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Habitat associations of demersal fishes and crabs in the Pribilof Islands region of the Bering Sea

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Abstract

Habitat associations of demersal fishes and crabs were determined from observations of videotapes recorded by a camera-equipped remotely operated vehicle (ROV) in the Bering Sea near the Pribilof Islands in September 1995 and 1997. We identified 42 taxa representing 16 families of fishes and 8 taxa from 3 families of crabs. Families Pleuronectidae (righteye flounders) and Cottidae (sculpins) were represented by the greatest number of taxa. *Lepidopsetta polyxystra* and *Chionoecetes opilio* were the most frequently observed fish and crab species. Other fish species in the families Pleuronectidae, Gadidae, Scorpaenidae, Agonidae, and Bathymasteridae were also encountered frequently. Six classifications based on substrate and cover were used to describe the habitat where each fish and crab was observed. Agonids and pleuronectids were typically observed on silt, mud, or sand substrate with no cover while other taxa, particularly cottids and bathymasterids, were encountered in more varieties of habitat including areas covered with rocks and boulders. Significant differences in species composition were found among habitats and stratified depth ranges. Similarity analyses showed that different taxa were responsible for these differences, but within each habitat type and depth range, two to five species contributed to 90% of the average similarity. Some ROV dives were paired with bottom trawls in the same general locations. Species compositions of the ROV observations were significantly correlated with that of the corresponding bottom trawl catch compositions. Overall, we believe that in situ observations provide useful information on fish habitats and behaviors not readily available from conventional trawling surveys.
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Keywords: Fishes; Crabs; Habitat; ROV; Bering Sea; Pribilof Islands

1. Introduction

There has been a recent surge of interest in ecosystem-based management of marine resources. Regulatory agencies are now mandated to identify,

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describe and protect essential fish habitats in order to sustain the long-term viability of these resources. Managers are often faced with the dilemma of defining and preserving critical fish-habitat associations without supporting scientific data, which renders any decisions made toward this objective tenuous at best. Anthropogenic effects on demersal habitats attributable to various sources but particularly mobile bottom fishing gear have been shown to have adverse and long-lived effects on biogenic structure and sediment quality (Auster et al., 1996; Collie et al., 1997, 2000; Jennings and Kaiser, 1998; Schwinghamer et al., 1998; Auster and Langton, 1999; Freese et al., 1999). The extent of habitat disturbance can be related to the size and type of gear used and the frequency and severity of impact, but the type and structure of the habitat itself is also an important consideration. There is increasing concern that fishing effort in many shelf systems has reached a level that it is negatively affecting the productivity and diversity of these ecosystems (Boehlert, 1996). Despite these concerns, we have little baseline data on the habitat requirements and utilization of most continental shelf regions of the world. This is particularly true in much of the North Pacific Ocean and Bering Sea.

Manned submersibles, underwater cameras carried by remotely operated vehicles (ROVs), and towed platforms have become widely used tools for conducting fishery research. These devices have provided the ability to observe fishes and invertebrates in their natural environment and have added a new dimension to fishery surveys beyond traditional net and hydroacoustic sampling (Gunderson, 1993). A majority of the studies utilizing these technologies has focused on characterizing the habitat utilized by a particular species or community (Carlson and Straty, 1981; Richards, 1986; Pearcy et al., 1989; Stein et al., 1992; Krieger, 1992, 1993; Felley and Veccionne, 1995; Auster et al., 1995; Norcross and Mueter, 1999; Johnson et al., 2003). In most of these studies, the behavior of individuals or groups of a particular species was observed and noted, and the characteristics of their habitat evaluated in terms of depth and substrate composition, size, or texture.

The National Marine Fisheries Service (NMFS) has been conducting fishery-independent bottom trawl surveys in the Eastern Bering Sea since the 1960s (Conners et al., 2002). These surveys have yielded important information on the distribution and ecology of Bering Sea fishes and invertebrates. However, little effort has been expended on examining smaller-scale association of the biota with the substrates they inhabit. With the exception of McConnaughey and Smith (2000) and Brodeur (2001), no studies have examined the relationship between bottom type and fish distribution in the Bering Sea. In this study, we describe small-scale habitat associations of demersal fishes and crabs in the southeastern Bering Sea using underwater video cameras mounted on a ROV. Seafloor habitat characteristics are described and substrate associations of several fish and commercially important crustacean species determined. In addition, we compare species composition observed using ROV-mounted video cameras to that determined from bottom trawl collections at the same general locations.

2. Materials and methods

2.1. Field operations

Cruises were conducted in the vicinity of the Pribilof Islands, a group of islands situated at the outer edge of the Bering Sea continental shelf some 370 km north of the Aleutian Islands Archipelago during 9–26 September 1995 and 8–18 September 1997 (Fig. 1). This research was conducted as part of an intensive multidisciplinary study of the frontal regions around the Pribilof Islands and a substantial amount of ancillary physical and biological data were collected at each deployment site (Brodeur et al., 2002). Most of the sites were chosen to represent the different hydrographic habitats (inner shelf, fronts, outer shelf) around the Pribilof Islands that were being studied. Other sites were added based on acoustic signals detecting high biomass near the bottom (e.g. Pribilof Canyon sites).

Underwater observations were made with video cameras mounted on a Deep Ocean Engineering Super Phantom II ROV deployed from the NOAA R/V *Miller Freeman*. ROV surveys were performed with a color CCD video camera (Hitachi Model HV-C20). The viewing area was illuminated by two 250 W tungsten–halogen lights mounted externally on the vehicle. We generally dimmed these lights to about 75% of full power to minimize the backscatter from biogenic particulate matter (organisms and marine snow) in the water column. In 1997, the ROV was also

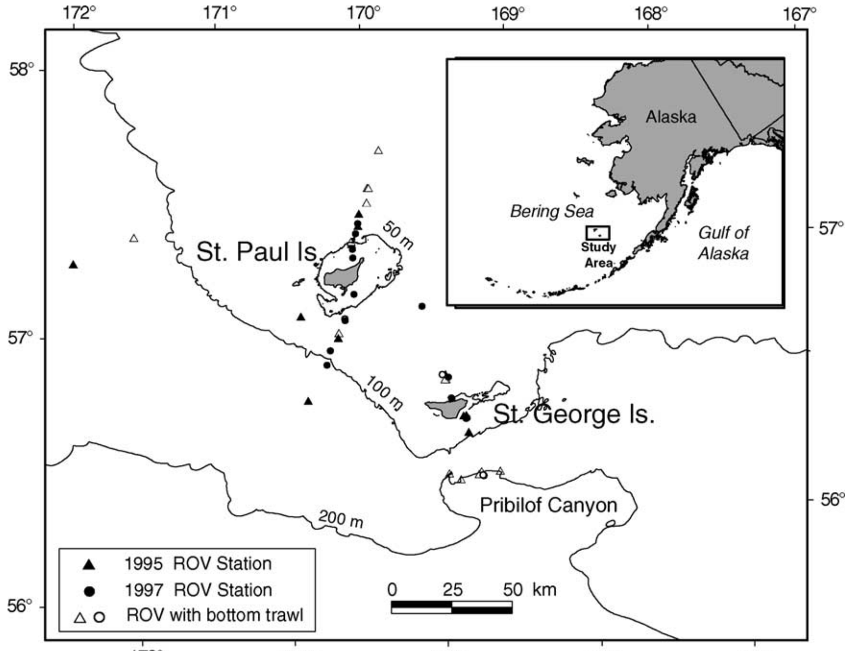

Fig. 1. Pribilof Island study area in the Southeast Bering Sea and station locations of 1995 and 1997 ROV deployments and bottom trawls. Multiple deployments were conducted at some stations.

fitted with a 35 mm still minicamera (Benthos Model 3782) and strobe. The ROV was deployed 25 times in 1995 and 16 times in 1997 (Fig. 1). Mean deployment time was 35.8 min (range 10–78 min).

During each deployment, the vessel drifted with the currents while maintaining a constant heading using its bow thruster. A 108-kg weight was attached 25 m from the end of the ROV umbilical cord to provide stability and reduce the angle of drift of the ROV away from the vessel. The ROV had the capability of moving in all directions within a 25 m radius sphere, but was generally propelled in a linear trajectory at a slow speed to keep it away from the weight. The bottom depth range over which observations were made was from 33 to 248 m. Video images were viewed in realtime using an on deck console that allowed the ROV operator to maneuver the vehicle and control the cameras and lights and provide the depth of the ROV which was annotated throughout the deployment. The video camera had zoom capability but was used only when necessary to identify organisms on transects. Continuous video recordings were made on two Hi-8 mm tape decks.

Following 13 ROV deployments in 1995 and 3 in 1997, a short tow was made along the ROV transect using a nylon northeastern bottom trawl with 1.5 m × 2.1 m steel doors fished without roller gear (Feldman and Rose, 1981). These sites were selected for having bottom types suitable for fishing with a bottom trawl (Fig. 1). The mesh size decreased 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 the trawl was estimated to be 13.4 m with a mean vertical opening of 9.2 m. The entire catch was processed on deck and the number and weights of all taxa were recorded.

2.2. Laboratory procedures

Videotape footage for each ROV transect was reviewed by two observers in the laboratory. Methods for data collection from videotape footage were similar to those used by Felley and Veccionne (1995) with some modifications. Observations of videotape footage were divided into 1-min intervals. Within each interval, all fishes and crabs were identified to the lowest possible taxa. Depth was recorded and substrate was characterized into categories of silt, mud or sand. Silt was categorized as very fine and could be disturbed into visible plumes by the ROV thrust propellers and moving organisms. Mud was notably more compact, had a slick appearance with a visible sheen on the surface, and could not be disturbed by ROV movements. Sand was notably coarser with no visible sheen and usually appeared as wavy bedforms. Substrate cover was categorized as absent or comprised of broken shell hash, gravel-cobble, or rocks-boulders.

2.3. Analytical methods

Habitat types are modified after Norcross and Mueter (1999). Six habitat classifications were identified from the video footage based on observations of substrate and cover (Table 2A). These habitats were: silt (1); mud (2); sand with no cover (3); silt, mud, or sand with broken shell hash (4); silt, mud, or sand with gravel and/or cobble (5); silt, mud, or sand with rocks and/or boulders (6). Habitats were distributed over similar depth intervals with minimum depths from 33 to 55 m and maximum depths from 207 to 248 m. Observations were stratified into depth intervals of ≤100, 101–150, 151–200, and >200 m. Because of the large number of gelatinous zooplankton encountered in midwater during most of the deployments (Brodeur, 1998), we were not able to use any external calibration scale on the ROV to measure the field of view. We estimated this to be about 1 m (wide) × 1 m (tall) for the Hitachi video camera based upon measurements made aboard the research vessel with a typical drifting altitude of about 1 m off bottom.

To examine fish assemblages and relate these to habitat classification, we used presence/absence data within 1-min time intervals as our sampling unit (Felley and Veccionne, 1995). This was found to be necessary as observations were often affected by water clarity. Species with less than 1% occurrence in all intervals were eliminated. To test if differences in species composition occurred among habitat classifications and depth intervals, we performed two analysis of similarity (ANOSIMs), using a Bray–Curtis similarity matrix of samples (1-min intervals). ANOSIM is a nonparametric, multivariate permutation test, analogous to the parametric, univariate ANOVA that is particularly applicable when analyzing multiple species data that do not meet the assumptions required for multivariate ANOVA (MANOVA) (Clarke and Green, 1988). Beginning with a matrix of Bray–Curtis similarity indices, which measures how similar the species composition is for each pair of samples, the matrix is ranked, and then reordered so that all samples within each habitat group are grouped together. An *R*-statistic is then calculated, which is defined as a measure of how the between-group variance compares to the within-group variance, as does an ANOVA. The formula is,

$$R = \frac{\bar{r}_{\mathrm{B}} - \bar{r}_{\mathrm{W}}}{\frac{1}{2}M}$$

where $\bar{r}_{\mathrm{B}}$ and $\bar{r}_{\mathrm{W}}$ are the average rank similarities for each pair of intervals for between- and within-groups, respectively, $M = n(n-1)/2$, and n is the sample size. Sample sizes for the different habitats do not need to be equal for an ANOSIM, as only the average rank similarities between- and within-groups are compared. We first tested for significant differences between habitats, and then between depth intervals. Whenever a significant difference was found, we followed this with pairwise ANOSIM tests between-groups using a Bonferroni correction. When significant differences were found by the ANOSIM, we then wanted to determine the discriminating species behind the differences. This was done with a SIMPER (similarity percentages) analysis that determines: (1) how much each species contributes to the dissimilarity between two groups and (2) how much each species contributes to the average similarity within a particular group (Clarke, 1993).

In order to compare the ROV data with the trawl data, a separate analysis was used. Instead of presence/absence data, densities per square kilometer were estimated for taxa collected with the bottom trawl using the area swept method as follows:

$$D = \frac{N \times 10^6 \mathrm{m}^2\,\mathrm{km}^{-2}}{L \times W}$$

where D is the density of fish per square kilimeter, N the number of fish observed, L the length of transect (m), and W is the width of transect (m). Sixteen stations where both ROV (standardized to numbers seen per 1 min) and bottom trawl data (standardized to catch per square kilimeter) occurred were selected and a separate Bray–Curtis similarity matrix of the fourth root transformed data was created for both the ROV and trawl data. A fourth root transformation was necessary so that rare taxa were not overwhelmed by the most common taxa. Although the ROV data could not be standardized by area sampled, we assumed that the speed of the ROV was constant, and therefore standardizing by the total number of intervals within each dive should yield comparable rank correlations between the two matrices. A nonparametric Mantel-type test using Spearman correlation coefficients between the two similarity matrices (RELATE procedure in PRIMER software) was used to determine if there was a relationship between the species compositions in the ROV and trawl data (Clarke and Gorley, 2001).

3. Results

3.1. Observations of fishes and crabs

Overall, 42 taxa representing 16 families of fishes were observed with the ROV with a total of 35 taxa identified in 1995 and 31 in 1997 (Table 1). The family Pleuronectidae was represented by the greatest number of taxa ($n = 8$) followed by Cottidae ($n = 7$). Identifications of fishes only to the family level (Cottidae or Pleuronectidae) were usually the consequence of rapid escape movement, the subject being visually obscured by suspended sediments or other particulate matter, or were based on smaller individuals (juveniles) for which we could not discern specific characteristics. Seven taxa of crabs representing three families were observed in 1995 and six in 1997. Table 1 also lists the number of observations in each habitat for each taxon of fishes and crabs identified and how each ranks if within the top 10 in the number of observations.

3.2. Habitat

Overall, a total of 1013 1-min intervals of videotape was examined for the presence of fishes and crabs and for determination of habitat type (Table 2). In 1995, the greatest number ($n = 260$) of ROV observation time intervals was conducted on silt substrate with no cover (habitat 1) followed by mud with no cover (habitat 2) ($n = 138$)(Table 2B). Habitats 3–6 were occupied for substantially lesser amounts of time (Table 2B). Fish or crabs were observed in 67% of the intervals overall. Habitats 2 and 6 had the highest percentage of intervals with fish or crabs observed (77%), followed closely by habitat 3 (76%), while habitat 4 had the lowest (42%).

In 1997, habitat 1 was again the most frequently encountered habitat type ($n = 157$) but was instead followed by habitat 4 ($n = 121$). Habitats 2 ($n = 54$), 5 ($n = 48$), and 6 ($n = 41$) were occupied for similar but substantially lesser amounts of time, and habitat 3 was only encountered once. Fishes or crabs were observed in 61% of the intervals overall and excluding habitat 3, habitat 6 had the highest percentage of intervals with fish or crabs observed (73%) and habitat 2 had the lowest (50%).

3.3. Habitat—species associations

Lepidopsetta polyxystra (Fig. 2A) was the most frequently observed fish ranking first overall in 1995 and second in 1997 (Table 1) and was most commonly encountered on habitat 2 at depths <100 m. *Leptagonus frenatus* (Fig. 2B) ranked second in number of observations overall and was found most often (76.9%) on habitat 1. *Bathymaster signatus* (Fig. 2C and D) ranked third and were usually observed in habitat 6 (68.6%) and sometimes in areas covered with gravel and cobble (habitat 5). *B. signatus* were typically encountered at depths <100 m but some observations were made at depths >200 m. *Sebastes alutus* (Fig. 2E) were most frequently observed (73.8%) on habitat 1 which was often covered with “forests” of the sea whip *Halipterus willemoesi* at depths near 200 m. More detailed descriptions of the habitat of *S. alutus* based on these and other observations can be found in Brodeur (2001). *Theragra chalcogramma* (juveniles and adults) ranked seventh in overall number of observations and were most frequently encountered over habitat 2 (34%) or habitat 4 (34%). *Limanda aspera* (Fig. 2F) were seen mostly on habitat 1 (71.5%) at depths <100 m. *Chionoecetes opilio* (Fig. 2G), the only crab species ranking in the top 10 for number of overall observations, was also encountered most frequently on habitat 1 (81.1%) at depths <100 m and sometimes at depths 101–150 m. Another crab species, *Paralithodes camtschaticus*, ranked fifth in 1997 but did not rank within the top 10 for both years combined. *Gadus macrocephalus* (Fig. 2H) ranked 10th in number of observations overall and was usually observed on habitat 1 (61.1%) at depths both <100 and >200 m. Observations of less frequently encountered taxa in specified habitats are summarized in Table 1.

Some individual taxa displayed associations with or were dominant in single or multiple habitats (Fig. 3).

Table 1
List of fish and crab taxa observed from video tapes recorded during 1995 and 1997 ROV deployments with number of observations in each habitat type and total number of observations

Family	Scientific name	Common name	Presence/absence		Numbers of observations Habitat type						Total no. of observations
			1995	1997	1	2	3	4	5	6	
Fishes											
Rajidae	Rajidae	Unidentified skates	×	×	3	1					4
	Bathyraja aleutica	Aleutian skate	×		1						1
	Bathyraja interrupta	Bering skate		×	1						1
	Bathyraja taranetzi	Mud skate		×	3						3
	Raja binoculata	Big skate	×		1				1		2
Gadidae		Unidentified cods	×	×	5	1			5	1	12
	Gadus macrocephalus	Pacific cod	×	×	22	4			7	3	36
	Theragra chalcogramma	Walleye pollock (juveniles and adults)	×	×	13	20		20		6	59
Scorpaenidae	*Sebastes* spp.	Unidentified rockfishes	×	×		1			2	3	6
	S. alutus	Pacific ocean perch	×	×	48		1		2	14	65
	S. ciliatus	Dusky rockfish		×						1	1
Hexagrammidae	*Hexagrammos* spp.	Unidentified greenlings		×				3			3
Cottidae		Unidentified sculpins	×	×	15	17	11	11	5	3	62
	Hemilepidotus jordani	Yellow Irish Lord	×	×	3	6		1	4	8	22
	Malacocottus spp.	Unidentified *Malacocottus*	×						1		1
	Malacocottus zonurus	Darkfin sculpin		×	1					2	3
	Myoxocephalus spp.	Unidentified *Myoxocephalus*	×			1					1
	Triglops spp.	Unidentified *Triglops*	×	×	4			3	4	2	13
	Triglops scepticus	Spectacled sculpin	×	×	3						3
Psychrolutidae	*Dasycottus setiger*	Spinyhead sculpin		×	1					1	2
	Psychrolutes paradoxus	Tadpole sculpin	×			4					4
	Psychrolutes sigalutes	Soft sculpin	×			2					2
Hemitripteridae	*Hemitripterus bolini*	Bigmouth sculpin	×	×	3	1					4
Agonidae		Unidentified poachers	×	×	19	6		2	2	2	31
	Leptagonus frenatus	Sawback poacher	×	×	70	5		10	3	3	91
	Podothecus acipenserinus	Sturgeon poacher	×	×	4			2			6

Cyclopteridae	*Aptocyclus ventricosus*	Smooth lumpsucker	×		1						1
Liparidae	*Careproctus* spp.	Unidentified snailfishes	×		1						1
Bathymasteridae	*Bathymaster signatus*	Searcher	×	×		1			21	48	70
Zoarcidae		Unidentified eelpouts	×	×	13	3		2			18
Stichaeidae		Unidentified pricklebacks	×	×	11						11
	Lumpenus spp.	Unidentified *Lumpenus*	×	×	13	1					14
Trichodontidae	*Trichodon trichodon*	Pacific sandfish	×		1						1
Zaproridae	*Zaprora Silenus*	Prowfish	×			1			1		2
Pleuronectidae		Unidentified flatfish	×	×	21	24		12	1	2	60
	Atheresthes spp.	Arrowtooth or Kamchatka flounder	×	×	8	5		2	12		27
	Glyptocephalus zachirus	Rex sole		×	3						3
	Hippoglossus stenolepis	Pacific halibut	×	×	8	3				2	13
	Hippoglossoides elassodon	Flathead sole	×		1						1
	Lepidopsetta polyxystra	Northern rock sole	1	×	32	106	28	67	7	6	246
	Limanda aspera	Yellowfin sole	×	×	35	6		8			49
	Pleuronectes quadrituberculatus	Alaska plaice	×	×	1			1			2
Total number of taxa		42	35	31							
Crabs											
Majidae	*Brachyura*	Unidentified crab	×	×	10	4		1			15
	Chionoecetes sp.	Unidentified Tanner crab	×		4						4
	C. bairdi	Tanner crab	×	×	7	5		4			16
	C. opilio	Snow crab	8	×	30	3		4			37
Lithodidae	*Paralithodes* spp.	Unidentified king crab		×		2					2
	Paralithodes camtschaticus	Red king crab	×	5	1	3		18	2	1	25
	P. platypus	Blue king crab	×			1					1
Atelecyclidae	*Erimacrus isenbeckii*	Korean horsehair crab	×	×	1	9		5	2	3	20
Total number of taxa		8	7	6							

Table 2
(A) List of habitat types, characteristics, depth ranges, and percentage of observations in selected depth intervals and (B) number of 1 min video observation intervals in each habitat with number and percentage of intervals where fish and/or crabs were observed for 1995, 1997, and combined ROV deployments

Habitat	Characteristics	Depth range (m)	Depth interval (m) (% of observations)			
			<100 m	101–150 m	151–200 m	>200 m
(A)						
1	Silt, no cover	55–248	32	16	8	44
2	Mud, no cover	50–207	96			4
3	Sand, no cover	50–247	97			3
4	Silt, mud, or sand covered with broken shell hash	33–208	95			5
5	Silt, mud, or sand covered with gravel-cobble	36–208	58		35	7
6	Silt, mud, or sand covered with rocks-boulders	36–222	74		6	20

Habitat	1995			1997			1995, 1997 combined		
	Total 1 min intervals	# w fish/crabs	% w fish/crabs	Total 1 min intervals	# w fish/crabs	% w fish/crabs	Total 1 min intervals	# w fish/crabs	% w fish/crabs
(B)									
1	260	169	65	157	99	63	417	268	64
2	138	106	77	54	27	50	192	133	69
3	37	28	76	1	1	100	38	29	76
4	50	33	66	121	71	59	171	104	61
5	67	28	42	48	29	60	115	57	50
6	39	30	77	41	30	73	80	60	75
Total	591	394	67	422	257	61	1013	651	64

For example, although dominant in habitats 2–4, *L. polyxystra* was present in all habitats, and had a wide range of substrate utilization. Cottidae (unidentified sculpins) was the only other taxon identified in all habitats. *L. frenatus* was dominant in habitat 1 but was also present in all other habitats except 3. *B. signatus* was the dominant taxon in habitats covered with cobble-gravel (5) and rocks-boulders (6). One noteworthy observation was the relatively high number of encounters of the pleuronectid flatfishes *Atheresthes* spp. and *L. polyxystra* on cobble-gravel (habitat 5). *L. aspera* were most frequently encountered on silt substrate (habitat 1) and at depths always less than 100 m. Crabs were most frequently observed on habitats 1 and 4 and were completely absent on habitat 3.

There were significant differences in species composition among habitats ($P < 0.01$, ANOSIM). Pairwise tests showed that (a) species assemblages on habitats 1–4 were all different from habitats 5 and 6 and (b) species composition of habitat 1 was different from habitats 2 and 4. The subsequent SIMPER analysis, corresponding to result (a) above, showed that in order of highest to lowest importance, *L. polyxystra*, *B. signatus*, *L. frenatus*, Cottidae, *Hemilepidotus jordani*, *Atheresthes* spp., *S. alutus*, Pleuronectidae, *T. chalcogramma*, *G. macrocephalus*, and Agonidae contributed to 75% of the average dissimilarity between combined habitats 1–4 and combined habitats 5 and 6, therefore making these the primary discriminating species for this difference. The second SIMPER analysis, corresponding to result (b) above, showed that, in order of highest to lowest importance, *L. polyxystra*, *L. frenatus*, Pleuronectidae, *T. chalcogramma*, Cottidae, *C. opilio*, *L. aspera*, *S. alutus*, Agonidae, and *G. macrocephalus* contributed to 75% of the average dissimilarity between habitat 1 and combined habitats 2 and 4, therefore making these species the primary taxa responsible for the observed difference.

Species composition was also significantly different among all four depth intervals ($P < 0.01$, ANOSIM). Subsequent SIMPER analysis showed that different sets of taxa were responsible for these differences, but within each depth interval, there were 2–5 taxa unique to that interval contributing to 90% of the aver-

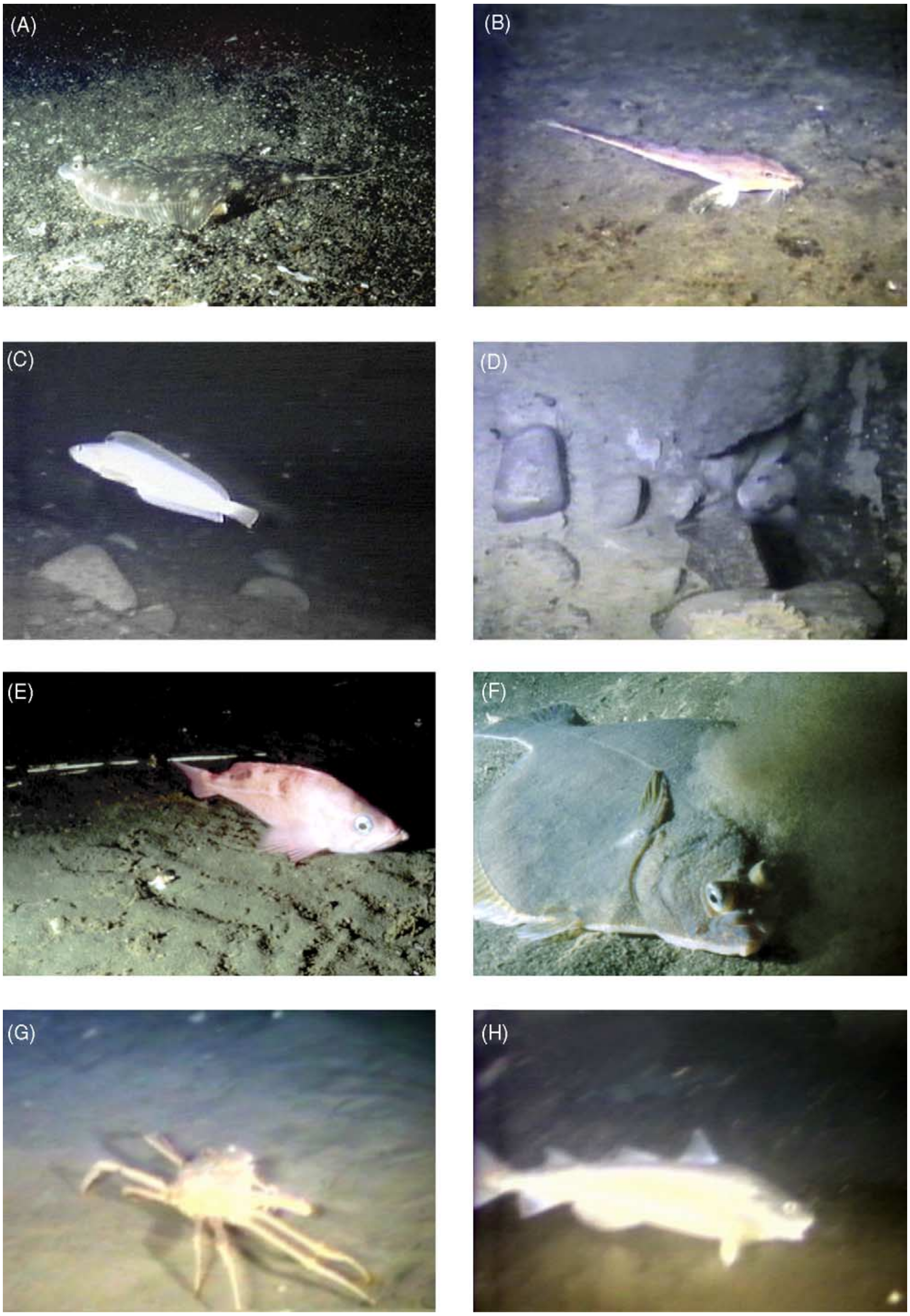

Fig. 2. Photographs and digitized video taped images of some of the most frequently observed fish and crab species. (A) *Lepidopsetta polyxystra* on sand with broken shell hash (habitat 4) depth 57 m. (B) *Leptagonus frenatus* on silt with no cover (habitat 1) depth 208 m. (C) *Bathymaster signatus* over silt with rocks and boulders (habitat 6) depth 175 m. (D) *Bathymaster signatus* hiding in hole in silt with rocks and boulders (habitat 6) depth 207 m. (E) *Sebastes alutus* on silt with no cover (habitat 1) depth 248 m; note downed sea whip *Halipterus willemoesi* in background. (F) *Limanda aspera* on silt with no cover (habitat 1) depth 62 m. (G) *Chionoecetes opilio* on silt with no cover (habitat 1) depth 114 m. (H) *Gadus macrocephalus* feeding in silt with no cover (habitat 1) depth 204 m.

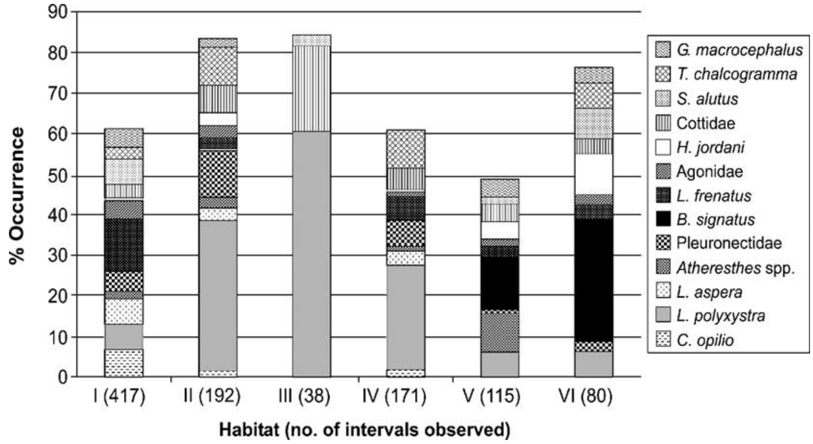

Fig. 3. Percent occurrence in each habitat type for some of the most frequently observed taxa.

age similarity. Listed by depth interval, the unique species were (<100 m) *L. polyxystra*, Pleuronectidae, *T. chalcogramma*, Cottidae, and *B. signatus*; (101–150 m) *C. opilio*, *Lumpenus* spp., Stichaeidae; (151–200 m) *S. alutus* and *Atheresthes* spp.; (>200 m) *L. frenatus*, *G. macrocephalus*, and Agonidae.

3.4. Comparisons of ROV observations with bottom trawl catches

Overall, 46 taxa of fishes and 8 taxa of crabs were collected in bottom trawls paired with ROV deployments in 1995 and 1997. Although we observed nine fish taxa on the tapes recorded from the ROV deployments that were not collected in bottom trawls, there were 21 taxa of fish and crabs identified in bottom trawls that were not seen in the video footage (Table 3). Among these was *Somniosus pacificus*, the only shark encountered in the study. Species composition and ranked abundances of taxa of the ROV observation data from dives paired with bottom trawls was significantly correlated with those of the bottom trawl data ($P < 0.01$, Mantel).

4. Discussion

4.1. Habitat observation

Video observations provided us with a wealth of information on microhabitat usage and behavior of fishes and crabs in the Eastern Bering Sea that would not be discernable from trawling. For example, *B. signatus* individuals were seen darting into crevices or burrows often in close proximity to rockpiles upon the approach of the ROV, and thus would likely not be caught by bottom trawls in these habitats. It is unknown whether they excavate these burrows themselves, similar to tilefishes (*Lopholatilus chamaeleonticeps*) in the Atlantic (Able et al., 1982, Grimes et al., 1986), or whether they occupy previously excavated holes. Most rockfishes (*Sebastes* spp.) were associated with rocky outcrops or with some sort of biogenic structure such as the sea whip ‘forest’ in Pribilof Canyon (Brodeur, 2001), anenomes or sponges. Although most of the habitats we surveyed lacked substantial vertical relief, many other fish and invertebrate taxa showed apparently thigmotactic responses to natural or biogenic features such as excavated pits, anemones and sponges, basket stars, and sand waves, as has been observed in other continental shelf habitats (Auster et al., 1991). We also observed large depressions in sand and mud that were occupied and apparently excavated by skates. *Lepidopsetta polyxtstra* were frequently seen swimming along troughs between sand waves. This behavior likely reduces their vulnerability to capture in bottom trawls. Several flatfish species including *Atheresthes* spp. and *L. polyxystra* were seen in small pockets of silt, sand, or mud surrounded by cobble-gravel (habitat 5) or rocks and boulders (habitat 6) (Fig. 3). In these untrawlable habitats, the ROV could be used as a means to enhance or “fine tune” trawl surveys.

Table 3
List of fish and crab taxa observed from video tapes recorded during 1995 and 1997 ROV deployments that were not collected in bottom trawls and fish and crab taxa collected in bottom trawls that were not observed on video tapes in paired ROV and bottom trawl deployments

ROV	Bottom trawl	
Bathyraja aleutica	*Somniosus pacificus*	Pacific sleeper shark
Bathyraja taranetzi	*Bathyraja parmifera*	Alaska skate
Hexagrammos spp.	*Clupea pallasi*	Pacific herring
Psychrolutes sigalutes	*Mallotus villosus*	Capelin
P. paradoxus	*Oncorhynchus keta*	Chum salmon
Aptocyclus ventricosus	*Sebastes aleutianus*	Rougheye rockfish
Stichaeidae	*S. zacentrus*	Sharpchin rockfish
Lumpenus spp.	*Anoplopoma fimbria*	Sablefish
Trichodon trichodon	*Artediellus pacificus*	Hookhorn sculpin
	Gymnocanthus galeatus	Armorhead sculpin
	Icelus spiniger	Thorny sculpin
	Myoxocephalus jaok	Plain sculpin
	M. polyacanthocephalus	Great sculpin
	Triglops forficata	Scissortail sculpin
	Triglops macellus	Roughspine sculpin
	Triglops pingelli	Ribbed sculpin
	Lycodes palearis	Wattled eelpout
	Atheresthes evermanni	Kamchatka flounder
	Reinhardtius hippoglossoides	Greenland halibut
	Hyas spp.	Lyre crabs
	Telmessus cheiragonus	Helmet crab

Common names of ROV taxa are given in Table 1.

This study provides the first descriptive community-wide account of demersal fishes and crabs and their habitat associations in the Bering Sea based on in situ observations. Video observation is a useful tool in many habitats, particularly where trawling is difficult, and it readily provides valuable information on habitat associations and behavior. However, this sampling gear does have its own drawbacks and difficulties in both collecting and analyzing data that are discussed here.

4.2. Species identifications

Identification of fish species images recorded on videotape is somewhat problematic because of viewing angles, flight responses, and cryptic behavior. In particular for this region of the Bering Sea near the Pribilof Islands, several congeners are similar in appearance and often require detailed examination to differentiate. Consequently, a large number of identifications were made to family and genus in the families Cottidae and Pleuronectidae in all habitats and depths. Among the Cottidae, *Myoxocephalus jaok* and *M. polyacanthocephalus* were identified in bottom trawls, but such distinctions could not be made from the video recordings, though it is highly likely both species were encountered. The same can be said for *Triglops forficata*, *T. macellus*, and *T. pingeli*.

In the family Pleuronectidae, we could not distinguish *Atheresthes evermanni* from *A. stomias* in video footage although both species were caught in bottom trawls. Although *L. polyxystra* is the only species of rock sole known from the Pribilof Island region, it would be extremely difficult to distinguish this species from *L. bilineata* in the Gulf of Alaska where the two species occur sympatrically (Orr and Matarese, 2000). The best characters for distinguishing *L. bilineata* from *L. polyxystra* require close examination of the lateral line, blind side of the fish, and gill rakers which would be impossible with a video camera. Similar detailed examinations are necessary to distinguish species within other pleuronectid genera such as *Hippoglossoides* and *Limanda*, and may limit the utility of the ROV as a survey tool for flatfishes in the Bering Sea. Perhaps with higher resolution cameras and increased zoom capabilities, these identifications can be accomplished.

4.3. Habitat distribution and human impacts

Although we did not collect and analyze sediment samples as part of this study, large areas of the eastern Bering Sea continental shelf, particularly around the Pribilof Islands, have been surveyed for surficial sediment particle sizes, degree of sorting, and composition (Smith and McConnaughey, 1999) and associated flatfish abundances (McConnaughey and Smith, 2000). Some generalized comparisons of our habitat observations and their sediment maps can be made. Our apparently finest unconsolidated substrate that we called silt (habitat 1) would be most similar to their mud while mud (habitat 2) and sand (habitat 3) approximate their sandy mud and muddy sand. Our remaining habitat types use these three categories for underlying substrate with cover of varying composition (broken shell hash—habitat 4) and size classes (gravel-cobble—habitat 5; rocks-boulders—habitat 6). We conducted several dives in Pribilof Canyon, south of St. George Island (Fig. 1), and observed silt (habitat 1) throughout the center with large fields of gravel-cobble (habitat 5) and rocks-boulders (habitat 6) near the edges of the canyon. Moving north from Pribilof Canyon to the south end of St. George Island, we encountered habitats 2 and 3 that were covered with gravel-cobble (habitat 5) and rocks-boulders (habitat 6) in dives closest to the island. All dives in the area between St. George and St. Paul Islands were either on habitats 1 or 2 suggesting that this large area has rather uniform and consistent substrate composition. This observation is consistent with those of Smith and McConnaughey (1999) who reported numerous collections of sandy mud and muddy sand in this area. Immediately north of St. Paul Island we encountered predominantly mud (habitat 2) and mud covered with broken shell hash (habitat 4). The northern and western most dives were on silt substrate (habitat 1).

On several occasions, we encountered evidence of human influence on the sea floor. This was usually in the form of "ghost" crab pots. Some of these had obviously been present for long periods of time and had been colonized by large anemones, sea stars, and barnacles. *Sebastes* spp. were usually seen in the vicinity of these objects. On one occasion, a clothes washer/dryer combination was collected in a bottom trawl and the drums found to be full of juvenile crabs (*C. opilio*). However, we observed few examples of bottom trawl tracks in our study region despite substantial trawling that has occurred here. This may be due in part, to the substantial near bottom tidal currents (>2 kts) that likely "erase" trawl tracks or naturally compacted sediments which resist scouring.

4.4. ROV-bottom trawl comparisons

We compared two methods of assessing fish distribution and habitats in our study. Trawling has some obvious advantages in that the specimens are captured so that positive identification, size, sex, age, and other biological variables can be determined. In addition, the effort tends to be more standardized and does not suffer from variability with respect to visibility and viewing angle as an ROV does. For purposes of habitat definition, trawling provides few details about the small-scale distribution patterns since it integrates the sample over the entire length of the trawl and provides almost no information on bottom type or topographic relief. Trawling also does not work well in rocky or high-relief environments. Even in flatter terrain, some flatfish are known to escape under the trawl footrope or through the meshes (Adams et al., 1995; Munro and Somerton, 2002). Finally, trawling provides little information about small-scale animal/substrate interactions that were readily apparent in our ROV observations (e.g. fishes that occupy burrows in the sediments).

Although the bottom trawl collected four more fish taxa than were identified on the videotapes, there are a few problems with this comparison that should be addressed. Firstly, three of these taxa collected in the bottom trawl (*Clupea pallasi*, *Mallotus villosus*, *Oncorhynchus keta*) are considered pelagic species and were most likely caught during deployment or retrieval of the bottom trawl and were unlikely to have been observed with an epibenthic video camera. With these three taxa removed from the trawl species list, the number of fish taxa nearly equals that observed on videotape (43 taxa versus 42 taxa). With these taxa excluded, a significant correlation in species composition and ranked abundance of taxa occurred between ROV observations and bottom trawls.

Although we were able to calculate densities of fish and crab taxa from bottom trawls, estimating densities from the video observations was more difficult. This is due to variations in altitude, pitch and roll of the ROV that affect the area of each view. Had we been able to measure the width of the video camera's field of view and distance traveled by the ROV accurately, a more meaningful comparison of the ROV and bottom trawl as sampling devices could have been made (e.g. Adams et al., 1995). Also, we have little information on how the presence of the ROV (e.g. lights, vibrations, and thruster noise) may have impacted the behavior of the fish in the path of the deployment. Previous studies have shown attraction, repulsion, and no apparent response to ROVs and submersibles (Carlson and Straty, 1981; Pearcy et al., 1989; Krieger, 1993; Adams et al., 1995; Norcross and Mueter, 1999). We were not able to directly address the effects of lights on the behavior of fishes although on several occasions, we turned off the lights for short periods of time and then turned them on and found no apparent 'startle' behavior for fish, although this reaction could still be occurring outside our visual range.

Another complicating factor encountered during the video survey was reduced and variable visibility levels. Reduced visibility was most frequently caused by large amounts of suspended sediment and other particulate matter mostly on unconsolidated substrate (e.g. silt). On several occasions, visibility was dramatically reduced by large swarms of euphausiids and other zooplankton in close proximity to the bottom during daylight hours. Moreover, in 1997, there was a pervasive bloom of the coccolithophore, *Emiliania huxleyi*, in the Eastern Bering Sea (Napp and Hunt, 2001) and at several locations, this bloom of highly-reflective particles extended to the bottom severely restricting visibility (Stockwell et al., 2001).

Our use of ROV video analysis of demersal fishes and crabs provided new and important information on the types of habitats utilized by these important taxa in the Bering Sea. Although the cost and logistic difficulties in using ROVs may prohibit their use for large-scale surveys, we feel that their potential advantages may someday make their widespread use more desirable in fishery surveys. Towed vehicles supporting underwater video cameras show promise as a lower cost alternative for habitat surveys (Barker et al., 1999). Future ROV video and manned submersible studies in the Bering Sea should be equipped with the necessary instrumentation to collect quantitative data (e.g. width of camera field of view and distance traveled) for estimating fish and crab abundance and to quantify the environment in which they occur.

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