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Mesopelagic nekton and associated physics of the southeastern Bering Sea

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Abstract

The mesopelagic community of fishes and squids are fundamental in the diet of apex predators, but in most cases their life histories and habitat requirements are poorly understood. In May 1999, a pilot study was conducted to identify mesopelagic nekton, describe dominant physical characteristics of their habitat, and compare their relative abundances over several study sites in the southeastern Bering Sea. Biological samples were collected at 250, 500, and 1000 m depths with an open pelagic rope trawl lined with 1.2-cm mesh in the codend. Net type, mesh size, and trawling techniques were designed to parallel those of extensive Russian research surveys in the western Bering Sea, permitting direct comparisons between study results. Forty-three species of fish and 15 species of cephalopods were identified, including a new species of gonatid squid and a range extension for *Paraliparis paucidens*, a snailfish never before observed in Alaskan waters. Faunal biomass was high with over 25,000 (1400 kg) fish and squid collected in only 13 trawls. Concentrations of fish in this area surpass published records from the western Bering Sea and North Pacific Ocean by an order of magnitude, driven primarily by *Leuroglossus schmidti*, a deep-sea smelt. Generally, specimens were of high quality, and new size records were established for several species of fish and squid. The physical environment as determined from altimetry, satellite-tracked drifters, and water properties (temperature and salinity) was typical of the last decade for this area. Spatial patterns in species distribution were observed, but further research is needed to determine whether these are a factor of mesoscale variability or of habitat characteristics.
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1. Introduction

Fish and squid living in the midwater, or mesopelagic zone (200–1000 m depths), are important components of the pelagic food web in the world's oceans. In the Bering Sea, mesopelagic fishes and squids are among the primary prey of endangered and depleted pinnipeds (Steller sea lions and northern fur seals, respectively), cetaceans (Kajimura and Loughlin, 1988), declining seabirds (Hunt et al., 1996), and commercially important groundfish (Lang and Livingston, 1996) and finfish (Brodeur et al., 1999; Pearcy, 1992). They, in turn, are primary consumers of zooplankton, euphausiids, larval, and juvenile fishes, and squids (Beamish et al., 1999; Sinclair et al., 1999). As strong vertical migrators, the nekton of the mesopelagic zone play a substantial role in the transport and redistribution of organic matter from rich surface waters to the benthos of the world's oceans (Willis and Pearcy, 1982).

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No directed studies have been previously conducted on the biomass and distribution of mesopelagic fishes and cephalopods in the eastern Bering Sea, or how the physical oceanography of the area influences their distribution (Sinclair et al., 1999). This study was a pilot effort to define species distributions, intraspecific size distributions with depth, and habitat characteristics of the midwater zone. Mesopelagic nekton inhabit a species-specific range of depths day and night, and typically undergo diel vertical migrations. Many species demonstrate ontogenetic migrations as well, living in epipelagic layers (0–200 m) as larval or early stage juveniles, and progressing to deeper layers of the water column as they develop (Willis and Pearcy, 1980).

Russian researchers have collected extensive biological data from the western Bering Sea during 20 years of directed annual surveys of the mesopelagic zone (Radchenko, 1992; Sinclair et al., 1999). However, the distribution, habitat characteristics, community composition, and life history of these critical faunal components in the eastern Bering Sea are virtually unknown. This lack of focused research is due to the limited commercial value of these fishes and squids. The absence of commercial interest in mesopelagic nekton contrasts sharply with their ecological importance. The deficit in our understanding of the mesopelagic community contributes to our inability to define key factors driving decadal scale changes in the Bering Sea. These changes include dramatic population declines of birds and mammals that prey upon mesopelagic fishes and squids (NRC, 1996).

Our study is set at three sampling stations within the pelagic extension of a broad, productive region of the eastern Bering Sea, aptly named the "green belt" (Springer et al., 1996). The relevance of the green belt to the Bering Sea ecosystem is well established (NRC, 1996; US GLOBEC, 1996). Physical processes at the shelf edge, including mixing and eddies in the Bering Slope Current (BSC) (Fig. 1), bring nutrients to the euphotic zone and contribute to enhanced primary production in this area estimated to be 60% greater than the adjacent outer shelf domain, and 270% greater than the oceanic domain. The dynamic hydro-

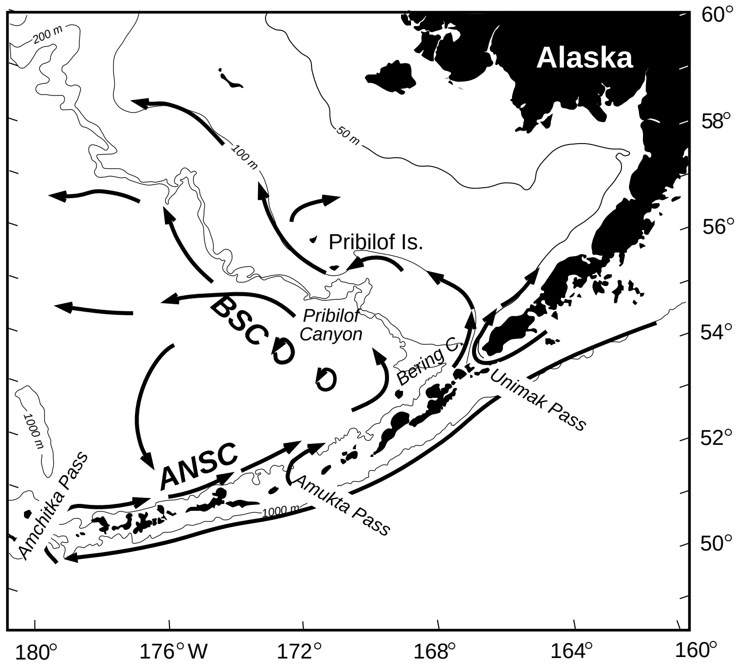

Fig. 1. Place names of primary currents and dominant physical features of the study area.

graphic characteristics (Kinder and Schumacher, 1981; Kinder et al., 1983) of this shelf-slope system form boundary layers that stratify and concentrate plankton, small forage species (Nishiyama et al., 1986) and their predators (marine mammals and birds) in both a horizontal and vertical plane (Sinclair, 1988; Sinclair et al., 1994). In this way, the green belt serves as a transition zone between shelf and basin waters, extending its relevance to the mesopelagic community.

The dominant currents (Fig. 1) in the southeast corner of the Bering Sea basin that ultimately feed the green belt region are the Aleutian North Slope Current (ANSC) and the BSC (Reed and Stabeno,

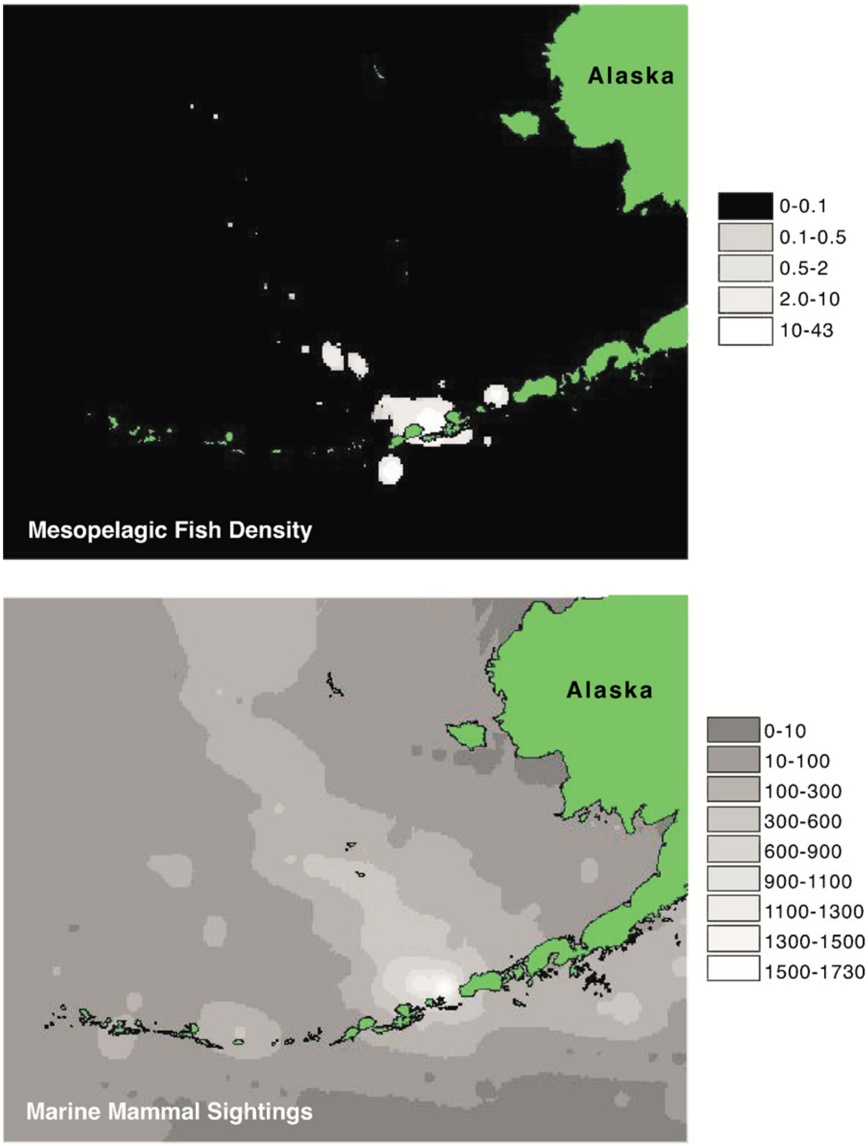

Fig. 2. (A) Mesopelagic fish density (kg/ha) as determined from bycatch estimates in research bottom trawls conducted across the continental shelf to slope edge in the eastern Bering Sea, 1978–1991; and (B) opportunistic marine mammal sightings 1958–1997, within and outside the green belt area of the eastern Bering Sea.

1999; Stabeno et al., 1999). North Pacific water flows northward through eastern Aleutian passes as the source of the ANSC, which then flows eastward along the northern slope of the Aleutian Islands. As it approaches the eastern shelf, it turns northwestward forming the BSC. The BSC is the eastern boundary current of the Bering Sea gyre, and as such, is the major dynamical feature along the continental slope. It bathes the eastern Bering Sea slope with relatively warm, saline water, and serves as a nutrient source for advection onto the shelf (Stabeno et al., 2002, 2003), as well as a dynamic influence in the exchange of water between the slope and shelf. Magnitude of transport in this system varies from less than $1 \times 10^6\,m^3\,s^{-1}$ to more than $8 \times 10^6\,m^3\,s^{-1}$.

A recent study based on research fisheries bycatch data (Sinclair et al., 1999) indicated areas of relatively high biomass among dominant families of mesopelagic fishes within the eastern Bering Sea green belt. Historical records of marine mammal distributions have also indicated high densities of marine mammals in the green belt area (Fig. 2). This pilot study was designed as a first step towards identifying midwater fish and squid communities within the pelagic extension of the southeastern Bering Sea green belt, and the physical mechanisms that define their habitat.

2. Methods

2.1. Biological sampling

A pilot survey was conducted during May 15–20, 1999 to identify mesopelagic fishes and cephalopods, and associated habitat characteristics in the southeastern Bering Sea green belt. A 60-m stern trawler (NOAA ship *Miller Freeman*) was used to conduct trawling, plankton and ichthyoplankton sampling, physical sampling, and marine mammal sightings. Results of the trawl survey and physical characteristics of the study area are reported here. A non-closing pelagic midwater trawl (Aleutian Wing Trawl) with head and footrope measurements of 81.7 m, and mesh size tapering from 8.9 to 3.3 cm was fitted with a knotless, small-mesh (1.2 cm stretch) codend liner. Mouth opening and net speed were monitored electronically during fishing and transmitted in real time from the net to the trawl house. True fishing depth and time fished at depth also were recorded by a bathythermograph attached directly to the net. Average vertical and horizontal opening of the trawl mouth during fishing was $25\,m \times 40\,m$. Mean trawl speed at target depth was 3.5 kts. Following methods standardized in Russian surveys (Sinclair et al., 1999), trawl speeds were increased at deployment and decreased at retrieval in order to reduce bycatch from depths shallower than target depth. Trawls were conducted day and night at three mean depths (250, 500, and 1000 m) in three pelagic sites at the eastern slope (haul numbers 2–4), Bogoslof (haul numbers 5–7, 13, 15), and Bering Canyon (haul numbers 8–12) (Fig. 3; Table 1). Two additional hauls (numbers 1, 14) were disrupted when the net twisted during trawling and are not included in this analysis.

2.2. Biological sample processing

Overall, the condition of the catch was good and frequently included live specimens. However, a substantial portion was not readily identifiable to species due to degraded body condition and subsequent loss of descriptive features, such as photophores and tentacles. Species identification was further complicated by the fact that physical characteristics of squid at various life stages have not been adequately described in the literature. To address these problems, the complete catch from each haul was rough-sorted on deck and weighed by species, or by family in cases where identification to species was not possible. With the exception of three subsampled species (*Leuroglossus schmidti*, *Bathylagus milleri*, and *B. pacificus*), the entire catch was then frozen and returned to the wetlab for measurement and microscopic examination of defining physical features. An identification key was developed based on species-specific features, which resulted from, or were resistant to damage due to trawling, such as coloration, persistent photophores, and cranial condition. The key will allow subsampling of material in future studies.

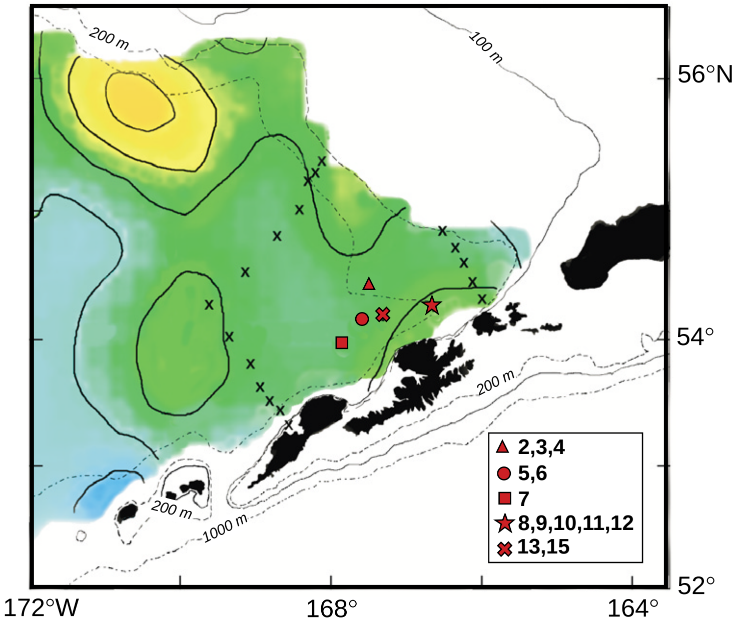

Fig. 3. The study area indicating trawl positions, general study sites, CTD locations, and general physical conditions as indicated by altimetry readings for May 15–20, 1999.

Table 1
Trawl locations and average temperature at target fishing depth

Haul	Date	Latitude (°N)	Longitude (°W)	Duration (h:min)	Temperature (°C)	Depth (m)	Time
1	Terminated						
2	5/15/99	54.528	167.455	2:00	3.7	239	Night
3	5/15/99	54.519	167.438	0:15	3.5	509	Day
4	5/15/99	54.510	167.416	1:10	3.5	547	Day
5	5/16/99	54.210	167.680	2:00	2.8	950	Day/night
6	5/16/99	54.195	167.677	2:00	3.3	707	Day
7	5/17/99	54.000	167.877	1:00	3.1	825	Day
8	5/17/99	54.283	166.360	1:00	3.4	251	Day/night
9	5/17/99	54.283	166.404	1:00	3.5	537	Day
10	5/17/99	54.282	166.375	1:00	2.9	896	Day
11	5/18/99	54.283	166.354	1:00	3.5	253	Night
12	5/18/99	54.272	166.428	0:30	3.6	477	Night
13	5/19/99	54.180	167.303	0:30	3.8	272	Day
14	Terminated						
15	5/20/99	54.180	167.301	1:00	2.9	899	Night

Individual body lengths and weights were collected from every fish (standard length) and squid (dorsal mantle length or gladius length) in good condition. Otoliths and beaks also were removed from a size-stratified series of fish and squid, respectively, for the development of body length regression formulae and energetics studies. Species identification and body size measurements are complete and reported here.

2.3. Analysis of catch

Results from this pilot survey provide an index of relative species abundance between areas and depths sampled. Relative abundance was evaluated based on the frequency of occurrence (FO) and catch weight standardized as kg/h of trawling for each species in each haul. Weight values were based on total weights obtained after rough deck sort to species or family level. Fish standard length (SL, mm) and squid gladius length or dorsal mantle length (DML, mm) measurements were analyzed by time of capture, depth of trawl, and sample location. A Density Analysis (S-plus, Clifford and Stephenson, 1975) was used to describe the characteristic size of the predominant fish species by depth and study area. Finally, potential community habitats were then compared using CTD data by depth, and temperature–salinity profiles by study area.

2.4. Physical sampling

Hydrographic data were collected at each trawl site and along a standard monitoring line sampled nine times between 1995 and 1999. Conductivity, temperature, depth (CTD) casts were taken along the monitoring line (X's, Fig. 3) to 1500, or 20 m from the bottom in shallower water. Casts at the tow sites were taken to 200 m beyond fishing depth (400–1200 m). All CTD casts were taken with Seabird SBE-911 Plus systems. Salinity samples were taken for calibration on all casts and analyzed on a shipboard laboratory salinometer.

Nine satellite-tracked drifters were deployed in the region to track daily current patterns and define eddy development. Each drifter was drogue centered at ~40 m; deep enough to minimize the influence of winds on the trajectory, but shallow enough to ensure retention of the drogue for >6 months. Typically, 12 or more position fixes (class II or better) were obtained daily through Service Argos, with a standard error of ~ 0.2 km (Reed and Stabeno, 1999).

3. Results

3.1. Physical observations

Eddies are a persistent feature of the BSC and the southeast Bering Sea basin (Stabeno et al., 2003). They range in diameter from 10 to 100 km and can reach a depth of >1500 m. As with other

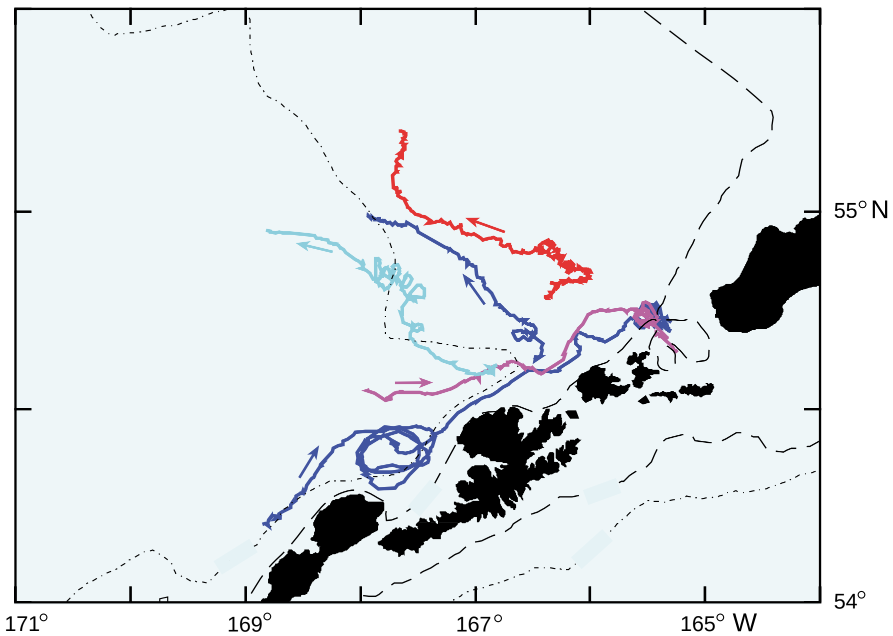

Fig. 4. Drifter data for May 1999 depicting current patterns and speed.

boundary regions (Wada, 1971; Willis, 1984; Olson and Backus, 1985; Nishiyama et al., 1986; Sinclair, 1988; Hunt et al., 1990; Hunt, 1991; Sinclair et al., 1994; Beamish et al., 1999) small schooling fish and squid may concentrate at the edge of eddies forming a ready and highly concentrated source of food for marine mammals and birds, which also congregate there. However, altimetry data in 1999 indicated that there were no large eddies in our study area that could have affected the patterns of variability in fish and squid distribution (Fig. 4).

Geostrophic transport in the ANSC/BSC from CTD's collected during May 1999 was $2.5 \times 10^6\,m^3\,s^{-1}$. The drifter trajectories show a stable BSC and ANSC during May that reaches into Bering Canyon. During the first half of May the trajectories show the ANSC turned northwestward following the shelf break. During the latter half of May, onshelf flow is evident in some of the trajectories; drifters deployed in the ANSC were transported onto the shelf and eventually reached Unimak Pass (Fig. 4). Velocities along the shelf break were $\sim 10\,cm\,s^{-1}$, which is typical for this region. In physical terms, 1999 appeared to be a typical year, indicating that the apparent high productivity in the study region was not the result of unusual physical conditions.

Hydrographic casts conducted before and after each trawl show similar water-column structure within and between each of the three geographic areas sampled (Bogoslof, Bering Canyon, and the eastern slope) (Fig. 5). At each geographic site, the surface mixed layer had begun to form in the upper 50 m. Below this surface layer, there was a relative minimum in temperature (100–200 m) that was the remnant of cold water formed during previous winters. This cool layer overlays a subsurface maximum in temperature. At Bering Canyon and the eastern slope, the maximum temperature occurred at a depth of 300–400 m, but at Bogoslof it was shallower at 250–300 m. Below 400 m, the temperature decreases linearly at all sites. This is a common temperature profile in the southeastern Bering Sea slope and basin when advection of North Pacific water through Amukta Pass occurs. When flow through Amukta Pass is weak or absent for a month or more, the subsurface temperature between 250 and 400 m is reduced. While both modes have been observed, flow through Amukta Pass is the more common of the two patterns.

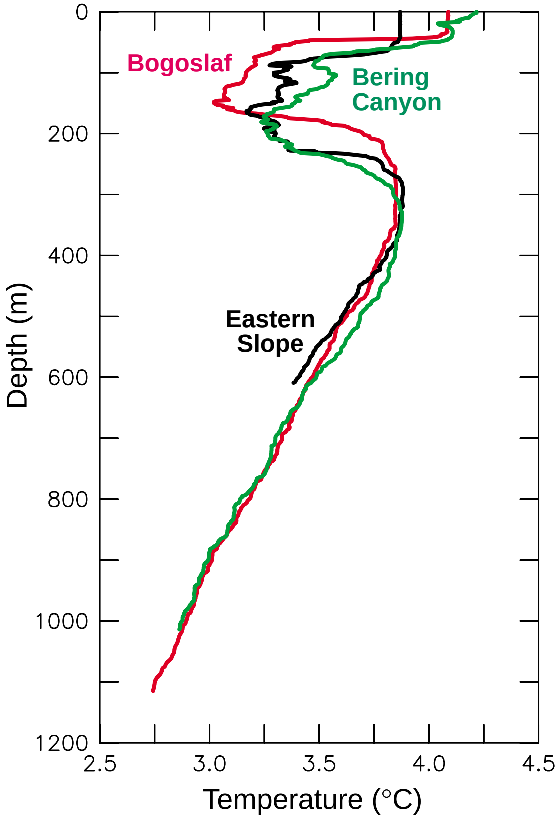

Fig. 5. Typical temperature profiles from each of the three geographic areas.

3.2. Biological observations

The composition of catches at depth were certainly influenced by the open net and inadvertent sampling of overlying water; however, patterns in relative abundance of species between depths and areas are probably representative, as indicated by higher volumes of catch in the upper two layers compared to the 1000 m depth. The long duration of most tows at depth (Table 1), as well as net speed adjustments at set and retrieval, served to reduce the effects of contamination from non-target layers.

A total of 43 species of fishes and 15 species of cephalopods were identified from 13 trawls (Table 2; Appendix A, Tables 3 and 4). Frequency of occurrence and catch by weight values (Table 2) indicate that mesopelagic biomass extending from depths of 250–1000 m in the eastern Bering Sea green belt region is dominated by the fish families Bathylagidae (especially *Leuroglossus schmidti*, *Bathylagus pacificus*, and *B. milleri*) and Myctophidae (especially *Stenobrachius leucopsarus* and *S. nannochir*) (Appendix A, Table 3), and by the squid family Gonatidae, most strongly represented by *Eogonatus tinro*, *Gonatopsis borealis*, and *Berryteuthis magister* (Appendix B, Table 4). Many other species of fishes and invertebrates occurred frequently (FO = 50–100%) in the hauls, but in small volumes (Table 2).

As a family, the bathylagids were the dominant group throughout the water column (Table 2). *Leuroglossus schmidti*, which alone comprised nearly half of total catch weight values, was most common. Total fish weights were highest in the lower mesopelagic at 500 m. Among the bathylagidae, *Leuroglossus schmidti* dominated the weight in trawls 500 m or shallower, while *B. pacificus* and *B. milleri* predominated in trawls at 1000 m. Myctophids also occurred in all trawls, but the dominant species (*Stenobrachius leucopsarus* and *S. nannochir*) appeared most numerous at 500–1000 m (Table 2; Appendix A, Table 3). Walleye pollock (*Theragra chalcogramma*) was present in 100% of hauls, and grenadiers (Macrouridae) were present in 100% of the hauls at 1000 m. Both occurred at significant weights due to their large body sizes, but neither walleye pollock nor grenadiers are considered part of the mesopelagic community for the purposes of this study. Cephalopods occurred in 100% of hauls, day and night. Total cephalopod weights were highest in the upper mesopelagic at 250 m depths where gonatid squids dominated the catch (Table 2; Appendix B, Table 4).

Density plots of *Bathylagus pacificus* demonstrated significantly distinct bimodal patterns in body size by depth ($P > 0.001$) where juvenile fish were concentrated at the 500 m level, and adults at 1000 m (Fig. 6). Although ontogenetic differences in depth distribution were not surprising, these results were encouraging considering the potential bias inherent in using an open net. Body size of *L. schmidti* was different in each of the three study sites, all depths combined. An increase in body size among *L. schmidti* became apparent as sampling effort moved from west to northeast. A developing bimodal pattern in body size among *L. schmidti* individuals was indicated in the Bogoslof and eastern slope study areas (Fig. 7). *Stenobrachius leucopsarus* also demonstrates a weak bimodal distribution; however, in contrast to *L. schmidti*, the pattern is consistent at all three sampling areas and between depths sampled (Fig. 8). That is, unlike *L. schmidti*, there is no apparent difference in size distribution among *S. leucopsarus* throughout the study area.

A new species of gonatid squid was identified (Sinclair and Walker, in preparation). A range extension also was documented for the snailfish, *Paraliparis paucidens*, previously observed only as far north as British Columbia at Dixon's Entrance, and never before in Alaskan waters. The cephalopod *Japatella heathi*, first identified in the western Bering Sea in 1990 (Radchenko, 1992; Sinclair, 1999), was caught in the lower mesopelagic depth range (500–1000 m) in this study.

The number of marine mammals sighted was markedly reduced compared to marine mammal surveys conducted in the area during 1978–1982 with the same methodology (National Marine Mammal Laboratory, unpublished data). Most noteworthy were decreased sightings of Dall's porpoise (*Phocoenoides dalli*), a significant consumer of mesopelagic fish and squid (Beamish et al., 1999; Crawford, 1981). This reduction in marine mammal sightings, especially Dall's porpoise, follows a trend observed throughout the 1990s (NMFS, unpublished data). Although marine mammal numbers were down overall, the highest counts were at the Bering Canyon study site with a single sighting of an estimated 75 killer whales observed. In addition, trawl catch values (kg/h) were up to 10 times higher here than at the other two study sites, driven primarily by high concentrations of deep-sea smelt (*Leuroglossus schmidti*) and juvenile gonatid squid, indicating that this region is biologically rich compared to surrounding sampled areas (Fig. 1).

Table 2
Summary of frequency of occurrence and weight values for primary groups or species caught by depth. Weight values are based on rough deck sort only, and day and night catch is combined

Catch summary—Deck sort	250 m trawls			500 m trawls			1000 m trawls		
	FO	Mean (kg/h)	Range (kg/h)	FO	Mean (kg/h)	Range (kg/h)	FO	Mean (kg/h)	Range (kg/h)
Petromyzontidae									
Lampetra tridentata—Pacific lamprey	1.0	1.1	0.3–2.8	0.8	0.6	0.0–1.0	0.2	0.1	0.0–0.4
Squalidae									
Somniosus pacificus—Pacific sleeper shark	0.2	1.6	0.0–6.5	0.0			0.0		
Nemichthyidae									
Avocettina gilli—Spaced snipe eel*	0.2	<0.1	0.0–<0.1	0.2	<0.1	0.0–<0.1	0.8	< 0.1	0.0–<0.1
Argentinidae									
*Nansenia candida**—Bluethroat argentine	0.0			0.2	<0.1	0.0–0.1	0.0		
Bathylagidae									
B. milleri & *B. pacificus*—Blacksmelt	0.5	0.1	0.0–0.2	0.5	0.4	0.0–1.0	1.0	27.4	24.4–32.8
*Bathylagus ochotensis**—Eared blacksmelt	1.0	0.10	<0.1–0.2	1.0	0.3	0.2–0.3	1.0	0.1	<0.1–0.1
Leuroglossus schmidti—Northern smoothtongue	1.0	55.2	26.1–122.7	1.0	135.5	29.8–343.4	1.0	17.0	5.1–28.1
Opisthoproctidae									
Macropinna microstoma—Barreleye*	0.0			0.2	<0.1	0.0–0.1	0.6	< 0.1	0.0–<0.1
Alepocephalidae									
Sagamichthys abei—Shining tubeshoulder*	0.0			0.2	<0.1	0.0–<0.1	0.0		
Gonostomatidae									
Cyclothone sp. cf. *C. pseudopallida**	0.2	<0.1	0.0–<0.1	0.2	<0.1	0.0–<0.1	1.0	< 0.1	<0.1–<0.1
*Gonostoma gracilis**	0.0			0.2	<0.1	0.0–<0.1	0.4	< 0.1	0.0–0.1
Chauliodontidae									
*Chauliodus sloani**—Pacific viperfish	0.2	<0.1	0.0–<0.1	1.0	0.3	0.2–0.6	1.0	0.3	0.1– 0.6
Melanostomiidae									
Tactostoma macropus—Longfin dragonfish*	0.0			0.2	<0.1	0.0–<0.1	0.2	< 0.1	0.0–<0.1
Scopelarchidae									
Benthalbella dentata—Northern perleye*	0.0			0.2	<0.1	0.0–0.1	0.8	0.1	0.0– 0.2
Notosudidae									
Scopelosaurus harryi—Scaly wearyfish*	0.0			0.2	<0.1	0.0–0.1	0.8	< 0.1	0.0– 0.1

Table 2 (*continued*)

Catch summary—Deck sort	250 m trawls			500 m trawls			1000 m trawls		
	FO	Mean (kg/h)	Range (kg/h)	FO	Mean (kg/h)	Range (kg/h)	FO	Mean (kg/h)	Range (kg/h)
Paralepididae									
*Lestidiops ringens**	0.2	<0.1	0.0–<0.1	0.2	<0.1	0.0–<0.1	0.2	< 0.1	0.0–<0.1
*Paralepis atlantica**	0.0			0.0			0.2	< 0.1	0.0–<0.1
Alepisauridae									
Alepisaurus ferox—Longnose lancetfish	0.0			0.0			0.4	4.3	0.0– 13.9
Myctophidae—Lampfish	1.0	4.9	2.1–11.3	1.0	12.8	6.8–26.4	1.0	6.2	4.7– 8.6
Macrouridae—Grenadier	0.0			0.2	0.6	0.0–2.5	1.0	17.2	1.5– 66.8
Gadidae									
Theragra chalcogramma—Walleye pollock	1.0	15.4	1.9–21.6	1.0	49.0	10.4–96.0	1.0	18.3	3.5–43.1
Oneirodidae—Dreamer*	0.0			0.2	0.1	0.0–0.2	0.8	0.2	0.0– 0.2
Melamphaidae									
M. lugubris and *P. crassiceps*	0.0			0.5	0.0	0.0–0.1	1.0	1.4	0.2– 2.9
Scorpaenidae									
Sebastes alutus	0.2	1.3	0.0–5.4	0.2	0.2	0.0–0.8	0.2	0.1	0.0– 0.7
Cyclopteridae									
Aptocyclus ventricosus—Smooth lumpsucker	0.5	1.0	0.0–3.7	0.0			0.0		
Paraliparis sp.									
Elassodiscus tremebundus—Snailfish	0.0			0.0			0.2	0.2	0.0– 0.8
Zoarcidae									
Lycodapus sp.—Eelpout	0.0			0.0			0.4	0.3	0.0– 1.3
Cnidaria	1.0	0.6	0.1–1.4	1.0	0.8	0.0–1.0	1.0	2.2	0.6– 3.8
Crustacea	1.0	0.1	<0.1–0.2	1.0	0.3	0.1–0.7	1.0	0.8	0.5– 1.4
Cephalapod	1.0	11.1	0.8–23.1	1.0	8.4	1.4–22.3	1.0	4.2	1.3– 12.1

*Species brought back to the lab for identification; weights were based on average weight of fish when not available.

Table 3

Fish	250 m trawls						500 m trawls						1000 m trawls					
	Daytime ($n = 2$)			Nighttime ($n = 2$)			Daytime ($n = 3$)			Nighttime ($n = 1$)			Daytime ($n = 3$)			Nighttime ($n = 2$)		
	Standard length*			Standard length			Standard length			Standard length			Standard length			Standard length		
	Number	Range	Mean	Number	Range	Mean	Number	Range	Mean	Number	Range	Mean	Number	Range	Mean	Number	Range	Mean
Petromyzontidae																		
Lampetra tridentata—Pacific lamprey	7	430–720	586	4	500–570	533	4	510–670	588	3	380–520	453	2	405–525	465			
Squalidae																		
Somniosus pacificus—Pacific sleeper shark				1	1250	1250												
Nemichthyidae																		
Avocettina gilli—Spaced snipe eel				1	457	457	2	400–500	450				7	420–525	472	1	480	480
Argentinidae																		
Nansenia candida—Bluethroat argentine							1	227	227									
Bathylagidae																		
Bathylagus milleri—Stout blacksmelt				2	88–89	89	34	81–173	119	12	69–102	92	11	90–190	144	1	89	89
Bathylagus ochotensis—Eared blacksmelt	11	88–118	105	15	80–128	106	68	74–132	101	7	89–124	112	20	85–124	105	21	89–136	112
Bathylagus pacificus—Slender blacksmelt							62	54–182	110	6	71–150	91	847	49–220	139	448	55–215	144
Leuroglossus schmidti—Northern smoothtongue	716	37–135	86	828	37–135	94	1436	42–157	96	846	40–133	88	1851	29–150	92	707	45–148	95
Opisthoproctidae																		
Macropinna microstoma—Barreleye							7	51–140	88				5	82–136	115			
Alepocephalidae																		
Sagamichthys abei—Shining tubeshoulder							1	166	166									
Gonostomatidae																		
Cyclothone sp. cf. *C. pseudopallida*	1	37	37				1	48					32	39–59	52	61	41–59	53
Gonostoma gracilis										8	134–146	140	6	131–143	137	2	130–132	131
Chauliodontidae																		
Chauliodus sloani—Pacific viperfish				1	92	92	19	126–310	207	5	76–174	122	26	99–258	186	11	147–239	184
Melanostomiidae																		
Tactostoma macropus—Longfin dragonfish							3	125–245	170				2	125–135	130			
Scopelarchidae																		
Benthalbella dentata—Northern pearleye							2	125–185	155				7	115–221	178	1	170	170
Notosudidae																		
Scopelosaurus harryi—Scaly wearyfish							1	185	185				2	206–272	239	2	240–254	247
Paralepididae																		
Lestidiops ringens				1	174	174				1	225	225	1	210	210			
Paralepis atlantica																1	183	183
Alepisauridae																		
Alepisaurus ferox—Longnose lancetfish													2	1140–1250	1195			
Myctophidae																		
Diaphus theta—California headlightfish	12	72–105	88	17	68–96	85				8	81–92	88	60	73–100	87	30	77–101	88
Lampanyctus jordani—Lampfish							26	105–136	123	5	121–133	127	90	99–143	121	7	100–128	114

Table 3 (*continued*)

Fish	250 m trawls						500 m trawls						1000 m trawls					
	Daytime ($n = 2$)			Nighttime ($n = 2$)			Daytime ($n = 3$)			Nighttime ($n = 1$)			Daytime ($n = 3$)			Nighttime ($n = 2$)		
	Standard length*			Standard length			Standard length			Standard length			Standard length			Standard length		
	Number	Range	Mean	Number	Range	Mean	Number	Range	Mean	Number	Range	Mean	Number	Range	Mean	Number	Range	Mean
Lampanyctus regalis—Pinpoint lampfish				1	193	193							30	111–200	144	24	97–190	142
Protomyctophum thompsoni—Lanternfish	4	48–58	53	1	53	53										1	55	55
Stenobrachius leucopsarus—Northern lampfish	1028	37–109	76	1826	35–110	74	2252	34–115	78	539	33–103	74	2041	35–112	80	1166	35–109	81
Stenobrachius nannochir—Garnet lampfish	5	57–115	87	5	51–83	67	1523	41–118	79	169	50–105	78	1364	48–119	85	697	42–130	86
Tarletonbeania crenularis—Blue lanternfish	2	58	58										1	59	59	1	61	61
Macrouridae																		
Albatrossia pectoralis—Giant grenadier													38	39–230	114	25	45–210	141
Coryphaenoides acrolepis—Roughscale rattail																4	235-260	246
Coryphaenoides cinereus—Black grenadier													21	29–250	61	12	23–160	46
Unid. Grenadier							21	40–150	87				103	50–130	71	11	40–150	95
Gadidae																		
Theragra chalcogramma—Walleye pollock	29	400–630	525	3	520–620	583	58	420–650	538	31	430–620	524	75	450–650	549	13	480–640	553
Oneirodidae																		
Oneirodes bulbosus—Bulbous dreamer													3	50–85	63	4	67–108	91
Oneirodes thompsoni—Alaska dreamer							3	96–102	98				6	62–160	101	1	98	98
Melamphaidae																		
Melamphaes lugubris—Highsnout melamphid							5	76–95	87	1	75	75	43	68–95	84	30	70–109	88
Poromitra crassiceps—Crested melamphid													116	84–131	107	111	72–127	108
Scorpaenidae																		
Sebastes alutus—Pacific ocean perch	10	295–410	365				1	380	380				1	370	370			
Cyclopteridae																		
Aptocyclus ventricosus—Smooth lumpsucker	1	265	265	1	92	92												
Elassadon tremebundus													2	265–305	285			
Bathymasteridae																		
Bathymaster sp.	3	37–39	38															
Zoarcidae																		
Bothrocara brunneum—Twoline eelpout													8	121–325	217	1	307	307
Lycodapus fierasfer—Blackmouth eelpout													126	65–150	112			
Lycodapus poecilus—Variform eelpout													14	97–128	113			*
Total :	1829		2707			5514			1641			6950			3338			

*All lengths in millimeters. Nomenclature follows Nelson, 1994.

Table 4

Cephalopods	250 m trawls						500 m trawls						1000 m trawls					
	Daytime ($n=2$)			Nighttime ($n=2$)			Daytime ($n=3$)			Nighttime ($n=1$)			Daytime ($n=3$)			Nighttime ($n=2$)		
	Number	DML Range	DML Mean	Number	DML Range	DML Mean	Number	DML Range	DML Mean	Number	DML Range	DML Mean	Number	DML Range	DML Mean	Number	DML Range	DML Mean
Gonatidae																		
Berryteuthis magister	175	20–270	43	83	30–320	80	19	37–240	108	15	51–240	120	31	23–220	84	8	36–185	69
Eogonatus tinro	10	54–120	70	4	65–144	92	6	27–138	71	2	55–78	67	4	47–150	90	7	66–200	117
Gonatopsis borealis	241	23–164	72	224	26–165	103	72	27–161	109	75	30–162	108	116	25–155	117	14	31–143	105
Gonatus berryi	4	28–170	109	5	63–140	124	4	85–183	124	8	36–138	92	5	55–170	103	2	106–200	153
Gonatus onyx	5	36–49	44	6	41–62	50	7	36–67	51	6	44–72	52						
Gonatus pyros	7	29–70	48	6	35–66	43	8	42–190	64	5	37–170	69	4	36–168	75	2	185–285	235
Gonatus sp. *Z*							6	97–191	125	2	97–108	103	3	96–328	196	3	92–170	125
Gonatus sp.				1	71	71												
Chiroteuthidae																		
Chiroteuthis calyx	1	75	75	4	30–205	146	4	80–202	141				1	115	115	1	202	202
Cranchiidae																		
Galiteuthis phyllura	1	62	62	3	47–68	58	2	61–282	172				8	60–300	189	4	100–281	182
Taonius borealis				2	175–205	190	1	255	255				5	110–482	251	5	143–290	184
Bolitaenidae																		
Japatella heathi										1	67	67				1	60	60

DML—Dorsal mantle length (in millimeters). *Berryteuthis* and *Gonatopsis* lengths are based on dorsal mantle measurements. All octopods lengths are based on ventral mantle measurements. All remaining cephalopods are based on gladius length.
I.S.—Incomplete specimen. Nomenclature follows Nesis, 1983.

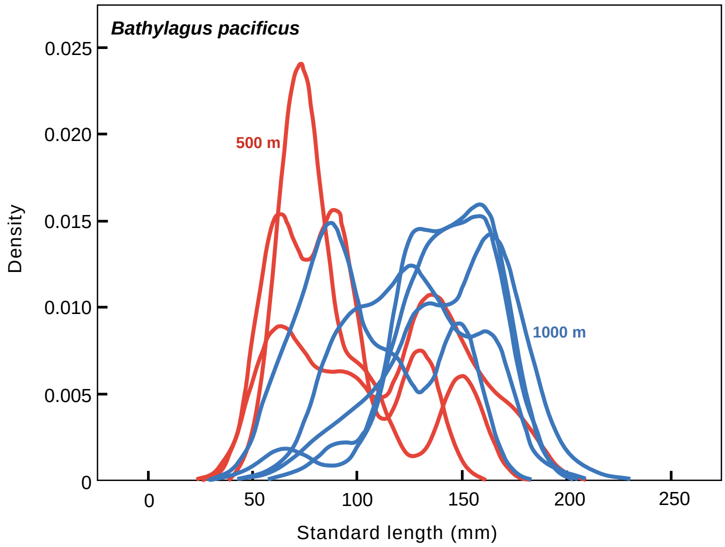

Fig. 6. Body size distribution of the slender blacksmelt, *Bathylagus pacificus*, by depth.

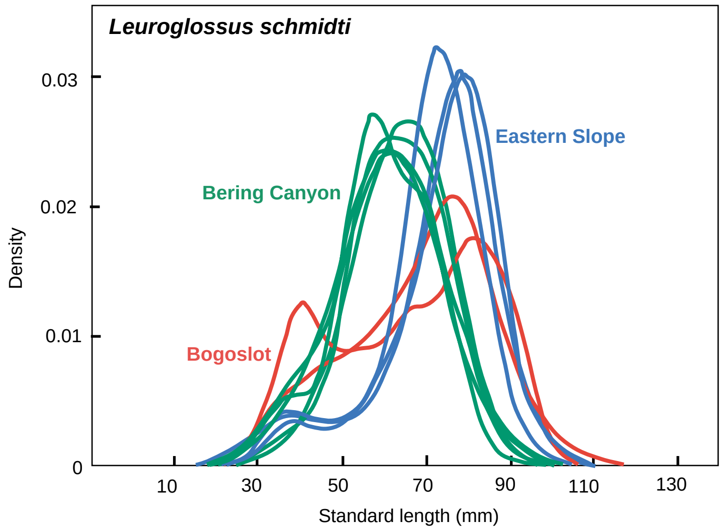

Fig. 7. Body size distribution of the northern smoothtongue, *Leuroglossus schmidti*, by sample area with all depths combined.

4. Discussion

Species abundances were greater than anticipated based on the small number of trawls and the results of previous studies in the North Pacific and western Bering Sea. In addition to the discovery of one new species and a range extension for another, many of the more common species were represented in a range of body sizes and conditions unavailable in museum research collections (Fig. 9). Others such as *Eogonatus tinro*, previously described from only a small number of collected specimens, were caught in abundance in this pilot survey. The success of relatively few trawls is due in part to the mesh size and buffering action of the codend net liner. The high volumes of fish and

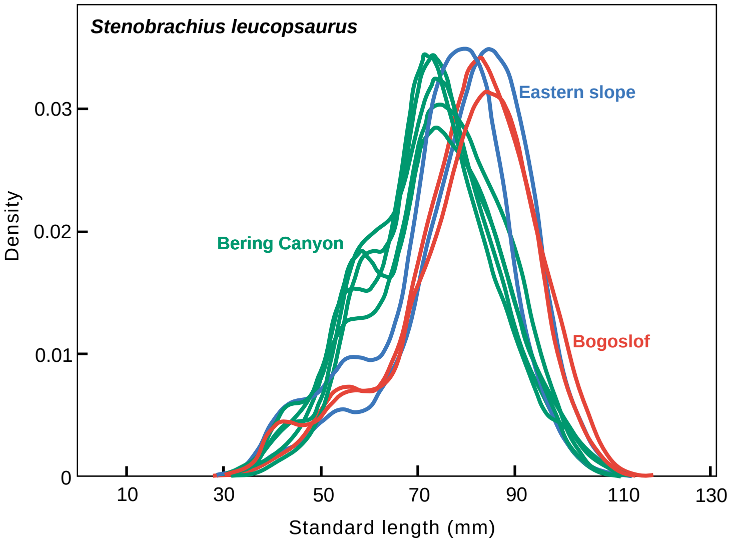

Fig. 8. Body size distribution of the northern lampfish, *Stenobrachius leucopsaurus*, by sample area with all depths combined.

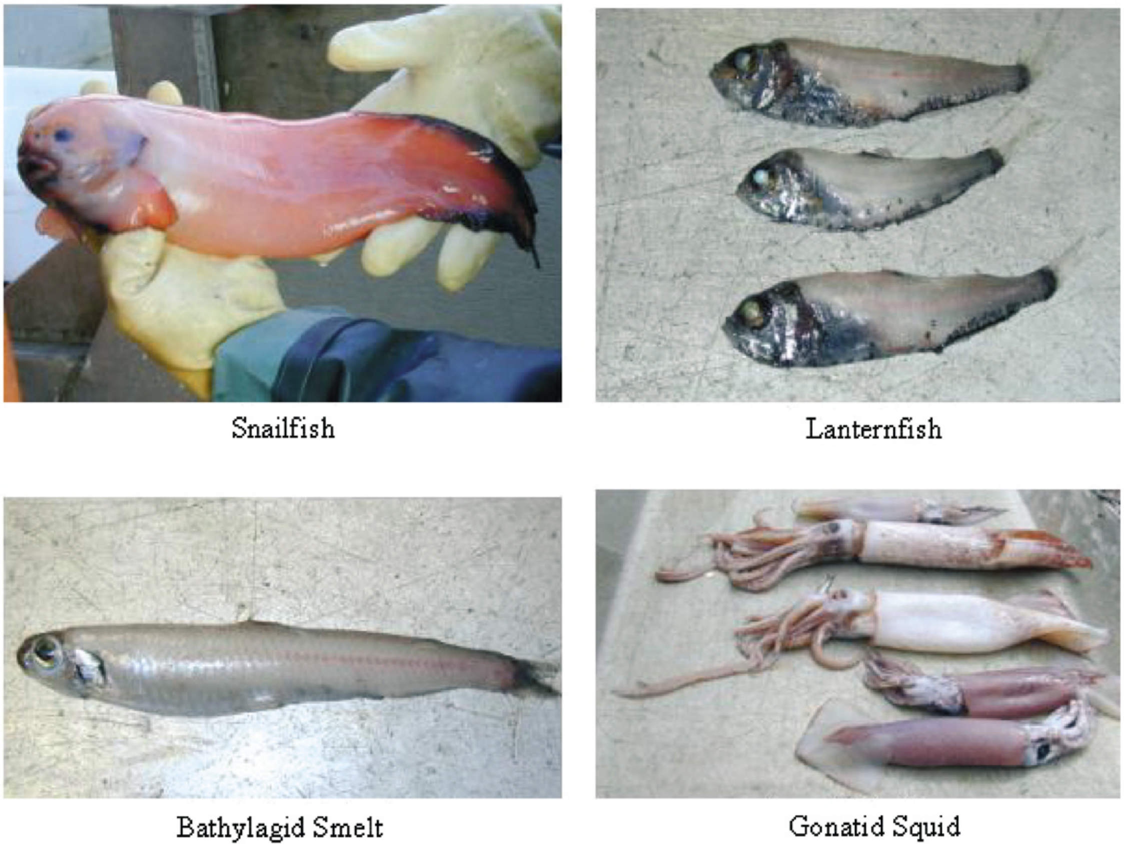

Fig. 9. Examples of the diversity and quality of samples collected during this study (May 15–20, 1999) in the southeastern Bering Sea. Snailfish: *Elassodiscus tremebundus*; Lanternfish: *Protomyctophum thompsoni*; Bathylagid Smelt: *Bathylagus ochotensis*.

squid in this study relative to others in the northern North Pacific (Pearcy and Laurs, 1966; Pearcy et al., 1979; Willis and Pearcy, 1980) also may be due to differences between nets and sampling methodology. Differences between this survey and those conducted in the western Bering Sea, however, are of greater interest since field methodologies were compatible (Sinclair et al., 1999).

Volumes per haul were overall higher in this study than in the extensive Russian surveys in the western Bering Sea, even though the total number of species represented in this study was lower (Sinclair et al., 1999). The latter was expected since numerous tows are required to obtain samples of rare or more highly dispersed members of the midwater community. However, the higher biomass values of fish per tow and the predominance of *L. schmidti* over *S. leucopsarus* and *S. nannochir* are more similar to patterns reported from the Okhotsk Sea than the western Bering Sea (Balanov and Il'inskii, 1992). Also in this study, cephalopod biomass was highest in upper mesopelagic depths (250 m depths), and fish biomass was highest in lower mesopelagic depths (500 m depths) in contrast to the western Bering Sea where both fishes and squids were more common at lower mesopelagic depths of 500–1000 m (Sinclair et al., 1999). Such differences in relative abundances and species dominance at depth between western and eastern Bering Sea surveys suggest that the physical environment may be driving increased levels of nekton concentrations or productivity in the eastern Bering Sea, or at the very least influencing species distributions at depth.

Physical characteristics of our study area during May 1999 indicate that it was not an unusual year. This leads to the premise that differences between species distributions and biomass between this study and extensive western Bering Sea mesopelagic surveys reflect differences between the physical environments of the eastern and western Bering Sea basin. The primary current of the eastern basin is the Bering Slope Current, which is a relatively shallow eastern boundary current (Fig. 1). The dominant current of the western basin is the deeper Kamchatka Current, which has transports ranging from 6×10^6 to $12\times10^6\,m^3\,s^{-1}$. While water was recently advected from the North Pacific through the Aleutian Passes into our study area, the water of the western basin resides in the Bering Sea for more than a year. In addition, temperatures in the upper 300 m can be much colder (May 1999, 0°C) in the western basin than in the southeastern Bering Sea basin. While there is a relative maximum temperature in the western part from 300 to 500 m, it tends to be slightly cooler than that observed in the southeastern basin. This alone could influence species dominance and relative depth distribution between the two regions. It should be noted that the southeastern corner of the Bering Sea basin, with its mixture of North Pacific water from the Aleutian passes and its proximity to the broad eastern shelf, may well form a unique habitat. Studies farther to the north in the green belt may provide different results.

An example of the broad trophic effects of horizontal structuring is provided by Wada (1971) for the Oyashio and Kushiro transition region off the Sanriku coast of Japan. Wada (1971) describes the close association of myctophid fishes with this boundary region and the subsequent and nearly exclusive consumption of myctophid fishes by northern fur seals there. Highest concentrations of myctophid and bathylagid fishes and mesopelagic squids also occurred near boundary regions such as the outer continental shelf and slope of the western Bering Sea (Radchenko, 1992; Sobolevsky, 1996; Sobolevsky et al., 1996; Beamish et al., 1999; Sinclair et al., 1999). This 'boundary effect' demonstrated in other areas may be relevant to the indicated high levels of mesopelagic nekton abundance in the green belt area.

Nishiyama et al. (1986) proposed that vertical stratification in temperature and salinity on the eastern Bering Sea shelf serves as a nursery layer for young-of-the-year pollock. Evidence for the importance of Bering Canyon near Unimak Pass as a spawning and nursery grounds was indicated for *Leuroglossus schmidti* in this study. The observed segregation in body size of *L. schmidti* by trawl area in this study, as well as known spawning time (February–May) and size at maturity (>61 mm) in more southerly portions of their range (Mason and Phillips, 1985) support the suggestion that a spawning area exists for this species in the vicinity of Bering Canyon. Depending upon current patterns, we suggest that larvae and early stage juveniles are carried by the ANSC as it flows eastward along the Aleutian Islands and finally northwestward with the BSC towards Pribilof Canyon (Figs. 1 and 7). However, larval data are needed to substantiate or refute this suggestion since the Bering Canyon area may serve only as a transport recipient for fish spawned in the North Pacific (Pearcy et al., 1979). The contrasting pattern seen with *Stenobrachias leucopsarus* across the study area suggests that larvae and adults remain in the spawning area together, which would be expected for a species that tends to stay deeper in the water column, beyond the direct influence of the shallower ANSC (Fig. 8).

Body size ranges for the predominant species in this study (*S. leucopsarus*, *S. nannochir*, *L. schmidti*, and *gonatid squid*) were comparable to results from western Bering Sea studies (Radchenko, 1992; Sobolevsky et al., 1996). For these same species of fish, however, body size ranges in this study were significantly greater than those reported for the northern North Pacific (Pearcy et al., 1979; Willis and Pearcy, 1980; Mason and Phillips, 1985). Although trawl gear again may be the explanation for body size differences between North Pacific and Bering Sea collections, we suggest that this serves as further evidence that the southern Bering Sea serves not only as the recipient of expatriates from the North Pacific (Pearcy et al., 1979), but as a viable reproductive center enhanced by the nutrient-rich transition waters of the ANSC and eastern shelf.

The high biomass of mesopelagic nekton indicated in this study contrasts with the extremely low numbers of marine mammals sighted and the persistent declines of these direct consumers of mesopelagic nekton throughout the eastern Bering Sea. Whether the concentrations of juvenile and adult fish and squid caught in our study area are indicative of biomass levels along the greater eastern Bering Sea shelf/slope region, or represent only a seasonal, short-lived pulse of productivity, will be determined by further studies. Lacking baseline surveys, we are unable to conclude whether the volume of mesopelagic nekton indicated are representative of historical abundances. Understanding the dynamics of the Bering Sea ecosystem, the spatial variability, and the variable influence of physics and climate as causal mechanisms will surely be enhanced by additional sampling of the type described here.

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Appendix A

Species list and body size range for fish caught by time of day and depth. Numbers represent the number of fish measured as opposed to the total number caught, but are proportional to the total numbers caught within species by depth. See Table 3.

Appendix B

Species list and body size range for cephalopods caught by time of day and depth. Numbers represent the number of cephalopods measured as opposed to the total number caught, but are proportional to the total numbers caught within species by depth. See Table 4.

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