alaska.

(A)



(B)

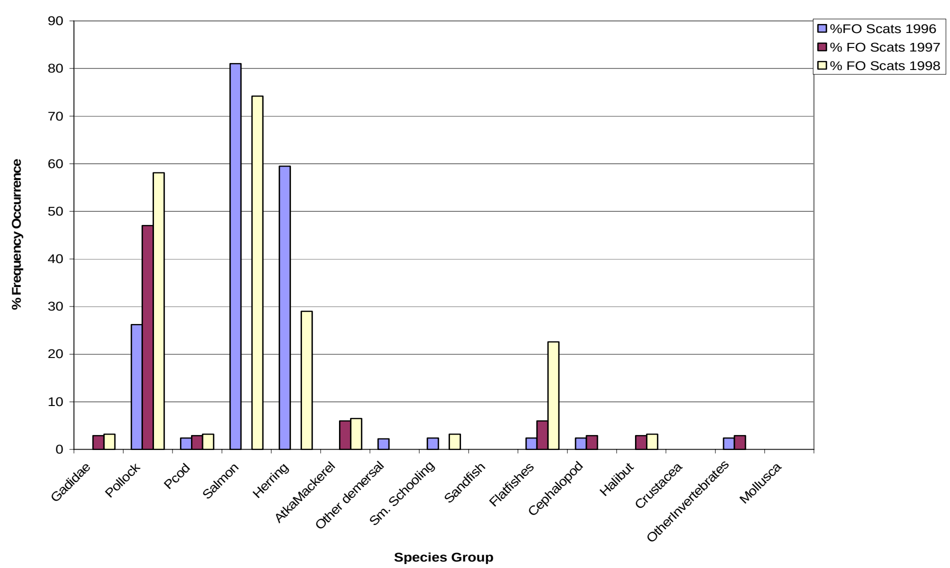
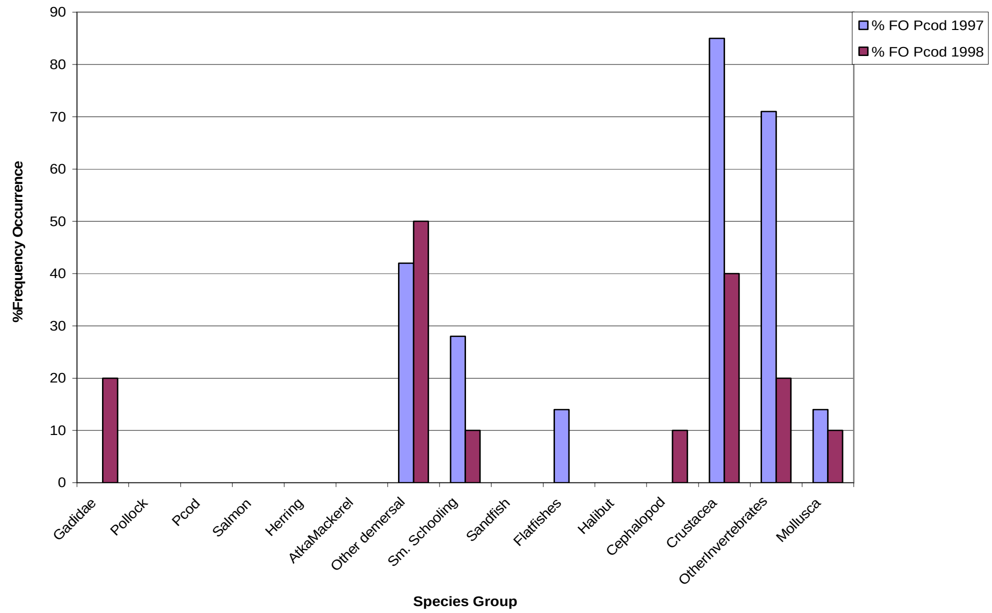


Fig. 15. Halibut stomach contents from longline surveys (A) and Steller sea lion scat samples (B) Summer 1996-98 at Ugamak Island, Alaska.

(A)



(B)

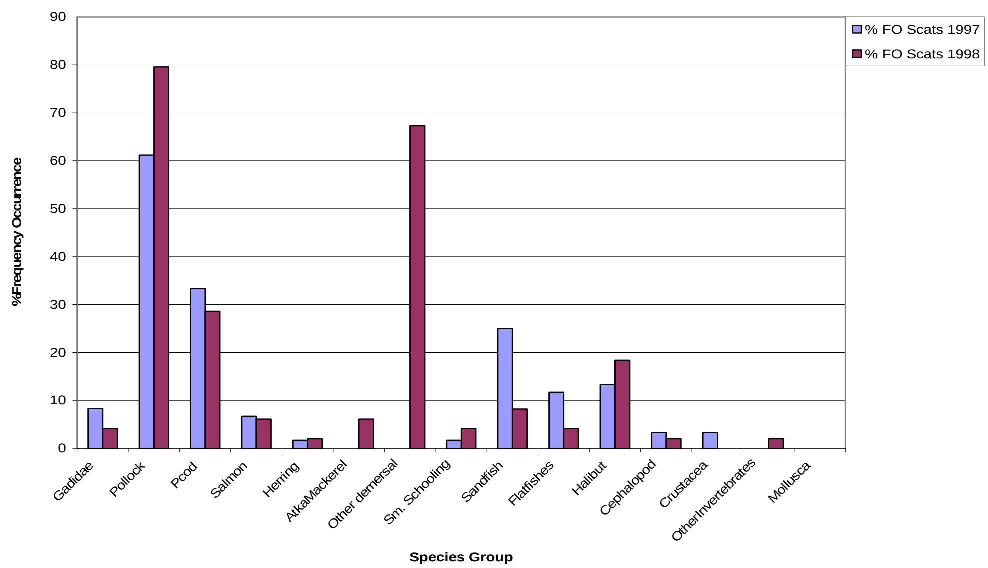
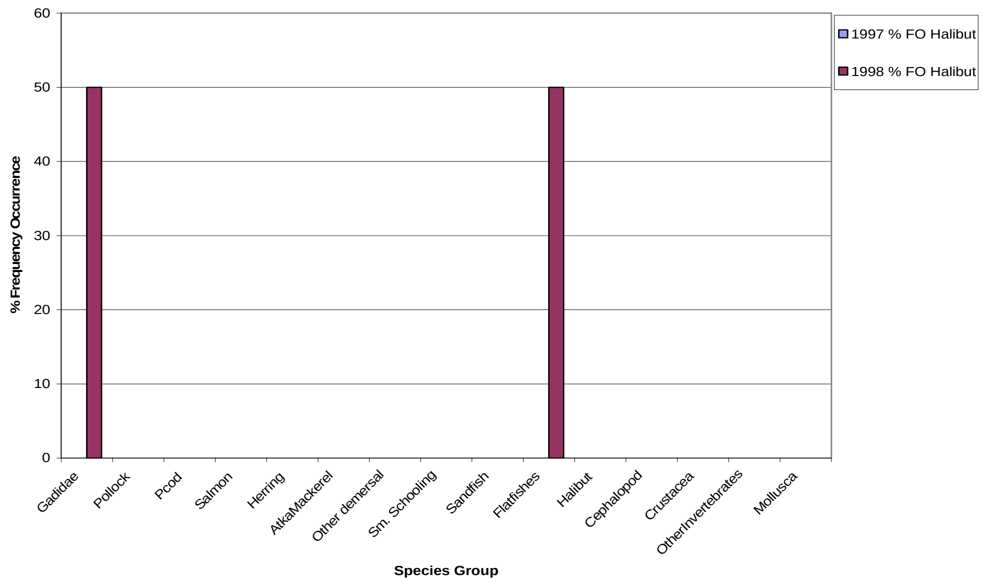


Fig. 16. Pacific cod stomach contents from longline surveys (A) and Steller sea lion scat samples (B) Winter 1997-98 at Ugamak Island, Alaska.

(A)



(B)

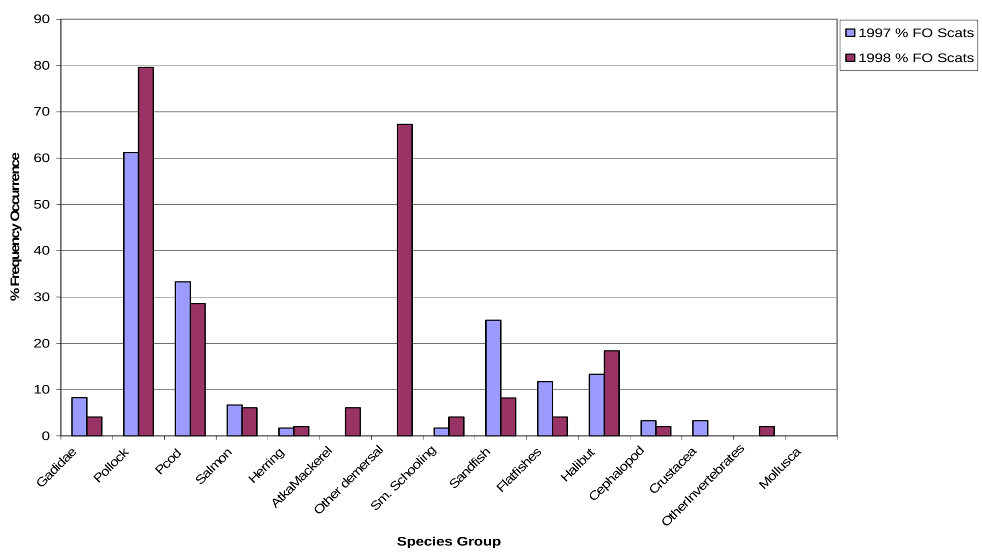


Fig. 17. Halibut stomach contents from longline surveys (A) and Steller sea lion scat samples (B) Winter 1997-98 at Ugamak Island, Alaska.

Pacific cod at Ugamak Island consumed a relatively large frequency of occurrence of other demersal fish (50%) crustacea (40%), gadids (20%), other invertebrates (20%), small schooling fish (10%), cephalopods (10%), and mollusks (10%) (Fig. 16) (Table 5). Pacific halibut averaged 118 cm in size (range 94-149 cm) with 2 empty stomachs reported during winter 1998. Pacific halibut consumed gadids (50%) and flatfish (50%) (Fig. 17) (Table 5).

DISCUSSION

Acoustically derived relative biomass estimation at Ugamak Island

For many years several species of seabirds and pinnipeds in the GOA and Bering Sea have exhibited signs of food stress such as low productivity, low recruitment, die-offs, and population declines (Piatt and Anderson 1996). Along the Alaska Peninsula, and in the EAI, the continental shelf narrows and there is less shelf habitat for commonly occurring forage fish species that are important to piscivorous seabirds and marine mammals, such as sandlance and capelin. The EAI area is notable for its dominance by only a few superabundant species (e.g. euphausiids, pollock, tufted puffins, shearwaters), a conspicuous scarcity of bank seabirds (e.g. murres and kittiwakes), a once large population of Steller sea lions, and a dynamic marine environment in the island passes between the GOA and Bering Sea. The food web found there is also typical of those found in the middle and outer shelf domains of the Bering Sea. The advection of fish and plankton to relatively stationary consumers appears to be an important phenomenon in this and other ecosystems (e.g. the northern Bering and Chukchi seas; Piatt et al. 1991, 1992).

Pelagic juvenile (age 0+) pollock are usually the dominant prey of piscivorus seabirds in this area during summer (Byrd et al. 1997). Juvenile pollock advected by prevailing currents in this area represent a fundamentally distinct food resource for puffins and other seabirds. The closest known spawning stocks are in the Shumagin Islands, the eastern Bering Sea shelf north of Unimak Island, and Bogoslof Island (Piatt and Hatch, unpubl. data, Piatt pers.comm.). While pollock recruitment depends largely on predation and environmental variability, the functional relationship between young pollock and their predators is not clear. Recognizing that there are interannual fluctuations in food webs within habitats, the Ugamak Island system may not reflect historical patterns of forage fish abundance (Byrd et al. 1997).

Estimation Variance Analysis (EVA)

Geostatistics offer the ecologist a variety of tools to organize and summarize spatial patterns. Applied statistical methods, such as geostatistics, are needed in ecological studies for modeling the strength and areal extent of spatial correlations. The geostatistical toolbox contains many instruments for characterizing not only the spatial continuity inherent in an organism's distribution or the spatial dependence of suspected environmental components, but also the spatial interdependence between the organism and its environment.

Geostatistical estimation of spatial patterns are more appropriate than classical random estimation of variance methods due to spatial dependency of the data. Ecological studies that produce data not amenable to standard parametric statistical treatment because of spatial or temporal autocorrelation may significantly benefit from geostatistical analysis. Autocorrelation is a potential problem in many if not most field sampling strategies, and its presence should be routinely evaluated. The application of geostatistics to studies with data that exhibit autocorrelation and to studies dealing explicitly with spatial or temporal patterning may substantially aid their interpretation (Robertson 1987). The EVA method of variance estimation is proving to be useful for monitoring abundance estimations over the years, on systematic surveys.

Relative biomass densities from Ugamak Island SMMOCI surveys were separated by large areas of empty water during some surveys and increasing or decreasing the intertransect spacing was considered. If relative biomass occurring between 0 and 3 nm was more uniformly distributed then increasing the intertransect spacing to greater than 3 nm could have been considered. Higher relative biomass produced by more uniformly distributed echo sign was seen during the winter 1999 survey. During most Ugamak Island surveys, however, relative biomass was more dispersed and patchy between 0-3 nm and if any intertransect spacing changes were made it would have been better to narrow the spacing to less than 3 nm. With a greater time and budget allotment for the SMMOCI project a decrease in transect spacing may have been an option worth consideration. However, ship-based surveys are expensive and a decrease in transect spacing would have added more transects to the survey area, decreased the already limited amount of time for trawling, limited the time to complete an entire survey of the area, and consequently cost more in ship time and money.

Trawl Surveys

Midwater trawl surveys

Opportunistic midwater trawling during hydroacoustic transect surveys is a common method of verifying echo sign encountered (Gunderson 1993, MacLennan and Simmonds 1992). Therefore, midwater trawling was not intended as a quantitative assessment but rather a qualitative assessment of midwater prey resources during SMMOCI surveys. Midwater trawl survey results demonstrated that there were prey species present that are important to Steller sea lions and piscivorous seabirds within the 20 nm NMFS fishery management area. Prey captured during midwater trawling included species important to predatory fish species such as pollock, age 1 gadids, hexagramids, and sandlance, as well as species which are important to those prey (copepods, euphausiids, age 0 gadids). Additionally these important prey species are present within the 0 to 50 m depth range of foraging juvenile Steller sea lions. With increased ship time and budget midwater trawl surveys could have provided a more quantitative assessment of midwater prey resources available to foraging Steller sea lions and seabirds.

Bottom Trawl surveys

In 1995 a total of 15 bottom trawls were conducted at Ugamak Island by the University of Alaska Fairbanks (UAF) as part of the SMMOCI study. During 1996 and 1997 there were 17 and 22 bottom trawls conducted, respectively (Fig. 6). The number of quantitative tows collected at Ugamak from 1995-97 are indicated in Table A1.

Results from the UAF bottom trawls showed the most abundant species in the total catch from all years combined were rock sole (*Lepidopsetta spp.,* 4339 specimens, 46.2% of total catch), walleye pollock (*Theragra chalcogramma*, 1456 specimens, 15.5% of total catch), Pacific halibut (*Hippoglossus stenolepis,* 927 specimens, 9.9% of total catch), northern sculpin (*Icelinus borealis,* 618 specimens, 6.6% of total catch), *Triglops* spp. (332 specimens, 3.5% of total catch), *Gymnocanthus* spp. (327 specimens, 3.5% of total catch), Pacific cod (*Gadus macrocephalus*, 223 specimens, 2.4% of total catch), slim sculpin (*Radulinus asprellus,* 98 specimens, 1.0% of total catch), and arrowtooth flounder

(*Atherestes stomias*, 91 specimens, 1.0% of total catch). Relative catch composition differed considerably among years. Rock sole was the most abundant species in 1995. However in 1996, catch of walleye pollock (782 specimens, 55.2% of total catch) exceeded that of rock sole. Although in much lower abundance than walleye pollock, Pacific cod were found in the same locations (Fig. 6). Many of these species were present in the diet of Steller sea lions (Merrick et al. 1997, Sinclair and Zeppelin 2002).

Standardized abundances and CPUE

Catch composition was summarized to illustrate species composition of bottom trawl catches by year. Interannual differences in catch composition could only be illustrated in a broad sense due to sampling design and variability in sampling effort in different depth strata. Catch abundances were standardized to the number of fish caught per 1000 m^2 (Mueter and Norcross 1998) (Table A2). Differences in relative species composition were seen between years at Ugamak Island. Gadids dominated catches in 1996, however, few were caught in 1995 or 1997. (Mueter and Norcross 1998; Holladay et al. 2000).

In summer 1995 Ugamak Island bottom trawl surveys caught in order of abundance, Pacific halibut, rock sole, northern sculpin, and walleye pollock. Ugamak Island had among the highest abundances of age-0 walleye pollock, with the average density of over 70 fish per 1000 m^2 at stations sampled near the island in 1996. Pacific cod were also abundant, however, they were found at much lower abundance than walleye pollock (Mueter and Norcross 1998) . In 1997, 30 fish taxa were caught in bottom trawls (Holladay et al. 2000).

Sculpin species occurred in low abundances at Ugamak Island and had no clear spatial patterns of abundance. Arrowtooth flounder were sparse or not observed near the Ugamak Island rookery area (Mueter and Norcross 1998) .

In 1997 the most commonly caught fishes at Ugamak Island were rock sole (76% of tows), Triglops spp. (71% of tows), and northern sculpin (41% of tows). The five most abundant taxa at Ugamak accounted for 79% of regional abundance, and included rock sole (30% CPUE), Triglops spp. (13% CPUE), walleye pollock (12% CPUE), poachers (12% CPUE), and northern sculpin (11% CPUE). Poachers were also among the most abundant group at Ugamak (Fig. A25) (Holladay et al. 2000).

Length Frequency Distribution

Length and frequency distributions were compared among years for the most abundant species caught during bottom trawl sampling. Differences in abundance between Ugamak Island and other rookeries were accompanied by clear differences in size and age composition of the most abundant species (Mueter and Norcross 1998). Most age 1 and older halibut were caught at Ugamak Island, along with large numbers of age 0 halibut.

Only gadids of age 0, ranging from 15 to 50 mm in size, were caught during the survey in 1995 and 1996. A large number of age 0 walleye pollock with a mode of 23 mm fork length were caught in 1996. Pacific cod were also smaller and more numerous in 1996 at Ugamak Island (Mueter and Norcross 1998).

The bottom trawl sampling gear primarily selected age-0 and age-1 fishes which were identifiable as clearly separated modes (Mueter and Norcross 1998). Age-0 gadids were caught by the sampling gear and were smaller and more numerous in 1996 at Ugamak Island. Size composition differences in sculpins among years and rookeries existed but were less obvious. Length frequency measurements by species category were not reported for bottom trawling surveys in 1997.

Species diversity

Species diversity from bottom trawl sampling at Ugamak Island, as measured by Simpson's complement, was quite variable but did not differ significantly among years (F=0.133, p=0.875 in 1996; F=2.071, p=0.097 in 1997) when compared by depth stratum (Mueter and Norcross 1998, Holladay et al. 2000). However, species diversity was significantly different among regions in 1997 within the <40 m depth stratum (F=5.305, p<0.05). Species diversity was significantly higher at Ugamak Island (0.53 ± 0.14) within the < 40 m depth stratum than in other study areas. Within the 40-70 m (F=1.143, p=0.357) or over the 70 m (F=2.607, p=0.067) depth stratum, species diversity was not significantly different in 1997.

Rough bottom topography and untrawlable or marginally trawlable bottom substrate was one of the main problems encountered during bottom trawl sampling, and common in the immediate vicinity of all rookeries sampled during the SMMOCI study including Ugamak Island. Trawling was limited to even bottom and small grain substrates, such as gravel, which severely restricted sampling. Therefore, bias in the data may have occurred as not all fish communities available to foraging sea lions were sampled. The composition of juvenile fish communities on rough untrawlable bottom near rookeries is likely to be different from fish composition at trawlable sites (Mueter and Norcross 1998) . This situation was confirmed in 1996 by use of a video camera lowered to the bottom in both trawlable and untrawlable nearshore areas. In reef type substrate or rocky bottom areas video observations did not show many juvenile fishes comparable in size to fishes caught in bottom trawl samples. Most of the fishes in this substrate were adults outside of the size range appropriate for juvenile sea lion prey. Video transects in the Kodiak Island area also showed very few small fishes on rocky bottom substrate compared to other bottom types (Norcross and Mueter 1999). Therefore, bias in trawl sampling for juvenile fishes may be relatively small (Mueter and Norcross 1998).

Bottom trawl sampling gear caught fishes in a very small size range and which were much smaller in size than those found in the stomach collections from juvenile Steller sea lions in the mid-1980s. Therefore, the species composition in the bottom trawl catches may not adequately represent the composition of the fish community which serves as potential prey for sea lions. The larger size range of fish consumed by sea lions was difficult to sample. However, the species composition of bottom trawl catches can serve as an index for the availability of potential prey in future years. High abundances of rock sole and halibut at Ugamak Island may have been due to depth and sediment effects. Age 0 and age 1 rock sole and Pacific halibut prefer sandy substrates and shallow depth (Norcross et al. 1995a, Norcross et al. 1997).

Holladay et al. (2000) suspected that due to species behavior, the bottom trawl may not have accurately assessed species abundance and distribution of some fish taxa. For example, Pacific sandlance have a varied distribution; school in surface water, and bury in beach and possibly deep water sediments (Hart 1980). Generally, the bottom trawl drags over the surface of the sediments and rarely digs into them. Pacific sandlance may have been collected only when the bottom trawl dug into the sediments and collected buried individuals. Schools of age-0 Pacific cod and walleye pollock caught by the bottom trawl had extremely patchy local distributions (Brenda Norcross, Institute of Marine Science, University of Alaska, pers. comm. Sept. 17, 2003), and infrequent catches of these schools may introduce data bias. Juvenile rockfishes, which are generally associated with rocky areas (Kreiger 1993; O'Connell and Carlile 1994) were avoided in the sampling design (Holladay et al. 2000).

Longline Surveys

Due to the difficulty of sampling the appropriate size range of fishes, predatory demersal fish sampling began by using longline sets in 1996. In July 1996, predatory fish stomach samples were collected from rough bottom areas and reflected prey similar in size range to those found in stomach collections of juvenile sea lions from the 1980's (Mueter and Norcross 1998).

Longline surveys of predatory demersal fish provided a means to sample rough untrawlable areas in the vicinity of the Ugamak Island sea lion rookery. As with other sampling methods, longline sampling has its limitations. Unlike trawling, during which species in the path of the trawl are collected, longline sampling is biased toward predatory species that are already hungry and once caught may have time to digest prey items in their stomachs until the set is retrieved. Although the SMMOCI longline sets were only allowed to soak on average for less than 3 hours, the digestion factor could lead to an underestimate of predatory fish diets.

The result that longline sampling did provide however, is that there were prey species in untrawlable areas around Ugamak Island that are important to Steller sea lions. Prey species that were found in the stomachs of Pacific cod and Pacific halibut from those areas included demersal fish, small schooling fish such as sandlance and gadids, and cephalopods, all of which are potentially important prey for young Steller sea lions.

Steller sea lion Food Habits Research

Predatory fish stomach collections

The high correlation between diet diversity and population change supports the hypothesis that diet is linked with the Steller sea lion population decline in Alaska (Merrick et al. 1997). Seabird abundance has also declined in the areas surveyed. Diet diversity has also been suggested as a potential cause of the declining population of northern fur seals (*Callorhinus ursinus*) in the Bering Sea (Sinclair et al. 1996, Sinclair et al. 1994).

Low abundances of potential sea lion prey in both trawl samples and predatory fish diets in the eastern part of the study area coincided with the highest observed declines in sea lion populations between 1994 and 1996 (Richard Merrick, NMFS, Northeast Fisheries Science Center, pers.comm.) suggesting a potential link between the availability of bottom fish as prey and sea lion declines (Mueter and Norcross 1998).

Steller sea lion stomach collections from the mid-1980s showed walleye pollock as the most common fish prey consumed by juvenile sea lions in the Gulf of Alaska (Calkins and Goodwin 1988, Merrick and Calkins 1996). Walleye pollock in the diet of juvenile sea lions ranged in size from 70 mm to 550 mm, with age 1 pollock at 208 mm as the average size consumed. The number of pollock over 250 mm was very small (Merrick and Calkins 1996). Small forage fish, such as capelin, Pacific herring, and Pacific sandlance, were found in 25% of juvenile sea lion stomachs and were the second most common prey. Flatfish occurred in the diet of 17.6% of adult sea lions but not in the diets of juvenile sea lions.

In contrast to the diet composition of juvenile sea lions in the mid-1980s, collections by Mueter and Norcross (1998) found demersal fishes, particularly flatfish composed of age-0 rock sole and Pacific halibut. In 1996, age-0 walleye pollock, ranging in size from 14 to 57 mm in length (average = 28.8 mm) dominated the species composition at Ugamak Island. They concluded that walleye pollock and other age-0 fish collected potentially serve as food for sea lions in the following year rather than at the time of sampling.

Small forage fish (capelin, Pacific herring, Pacific sandlance) were the second most common prey group found in juvenile sea lion stomachs during the 1980s, but were rarely found in SMMOCI bottom trawl collections. Since they are midwater fish, no Pacific herring were caught and only 68 Pacific sandlance were caught in 3 years of sampling. However, Pacific sandlance may not have been adequately sampled by the trawl gear used, due to their elongate body shape and tendency to bury in the sediment (Mueter and Norcross 1998). The occurrence of small forage fish at Ugamak Island was confirmed by their presence in the diet of predatory demersal species such as Pacific cod and Pacific halibut which were sampled by longline in those areas (Mueter and Norcross 1998).

Based on other collections, three groups of commercially important species which dominated bottom trawl collections or were important components of halibut diets served as potential prey for sea lions are gadids, osmerids, and, to a lesser extent, flatfishes (Merrick and Calkins 1996, Merrick et al. 1997). All of these groups were abundant in bottom trawls and/or halibut stomachs from the Ugamak Island region (Table 5, Table A1).

The limited number of sampling years preclude analysis of trends in interannual fluctuations of commercially important species around Steller sea lion rookeries (Mueter and Norcross 1998). Comparisons of prey species abundance collected from bottom trawl samples and prey species consumed by predatory fishes were hampered by the fact that species caught in bottom trawls were in fairly good condition and were able to be identified to species level while predatory fish stomach samples contained specimens exhibiting varying degrees of digestion. For example the prey species category in stomach content analysis samples referred to as gadids is composed of a combination of both pollock and cod, while pollock and cod are much easier to differentiate in bottom trawl samples where samples are freshly caught and digestion is not a factor.

Scat collections

Data on diet composition from stomach samples of juvenile sea lions are not available for the years of this study for direct comparison with those from the 1980s. Due to the declining population and endangered status of Steller sea lions in the western stock, stomach collections for food habits research are no longer possible. Scat (fecal) sample collection is a common method currently utilized to study pinniped diet, however, the inability to differentiate scat material collected on rookeries by sea lion age group makes differentiating juvenile sea lion diets from other age group diets impossible (Bigg and Olesiuk 1990, Merrick et al. 1997, Sinclair and Zeppelin 2002). Regardless, scat material is collected from rookeries and haulouts and gives a general view of seasonal sea lion food habits. Steller sea lion diet data analyzed from scat samples collected from 1995 to 1998 at Ugamak Island show similarities to SMMOCI predatory demersal fish stomach food habits data. Scat samples were collected during summer and winter with walleye pollock dominating as the most prevalent prey species. During summer scat collections walleye pollock had the highest frequency of occurrence (51% FO) followed by salmon (48% FO) and Pacific herring (33% FO). During winter scat collections walleye pollock was the primary prey species (81% FO), followed by sandfish (64% FO) and Pacific cod (36% FO) (Merrick et al. 1997, Sinclair and Zeppelin 2002). Scat samples collected during winter from nearby Aiktak Island, between 1995 and 1997, contained walleye pollock (83% FO), Pacific cod (16% FO) and Irish lord (12% FO).

Pacific cod showed a summer diet preference for crustacea and other benthic invertebrates but also contained other demersal fish (28-50% FO) and small schooling fish (43-50% FO) (Figs. A15-A17). Winter Pacific cod diets were comprised of mostly crustacea and other benthic invertebrates but also included other demersal fish (42-50% FO), gadids (20% FO), and small schooling fish (10-28% FO) (Figs A18-A19) (Table 5).

Although sample sizes were much smaller, longline surveys showed that Pacific halibut summer diets contained other demersal fish (33-80% FO) and gadids (walleye pollock and cod, 35-80% FO) (Figs. A20-A22). During winter halibut diets contained gadids (50% FO) and flatfishes (50% FO) (Figs. A23-A24).

Again, species identification comparisons between scat sample specimens, stomach sample specimens, and bottom trawl specimens were problematic. Species identification during scat analysis is done using bone fragments. There are particular bone elements that are diagnostic to species in some prey fishes, such as pollock and cod. These samples are actually easier to identify to species by bone elements than pollock and cod specimens found in stomach samples of predatory fishes. Most of the specimens in predatory fish stomachs have undergone varying amounts of digestion, but not complete digestion, and thus have tissue attached whereas bone fragments in scat samples are generally devoid of tissue. Therefore, the prey species identified from predatory fish stomach collections are reported as gadids with fewer reported to species level of pollock or cod and prey species identified from scat collections are more often reported as pollock, cod or gadids. While species diversity is higher at Ugamak Island than in other study areas, it is unknown whether or not diversity or abundance are high enough to sustain foraging juvenile Steller sea lions (Merrick et al. 1997, Sinclair and Zeppelin 2002).

Foraging distribution of Steller sea lions

Reduced prey availability for foraging sea lions may be linked to environmental changes or commercial fishing impacts, or both, and are a possible cause of the Steller sea lion population decline (Loughlin and Merrick 1989; Merrick 1995). Ugamak Island has historically supported one of the largest Steller sea lion rookeries in the world (Loughlin et al. 1984, Merrick et al. 1988). Satellite telemetry research conducted by Merrick and Loughlin (1997) showed that adult female sea lions foraged for approximately the same amount of time in both summer (breeding) and winter (non-breeding) seasons. However, the time used during foraging was different between the two seasons. During winter adult females spent more time at sea, dove deeper, and had greater home ranges than did adult females during summer. During the breeding season adult females stayed closer to shore (more time within 20 nm radius) due to dependent young on the rookery (Merrick and Loughlin 1997).

Juvenile Steller sea lion foraging research

Use of dive and time-depth recording instrumentation has become a common research method for studying foraging ecology of pinnipeds (Kooyman et al. 1983; Gentry and Kooyman 1986). The instruments and data may be retrieved after the animal returns from feeding trips, as is common with use of the time-depth recorders (TDR) or the data may be transmitted to a satellite and accessed by the researchers, as in the satellite-linked time depth recorder (SLTDR) or the newer satellite dive recorder (SDR) instruments (Goebel et al. 1991; Boyd et al. 1994; Merrick et al. 1994; Werner and Campagna 1995).

While relatively few data characterizing the general foraging ecology of young Steller sea lions are available, several studies have occurred in the past few years focusing on juvenile and young of the year animals using satellite-linked dive recording instruments.

In terms of prey availability, the most critical time for foraging juvenile Steller sea lions is most likely to be in the winter when availability of juvenile fishes is restricted due to the seasonal movements of many species into deeper waters and off the continental shelf (Merrick and Loughlin 1997; Mueter and Norcross 1998). Merrick and Loughlin (1997) described diving and trip behavior of endangered western stock adult and juvenile Steller sea lions. Based on their telemetry data, and due to concerns over prey availability, NMFS enacted fisheries management measures to reduce spatial overlap of potential sea lion foraging areas and impact of fisheries in those areas. Although the precise date of weaning in Steller sea lions is unknown, it has been hypothesized that weaning most likely occurs for most animals when pups reach 10-12 months of age, just prior to the next summer breeding season (Calkins and Pitcher 1982; Trites and Porter 2002). Diving ability increases throughout the first year of age and animals 10-12 months of age are capable of diving up to 288 m, although the average dive depth for this age group is 16.6 m (Loughlin et al. 2002).

Young of the year and juvenile sea lions from Ugamak Island, nearby Aiktak Island, and vicinity have been instrumented during both winter (Nov.-Mar.) and summer (Apr.-July) months (Loughlin et al. 2002; Fadely et al. 2005). Fadely et al. (2005) found that a majority of foraging young of the year and juvenile sea lions captured at or in the vicinity of Ugamak Island during winter months stayed close to shore, and traveled less than 15 nm from shore. They made dives within the 0-50 m depth range with the majority of dives less than 20 m in depth. Dive patterns during summer months showed that young of the year and juvenile sea lions traveled farther from shore and dove deeper during May trips, but returned to similar nearshore diving patterns as during winter months for the months of June and July (Fadely et al. 2005).

Juvenile and young of the year sea lion diving patterns associated with nearshore trips could be attributed to several different scenarios. Young, not yet weaned, sea lions could be fully or partially dependent on their mothers and potentially following them on foraging trips (Trites and Porter 2002). Learning to forage, independent foraging, or play behavior in association with other young animals are other possibilities for the nearshore diving patterns displayed by young sea lions (Fadely et al. 2005).

While it may be tempting to conclude that the nearshore diving patterns of young of the year Steller sea lions within the Ugamak Island fishery management area indicate that adequate prey is available, there is no historic (pre-decline era) baseline prey resource data available for comparison. Biomass abundance and prey species composition in the Ugamak Island area during the pre-decline era is unknown, precise impacts of fisheries in the area during pre-decline years are unknown as well as the effects of localized prey depletion, and the pre-decline diving and foraging patterns of sea lions at Ugamak Island are unknown. Knowing the foraging habits and dive patterns exhibited by young Steller sea lions in the Ugamak Island area and abundance of prey species available locally by depth range may facilitate detecting or predicting changes in sea lion foraging patterns, and ultimately the impact those changes could have on juvenile sea lion survival. Whether the reasons for young Steller sea lion diving activity are precisely defined at present or not, it is important to know prey resource abundance and distribution within the nearshore marine environment around Ugamak Island as it is an important, and perhaps critical, part of the foraging habitat of young endangered Steller sea lions during winter and summer months.

What is known is that Ugamak Island was formerly the largest Steller sea lion rookery in Alaska and supported approximately 11,000 sea lions during the breeding season before the population decline began. As of 2004 there were approximately 1,400 sea lions at Ugamak Island during the summer breeding season. Between 1994 and 2000 the Steller sea lion population at Ugamak Island decreased by 21%. Since 2000 the same population has experienced a 40% increase. Additionally, juvenile sea lions are the age group experiencing the sharpest decline in the population and could be driving the overall current population decline in the western stock of endangered Steller sea lions.

Prey species important to Steller sea lions, as well as the prey of those fish species, were present in the 20 nm fishery managment area surrounding Ugamak Island during the study. Prey diversity was higher at Ugamak Island during this study than at other locations surveyed.

Decline in optimal habitat conditions has contributed to the decline of many species. Detecting changes in habitat is of high ecological significance for endangered species in general. Indices of relative biomass collected during this study contribute to the habitat information for the nearshore waters surrounding Ugamak Island and are the first indices of this type collected not only in the habitat around Ugamak Island but in the western stock of Steller sea lions. Results from this study provided baseline data needed to explore the relationships between biomass density changes and the effects on endangered Steller sea lions foraging at Ugamak Island, Alaska. Dedicated systematic prey surveys, such as those conducted during this study, can be used as a monitoring tool on an annual and seasonal basis to assess a relative index of prey biomass and species composition available to foraging endangered Steller sea lions, seabirds, and other species dependent on the nearshore waters surrounding Ugamak Island for survival.

Because walleye pollock are important prey for predators, and support an enormous commercial fishery, over fishing of pollock has been implicated as a source of predator population declines (Merrick et al. 1987, Piatt and Anderson 1996). With proposed increased fishing quotas in the central and western Aleutian islands for important prey species such as Atka Mackerel, proposed fishery removal experiments, and possible changes in no trawl zones around rookeries and haulouts, SMMOCI surveys provided an important baseline of data prior to experimentation. The SMMOCI prey assessment surveys were the only joint oceanographic and fisheries research surveys being consistently conducted in the vicinity of Steller sea lion rookeries and haulouts and in NMFS regulated fishery management areas during 1995-99. In addition to surveys conducted by NMML, replicate and comparable surveys have been conducted by AMNWR at nearby Aiktak Island (pers. comm. V. Byrd, USFWS/AMNWR) and by the Gulf of Alaska Apex Predator Prey study (GAP) in the Kodiak archipelago (pers. comm. R. Foy University of Alaska Fairbanks). This research is providing important descriptive information about the nearshore marine ecosystem including relative prey biomass estimates in these areas from year to year. Results from the SMMOCI surveys show that these studies can describe nearshore marine ecosystem components and may ultimately help reveal patterns that demonstrate the response of top-level predators to fluctuations in prey resources available to marine mammals and seabirds (Byrd et al. 1997). Additionally, this research may characterize area conditions adequately enough to be utilized as a yearly monitoring survey tool for management of declining and endangered sea lions and seabirds (pers. comm. V. Byrd, USFWS/AMNWR). However, a longer time series and more ship time for trawling is needed for more accurate biomass estimations on future surveys at Ugamak Island.

General Recommendations

- Although it is difficult to link direct cause and effect between closed fishing areas and Steller sea lion population increase or decrease correlation analyses should be explored.
- Fishery regulatory management measures should continue in order to detect changes in prey species diversity and abundance in the 20 nm vicinity of the Ugamak Island rookery.
- Dedicated summer and winter prey abundance surveys should be resumed in the Ugamak Island fishery management area as a long term monitoring tool in trend site areas where Steller sea lion populations are both stable and declining.
- Satellite telemetry research being conducted on foraging Steller sea lions should be accompanied with simultaneous prey surveys.

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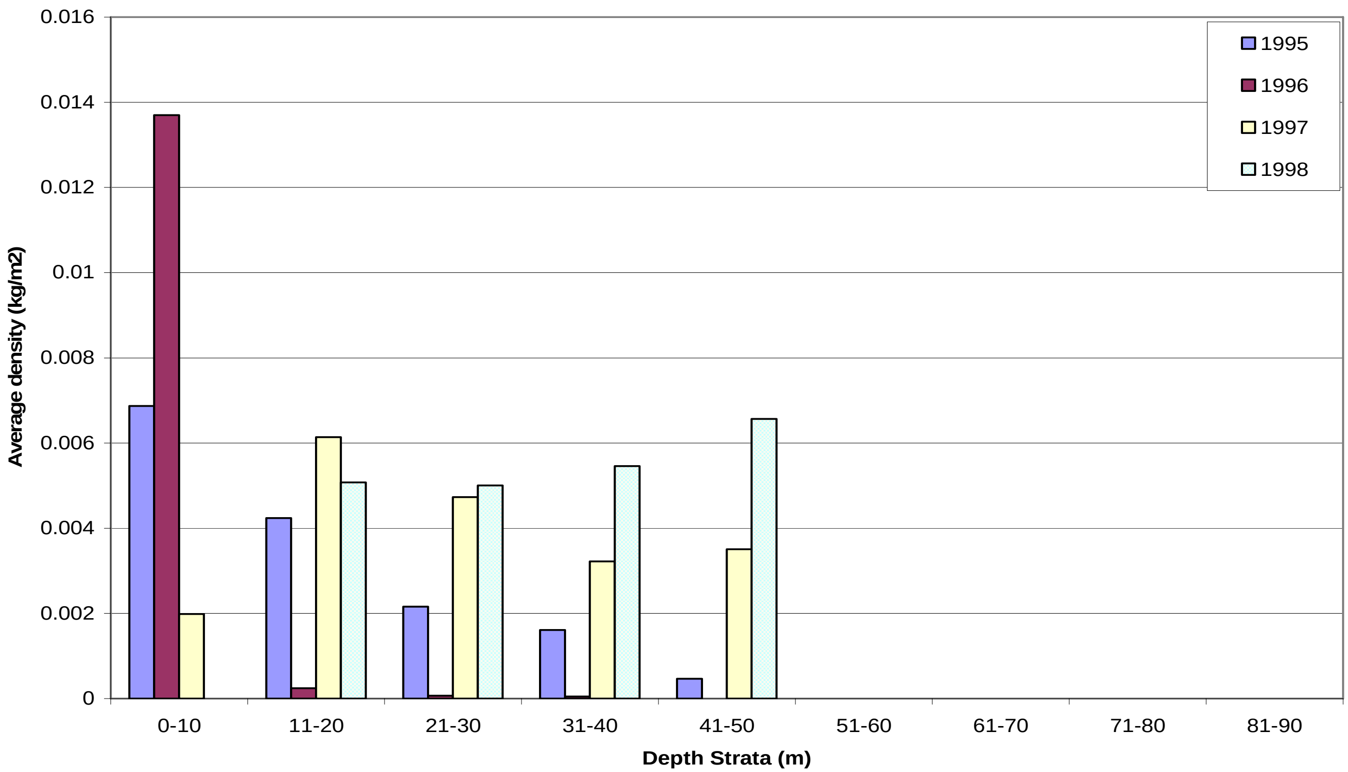
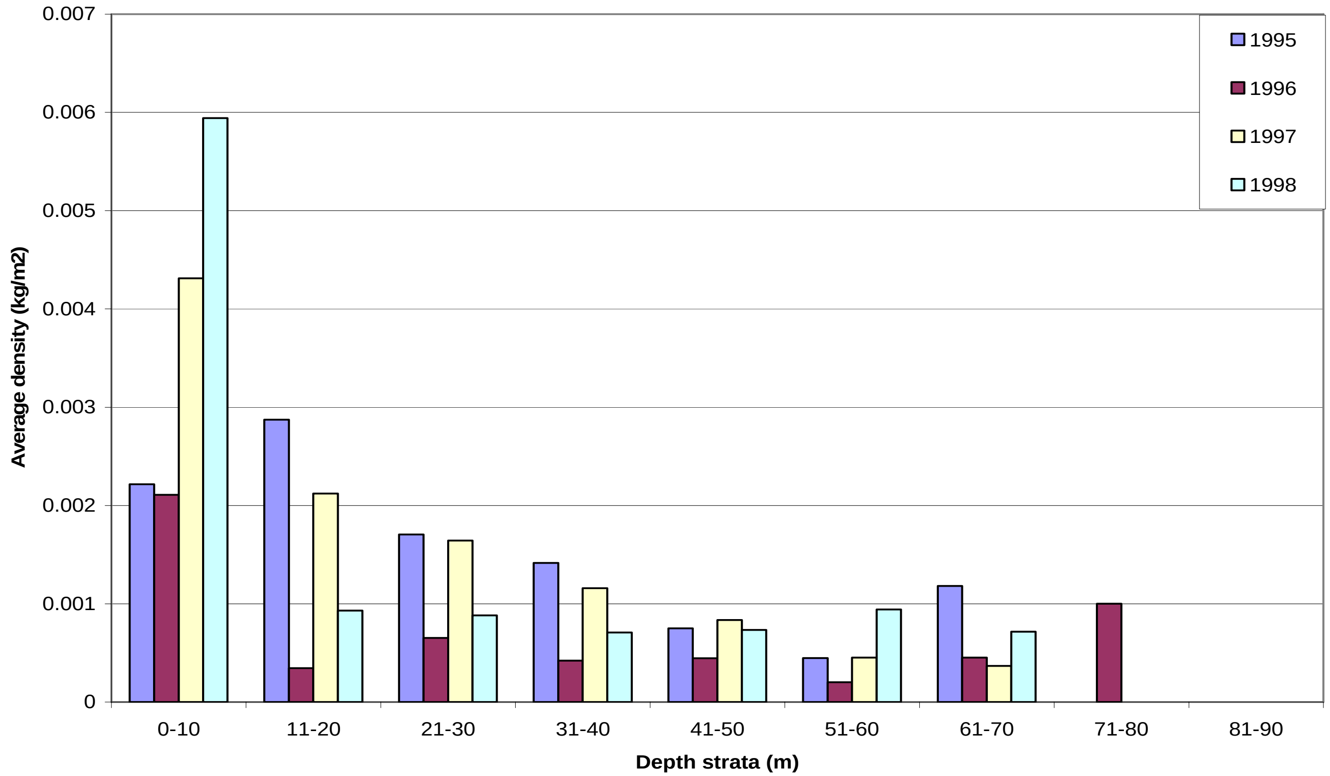


Fig. A1. Transect 1, Strata 1-9, Summer 1995-98, Ugamak Island, Alaska



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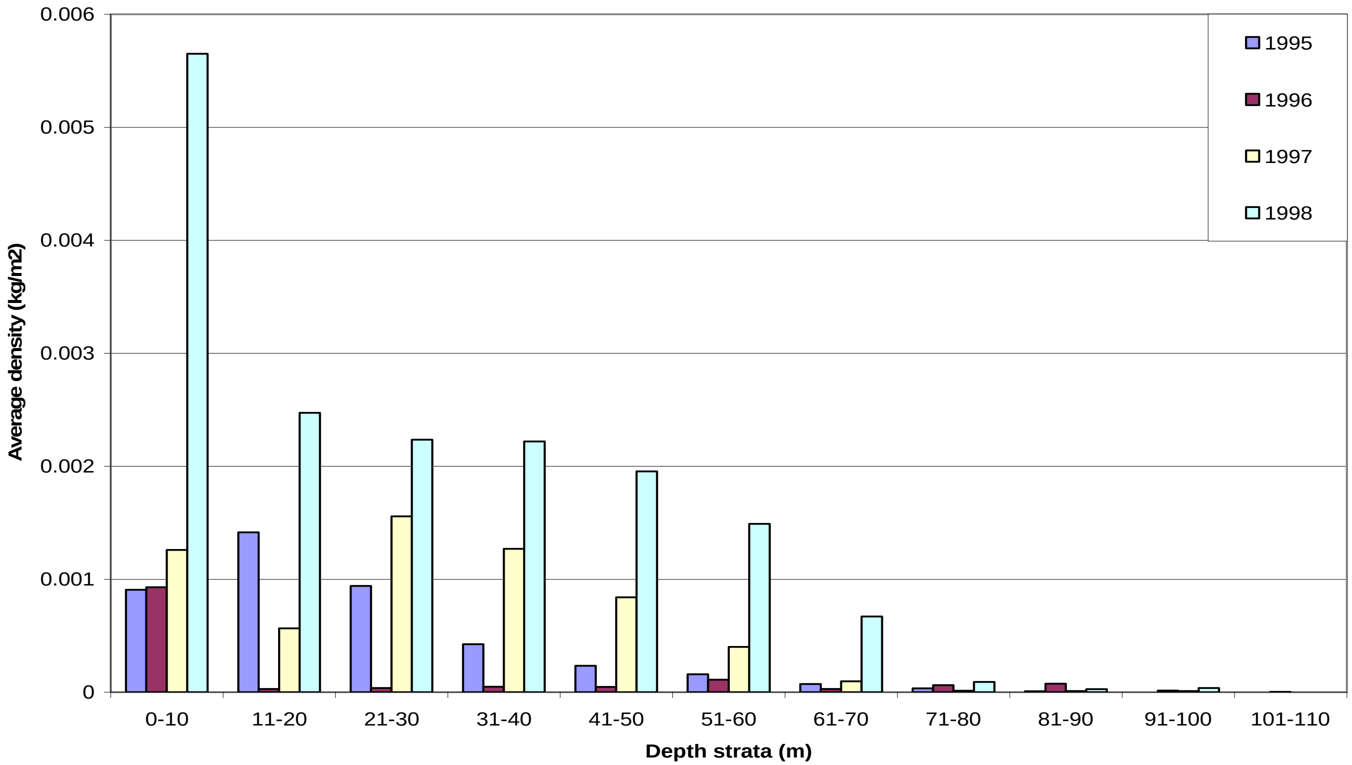

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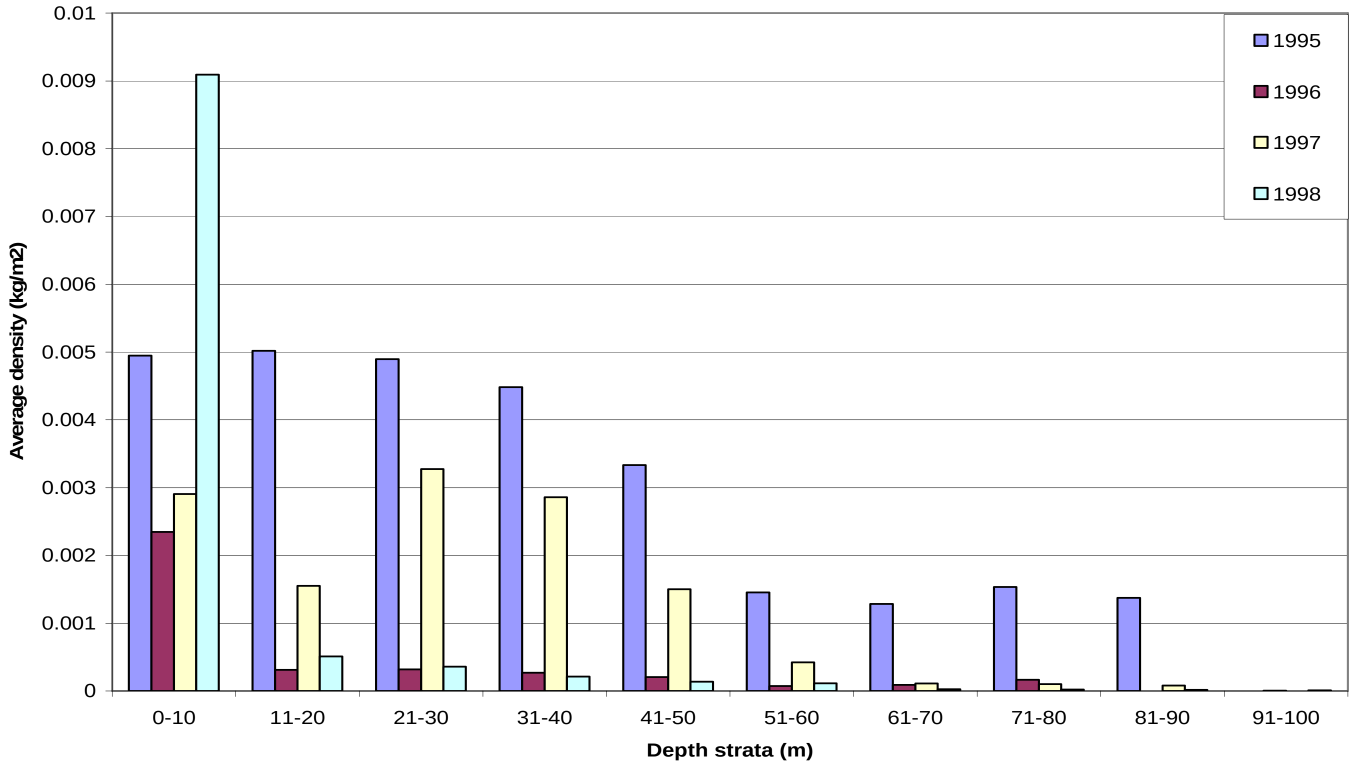
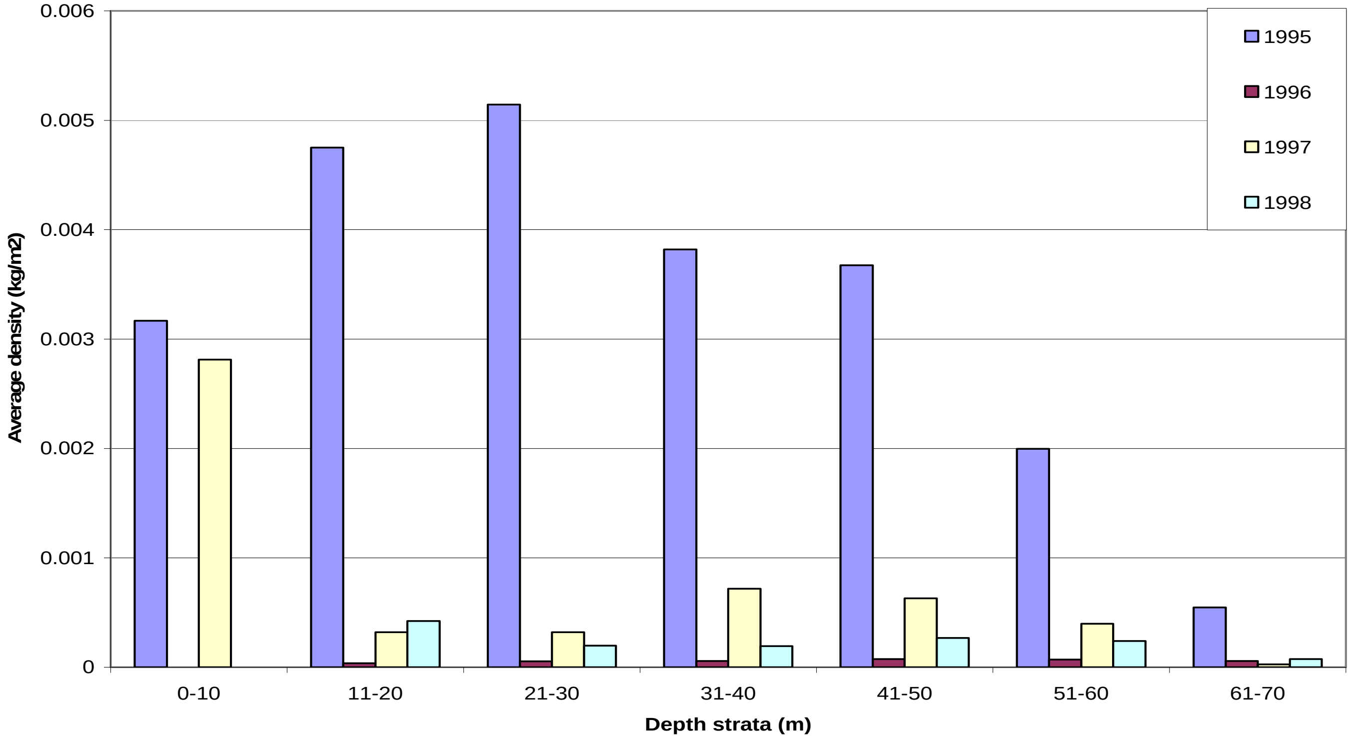


Fig. A4. Transect 4, Strata 1-10, Summer 1995-98 Ugamak Island, Alaska.



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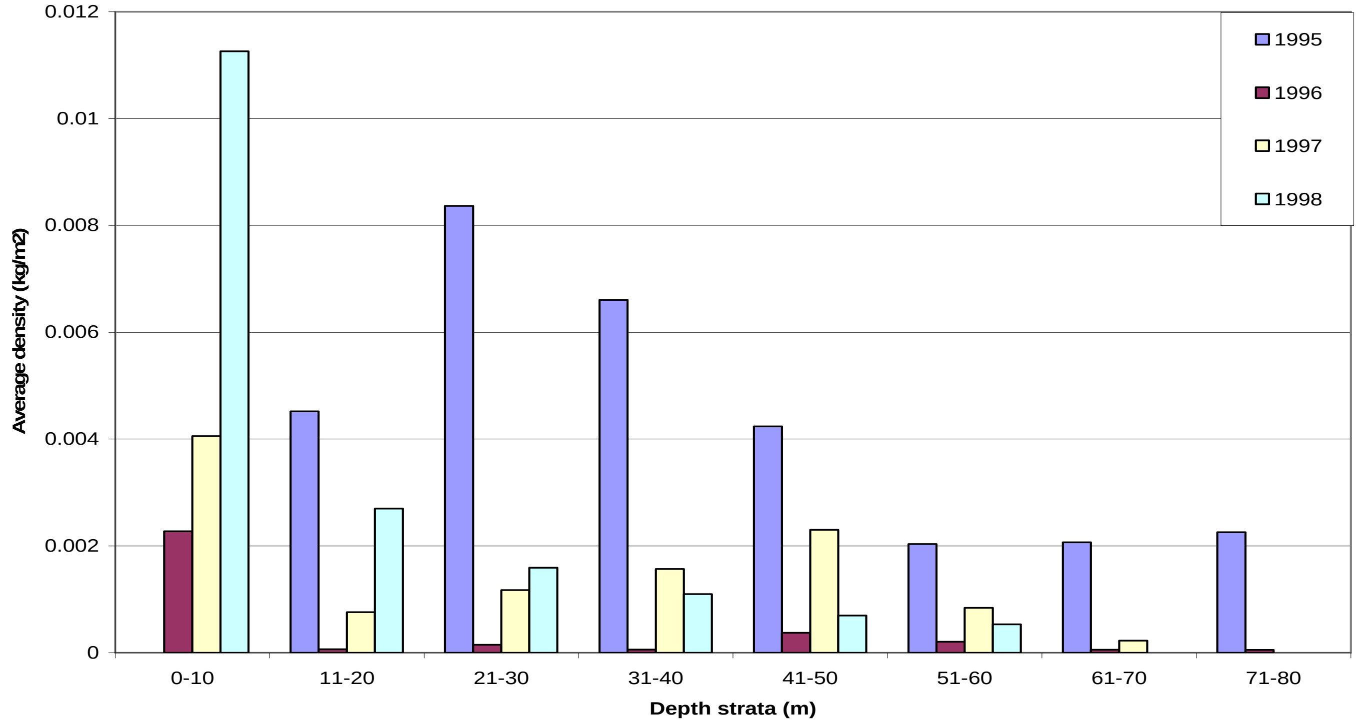


Fig. A6. Transect 6, Strata 1-8 (m), Summer 1995-98 Ugamak Island, Alaska.

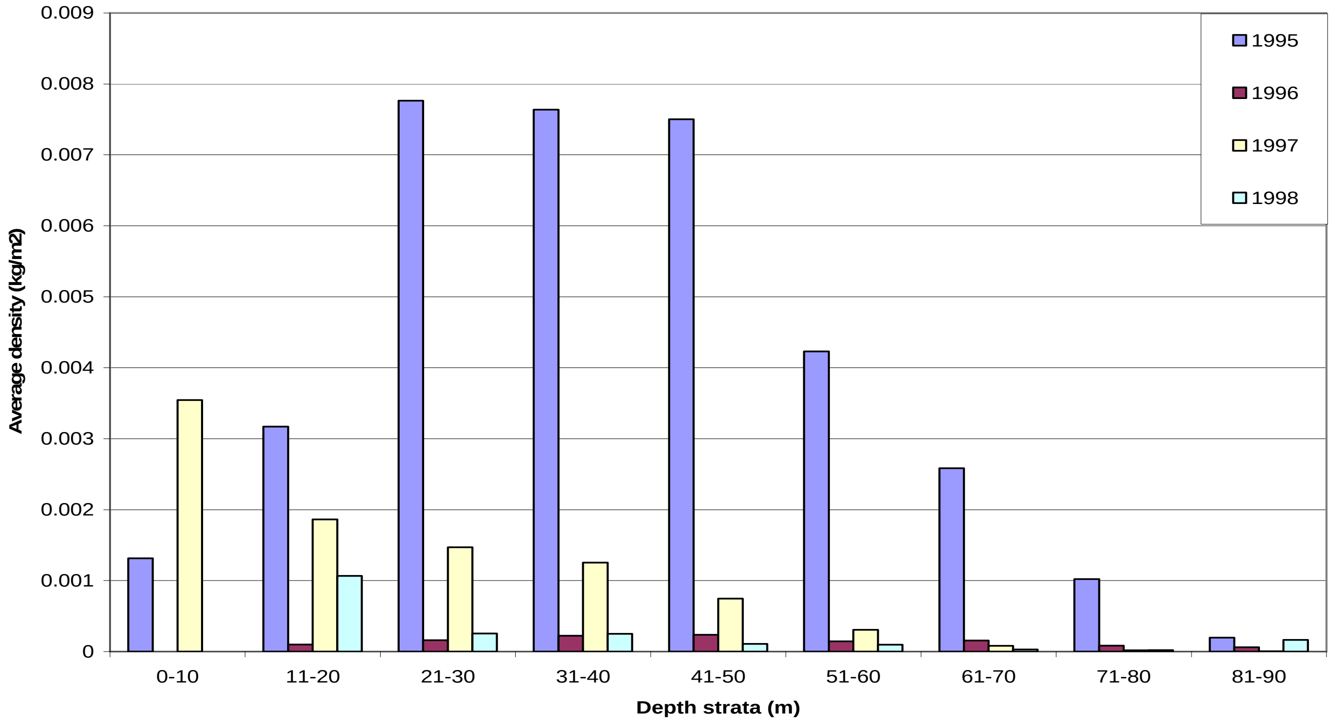


Fig. A7. Transect 7, Strata 1 - 9 (m), Summer 1995-98 Ugamak Island, Alaska

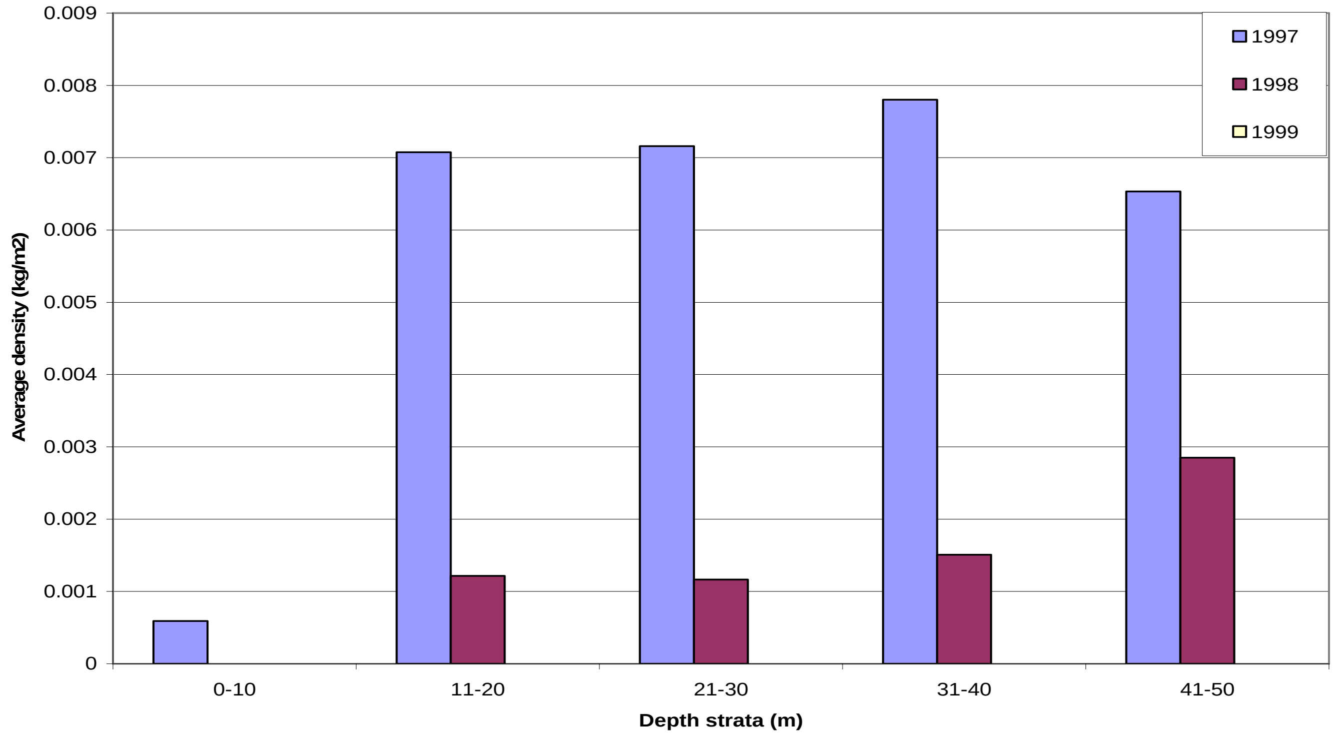
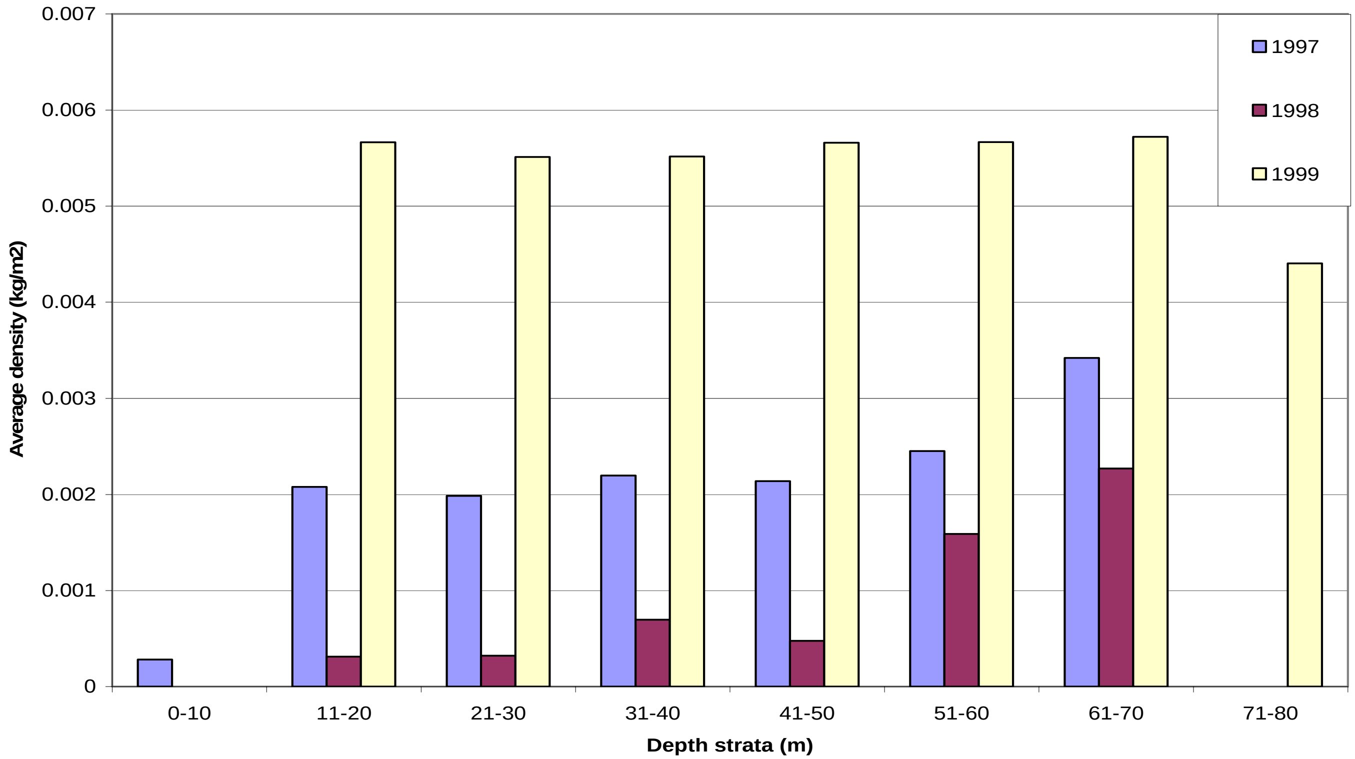


Fig. A8. Transect 1, Strata 1-5, Winter 1997-99 Ugamak Island, Alaska



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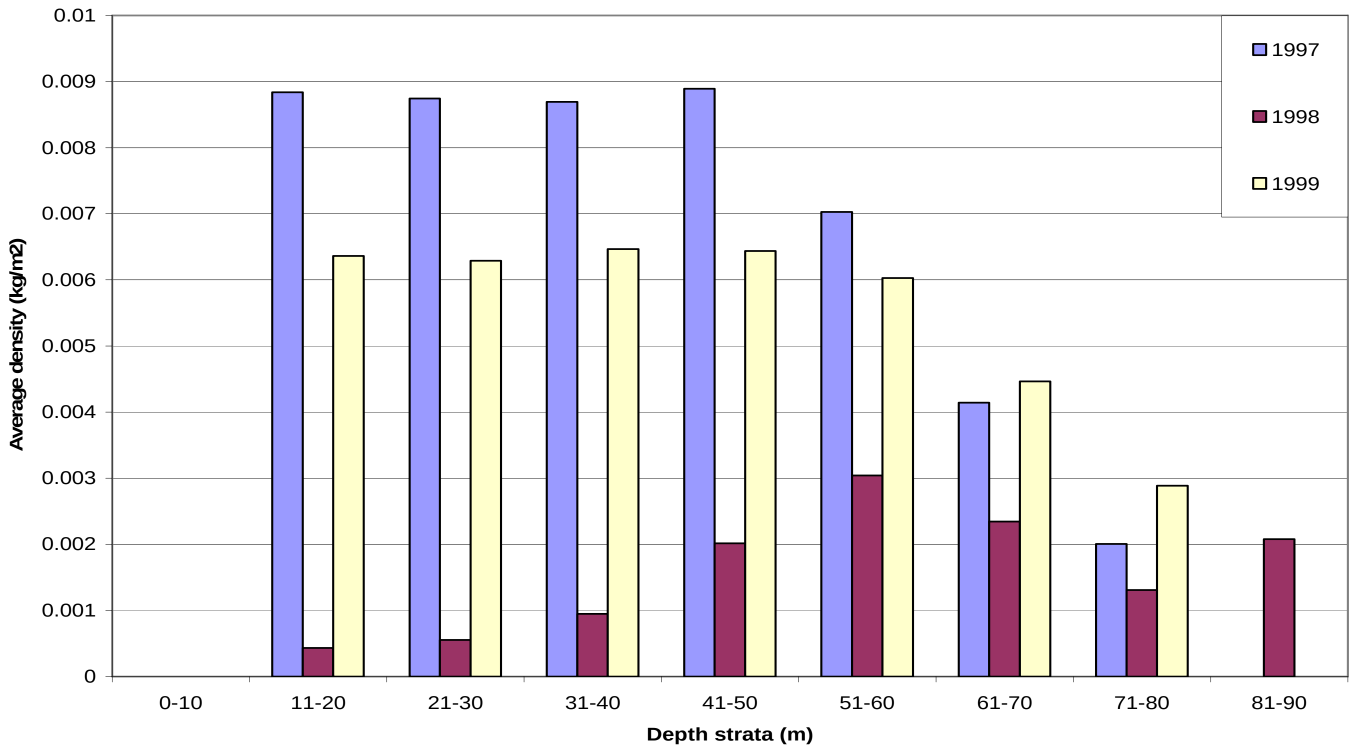


Fig. A10. Transect 3, Strata 1-8, Winter 1997-99 Ugamak Island, Alaska.

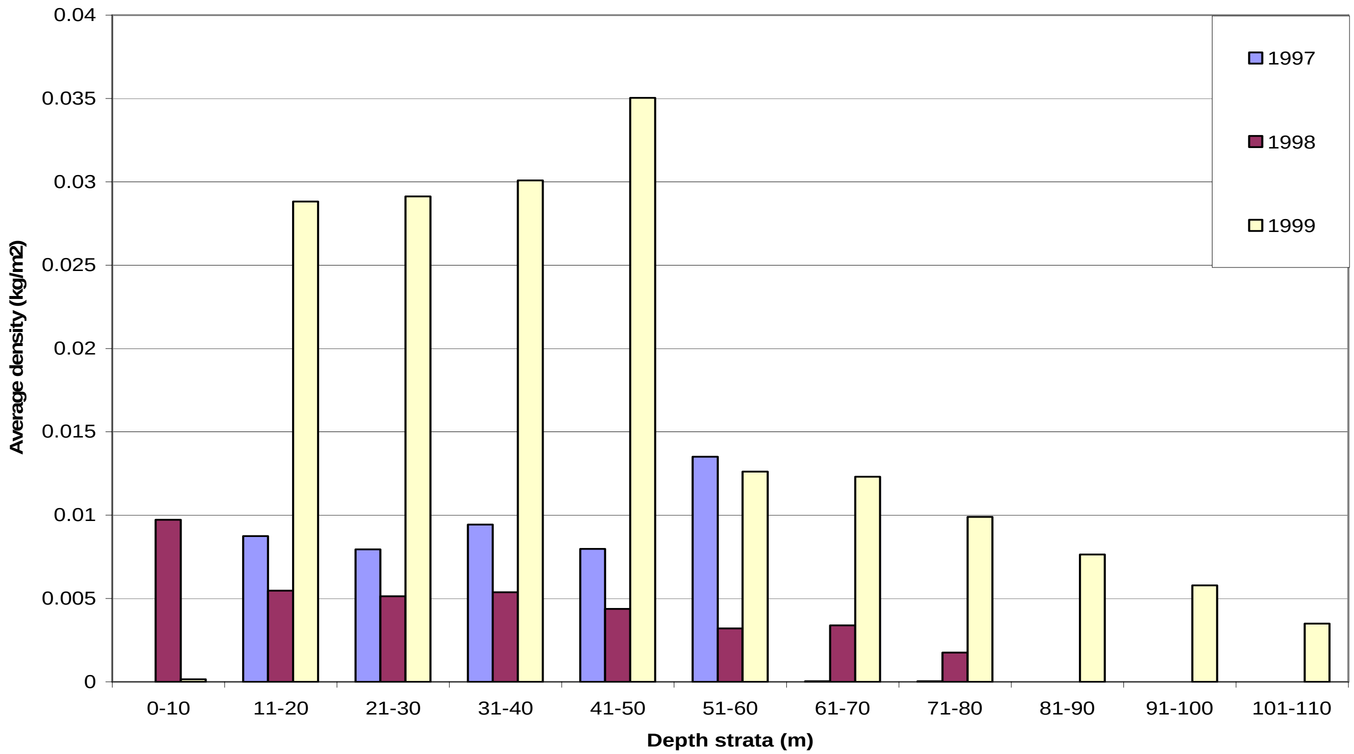


Fig. A11. Transect 4, Strata 1-11, Winter 1997-99 Ugamak Island, Alaska

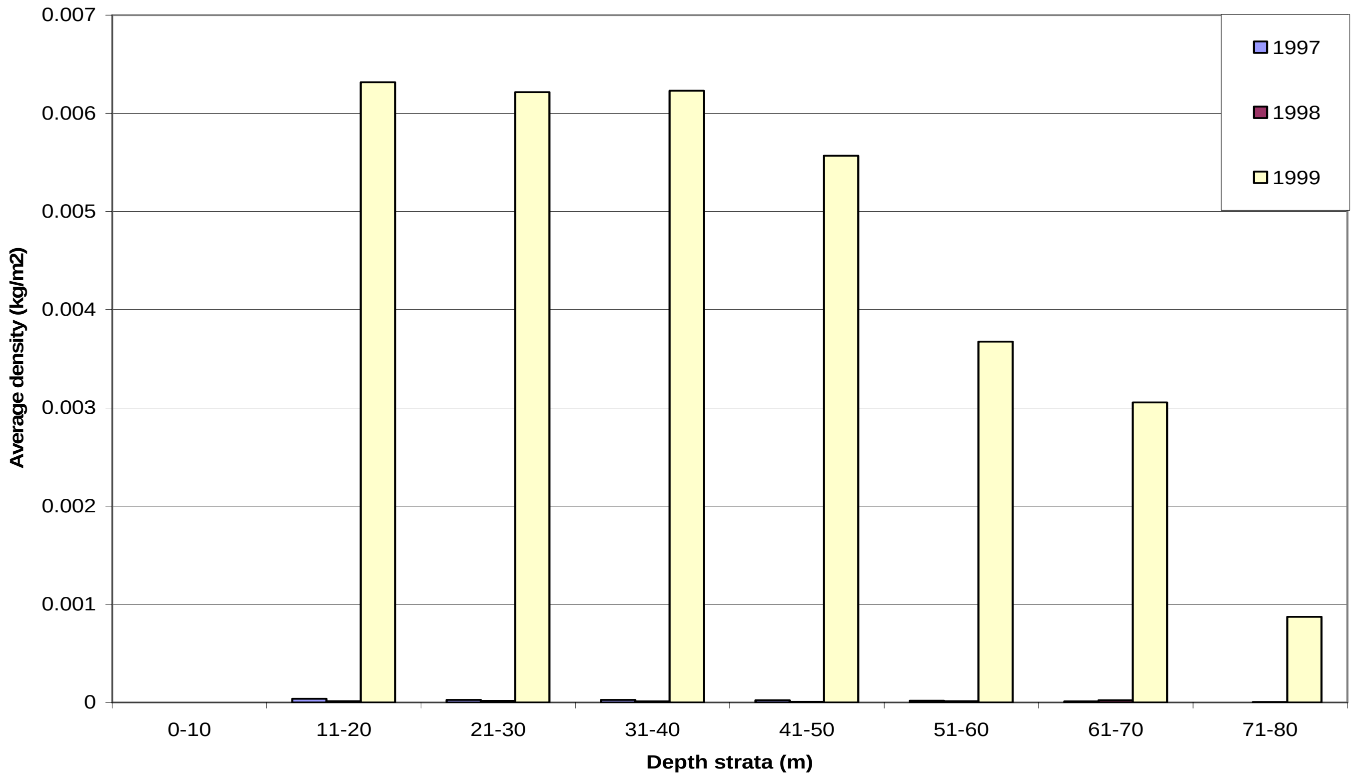


Fig. A12. Transect 5, Strata 1-8, Winter 1997-99 Ugamak Island, Alaska

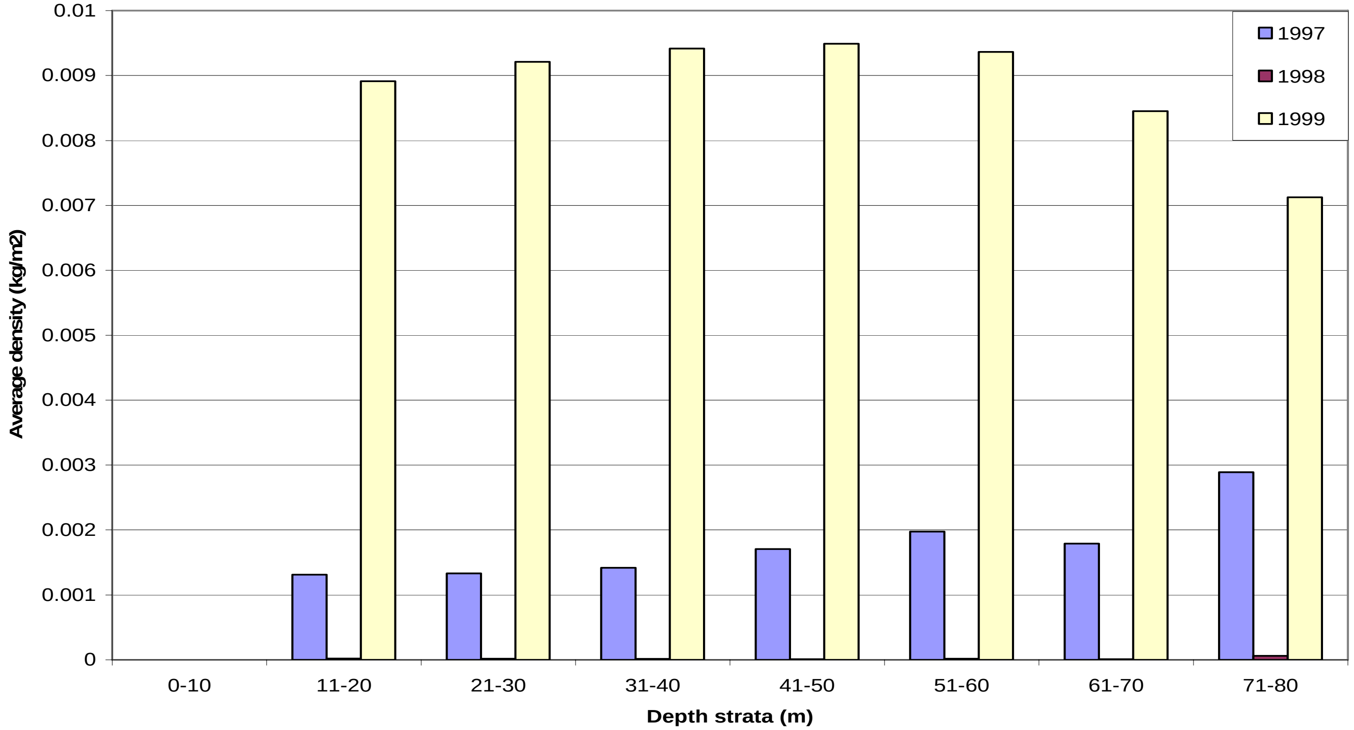
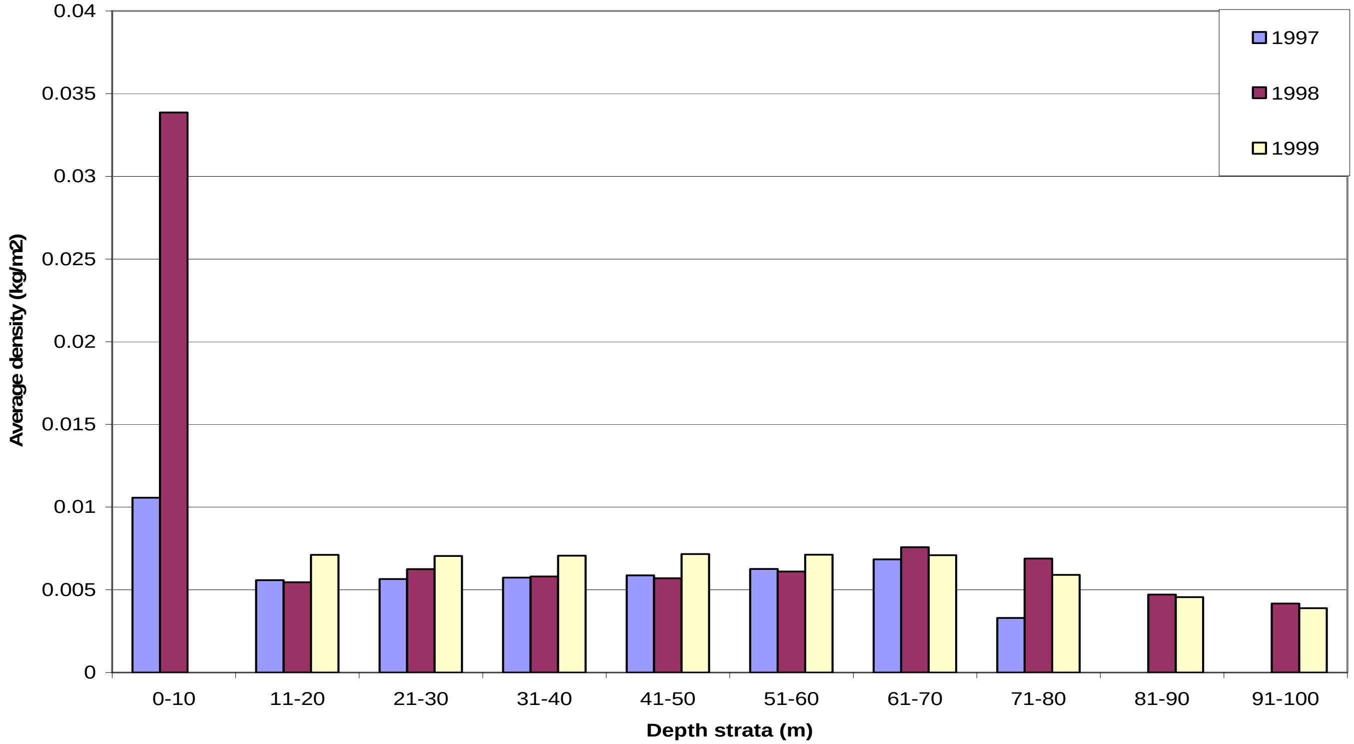


Fig. A13. Transect 6 Strata 1-8, Winter 1997-99 Ugamak Island, Alaska



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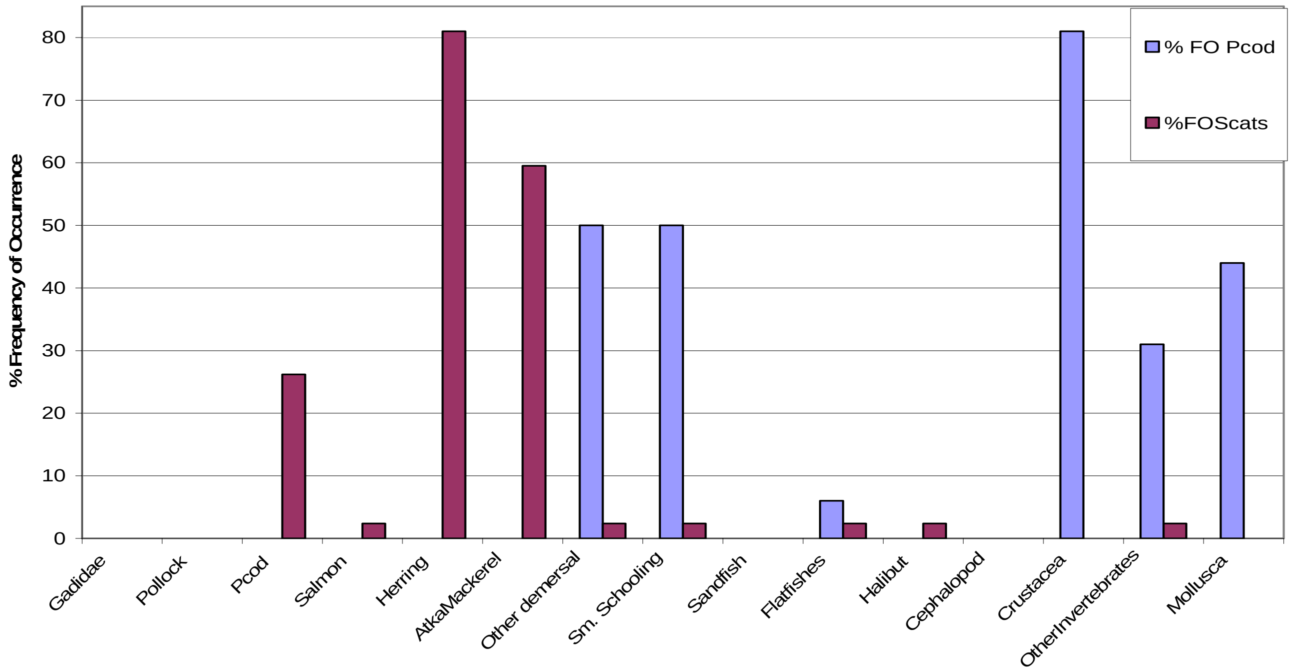


Fig. A15. Pacific cod stomach samples from SMMOCI longline surveys and Steller sea lion scat samples, June 1996 at Ugamak Island, Alaska

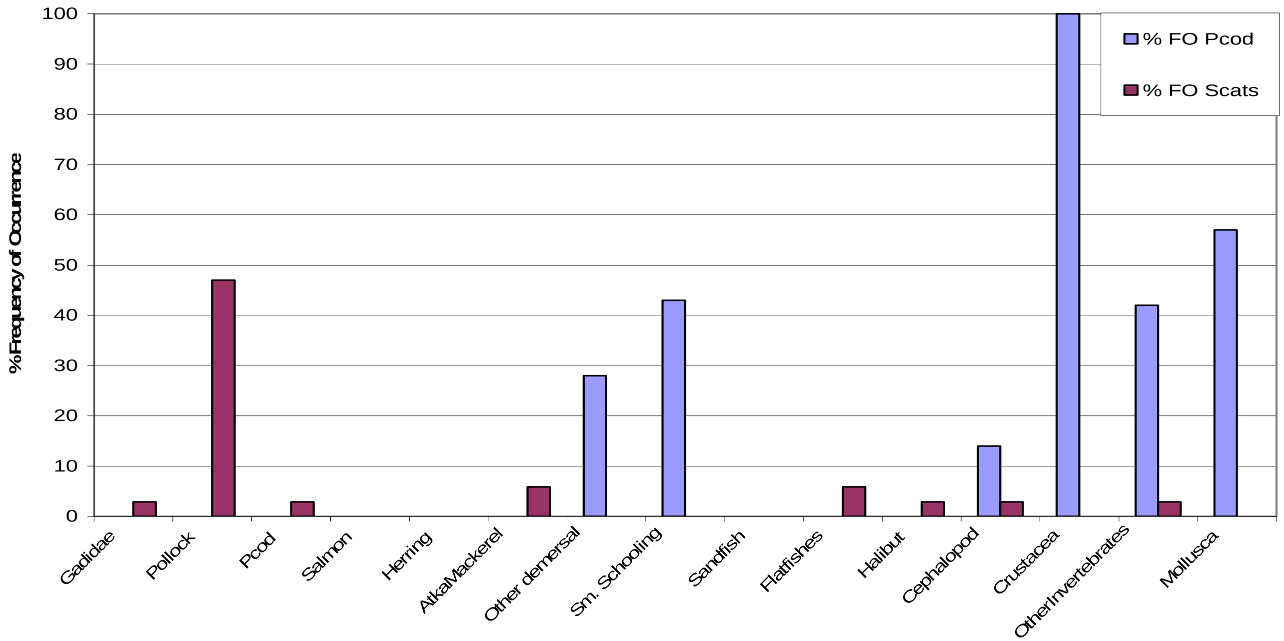


Fig. A16 Pacific cod stomach contents from SMMOCI longline surveys and Steller sea lion scat samples, June-July 1997 at Ugamak Island, Alaska.

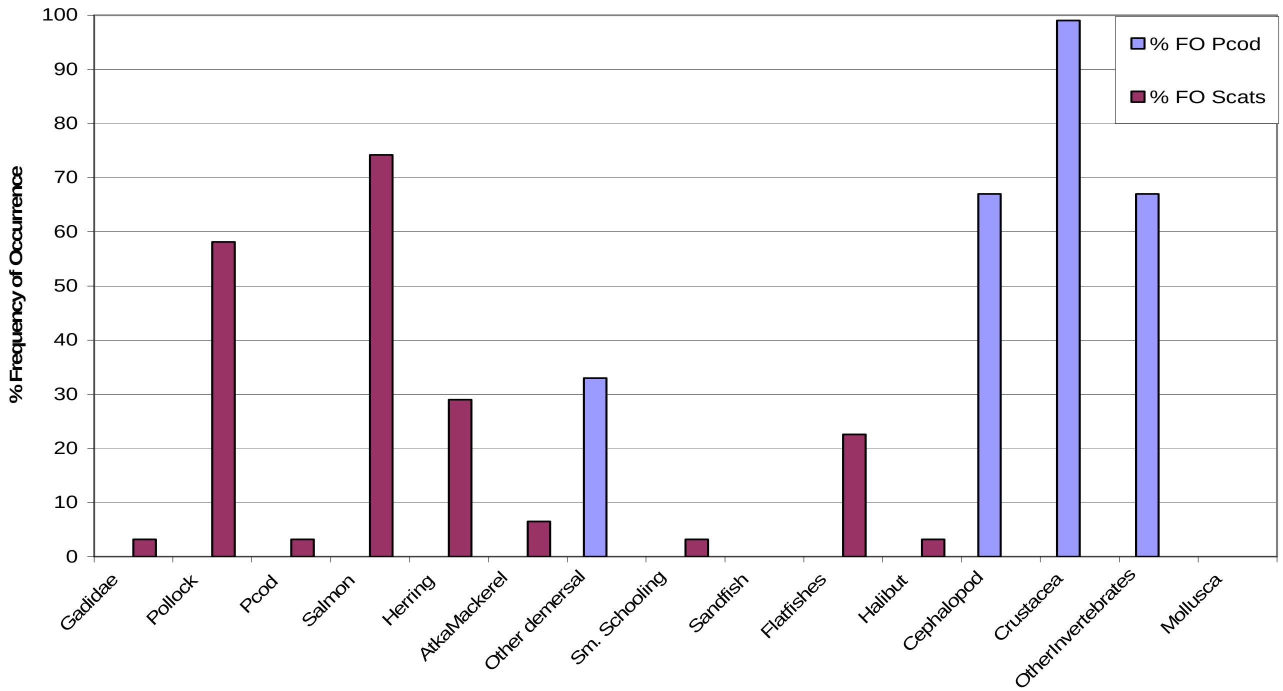


Fig. A17. Pacific cod stomach contents from SMMOCI longline surveys and Steller sea lion scat samples, June-July 1998 at Ugamak Island, Alaska.

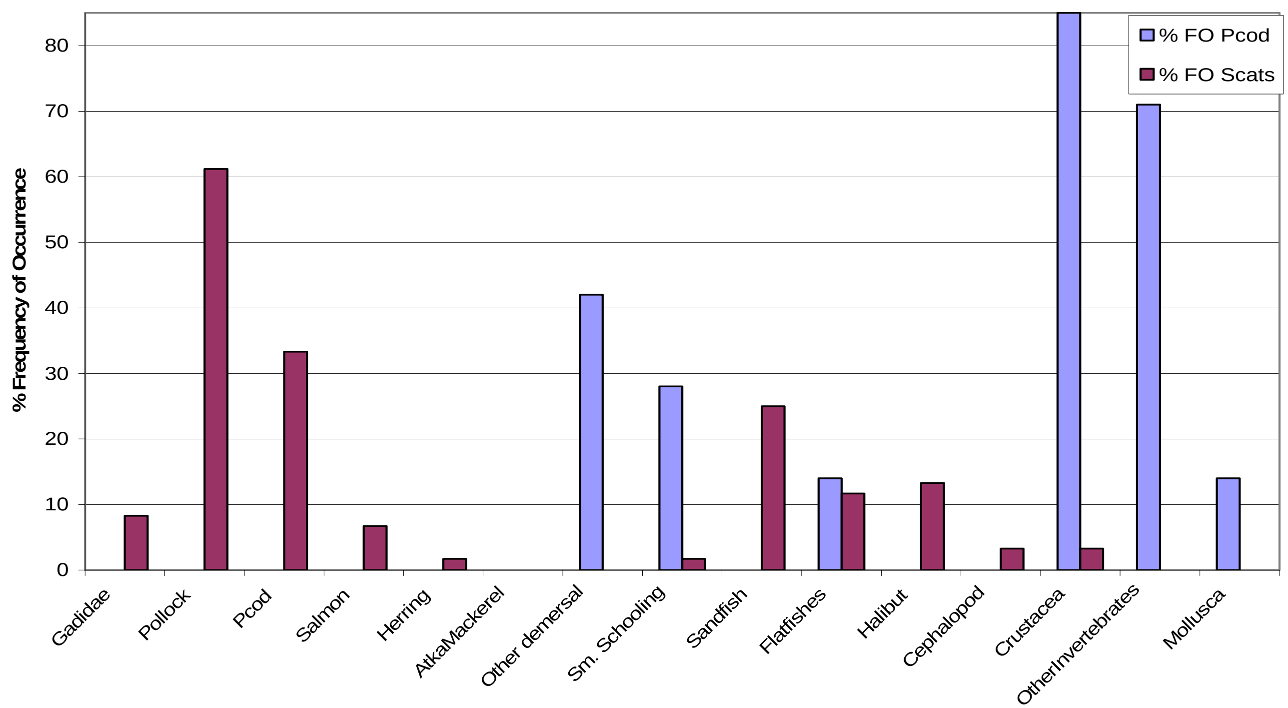
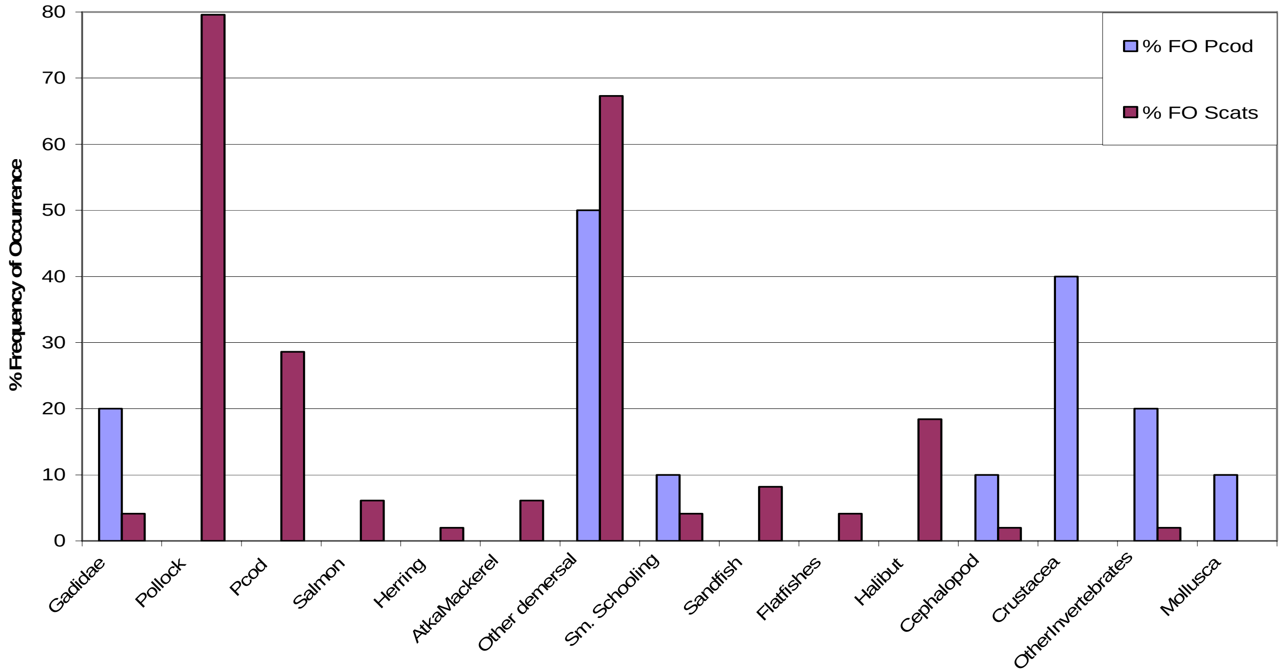


Fig. A18. Pacific cod stomach contents from SMMOCI longline surveys and Steller sea lion scat samples, March 1997 at Ugamak Island, Alaska



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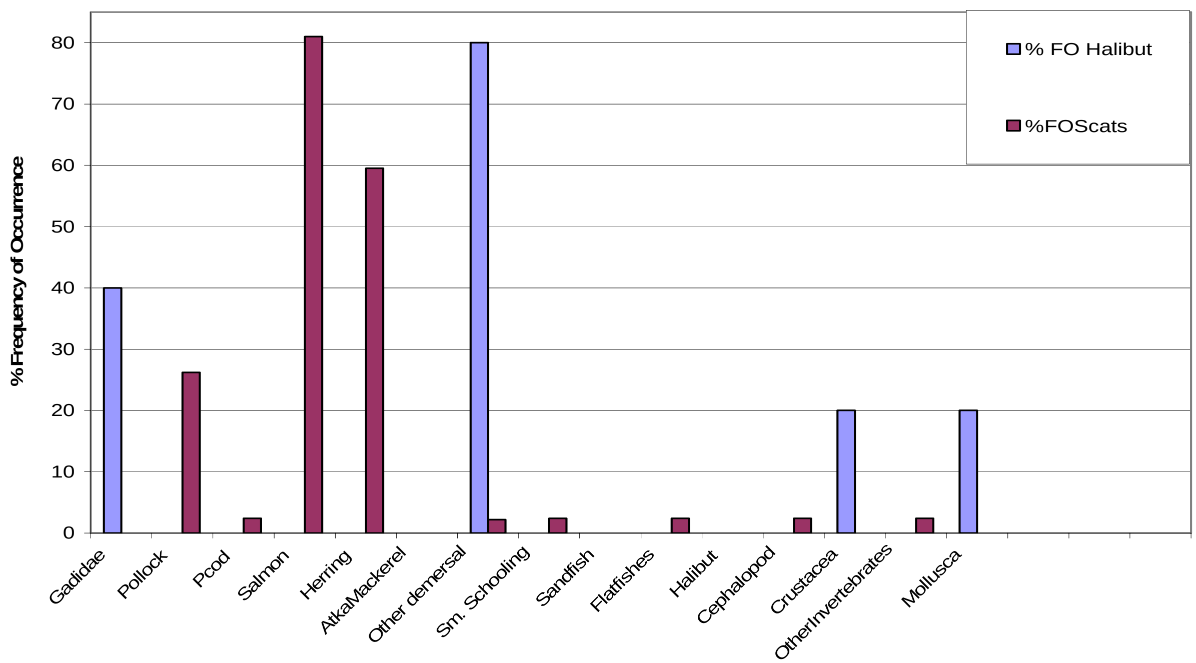
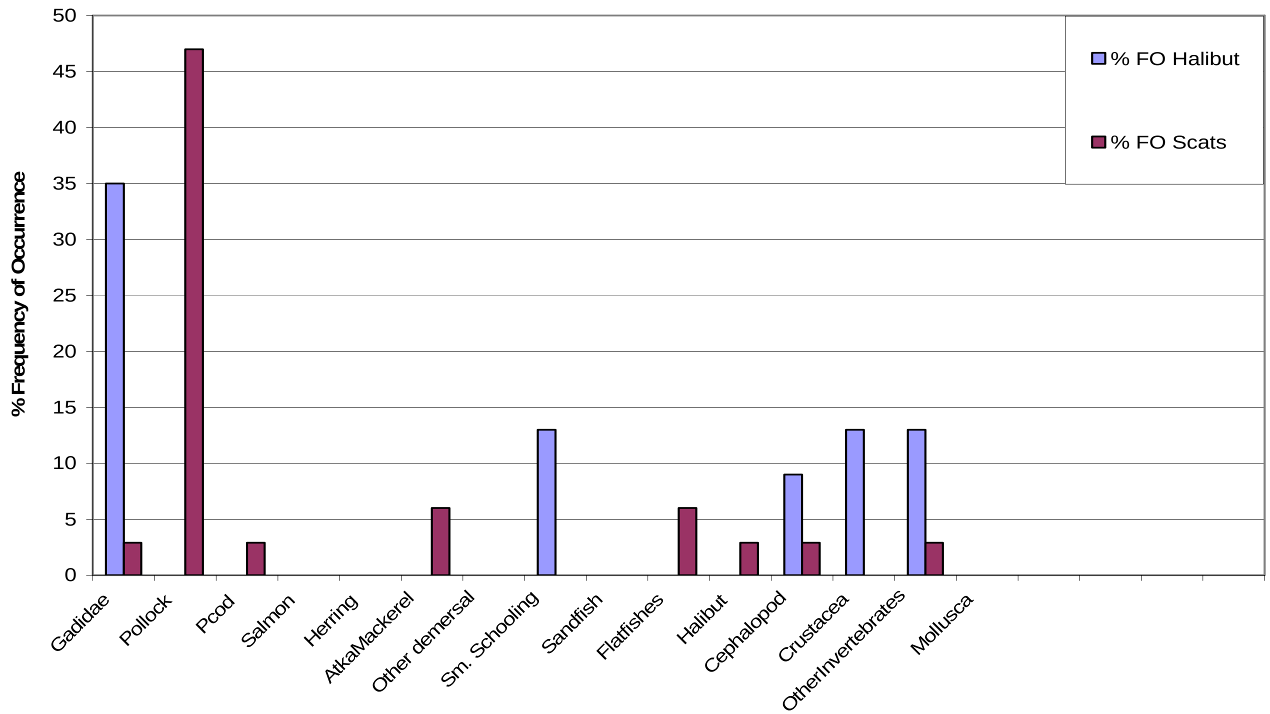


Fig. A20. Halibut stomach contents from SMMOCI longline surveys and Steller sea lion scat samples, June-July 1996 at Ugamak Island, Alaska



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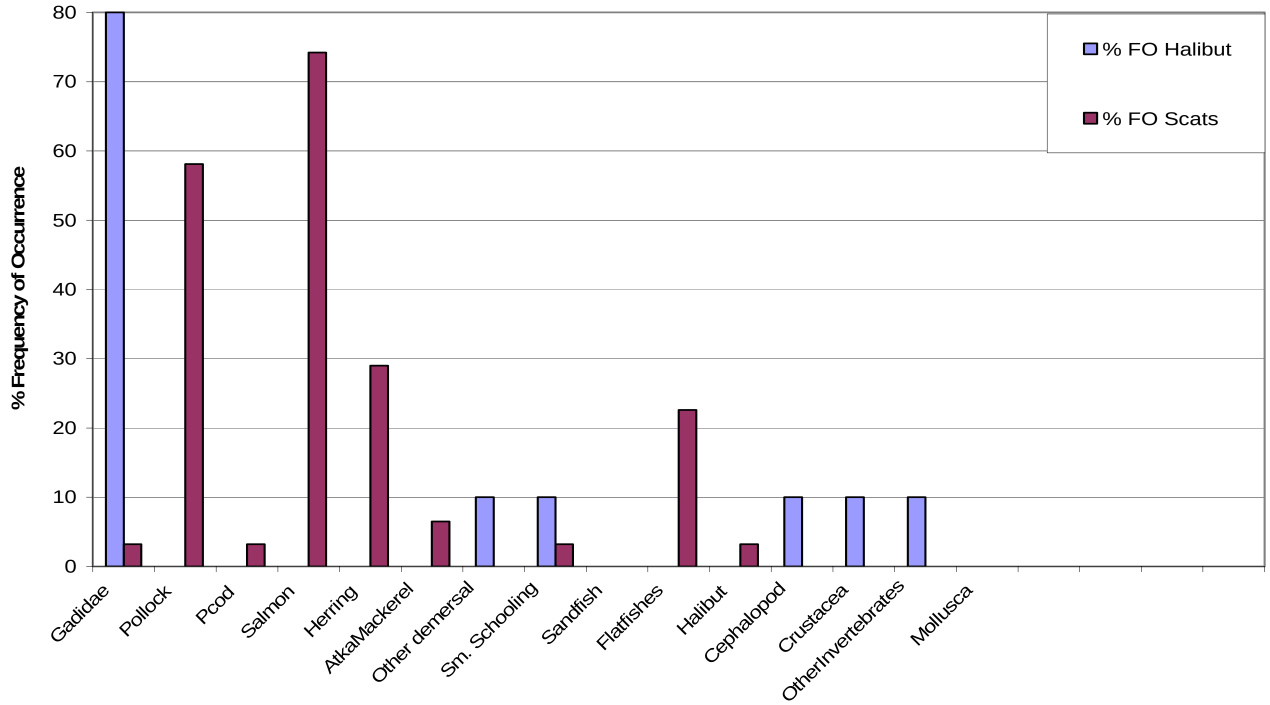

Fig. A22. Halibut stomach contents from SMMOCI longline surveys and Steller sea lion scat samples, June-July 1998 at Ugamak Island, Alaska

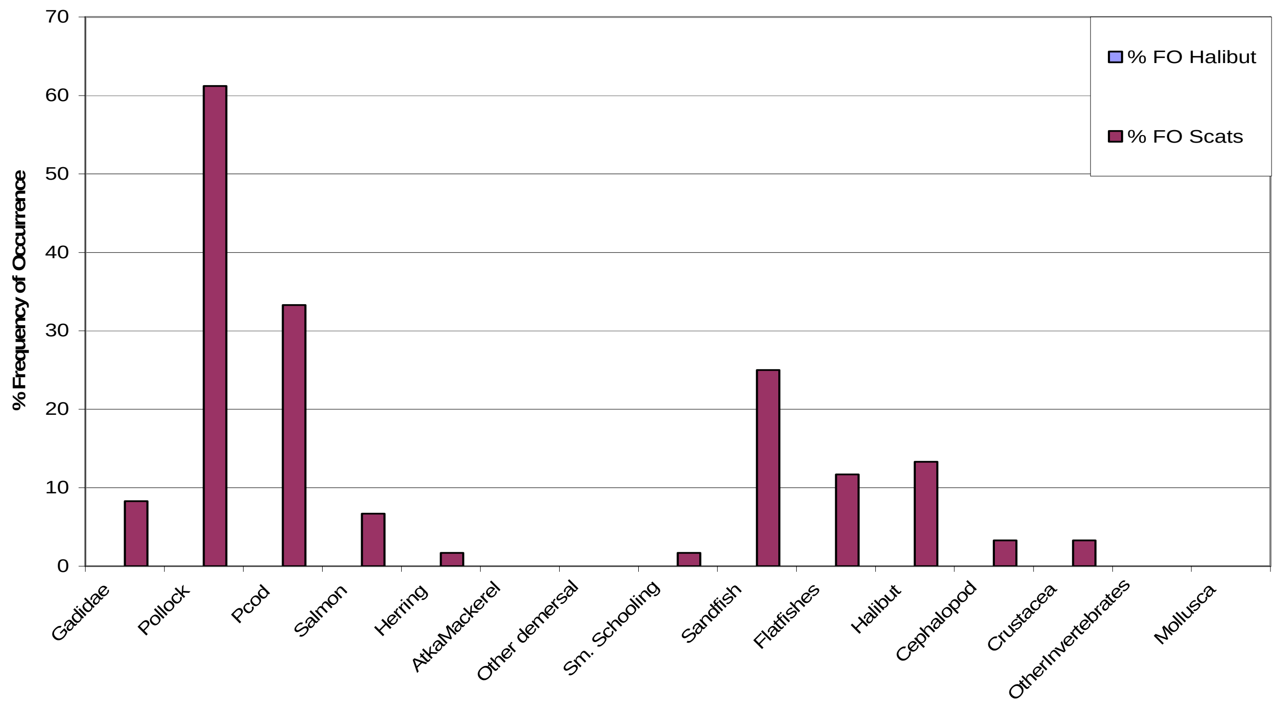

Fig. A23. Halibut stomach contents from SMMOCI longline surveys and Steller sea lion scat samples, March 1997 at Ugamak Island, Alaska

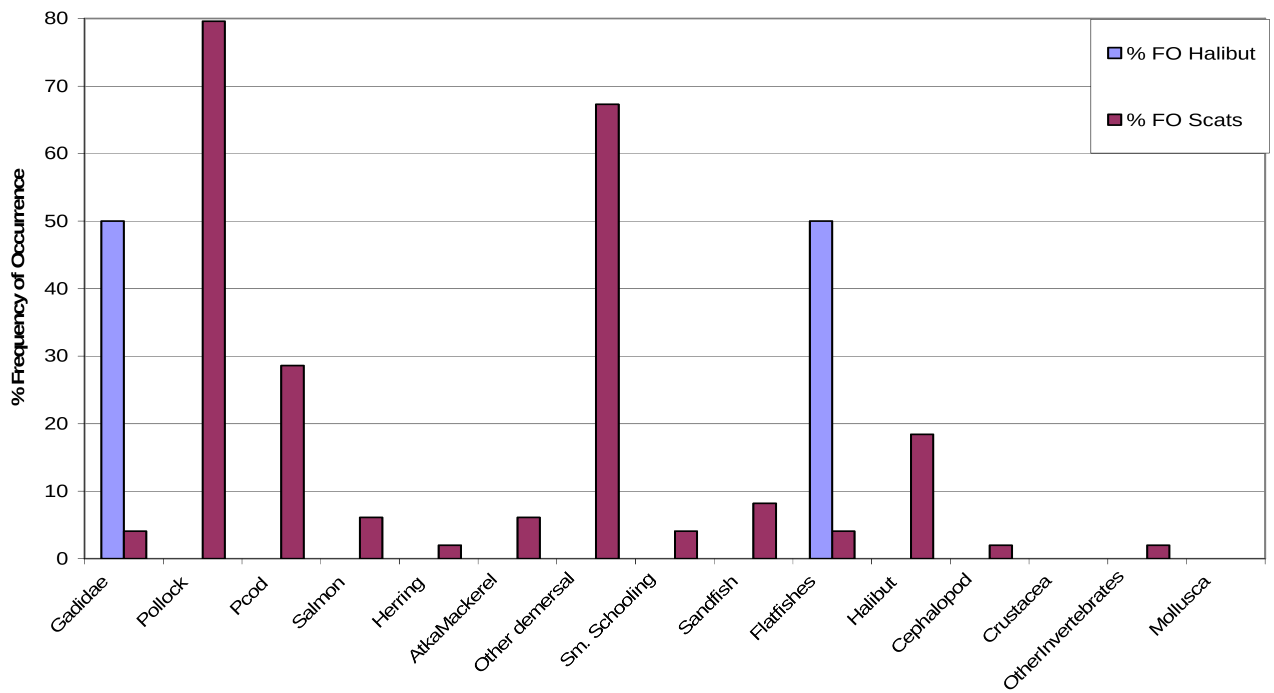

Fig. A24. Halibut stomach contents from SMMOCI longline surveys and Steller sea lion scat samples, March 1998 at Ugamak Island, Alaska

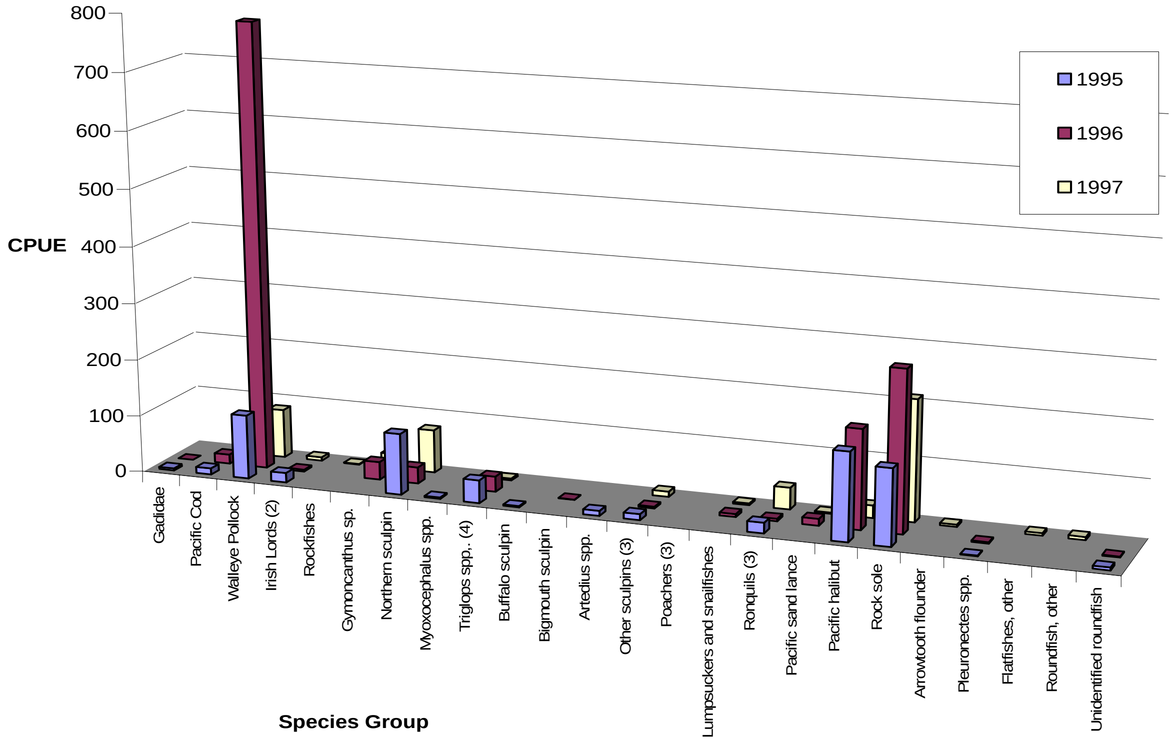

Fig. A25. Bottom Trawl CPUE at Ugamak Island, Alaska, June-July 1995-97

Table A1. Location of bottom trawls at Ugamak Island, AK, June-July 1995-98 (Flag =quantitative tows (1), non-quantitative tows (2), and bad tows that were not kept (3); dashes = no data)

Station	Tow	Date	Time	Beginning Lat. (N)	Long. (W)	Ending Lat. (N)	Long. (W)	Dur. (min)	Depth (m) min.	Flag
1	1	6/25/95	8:25:00	54 12.43	164 47.62	54 12.24	164 47.76	10.0	25.0	1
1	2	6/25/95	9:55:00	54 12.17	164 47.61	54 12.06	164 47.58	4.0	33.0	2
1	3	6/25/95	10:25:00	54 12.39	164 47.56	54 12.24	164 47.52	10.0	27.0	1
3	1	6/25/95	12:05:00	54 11.26	164 47.13	54 11.28	164 47.04	10.0	51.0	3
4	BT4-1	6/25/95	14:35:00	54 10.31	164 47.12	--	--	10.0	65.0	1
4	BT4-2	6/25/95	15:08:00	54 10.29	164 46.36	54 10.74	164 46.68	10.0	65.0	1
5	BT5-1	6/25/95	16:18:00	54 11.05	164 45.41	54 11.04	164 45.24	10.0	68.0	2
5	BT5-2	6/25/95	16:55:00	54 11.10	164 45.13	54 10.86	164 45.72	10.0	66.0	1
6	BT6-1	6/25/95	19:14:00	54 11.16	164 46.35	54 11.16	164 45.54	10.0	61.0	3
6	BT6-2	6/25/95	20:45:00	54 11.18	164 45.98	54 11.22	164 46.02	10.0	62.0	
8	BT8-1	6/26/95	0:10:00	54 07.01	164 43.82	54 07.14	164 44.46	10.0	82.0	
8	BT8-2	6/27/95	1:20:00	54 07.14	164 44.49	54 07.32	164 45.30	10.0	82.0	
8	BT8-3	6/27/95	1:57:00	54 07.21	164 45.09	54 07.32	164 45.36	10.0	88.0	
10	BT10-1	6/27/95	8:28:00	54 10.03	164 47.38	54 09.90	164 47.16	5.0	57.0	
11	BT11-1	6/27/95	9:30:00	54 11.87	164 48.51	--	--		31.0	
1	1	6/27/96	9:34:00	54 12.31	164 47.51	54 12.08	164 47.44	10.0	28.0	
2	1	6/27/96	10:36:00	54 12.3	164 47.75	54 12.04	164 47.69	10.0	29.0	
3	1	6/27/96	11:53:00	54 12.18	164 47.71	54 12.47	164 47.62	10.0	35.0	
4	1	6/27/96	13:00:00	54 12.19	164 47.40	54 11.90	164 47.51	10.0	30.0	
5	1	6/27/96	15:38:00	54 11.56	164 45.80	54 11.77	164 45.98	10.0	50.0	
5	2	6/27/96	16:32:00	54 11.35	164 46.05	54 11.53	164 46.39	10.0	60.0	
5	3	6/27/96	17:22:00	54 11.38	164 45.90	54 11.60	164 46.20	10.0	59.0	
6	1	6/27/96	20:23:00	54 12.30	164 47.19	54 12.22	164 47.18	3.0	27.0	
7	1	6/27/96	21:14:00	54 10.59	164 46.56	54 10.78	164 46.94	10.0	67.0	
8	1	6/28/96	11:18:00	54 11.29	164 45.36	54 11.38	164 45.52	8.5	66.0	
9	1	6/28/96	12:35:00	54 11.29	164 45.37	54 11.27	164 46.01	10.0	63.0	
10	1	6/28/96	21:08:00	54 12.21	164 47.47	54 12.45	164 47.63	12.0	26.0	
11	1	6/28/96	22:19:00	54 12.40	164 47.26	54 12.20	164 47.50	10.0	24.0	
12	1	6/28/96	23:15:00	54 12.29	164 47.45	54 12.10	164 47.80	10.0	30.0	
13	1	6/29/96	0:01:00	54 11.75	164 47.80	54 11.60	164 47.70	19.0	35.0	
14	1	6/29/96	1:28	54 10.54	164 46.63	54 10.25	164 46.85	10.0	67.0	
15	1	6/29/96	3:08:00	54 07.19	164 45.09	54 07.21	164 45.60	10.0	89.0	

16	1	6/29/96	4:28:00	54 07.35	164 45.45	54 07.42	164 45.90	10.0	84.0	
17	1	6/29/96	5:47:00	54 10.60	164 45.30	54 10.22	164 45.30	10.0	67.0	
18	1	6/30/96	1:37:00	54 10.90	164 45.10	54 10.80	164 45.12	10.0	68.0	
39	1	7/7/97	0:09:00	54 11.77	164 46.31	54 11.95	164 46.40	10.0	54.0	
39	2	7/7/97	0:42:00	54 11.87	164 46.29	54 11.92	164 46.29	10.0	53.0	
40	1	7/7/97	1:34:00	54 11.13	164 46.02	54 10.98	164 45.95	10.0	66.0	
40	2	7/7/97	2:34:00	54 11.13	164 45.99	54 10.92	164 45.90	10.0	65.5	
40	3	7/7/97	2:54:00	54 11.15	164 46.01	54 10.90	164 45.94	10.0	66.5	
41	1	7/7/97	3:25:00	54 11.02	164 45.30	54 10.85	164 45.46	10.0	70.5	
42	1	7/7/97	4:24:00	54 10.49	164 46.47	54 10.65	164 46.56	5.0	68.5	
43	1	7/7/97	5:36:00	54 07.19	164 44.96	54 07.36	164 45.31	10.0	90.5	
44	1	7/7/97	15:55:00	--	--	--	--	0.0		
45	1	7/7/97	17:05:00	54 12.22	164 47.24	54 12.14	164 47.26	10.0	36.5	
45	2	7/7/97	17:31:00	54 12.25	164 47.20			10.0	33.0	
46	1	7/7/97	17:49:00	54 12.28	164 47.51	54 12.12	164 47.48	10.0	33.5	
47	1	7/7/97	19:02:00	54 12.11	164 47.38	54 12.03	164 47.37	0.1	40.5	
48	1	7/7/97	20:16:00	54 12.50	164 47.54	54 12.44	164 47.51	10.0	25.5	
49	1	7/7/97	22:18:00	54 07.18	164 45.48	54 07.19	164 44.96	10.0	90.0	
50	1	7/7/97	23:14:00	54 07.46	164 45.46	54 07.26	164 45.09	10.0	87.0	
53	1	7/12/97	13:59:00	54 12.22	164 47.57	54 12.41	164 47.30	10.0	32.5	
53	2	7/12/97	14:35:00	54 12.22	164 47.52	54 12.41	164 47.60	10.0	32.5	
54	1	7/12/97	15:40:00	54 10.89	164 48.14	--	--	10.0	48.0	
54	2	7/12/97	15:55:00	54 11.06	164 48.04	--	--	5.0	43.0	
55	1	7/12/97	18:56:00	54 11.12	164 46.16	54 11.14	164 46.36	0.3	63.5	
56	1	7/12/97	19:43:00	54 11.10	164 45.00	54 11.03	164 45.36	10.0	68.0	
57	1	7/12/97	20:57:00	54 10.58	164 46.64	54 10.51	164 47.07	10.0	68.0	
58	1	7/12/97	21:58:00	54 10.07	164 47.36	54 10.28	164 47.55	10.0	60.0	
59	1	7/12/97	22:51:00	54 07.23	164 45.23	--	--	10.0	90.0	
59	2	7/12/97	23:18:00	54 07.23	164 45.26	54 07.38	164 45.48	10.0	90.0	
983100101		7/7/98	23:09:00	54 07.22	164 44.98	54 07.21	164 45.36	10.0	88.0	1
983100201		7/8/98	0:13:00	54 07.25	164 45.27	54 07.38	164 45.61	10.0	87.0	1
983100202		7/10/98	8:22:00	54 07.28	164 45.43	54 07.10	164 44.90	10.3	84.0	3
983100301		7/8/98	1:23:00	54 07.31	164 45.37	54 07.51	164 45.68	10.0	86.0	1
983100401		7/8/98	2:57:00	54 10.50	164 47.04	54 10.60	164 46.61	10.0	67.0	3
983100402		7/8/98	3:30:00	54 10.51	164 46.90	54 10.56	164 46.49	10.0	67.0	1
983100501		7/8/98	4:48:00	54 11.23	164 46.28	--	--		59.0	3
983100502		7/8/98	5:05:00	54 11.21	164 46.07	--	--		61.0	3
983100601		7/9/98	8:50:00	54 12.30	164 47.40	54 12.15	164 47.42	5.0	29.0	1
983100602		7/10/98	9:33:00	54 12.35	164 47.58	54 12.28	164 47.41	5.0	27.0	1

983100701		7/9/98	9:28:00	54 12.21	164 47.86	54 12.20	164 47.98	5.0	30.0	1
983100801		7/9/98	10:03:00	54 12.14	164 47.21	54 12.06	164 47.12	4.0	38.0	2
983100901		7/9/98	11:26:00	54 12.02	164 46.02	54 11.07	164 45.70	5.5	47.0	3
983101001		7/9/98	13:06:00	54 11.74	164 45.60	--	--	1.0	58.0	3
983101101		7/9/98	14:34:00	54 11.13	164 46.22	54 11.25	164 46.27	5.0	59.0	3
983101201		7/9/98	15:19:00	54 11.01	164 46.21	54 11.20	164 46.25	7.3	60.0	1
983101301		7/9/98	17:36:00	54 12.08	164 47.69	--	--	0.3	35.0	3
983101302		7/9/98	17:55:00	54 12.12	164 47.78	54 12.24	164 47.74	4.0	34.0	3
983101501		7/10/98	7:12:00	54 11.05	164 45.28	54 11.27	164 44.92	10.0	66.0	1

Table A2. Summary CPUE and fish taxa during quantitative beam trawl surveys at Ugamak Island, AK, summer 1995-97. (CPUE = catch per unit effort)

	1995	1996	1997
Fish cumulative CPUE (# fish/1000 m^2)			
Range	1.4 - 154.1	.76 - 782.3	1.8 - 211.9
Average + Std Dev	25.9 ± 46.1	49.9 ± 155.7	38.0 ± 54.7
# Total Fish taxa	23	28	30
# Fish taxa/tow			
Range	1 - 12	4 - 15	1 -10
Average + Std Dev	6.3 ± 3.6	7.0 ± 3.2	5.3 ± 2.8
# Tows	12	17	17
Tow depth (m)			
Range	6 - 90	24 - 90	26 - 91
Average + Std Dev	55.9 ± 26.4	52.9 ± 22.0	58.5 ± 21.4