



PERGAMON

Continental Shelf Research 21 (2001) 207–224

CONTINENTAL SHELF
RESEARCH

www.elsevier.com/locate/csr

Habitat-specific distribution of Pacific ocean perch (*Sebastes alutus*) in Pribilof Canyon, Bering Sea

Richard D. Brodeur¹

National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115 USA

Received 6 December 1999; received in revised form 17 July 2000; accepted 18 July 2000

Abstract

Shelf edge canyons are well-known sites of enhanced biomass due to on-shore transport and concentration of zooplankton along their axes, both of which contribute to the high densities of nekton frequently found in these canyons. Using a combination of acoustics, trawling, and in situ observations with a remotely operated vehicle (ROV), the distribution of pelagic and demersal biota within Pribilof Canyon in the Bering Sea was examined in September of 1995 and 1997. Near-bottom acoustic scattering patterns in the 38 kHz data showed high concentrations of biomass beginning around the 180 m bottom depth contour and continuing to about 220 m, which were presumed to be adult fish based on their target strength distributions. The 120 kHz data also showed very strong scattering in the water column between 150 and 175 m, which was absent from the 38 kHz data, and therefore attributed mainly to zooplankton. The dominant taxa collected in bottom trawls and mid-water plankton tows were adult rockfishes (Pacific ocean perch, *Sebastes alutus*) and euphausiids (*Thysanoessa* spp.), respectively. In situ videos revealed dense aggregations of these rockfishes inhabiting a “forest” of attached sea whips, *Halipteria willemoesi*, during night deployments of the ROV, while areas with damaged sea whips had far fewer rockfish, and areas without this biotic habitat structure had no rockfish. During the day, the rockfishes were seen above the “forest”, where they were apparently feeding on dense swarms of euphausiids. It appears that these rockfish utilize this predictable and abundant food resource in the canyon during the day and are associated with the sea whip habitat at night during periods of inactivity. More research is needed on these slow-growing biotic habitats and how fishing activities in the Bering Sea and elsewhere may impact these habitats. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Habitat; Acoustics; Demersal fishes; Zooplankton; Bering Sea; Pribilof Canyon

E-mail address: rick.brodeur@noaa.gov (R.D. Brodeur).

¹Present address: National Marine Fisheries Service, Northwest Fisheries Science Center, Hatfield Marine Science Center, Newport, OR 97365, USA. Tel.: +1-541-867-0336; fax: +1-541-867-0389

0278-4343/01/\$ - see front matter © 2001 Elsevier Science Ltd. All rights reserved.

PII: S0278-4343(00)00083-2

1. Introduction

Submarine canyons are a common feature of many of the world's continental shelf breaks. Owing to their abrupt and steep topography, these canyons often modify the downstream circulation and increase shelf-slope exchange of water masses and nutrients (Klinck, 1996; Hickey, 1997). They are known to be areas of enhanced productivity due to topographically induced upwelling along their axes (Freeland and Denman, 1982). Canyons also transport large quantities of organic matter offshore through sediment flushing (Okey, 1997; Granata et al., 1999), thus enriching the deep ocean (Rowe, 1971). These physical processes enrich canyon regions (Denman and Powell, 1984), which may show enhanced concentrations of macrobenthos (Haedrich et al., 1980; Sardà et al., 1994; Vetter and Dayton, 1998), micronekton (Cartes et al., 1994; Macquart-Moulin and Patrìti, 1996), demersal fishes (Stefanescu et al., 1994), and cetaceans (Kenney and Winn, 1987; Schoenherr, 1991) relative to the slope as a whole.

Another mechanism by which accumulations of planktonic organisms occur in canyons involves the interaction of diel vertical migration and onshore transport. In the case of large offshore euphausiids normally found over deeper water, onshore advection of individuals near the surface at night deposits them over bottom depths shallower than their normal daytime depths (Isaacs and Schwartzlose, 1965; Koslow and Ota, 1981; Genin et al., 1988). This process may deposit large aggregations of euphausiids near bottom at the upstream end of canyons (Koslow and Ota, 1981; Greene et al., 1988), where they become easy prey for planktivorous fishes (Mackas et al., 1997). In the North Pacific Ocean, rockfishes in the genus *Sebastes* often inhabit the offshore edges of banks or canyons and are known to capitalize on these advected prey resources (Isaacs and Schwartzlose, 1965; Pereyra et al., 1969; Brodeur and Percy, 1984; Chess et al., 1988; Genin et al., 1988).

In 1994, a dense acoustic scattering of near-bottom fish was detected at the upstream end of the Pribilof Canyon in the Bering Sea. Trawling through this acoustic sign revealed that it was comprised almost entirely (> 92% of total catch) of Pacific Ocean perch (*Sebastes alutus*). In this paper, acoustic and trawl data collected from 1995 and 1997 are presented along with in situ observations using remotely operated vehicle (ROV) videos that revealed a biogenic habitat association between Pacific Ocean perch and pennatulaceans in Pribilof Canyon.

2. Methods

2.1. Study site

Surveys were conducted at the head of Pribilof Canyon, a large canyon situated at the outer edge of the Bering Sea continental shelf some 370 km from the Aleutian Island Chain and approximately 40 km south of St. George Island, the southernmost of the Pribilof Islands (Fig. 1). The Pribilof sea valley begins at a depth of 130 m and drops off to a maximum depth of 3200 m (Carlson and Karl, 1988), with the main incision of the canyon cutting from 100 to 1000 m into the slope (Kotenov, 1965). The upper part of the canyon is bifurcated (Fig. 1), forming a trough 90 km long and 30 km wide parallel to the continental margin (Scholl et al., 1970). The total canyon volume is 1300 km³, which classifies it among the largest canyons in the world (Carlson and Karl, 1988).

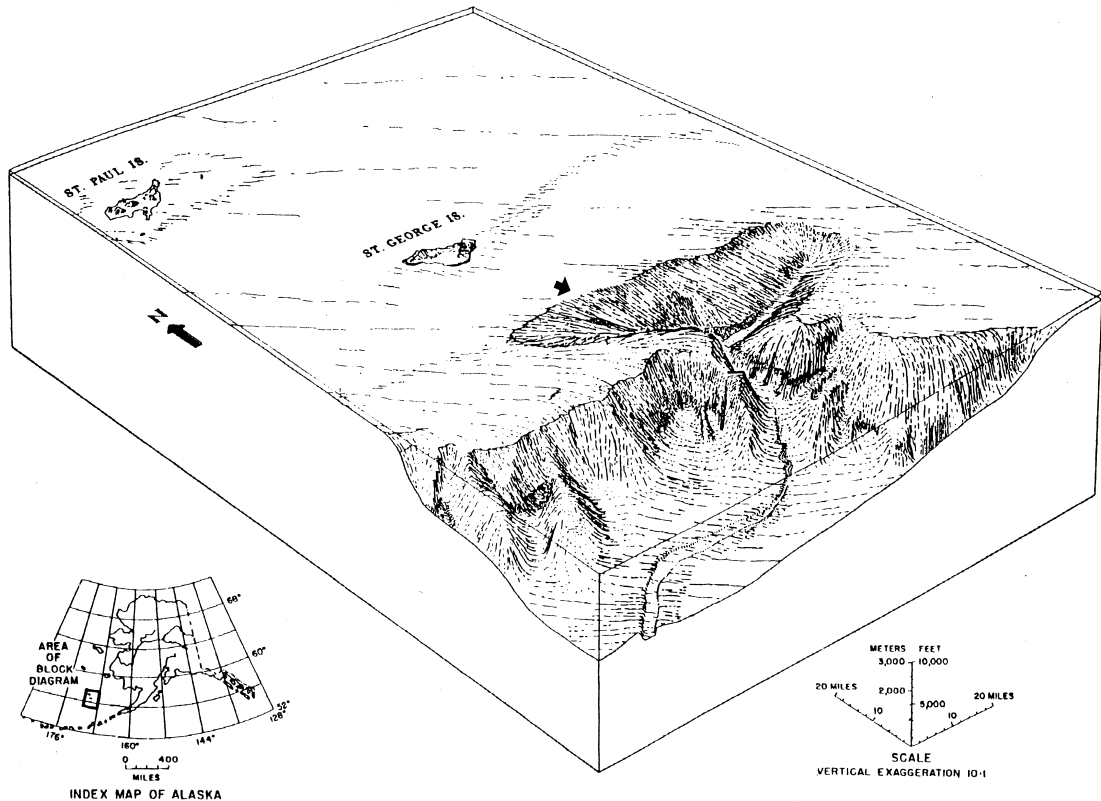


Fig. 1. Physiographic plot of Pribilof Canyon looking onto the shelf showing the study area (arrow) relative to the Pribilof Islands (modified from Scholl et al., 1970).

Results from hydrographic surveys, satellite track buoys and moored current meters in the vicinity of Pribilof Canyon suggest the presence of two circulation features: the Bering Slope Current (Schumacher and Reed, 1992) and a flow over the outer continental shelf (Schumacher and Stabeno, 1998). The Bering Slope Current is most marked in the upper 300 m of the water column, flowing along isobaths generally toward the northwest at speeds of $0.1\text{--}0.2\text{ m s}^{-1}$. The increased speed of the outer shelf current apparently results from the marked decrease in width of the outer shelf (from $\sim 160\text{ km}$ to less than 30 km) in the canyon area. Satellite-tracked buoy trajectories support the existence of this stronger flow. Exchange of slope water onto the shelf occurs in the vicinity of Pribilof Canyon. Interaction of tidal currents with canyon topography results in rectified onshore flow, and the acceleration of the outer slope current appears to draw deeper nutrient-rich water up onto the outer shelf (Stabeno et al., 1999).

2.2. Field sampling

The observations reported here were part of a multi-disciplinary study of biophysical interactions between fish and zooplankton in the area of the Pribilof Islands (Brodeur et al., 1997).

Cruises were conducted during 9–26 September, 1995, and 8–18 September, 1997 and a broad suite of physical and biological measurements were made in the Pribilof Canyon area (Table 1; Fig. 2) from the NOAA vessels *Miller Freeman* and *Surveyor* working in tandem.

In situ water temperatures and light levels were recorded at several stations within the canyon (Table 1). Conductivity-temperature-depth (CTD) casts were taken using a Sea-Bird SEE-9 system and light and light measurements were made with an IL1700 Research Radiometer (International Light, Newburyport, MA).

2.3. ROV deployments

Underwater observations in the Pribilof Canyon were made using video cameras mounted on a Deep Ocean Engineering Super Phantom II ROV deployed from the *Miller Freeman*. Most surveys were done with a color CCD video camera (Hitachi Model HV-C20) with the viewing area illuminated by two confocal 250 W tungsten–halogen lights mounted externally on the vehicle. These lights were dimmed to about 75% of full power to minimize the backscatter from biogenic

Table 1

Operations carried out in Pribilof Canyon region in 1995 and 1997. The first station conducted in 1995 (S80) was done by the ship *Surveyor*. All other stations were done by the *Miller Freeman*. Bottom depth is the maximum depth encountered during the operation

Station No.	Haul No.	Date	Time (ADT)	Latitude °N	Longitude °W	Bottom depth (m)	Operation
<i>1995</i>							
S80	1	16-September	19:17	56.28	169.44	246	CTD
29	1	16-September	20:06	56.30	169.44	203	ROV
29	2	16-September	22:41	56.29	169.47	215	Bottom trawl
29	4	17-September	0:58	56.29	169.45	214	Methot trawl
29	6	17-September	3:44	56.29	169.46	211	ROV
30	1	17-September	5:06	56.28	169.44	240	Acoustic transect
56	1	23-September	8:02	56.28	169.43	236	Bottom trawl
57	1	23-September	9:14	56.28	169.44	230	Acoustic transect
59	1	23-September	19:47	56.31	169.68	209	ROV
59	2	23-September	21:59	56.31	169.68	200	Bottom trawl
60	1	24-September	2:41	56.28	169.60	184	ROV
60	3	24-September	5:40	56.28	169.60	205	Bottom trawl
61	2	24-September	14:16	56.29	169.30	197	ROV
<i>1997</i>							
1	1	9-September	13:31	56.28	169.44	256	CTD
1	2	9-September	14:23	56.28	169.44	246	CTD
10	2	10-September	3:59	56.28	169.44	264	Acoustic transect
14	1	10-September	13:46	56.28	169.44	257	Acoustic transect
15	1	10-September	15:22	56.28	169.43	243	ROV
15	2	10-September	17:47	56.28	169.43	248	Bottom trawl
15	3	10-September	21:41	56.28	169.43	234	ROV
16	1	11-September	0:41	56.28	169.47	234	Methot trawl

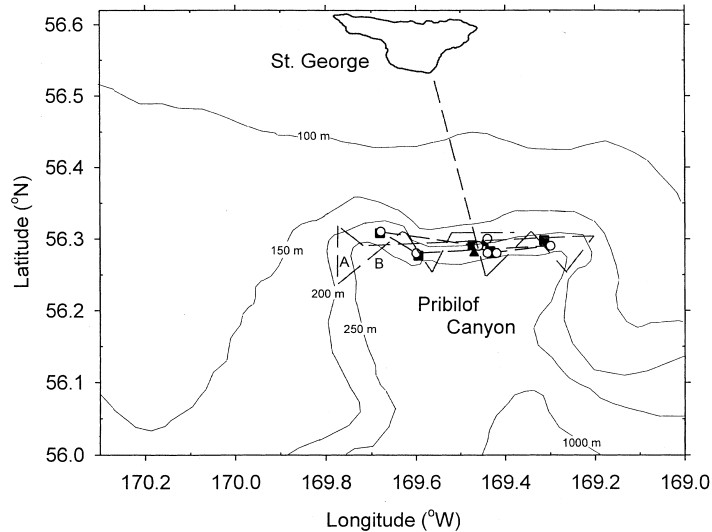


Fig. 2. Locations of ROV deployments (circles), bottom trawls (squares), Methot trawls (triangles) and acoustic transects (dashed lines) in Pribilof Canyon during September 1995 and 1997. Also shown are acoustic transect lines A and B shown in Figs. 4a and b, respectively.

particulate matter in the water column. A silicon intensifier target low-light level black and white camera (Osprey OE1323), which provided a 110° field of view, was used to initially survey each site. In addition, still photos were taken in 1997 using a submersible camera (Benthos Model 3782) and strobe on the ROV.

The ROV was lowered from the vessel using a 300 m umbilical cord while the vessel maintained a constant heading using its bow thrusters. A 108 kg down weight was attached 25 m from the end of the umbilical cord to provide stability and reduce the angle of drift of the ROV away from the vessel. The ROV was generally propelled at slow speed to keep it in front of the down weight and the speed over ground was less than 1 knot ($<1.6 \text{ km h}^{-1}$) for all deployments in the canyon. Video images were viewed in real time at an on-deck console that allowed the operator to maneuver the vehicle and control the cameras and lights. The depth of ROV was annotated onto the tape by observers throughout the deployment. Recordings were made on two Hi-8 VHS tape decks and identification of organisms and characterization of habitats were made during playback.

2.4. Acoustic transects

Acoustic backscatter data were collected along transects radiating from the Pribilof Islands, including one transect south of St. George Island which bisected the canyon, to quantify midwater and bottom acoustic sign (see Swartzman et al., 1999a, b, for detailed collection and analytical methodology). A Simrad EK-500 echosounder, equipped with calibrated split-beam 38 and 120 kHz transducers (7° beam width), provided estimates of echo integration and target strength, which is indicative of the approximate size of the scatterers. The transducers were mounted in the

centerboard of the ship at a depth of 10 m. The system was calibrated before the survey using a copper ball of known acoustic properties suspended below the ship. Shorter acoustic transects were also conducted across the axis of the canyon to determine the east-west extent of the echosign (Fig. 2). The position at the start and end of each transect was recorded using GPS.

Mean backscattering area per square nautical mile (nm) of sea surface (S_A) was calculated for each 5 m depth interval [units in $\text{m}^2 \text{nm}^{-2}$] as follows:

$$S_A = 4\pi r_0^2 1852^2 \int_{z=r_1}^{z=r_2} S_v dz,$$

where z is the depth, r_0 is the reference range for backscattering strength (1 m), r_1 and r_2 are the top and bottom of the 5 m depth intervals which ranged from 10 to 250 m, and S_v is the volume backscattering strength.

2.5. Net tows

Short (< 1 h) bottom tows were made in areas of substantial near-bottom acoustic backscatter and along several of the ROV transects using a nylon Nor'eastern bottom trawl with 1.5 m \times 2.1 m steel doors fished with roller gear. The mesh size varied from 13 cm in the forward part of the net to 8.9 cm in the codend, which was also equipped with a 3.2 cm liner. The mean effective path width of this trawl was estimated to be 13.4 m with a mean vertical opening of 9.2 m. The entire catch was processed aboard deck and numbers and weights of all taxa were recorded. Length measurements were made to the nearest centimeter on all fish species. Subsamples of rockfish were frozen and transported to shore for later laboratory processing. Number and biomass per km^2 were then estimated for all taxa using the area-swept method.

Macrozooplankton and micronekton were collected in 1995 and 1997 using a 5 m^2 Methot mid-water trawl with 3 mm \times 2 mm oval mesh in the body and 1 mm mesh in the codend. The net was fished obliquely to within 10 m of the bottom to obtain depth-integrated abundance estimates of zooplankton and fish (Brodeur et al., 1997). The depth of tow was monitored using a SCANMAR acoustic sensor on the frame of the trawl and volume filtered was estimated by mounting flowmeters in the center of the frame. Since euphausiids and other micronekton are known to exhibit significantly lower daytime densities with this gear (e.g., Sugisaki et al., 1998), I examined only the night samples collected in the Pribilof Canyon area in this analysis.

2.6. Laboratory analysis

Methot collections were sorted into major taxonomic categories in the laboratory and fish, euphausiids and chaetognaths were identified to species. Raw counts were converted to numbers per 1000 m^3 . Stomach contents of Pacific Ocean perch were analyzed in the laboratory. Because of the closed nature of rockfish swimbladder and the great depth from which they were collected, many of the stomachs that were brought back to the lab were empty and believed to be regurgitated. The stomachs containing food were examined under a dissecting microscope and the contents were identified to the lowest possible taxon. Otoliths of a representative subsample of Pacific Ocean perch were removed at sea for age determination in the laboratory by two experienced readers at the Alaska Fisheries Science Center using the break and burn technique.

3. Results

3.1. ROV deployments

ROV deployments were made in the vicinity of the canyon in both years and at different times of the day (Table 1). Transects were made both perpendicular and parallel to isobaths. On several descents to the bottom, the ROV passed through layers of squid (*Beryteuthis* sp.) and dense aggregations of euphausiids. The bottom generally was composed of compacted mud and silt. Occasionally rocks and small boulders were present but the bottom generally contained little geologic relief. However, in five out of seven of the deployments in the canyon, the ROV passed through areas containing dense aggregations of 1–2 m high sea whips (*Halipterus willemoesi*) evenly spaced about 2 m apart. During nighttime observations, hundreds of rockfishes (mainly Pacific Ocean perch) were seen inside the sea whip “forest” (Fig. 3). These rockfish were all oriented in the same direction (generally facing into the current) and were also evenly dispersed with approximately 3–4 m between adjacent fish. The rockfish appeared to be in a resting state and did not move until the ROV approached within a few meters. The sea whips and associated rockfish were observed over the depth interval of 185–240 m, but the highest densities (> 30 fish min^{-1}) were recorded around 198 m. Other fishes were occasionally seen within the sea whip habitat, including arrowtooth flounders (*Atheresthes stomias*), sawback poachers (*Leptagonus frenatus*), and big skates (*Raja binoculata*), but none seemed to be consistently associated with this habitat as the rockfish. Several large areas contained numerous sea whips that were no longer upright and had much lower rockfish densities (< 2 fish min^{-1}).

During the day, the Pacific Ocean perch were more active and in some cases were seen milling above the forest, presumably feeding on the euphausiids. In the two canyon deployments in which

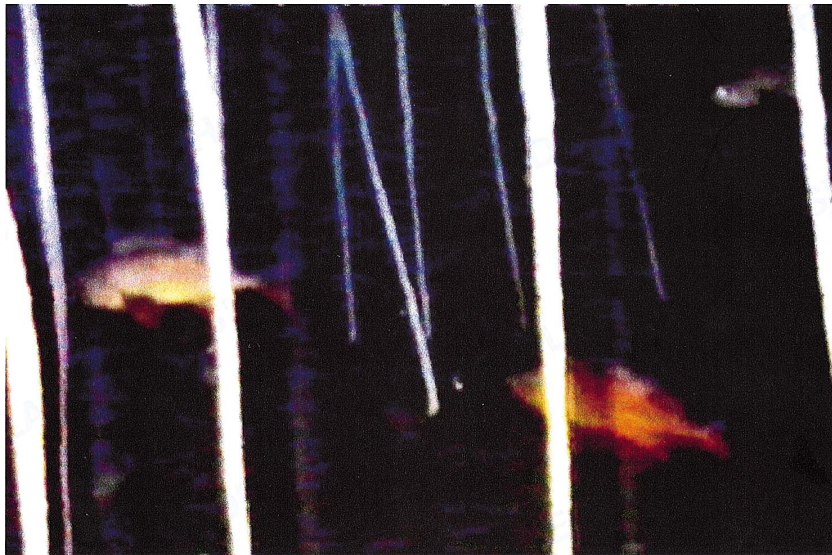


Fig. 3. Photograph of several adult Pacific Ocean perch inside sea whip “forest”. The slanting vertical lines are the center portions of sea whips which are around 2 m high.

no sea whips were observed (depth range 181–224 m), there were also no Pacific Ocean perch observed, although many other bottom fishes such as Pacific cod (*Gadus macrocephalus*), arrowtooth flounders, and sawback poachers were observed. These were the easternmost and shallowest of the deployments, and apparently missed the main sea whip habitat, which appeared to be mainly in the central and western flank of the canyon. In addition to the sea whips, the most obvious invertebrate macrofauna observed in the canyon were king crabs (*Paralithodes* spp.), large anenomes (*Metridium giganteum* and *Urticina* spp.) and large basket stars (*Gorgonocephalus eucremis*). Most of the basket stars had their arms extended indicating that they were actively feeding.

3.2. Acoustic transects

Transects along the shelf break (ca. 210 m) and those that crossed the axis of the canyon both showed substantial near-bottom aggregations of large scatterers at the upper edge of the canyon (Fig. 4). These large scatterers extended generally less than 10 m off bottom and were present in both the 38 and 120 kHz images. In addition, the 120 kHz echograms contained a dense layer of smaller scatterers above the larger ones that at times extended down to and overlapped the vertical distribution of the large scatterers (Fig. 4a), but was restricted to mid-water when it crossed the canyon axis (Fig. 4b).

Based on the mean acoustic backscatter from 4 inshore-offshore transects (2 each year) in the central and western part of the canyon for the 10 m above the bottom (38 kHz) and the layer between 150 and 175 m (120 kHz), these aggregations mainly occurred over a very narrow bottom

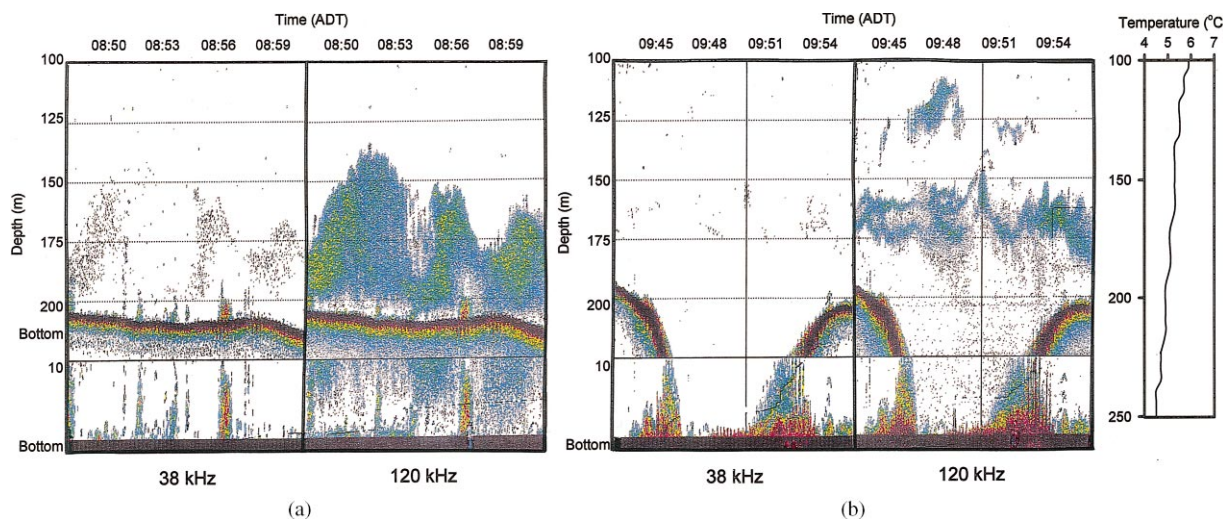


Fig. 4. Acoustic transect showing backscatter signals (a) along the 210–220 m isobath and (b) across the northwest end (Fig. 2) of Pribilof Canyon on 23 September 1995 for 38 kHz (left panel) and 120 kHz (right panel). The top part of each panel shows the water column from 100 m to the bottom or 250 m. The bottom part of each panel is an expanded view of the 10 m of the water column right above bottom. The time of day is shown at the top of the panel. To the right is the distribution of temperature with depth measured from a nearby CTD cast.

depth range. High acoustic backscatter first became apparent around 180 m depth, peaked around 200 m, and declined after 220 m at both frequencies (Fig. 5). The mean areal backscatter at the 200 m isobath was 2233 and 59,443 m² nm⁻² for these depth strata using 38 and 120 kHz data,

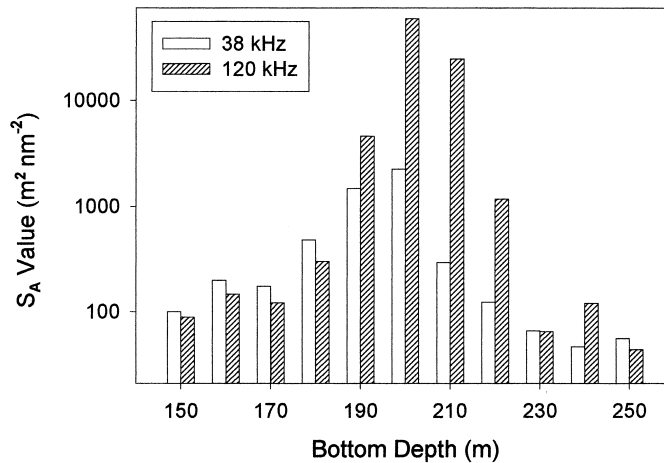


Fig. 5. Acoustical backscatter (S_A) from the EK-500 for the 10 m directly above bottom (38 kHz) and the layer between 150 and 175 m in the water column (120 kHz) by 10 m bottom depth intervals. Data are averaged by depth bin for four transects (two each in 1995 and 1997) in the northwest part of the canyon. Note that the ordinate scale is logarithmic.

Table 2

Fish catches (density and biomass) from bottom trawls ranked in order of decreasing mean density for 1995 and 1997. Shown only are the species which made up greater than 0.1 of the numerical catch. The 1995 data represent the mean of four tows

Common name	Scientific name	1995 (n = 4)				1997 (n = 1)			
		No./km ²	(%)	Kg/km ²	(%)	No./km ²	(%)	Kg/km ²	(%)
Pacific Ocean perch	<i>Sebastes alutus</i>	1106.2	87.7	793.5	71.8	366.7	34.6	288.1	43.0
Arrowtooth flounder	<i>Atheresthes stomias</i>	100.0	7.9	152.1	13.8	126.4	11.9	178.7	26.7
Pacific cod	<i>Gadus macrocephalus</i>	17.4	1.4	67.0	6.1	46.8	4.4	141.2	21.1
Darkfin sculpin	<i>Malacocottus zonurus</i>	10.3	0.8	4.5	0.4	—	—	—	—
Sturgeon poacher	<i>Podothecus acipenserinus</i>	8.7	0.7	0.2	<0.1	—	—	—	—
Spectacled sculpin	<i>Triglops szepticus</i>	3.3	0.3	0.3	<0.1	—	—	—	—
Sawback poacher	<i>Leptagonus frenatus</i>	2.3	0.2	0.1	<0.1	449.2	42.3	18.9	2.8
Alaska ronquill	<i>Bathymaster caeruleofasciatus</i>	2.3	0.2	0.5	<0.1	—	—	—	—
Big skate	<i>Raja binoculata</i>	1.8	0.1	19.5	1.8	—	—	—	—
Sablefish	<i>Anoplopoma fimbria</i>	1.3	0.1	2.5	0.2	—	—	—	—
Flathead sole	<i>Hippoglossoides elassodon</i>	1.0	0.1	0.5	<0.1	51.4	4.8	23.4	3.5
Prowfish	<i>Zaprora silenus</i>	1.0	0.1	5.7	0.5	—	—	—	—
Rex sole	<i>Errex zachirus</i>	1.0	0.1	0.4	<0.1	19.2	1.8	17.2	2.6
Pacific sleeper shark	<i>Somniosus pacificus</i>	0.8	0.1	42.7	3.9	—	—	—	—
Dusky rockfish	<i>Sebastes ciliatus</i>	0.8	0.1	1.2	0.1	—	—	—	—
Sharpchin rockfish	<i>Sebastes zacentrus</i>	—	—	—	—	1.1	0.1	2.2	0.3
Total catch		1229.5	100.0	1104.6	100.0	1060.8	100.0	669.7	100.0

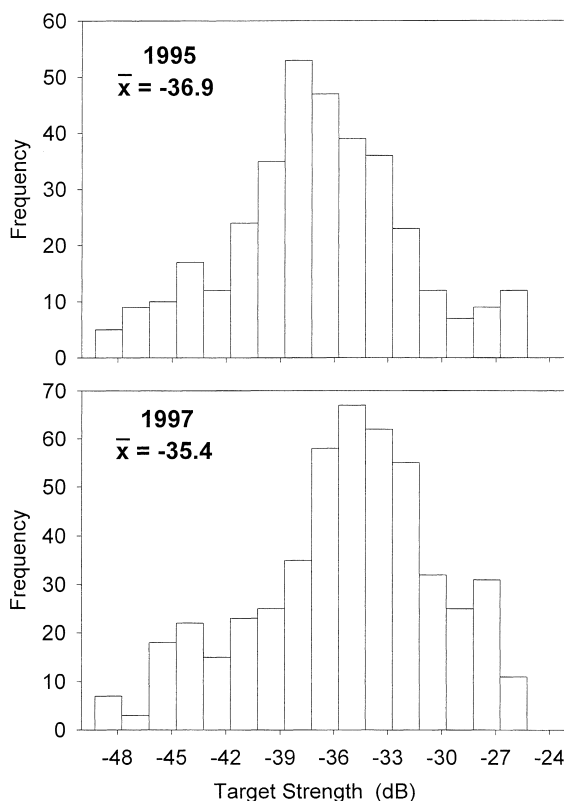


Fig. 6. Distribution of 38 kHz target strengths in the 10 m directly above bottom for 1995 (top) and 1997 (bottom). Shown also is the mean overall target strength by year.

respectively. Mean backscatter for two transects over similar bottom depth ranges in the easternmost head of Pribilof Canyon (Fig. 2) was $63.6 (\pm 11.3 \text{ SE})$ and $79.3 (\pm 10.4) \text{ m}^2 \text{ nm}^{-2}$ for these two frequencies, respectively.

The target strength (TS) distributions for 38 kHz were similar for both years, although the values were about 1.5 dB higher in 1997, indicating larger scatterers were present that year (Fig. 6). The target strengths obtained with the 120 kHz were similar in both years (mean $\text{TS} = -75.1$ and -76.0 dB for 1995 and 1997, respectively), but were substantially lower than those seen with the 38 kHz, suggesting that these scatterers were predominantly zooplankton.

3.3. Net tows

A diverse group of shelf and deepwater teleost and elasmobranch species were collected in the five bottom trawls (Table 2). In 1995, Pacific Ocean perch was the dominant species both in terms of number and biomass caught. The only other species comprising at least 5% of either the number or biomass were arrowtooth flounder and Pacific cod. In the one tow taken in 1997, Pacific Ocean perch was again the dominant species by weight but the smaller sawback poachers

Table 3

Densities (number per 1000 m³) of macrozooplankton and micronekton collected in Methot tows in the Pribilof Canyon region by year

Taxa	1995		1997	
	Density	% of total	Density	% of total
Cnidaria	13.0	3.7	25.9	1.5
Chaetognatha				
<i>Sagitta elegans</i>	2.0	0.6	0.3	0.0
<i>Eukrohnia hamata</i>	1.3	0.4	—	—
Hyperiidea	0.2	0.1	—	—
Gammaridea	2.5	0.7	—	—
Euphausiacea				
<i>Thysanoessa inermis</i>	194.6	56.0	1124.1	63.5
<i>Thysanoessa longipes</i>	85.4	24.6	490.5	27.7
<i>Thysanoessa raschii</i>	—	—	51.1	2.9
<i>Thysanoessa spinifera</i>	22.1	6.4	61.3	3.5
Decapoda Natantia	1.0	0.3	—	—
Osteichthyes				
<i>Theragra chalcogramma</i>	22.7	6.5	16.3	0.9
<i>Anoplopoma fimbria</i>	0.9	0.3	—	—
<i>Hexagrammos decagrammus</i>	0.8	0.2	0.2	0.0
<i>Lumpenus maculatus</i>	—	—	0.2	0.0
<i>Atheresthes stomias</i>	0.9	0.3	—	—
<i>Lepidopsetta bilineata</i>	—	—	0.2	0.0
Total	347.3	100.0	1770.0	100.0

were more important numerically (Table 2). Other rockfish species (*Sebastes* spp.) were caught in both years, but these made up a minor component of the total biomass. Many sea whips were also collected in the trawls during both years, but these could not be quantitatively assessed due to loss through the trawl meshes.

The catch of the Methot tows was dominated by euphausiids, which comprised 87.0 and 97.6% of the total densities in 1995 and 1997, respectively (Table 3). *Thysanoessa inermis* was more than twice as abundant as the next most important species, *T. longipes*. Small cnidarian jellyfish were the only other invertebrate taxa collected in moderate densities. Several juvenile fishes were collected but, other than walleye pollock (*Theragra chalcogramma*), they were of negligible importance.

The size distributions of Pacific Ocean perch caught in the bottom trawls were similar in both years, although in 1997 slightly larger fish were caught (Fig. 7). These fish ranged in age from 8 to 15 yr (median = 11 yr) and were all classified as mature adults. Out of the 306 fish examined for stomach contents in both years, only 26 were found to contain food. Of these, 25 contained mainly euphausiids, most of which were *Thysanoessa inermis*. The remaining stomach contained a juvenile squid, *Berryteuthis magister*. A few other stomachs contained well-digested squid and fish remains and could not be formally analyzed.

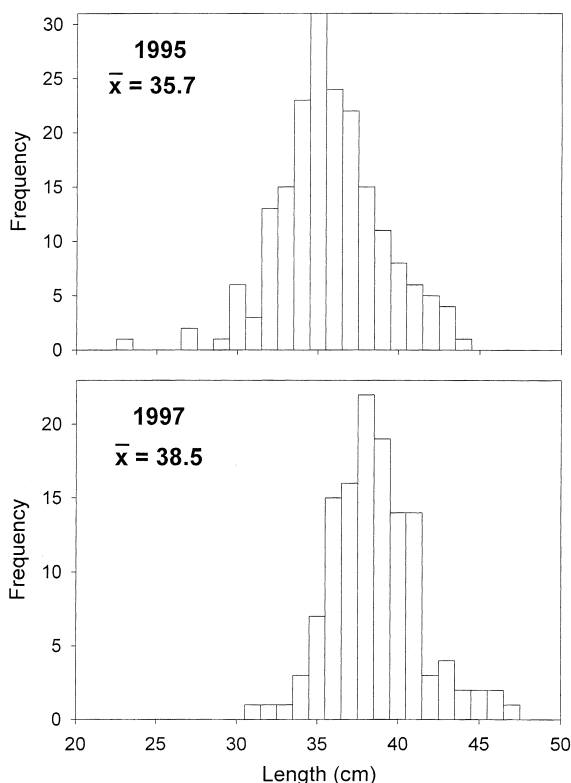


Fig. 7. Size distribution of Pacific Ocean perch collected in four bottom trawls in 1995 (top) and one bottom trawl in 1997 (bottom). Shown also is the mean size by year.

3.4. Environmental conditions

Temperatures at the bottom generally varied between 4 and 5°C on all CTD deployments (Fig. 4), which is typical of the offshore waters at these depths (Stabeno et al., 1999). Ambient light levels measured around 200 m in the canyon were very low both day and night (4.3×10^{-6} and $6.2 \times 10^{-7} \mu\text{E s}^{-1} \text{m}^{-2}$, respectively), but were at or above threshold feeding levels of typical planktivorous fishes (Ryer and Olla, 1999).

4. Discussion

Many in situ studies examining the habitat preferences of demersal fishes show that these fishes are not randomly distributed but are often generally aggregated near some structure on the bottom (Auster et al., 1995). In some instances, these structures can be of biogenic origin, such as depressions or holes dug into the substrate (Able et al., 1982). In rockfishes of the genus *Sebastes*, however, the majority of studies have revealed a dependence on hard bottom substrates, often with substantial vertical relief (Richards, 1986, 1987; Percy et al., 1989; O'Connell and Carlile,

1993; Krieger and Ito, 1999). Krieger (1992), however, found that adult Pacific Ocean perch were more likely to inhabit flat, pebble substrate based on submersible observations off Southeast Alaska. In ROV observations in other shelf and slope areas of the Bering Sea, Pacific Ocean perch were occasionally found in other deepwater deployments outside the canyon, but these were for the most part solitary individuals associated with large boulders (Busby and Brodeur, in prep.).

In this study, the highest densities of Pacific Ocean perch were found at the northwest edge of the canyon based on both ROV observations and trawl collections, and were clearly associated with the sea whip ‘forest’. Krieger (1992), in a photograph taken by submersible, also shows an aggregation of adult Pacific Ocean perch near several sea whips in the Gulf of Alaska. Similar to the present study, he found these fish to be evenly spaced and oriented into the current. This utilization of the sea whip ‘forest’ by Pacific Ocean perch apparently satisfies some need by this species to associate with a high-profile substrate in the absence of high relief rock substrates.

The high densities of vertebrate and invertebrate macrofauna in the canyon attest to the high productivity in this area. In addition to the sea whips, the high densities of other filter-feeding organisms such as anenomes and basket starfish suggest the presence of a substantial near-bottom flow containing high concentrations of zooplankton. This flow is apparently quite consistent over time to develop such a complex assemblage of sessile or slow-moving organisms. A cross section of a calcareous axial rod in several sea whip specimens revealed up to 130 circuli (M. Wilson, AFSC, personal communication). Presently, it is unknown whether these growth rings represent annual growth rings, but other related deep-sea sessile invertebrates are known to have extended life spans (Druffel et al., 1995).

It seems likely that the high densities of euphausiids found in the water column at the western head of the canyon originate from deeper areas of the Bering Sea Basin and are advected up the canyon by the prevailing currents. Most of the specimens found in the Methot mid-water tows and stomach contents of Pacific Ocean perch were *Thysanoessa inermis*, a characteristic euphausiid species of the outer shelf and basin of the Bering Sea (Smith, 1991; Sugisaki et al., 1998; Stockwell et al., in press). These euphausiids then impinge on the bottom at the head of the canyon as they attempt to migrate down to their normal daytime depths, similar to that observed in other canyons (Mackas et al., 1997). Although no depth-discrete plankton tows were conducted in this study area, other studies in the outer shelf region of the Pribilof Islands show higher concentrations of euphausiids in the epibenthic layer than in the water column, especially during the day (Coyle and Cooney, 1993; J. Napp, AFSC, unpublished data). An intense acoustic player layer of the type shown here has been consistently observed at the head of the Pribilof Canyon, but nowhere else, every year (1994–1999) that fall acoustic surveys have been conducted in this area (G. Swartzman, University of Washington, personal communication).

The foraging behavior of most shelf rockfish appears to be highly opportunistic and they are known to take advantage of oceanic mesopelagic prey that are advected onto the shelf near canyons or offshore banks (Pereyra et al., 1969; Brodeur and Percy, 1984; Chess et al., 1988; Genin et al., 1988). Information on the diet of Pacific Ocean perch in the Bering Sea is fragmentary, perhaps due in part to the difficulty in obtaining non-inverted stomachs from deep-water tows. Brodeur and Livingston (1988) found that of the 50 stomachs of this species examined, only 19 contained food, with euphausiids and caridean shrimp dominating the diet. Poltev (1999) found *S. alutus* on a seamount off the Kuril Islands were feeding mainly on euphausiids (86.3% by volume) with smaller contributions by fish (4.6%) and squid (3.2%) during

September 1997. These fish were not observed to undergo pronounced diel vertical migrations but did feed exclusively during the daytime. Although the number of stomach samples available in the present study was insufficient to elucidate the diel feeding cycle of Pacific Ocean perch in Pribilof Canyon, it seems likely that they are feeding mainly during the day when their activity level is higher and they are swimming above the ‘forest’. This was also the time when high densities of euphausiids were seen in the ROV videos swarming in a layer just above the bottom.

It is not presently known what the predation impact of these large aggregations of rockfishes is on the euphausiid biomass advected over them on a daily basis. Demersal rockfishes have been shown to deplete populations of euphausiids advected over shallow banks off Southern California during the day such that ‘gaps’ appear in the acoustic echograms (Genin et al., 1988, 1994). Estimation of this predation impact by Pribilof Canyon rockfish on euphausiids will require more precise abundance estimates of both predator and prey as well as daily ration estimates of Pacific Ocean perch.

Although trawling and ROV deployments took place in a relatively small subarea of the canyon, it appeared to be one of the main aggregation areas based on the densities of near-bottom acoustic scatterers. It is highly probable that most of the acoustic sign observed near-bottom around 200 m was due to rockfish. The only other species with a swimbladder that was collected in any abundance in the trawls was Pacific cod, although their abundances were relatively low compared to Pacific Ocean perch. Although no in situ target strength measurements exist for Pacific Ocean perch, I applied Foote’s (1987) generic target strength (TS) to length (L) relationship for physoclist fishes ($TS = 20 \log L - 67.5$ dB), which appears to be appropriate for rockfishes in general (R. Kieser, Pacific Biological Station, DFO, Nanaimo, B.C. Canada, personal communication), to the mean size of Pacific Ocean perch caught in the trawls. The predicted TS from this relationship would be -36.88 and -35.42 dB for 1995 and 1997, respectively, reasonably close to the observed mean TS of -36.44 and -35.77 dB for these two years. More systematic acoustic surveys of the entire canyon region could yield more precise estimates of the total rockfish population inhabiting this area.

Similarly, no target strength measurements exist for the dominant euphausiid species (*Thysanoessa inermis*) collected in the Methot trawls, but the values taken with the 120 kHz echosounder are within the range expected for similar-sized euphausiids, based on theoretical scattering models (Stanton, 1989; Miyashita et al., 1997; Simard and Lavoie, 1999). However, other organisms that were caught in the Methot trawls, such as gelatinous zooplankton, could also fall within this range of target strengths.

This study is the first to show the importance of the Pribilof Canyon in general and the sea whip ‘forest’ in particular as a distinctive habitat for adult Pacific Ocean perch in the Bering Sea. Past attempts to define marine habitats of this species have relied on physical variables such as temperature and depth (Scott, 1995). Although this may narrow the range of possible habitats that could be occupied, the utilization of species such as Pacific Ocean perch of highly predictable but dynamic food sources and relatively static physical features renders such simple classifications inadequate.

The sea whips in this region may provide important structural habitat for Pacific Ocean perch in an otherwise featureless environment. An important consideration in this habitat is the slow growth rates and potential longevity of the sea whips providing this habitat. If they do indeed live for extended periods of time, fishing operations that disturb the bottom and uproot the sea whips

may have a lasting effect on the rockfish populations inhabiting this region that could be potentially more detrimental than the direct effects of removing fish. The similar orientation of the sea whips observed in the ROV videos that had been apparently knocked down and were lying on the seabed suggests that fishing operations, including possibly some of my own trawl sampling, could have uprooted them. The substantially lower densities of Pacific Ocean perch observed in this perturbed habitat suggests that it is less preferred by this species compared to the undisturbed “forest”. Destructive fishing methods have been widely observed to have major and long-lasting effects on sessile benthic megafauna (Jennings and Kaiser, 1998; Freese et al., 1999). More research needs to be done to determine the importance of areas such as Pribilof Canyon to Pacific Ocean perch production in the Bering Sea, so that we may protect and allow restoration of these utilized habitats for commercially and ecologically important species such as rockfishes.

Acknowledgements

I thank Lance Horn and Glenn Taylor for their skillful piloting of the ROV and the scientists and crew aboard the NOAA ships *Miller Freeman* and *Surveyor* for their assistance with all phases of the sampling. I am grateful to Morgan Busby and Jay Orr for their assistance in identifying fish on the videos, Craig Kestelle and Betty Goetz for preparing and reading otoliths, and Matt Wilson for his analysis of trawl catches. I thank Art Kendall, Tom Okey, Gordie Swartzman, Mark Zimmerman, and two anonymous reviewers for helpful comments on the manuscript. Funding for the ROV in 1995 and 1997 was provided by the National Undersea Research Center in Fairbanks, Alaska. This research was sponsored in part by the NOAA Coastal Ocean Program through the Southeast Bering Sea Carrying Capacity program and is FOCI Contribution No. S368.

References

- Able, K.W., Grimes, C.B., Cooper, R.A., Uzmann, J.R., 1982. Burrow construction and behavior of tilefish, *Lopholatilus chamaeleonticeps*, in Hudson Canyon. *Environmental Biology of Fishes* 7, 199–205.
- Auster, P.J., Malatesta, R.J., LaRosa, S.C., 1995. Patterns of microhabitat utilization by mobile megafauna on the southern New England (USA) continental shelf and slope. *Marine Ecology Progress Series* 127, 77–85.
- Brodeur, R.D., Percy, W.G., 1984. Food habits and dietary overlap of some shelf rockfishes (Genus *Sebastes*) from the northeastern Pacific Ocean. *Fishery Bulletin* 82, 269–293.
- Brodeur, R.D., Livingston, P.A., 1988. Food habits and diet overlap of various Eastern Bering Sea fishes. NOAA Tech. Memo. NMFS F/NWC-127, 76 pp.
- Brodeur, R.D., Wilson, M.T., Napp, J.M., Stabeno, P.J., Salo, S., 1997. Distribution of juvenile pollock relative to frontal structure near the Pribilof Islands, Bering Sea. *Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems, Alaska Sea Grant AK-97-01*, pp. 573–589.
- Carlson, P.R., Karl, H.A., 1988. Development of large submarine canyons in the Bering Sea, indicated by morphologic, seismic, and sedimentologic characteristics. *Geological Society of America Bulletin* 100, 1594–1615.
- Cartes, J.E., Company, J.B., Maynou, F., 1994. Deepwater decapod crustacean communities in the Northwestern Mediterranean: influence of submarine canyons and season. *Marine Biology* 120, 221–229.
- Chess, J.R., Smith, S.E., Fischer, P.C., 1988. Trophic relationships of the shortbelly rockfish, *Sebastes jordani*, off Central California. *California Cooperative Oceanic Fisheries Investigations Reports* 29, 129–136.

- Coyle, K.O., Cooney, R.T., 1993. Water column scattering and hydrography around the Pribilof Islands, Bering Sea. *Continental Shelf Research* 13, 803–827.
- Denman, K.L., Powell, T.M., 1984. Effects of physical processes on planktonic ecosystems in the coastal ocean. *Oceanography and Marine Biology Annual Review* 22, 125–168.
- Druffel, E.R.M., Griffin, S., Witter, A., Nelson, E., Southon, J., Kashgarian, M., Vogel, J., 1995. *Gerardia*: Bristlecone pine of the deep-sea?. *Geochemica and Cosmochimica Acta* 59, 5031–5036.
- Foote, K.G., 1987. Fish target strengths for use in echo integrator surveys. *Journal of the Acoustic Society of America* 82, 981–987.
- Freeland, H.J., Denman, K.L., 1982. A topographically controlled upwelling center off Southern Vancouver Island. *Journal of Marine Research* 40, 1069–1093.
- Freese, L., Auster, P.J., Heifetz, J., Wing, B.L., 1999. Effects of trawling on seafloor habitat and associated invertebrate taxa in the Gulf of Alaska. *Marine Ecology Progress Series* 182, 119–126.
- Genin, A., Haury, L., Greenblatt, P., 1988. Interactions of migrating zooplankton with shallow topography: predation by rockfishes and intensification of patchiness. *Deep-Sea Research* 35, 151–175.
- Genin, A., Greene, C., Haury, L., Wiebe, P., Gal, G., Kaartvedt, S., Meir, E., Fey, C., Dawson, J., 1994. Zooplankton patch dynamics: daily gap formation over abrupt topography. *Deep-Sea Research* 41, 941–951.
- Granata, T.C., Vidondo, B., Duarte, C.M., Satta, M.P., Garcia, M., 1999. Hydrodynamics and particle transport associated with a submarine canyon off Blanes (Spain), NW Mediterranean Sea. *Continental Shelf Research* 19, 1249–1263.
- Greene, C.H., Wiebe, P.H., Burczynski, J., Youngbluth, M.J., 1988. Acoustical detection of high-density krill demersal layers in the submarine canyons off Georges Bank. *Science* 241, 359–361.
- Haedrich, R.L., Rowe, G.T., Polloni, P.T., 1980. The megabenthic fauna in the deep sea south of New England, USA. *Marine Biology* 57, 165–179.
- Hickey, B.M., 1997. The response of a steep-sided narrow canyon to strong wind forcing. *Journal of Physical Oceanography* 27, 697–726.
- Isaacs, J.D., Schwartzlose, R.A., 1965. Migrant sound scatterers: Interactions with the seafloor. *Science* 150, 1810–1813.
- Jennings, S., Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. *Advances in Marine Biology* 34, 201–352.
- Kenney, R.D., Winn, H.E., 1987. Cetacean biomass densities near submarine canyons compared to adjacent shelf/slope areas. *Continental Shelf Research* 7, 107–114.
- Klinck, J.M., 1996. Circulation near submarine canyon: a modeling study. *Journal of Geophysical Research* 101, 1211–1223.
- Koslow, J.A., Ota, A., 1981. The ecology of vertical migration in three common zooplankters in the La Jolla Bight, April–August 1967. *Biological Oceanography* 1, 107–134.
- Kotenov, B.N., 1965. Sea valleys in the continental slope of the Bering Sea. In: Moiseev, P.A. (Ed.), *Soviet Fisheries Investigations in the Northeast Pacific Part IV*, pp. 23–32 (translated by the Israel Program for Scientific Translations, Jerusalem, 1968).
- Krieger, K.J., 1992. Distribution and abundance of rockfish determined from a submersible and by bottom trawling. *Fishery Bulletin* 91, 87–96.
- Krieger, K.J., Ito, D.H., 1999. Distribution and abundance of shortraker rockfish, *Sebastes borealis*, and rougheye rockfish, *S. aleutianus*, determined from a manned submersible. *Fishery Bulletin* 97, 264–272.
- Mackas, D.L., Kieser, R., Saunders, M., Yelland, D.R., Brown, R.M., Moore, D.F., 1997. Aggregations of euphausiids and Pacific hake (*Merluccius productus*) along the outer continental shelf off Vancouver Island. *Canadian Journal of Fisheries and Aquatic Sciences* 54, 2080–2096.
- Macquart-Moulin, C., Patrìti, G., 1996. Accumulation of migratory micronekton crustaceans over the upper slope and submarine canyons of the northwestern Mediterranean. *Deep-Sea Research* 43, 579–601.
- Miyashita, K., Aoki, I., Seno, K., Taki, K., Ogishima, T., 1997. Acoustic identification of isada krill, *Euphausia pacifica*, off the Sanriku coast, north-eastern Japan. *Fisheries Oceanography* 6, 266–271.
- O'Connell, V.M., Carlile, D.W., 1993. Habitat-specific density of adult yelloweye rockfish *Sebastes ruberrimus* in the eastern Gulf of Alaska. *Fishery Bulletin* 91, 304–309.

- Okey, T.A., 1997. Sediment flushing observations, earthquake slumping, and benthic community changes in Monterey Canyon head. *Continental Shelf Research* 17, 877–898.
- Pearcy, W.G., Stein, D.L., Hixon, M.A., Pikitch, E.K., Barss, W.H., Steiner, R.M., 1989. Submersible observations of deep-reef fishes of Heceta Bank, Oregon. *Fishery Bulletin* 87, 955–965.
- Pereyra, W.T., Pearcy, W.G., Carvey Jr. F.E., 1969. *Sebastes flavidus*, a shelf rockfish feeding on mesopelagic fauna, with consideration of the ecological implications. *Journal of the Fisheries Research Board of Canada* 26, 2211–2215.
- Poltev, Y.N., 1999. Some characteristics of the biology of the Pacific Ocean perch *Sebastes alutus* in the area of the northern Kurils. *Journal of Ichthyology* 39, 233–241.
- Richards, L.J., 1986. Depth and habitat distributions of three species of rockfish (*Sebastes*) in British Columbia: observations from the submersible PISCES IV. *Environmental Biology of Fishes* 17, 13–21.
- Richards, L.J., 1987. Copper rockfish (*Sebastes caurinus*) and quillback rockfish (*Sebastes maliger*) habitat in the Strait of Georgia, British Columbia. *Canadian Journal of Zoology* 65, 3188–3191.
- Rowe, G.T., 1971. Observations on bottom currents and epibenthic populations in Hatteras Submarine Canyon. *Deep-Sea Research* 18, 569–581.
- Ryer, C.H., Olla, B.L., 1999. Light-induced changes in the prey consumption and behavior of two juvenile planktivorous fish. *Marine Ecology Progress Series* 181, 41–51.
- Sardà, F., Cartes, J.E., Company, J.B., 1994. Spatio-temporal variations in megabenthos abundance in three different habitats of the Catalan deep-sea (Western Mediterranean). *Marine Biology* 120, 211–219.
- Scholl, D.W., Buffington, E.C., Hopkins, D.M., Alpha, T.R., 1970. The structure and origin of the large submarine canyons of the Bering Sea. *Marine Geology* 8, 187–210.
- Schoenherr, J.R., 1991. Blue whales feeding on high concentrations of euphausiids around Monterey Submarine Canyon. *Canadian Journal of Zoology* 69, 583–594.
- Schumacher, J.D., Reed, R.K., 1992. Characteristics of currents over the continental slope of the Eastern Bering Sea. *Journal of Geophysical Research* 97, 9423–9433.
- Schumacher, J.D., Stabeno, P.J., 1998. The continental shelf of the Bering Sea. In: Robinson, A.R., Brink, K.H. (Eds.), *The Sea*, Vol. 11. Wiley, New York, pp. 789–822.
- Scott, B., 1995. Oceanographic features that define the habitat of Pacific Ocean perch, *Sebastes alutus*. *Fisheries Oceanography* 4, 147–157.
- Simard, Y., Lavoie, D., 1999. The rich krill aggregation of the Saguenay-St. Lawrence Marine Park: hydroacoustic and geostatistic biomass estimates, structure, variability, and significance for whales. *Canadian Journal of Fisheries and Aquatic Sciences* 56, 1182–1197.
- Smith, S.L., 1991. Growth and distribution of the euphausiids. *Thysanoessa raschii* (M. Sars) and *Thysanoessa inermis* (Kroyer) in the southeastern Bering Sea. *Polar Research* 10, 461–478.
- Stabeno, P.J., Schumacher, J.D., Salo, S.A., Hunt Jr. G.L., Flint, M., 1999. The Pribilof Islands: physical environment. In: Loughlin, T.R., Othani, K. (Eds.) *Dynamics of The Bering Sea*. Alaska Sea Grant Pub. AK-SG-99-03, Fairbanks.
- Stanton, T.K., 1989. Simple approximate formulas for backscattering of sound by spherical and elongated objects. *Journal of the Acoustic Society of America* 86, 1499–1510.
- Stefanescu, C., Morales-Nin, B., Massutí, E., 1994. Fish assemblages on the slope in the Catalan Sea (Western Mediterranean): Influence of a submarine canyon. *Journal of the Marine Biological Association of the UK* 74, 499–512.
- Stockwell, D.A., Whitley, T.E., Zeeman, S.I., Coyle, K.O., Napp, J.M., Brodeur, R.D., Pinchuk, A.I., Hunt, Jr. G.L., Anomalous conditions in the Southeastern Bering Sea, 1997: nutrients, phytoplankton, and zooplankton. *Fisheries Oceanography* 10, in press.
- Sugisaki, H., Brodeur, R.D., Napp, J.M., 1998. Summer distribution and abundance of macrozooplankton in the western Gulf of Alaska and Southeastern Bering Sea. *Memoirs of the Faculty of Fisheries, Hokkaido University* 45, 96–112.
- Swartzman, G., Brodeur, R., Napp, J., Walsh, D., Hewitt, R., Demer, D., Hunt, G., Logerwell E., 1999a. Relating spatial distributions of acoustically-determined patches of fish and plankton: data viewing, image analysis, and spatial proximity. *Canadian Journal of Fisheries and Aquatic Sciences (Suppl. 1)* 56, 188–198.

- Swartzman, G., Brodeur, R., Napp, J., Hunt, G., Demer, D., Hewitt, R., 1999b. Spatial proximity of age-0 walleye pollock (*Theragra chalcogramma*) to zooplankton near the Pribilof Islands, Bering Sea, Alaska. *ICES Journal of Marine Science* 56, 545–560.
- Vetter, E.W., Dayton, P.K., 1998. Macrofaunal communities within and adjacent to a detritus-rich submarine canyon system. *Deep-Sea Research II* 45, 25–54.