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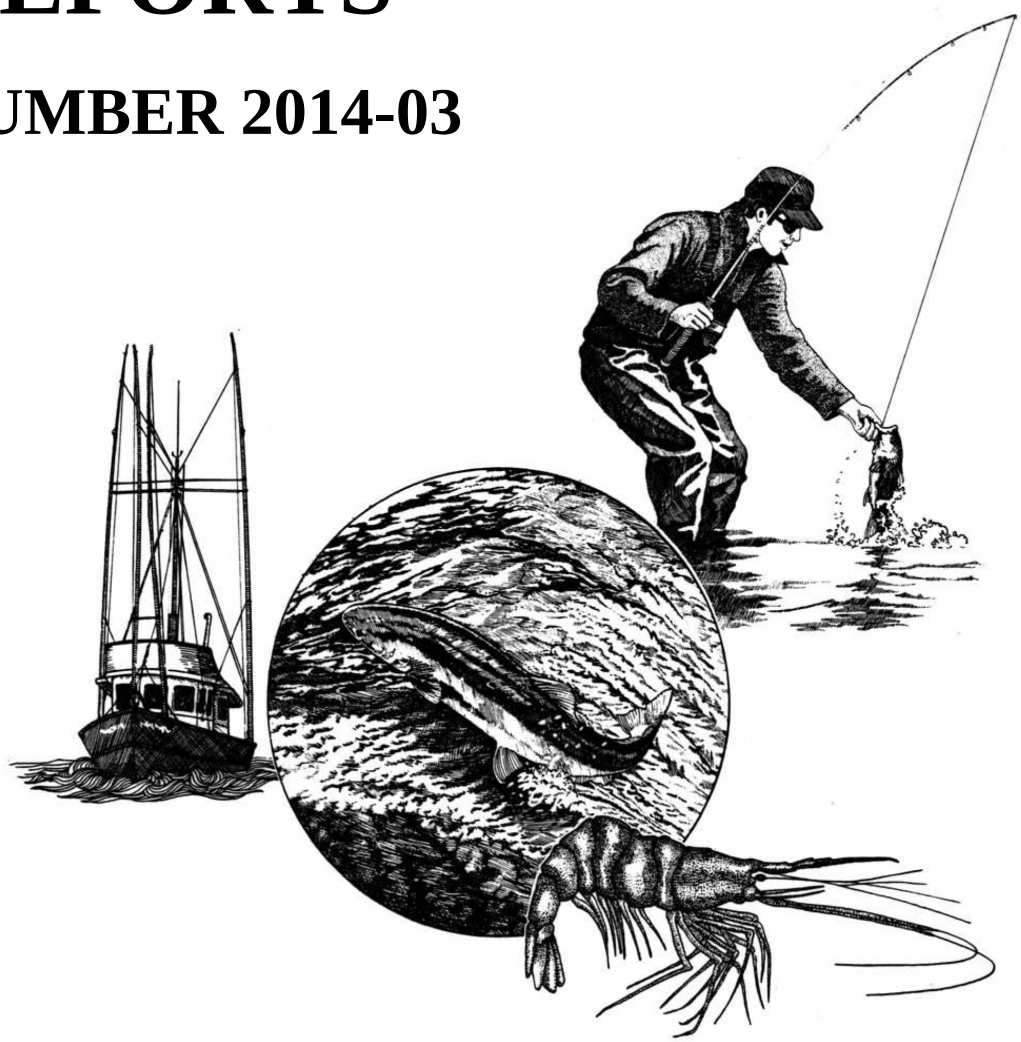

FISH DIVISION
Oregon Department of Fish and Wildlife

A comparison of 2007 and 2013 macroinvertebrate surveys of mud habitats at Nehalem Bank, Oregon: changes in areas with continued trawling and those closed to trawling in 2006

A comparison of 2007 and 2013 macroinvertebrate surveys of mud habitats at Nehalem Bank, Oregon: changes in areas with continued trawling and those closed to trawling in 2006

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Introduction

In June 2006, in an effort to protect specific seafloor habitats from the negative impacts of bottom trawl gear, the Pacific Fishery Management Council (PFMC) closed a number of areas on the U.S. west coast to bottom trawling, including a section of shelf rocky reef habitat at Nehalem Bank, Oregon (Figure 1, Hannah et al. 2010). The Nehalem Bank trawl closure included both rocky reef and some mud habitat, creating an opportunity to study how the macroinvertebrate populations inhabiting the trawlable mud habitats would change after the areas were closed to all trawling. This was of interest because the trawl fishery for ocean shrimp (*Pandalus jordani*) is conducted almost exclusively over mud habitat, and little is known about how severely shrimp trawling is impacting the macroinvertebrate populations in the fished areas.

Shortly after the Nehalem Bank area was closed to trawling, the Oregon Department of Fish and Wildlife's Marine Resources Program (MRP) staff conducted a visual survey of four mud habitat sites (Figure 1) with a remotely operated vehicle (ROV, Hannah et al. 2010). Two of the four sites surveyed were within the new closure area (Figure 1, areas 1A and 2A) and two were located east of the closure in areas that continued to be trawled (1B and 2B), primarily, but not exclusively, by shrimp trawl vessels. The purpose of the 2007 survey was to establish baseline data on macroinvertebrate abundance and distribution in both types of sites so that the recovery process from trawl impacts in closed areas, and the evolving condition of sites where trawling continued, could be better understood.

The results from the 2007 ROV survey, relating the observed macroinvertebrate densities to the trawling history of the four sites, were presented in detail Hannah et al. (2010). Briefly, that study showed that densities of some important macroinvertebrate taxa, including sea whips (*Halipterus* spp), the flat mud star (*Luidia foliolata*), and unidentified Asteroidea were lower in the 2 areas that had been more heavily trawled historically and that these areas also had reduced invertebrate diversity. However, the study also found high variability in macroinvertebrate densities between the the northern and southern site pairs (Figure 1), making it difficult to clearly link current abundance levels to just trawl-related impacts.

Sea whips were the dominant structure-forming macroinvertebrates found in these deep mud habitats, and they are very clearly impacted by shrimp trawl groundlines (Hannah et al. 2013). However, the ecosystem effects of these trawl-related impacts are not well understood. Because sea whips are believed to be slow growing and long-lived (Wilson et al. 2002), it may take many decades for protected sites to fully recover from the effects of trawling, and the rate of recovery in the abundance and size composition of sea whips and other macroinvertebrates in these habitats is unknown. Thus, repeated visual surveys of these four sites over time has the potential to improve our understanding of the magnitude of the ecosystem effects of trawling in mud habitats.

The four mud habitat survey sites at Nehalem Bank (Figure 1) were re-surveyed with MRP's ROV in 2013 to determine how macroinvertebrate populations at the sites had changed since 2007. The primary purpose of this report is to document the results from this recent survey and discuss the changes that have been observed over the past 6 years. Because the data generated in the 2007 and 2013 surveys may prove useful for comparison purposes over the next several decades, an additional objective of this report is to document the data from both surveys, by individual transect, so that future statistical comparisons can be made using just the information in this report.

Methods

The field and analytical methods used for the 2007 survey have been documented in Hannah et al. (2010) and will not be repeated in great detail here. The methods employed in collection and analysis of the 2013 Nehalem Bank survey data were generally similar to the 2007 survey, with a few differences.

Field methods

As in the 2007 survey, several visual transects were conducted with the ROV across the four survey sites shown in Figure 1. The number of transects completed in 2007 and 2013 differed, with 5-6 transects completed per site in 2007 and only 4 transects per site completed in 2013 (Figures 1 and 2). In 2007, the ROV utilized a standard definition video camera, but was upgraded to a high-definition camera prior to the 2013 survey. The high-definition camera also had a wider angle of view than the camera used in 2007. The 2007 survey was conducted from a shrimp trawl vessel that lacked precise maneuvering capability, particularly while the ROV was deployed. Due to this limitation, drift transects were completed, resulting in the transect path across each site varying some during the survey (Figure 1). ROV position data was also lost at times during the 2007 survey, resulting in the patchwork pattern of transects shown in Figure 1. The improved maneuvering capability of the vessel used for the 2013 survey, the R/V Pacific Surveyor, allowed the transects to be accurately followed, in a general north to south or south to north direction (Figure 2).

Video analysis

The analysis of video transect data from the 2013 survey followed closely the standardized procedures developed by the Marine Habitat Program for ROV video. Each video transect was reviewed multiple times, each with a different primary focus for the video analyst. On the first pass-through of the video footage, the quality of the video feed was evaluated to identify useable and unusable sections of video for enumerating organisms and other seafloor features. On the second pass-through, the viewable width of the transect was estimated, after each 30 seconds of video, based on the measured screen-width of the paired lasers on the seafloor and the known inter-laser spacing of 10 cm. Additional passes were completed to count habitat features, such as trawl tracks and hagfish burrows, as well as to count and identify macroinvertebrates and then fishes. During the enumeration of macroinvertebrates, sea whip lengths were also estimated as multiples of the inter-laser width. In some cases, the entire sea whip was not viewable on the screen, and was simply assigned a length of 5 inter-laser widths. As in video analysis conducted for the 2007 survey, features, macroinvertebrates and fishes were counted only if they were visible at the "50% line", the vertical midpoint of the viewing screen. Although fishes were counted, no fish count data are presented here, due to concerns that fish may have been avoiding the ROV. This was suspected due to the high frequency with which "mud clouds" were observed, indicative of a fish having recently fled the viewable area.

Although the video review procedures used for the 2013 Nehalem Bank ROV survey were very similar to those used for the 2007 survey, there were some differences worth noting. First, different video analysts reviewed the video from the two surveys, making it difficult to standardize the identification of some features between the two surveys. It was not possible, in particular, to standardize what constituted a "hagfish burrow", so any comparsion of these numbers between the two surveys should be approached with caution. Also, in the 2007 video data analysis, hagfish burrows were estimated based on expansion of 2-minute randomized video subsamples, while for the 2013 video data, they were simply counted. The higher resolution of the video from the 2013 survey, along with some improved taxonomic reference materials, showed that the sea pens identified in Hannah et al. (2010) as the orange sea pen *Ptilosarcus gurneyi*, are actually a white sea pen, most likely *Stylatula elongata*. Sea pen counts for both surveys are reported here simply as family Virgulariidae. Finally, the video analysis conducted on the 2007 survey enumerated macroinvertebrates, fish and seafloor features from all useable segments of the transects, regardless of whether that portion of the transect was within or outside of the square box defining the sampling site (Figure 1). The standardized analysis procedures used for for the 2013 ROV survey included only the useable portions of the transects that were within the defined square sampling site (Figure 2).

Standardization of counts by area viewed

The procedures used to standardize the video count data from the 2007 ROV survey by the area viewed (ha) could not be duplicated with the position data from the 2013 survey. For the 2007 survey data, the area of each belt transect was estimated from the change in the ROV position over time in combination with the periodic (every 30 sec) measurements of the video view width, as detailed above and in Hannah et al. (2010). ROV position data were smoothed with a 9-point moving average before these calculations were made for each 30-second video interval. In the 2013 survey, a discrepancy in the alignment of the hydrophone onboard the survey vessel resulted in a systematic error in the estimated ROV position on the seafloor; a large-scale, low-frequency artifact that could not be effectively removed statistically. The vessel position data was therefore used as a proxy for the ROV position to estimate the distance traveled by the ROV every 30 seconds and, in combination with the estimates of the view width, were used to calculate the total area of seafloor surveyed during each transect.

Shrimp trawling at Nehalem Bank

The four survey sites at Nehalem Bank are areas that have historically been predominantly impacted by trawling for ocean shrimp, not groundfish (Hannah et al. 2010). Accordingly, we updated the information on the history of trawling at the 4 survey sites at Nehalem Bank using shrimp logbook data. It should be noted that shrimp logbook data is not a complete accounting of shrimp trawl effort in these areas as it consists of a large subsample of the available logbooks each year. Also, logbook data only provides the start and end locations of hauls, not the actual path trawled. We utilized the average number of trawl start locations in these four square survey sites for several multi-year periods from 1988 to 2013 to show how shrimp trawling has varied over time. Since subsample rates vary from year to year, this analysis gives only a very approximate and relative measure of how much trawling has occurred historically at the four sites. It should be noted however, that all trawl vessel activity is monitored by the National Marine Fisheries Service mandatory vessel monitoring system (VMS), so any actual trawl fishing within the closed areas, 1A and 2A, is very unlikely to have ocurred since 2006.

Results

The 2013 survey of the 4 sites at Nehalem Bank (Figure 2) was completed in August 2013. The area of the seafloor surveyed for each of the four sites ranged from 0.67 to 0.77 ha (Table 1). This is much less than the area surveyed in 2007 at sites 1A, 1B and 2A, and a little more area than surveyed at site 2B, which was reduced by some loss of ROV position data in 2007 (Table 2).

Analysis of the available shrimp trawl logbook data showed that since 2007 virtually no shrimp trawling has occurred at Nehalem Bank sites 1A and 2A, but that shrimp trawling has continued at sites 1B and 2B (Figure 3). For the 2008-2013 time period, the frequency of shrimp trawling at these two sites has been reduced some from prior historical levels, consistent with an overall drop in fishing effort in the shrimp trawl fishery (Figure 4).

A comparison of the standardized mean density estimates (number/ha) from the 2013 and 2007 surveys shows that the primary structure-forming invertebrates at the Nehalem Bank sites, sea whips, sea pens and unidentified anemones, have fared very differently in the years since 2007. Mean densities of sea whips at all 4 survey sites have increased greatly since 2007 (Tables 3 and 4, Figure 5). All four sites now have sea whip densities higher than were observed at any of the sites in 2007, with the largest increases at the 2 southern sites, one of which has remained open to trawling (2B, Figure 5). Unidentified anemones have increased markedly at the untrawled sites, but show only minor increases in density at the sites that remained open to trawling (Figure 6). In contrast, sea pen densities have not changed in a systematic way in the intervening 6 years at Nehalem Bank, with a reduction in densities at site 2A, and essentially no change at the other 3 sites (Figure 5).

A comparison of sea whip length frequency data between the two surveys (Figures 6 and 7) shows that the increase in sea whip densities is almost exclusively in the 2 smallest size classes of sea whips. This suggests that one or more large sea whip recruitment events has occurred in the 6 years since the 2007 survey.

There are a few other notable differences between the macroinvertebrate densities observed in the 2013 and 2007 surveys at Nehalem Bank. Heart urchins *Brisaster* sp. and squat lobsters (Unidentified Galatheoidea) decreased at most sites between 2007 and 2013 (Tables 3 and 4). In contrast, bobtail squid *Rossia* sp. have become more abundant at all 4 survey sites since 2007 (Tables 3 and 4). Sea urchins (unidentified echinoidea) and basket stars (unidentified Ophiuroidea) were noted at many of the sites in 2007, but were not observed at any of the sites in 2013 (Tables 3 and 4). In contrast, densities of sea cucumbers (unidentified Holothoroidea) showed little change, remaining at very low densities at all sites except site 2A.

Discussion

The data and analysis presented here show that densities of sea whips, the dominant structure-forming macroinvertebrate inhabiting the deep mud habitats at Nehalem Bank, can increase very rapidly under favorable conditions, even with some trawl fishing occurring. However, the sea whip length frequency data suggest that re-establishing an "old growth forest" of sea whips will likely take at least an additional decade, or longer, in areas closed to trawling. This finding is consistent with prior studies of the age and growth of sea whips (Wilson et al. 2002). This will also depend on levels of natural mortality of sea whips which are unknown. Whether such a size structure can also develop over time in areas that remain open to trawling is a question that can perhaps be answered with periodic future ROV surveys at Nehalem Bank. Of course, the sea whip densities and size frequency that ultimately develop in the survey sites that remain open to trawling may also depend on how the level of trawl fishing effort changes in the shrimp fishery, both in amount and spatial distribution.

The large increase in unidentified anemones at the two survey sites that were closed to trawling is surprising, in that these survey sites are predominantly soft mud habitats and most species of anemones are more typically found on hard substrates. It's possible that the increased densities are a sampling artifact from the ROV encountering more small patches of hard substrate at the sites that are closer to the rocky reefs at Nehalem Bank (Figure 2), or that the anemones observed were species that burrow in soft-bottom habitats. Another possibility is that the densities of anemones in these marginal habitats could be very sensitive to even minor disturbance from a minimal amount of trawling. If this is the case, then the large increases at sites 1A and 2A are also indicative of how quickly anemone populations in predominantly mud habitats can increase when these areas are protected from trawling. Conversely, the lack of much consistent change in sea pen densities suggests that they may take much longer to increase in density following the elimination of trawling, or that their populations are primarily limited by factors other than physical trawl impacts. More extensive and repeated visual surveys of areas with different levels of historical trawling will be needed to better clarify these questions.

The Nehalem Bank ROV surveys represent a very modest start towards developing a better understanding of the ecosystem effects of trawl fishing on these deepwater mud habitats. Having even small areas of mud habitat closed to trawling allows the development of a better understanding of the structure and natural variation of these habitats in the absence of physical effects from trawling. Effectively managing the ecosystem effects of trawling requires a level of understanding of the ecology of these habitats and the species that live there that currently does not exist. There are, however, efforts that can provide incremental progress on this complex issue. Visual surveys of areas of mud habitat that are more routinely and heavily trawled can help determine if the eastern sites at Nehalem Bank are representative of the majority of mud habitats in which trawling is continuing, which would improve our understanding of the potential magnitude of trawl impacts in Oregon waters. Also, additional studies that directly evaluate how trawl footrope components generate the physical disturbance of macroinvertebrates, similar to the study by Hannah et al. (2013), can facilitate the development of footrope components that have reduced impacts on seafloor invertebrates.

Acknowledgements

The captain and crew of the research vessel *Pacific Surveyor* provided a sampling platform and assisted with ROV field sampling for the 2013 survey. The captain and crew of the shrimp trawl vessel *Miss Yvonne* provided a sampling platform and assisted with field sampling for the 2007 survey.

References

Hannah, R.W., S.A. Jones, W. Miller, J.S. Knight. 2010. Effects of trawling for ocean shrimp (*Pandalus jordani*) on macroinvertebrate abundance and diversity at four sites near Nehalem Bank, Oregon. Fish. Bull. 108:30-38.

Hannah, R.W., M.J.M. Lomeli and S.A. Jones. 2013. Direct estimation of disturbance rates of benthic macroinvertebrates from contact with standard and modified ocean shrimp (*Pandalus jordani*) trawl footropes. Journal of Shellfish Research 32(2):551-557.

Wilson, M.T., A.H. Andrews, A.L. Brown, and E.E. Cordes. 2002. Axial rod growth and age estimation of the sea pen, *Halipterus willemoesi* Kölliker. Hydrobiologia 471,133-142.

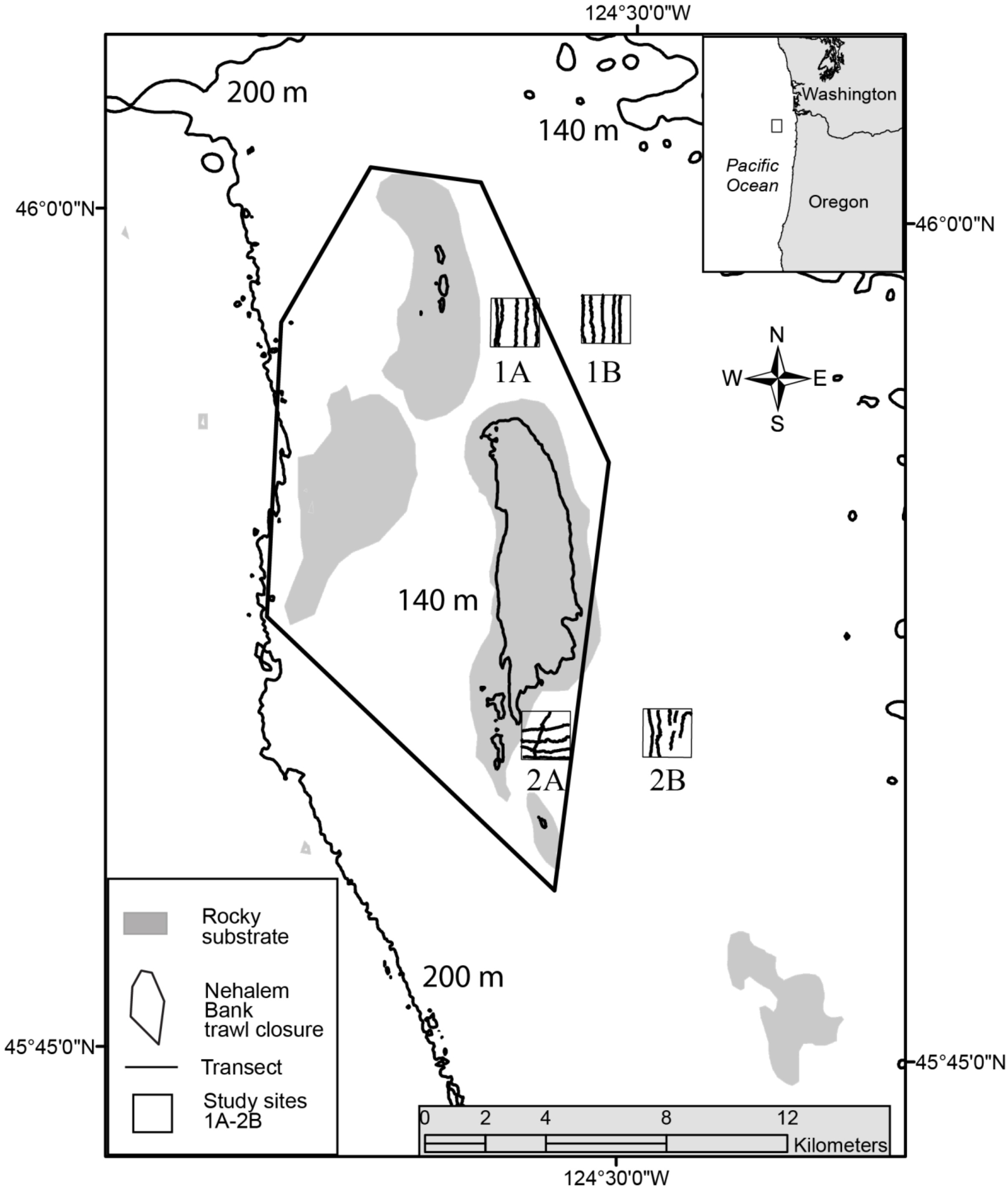

Figure 1. Map of the study area at Nehalem Bank, Oregon, showing the four study sites (1A, 1B, 2A, 2B) and transect paths surveyed with an ROV in 2007.

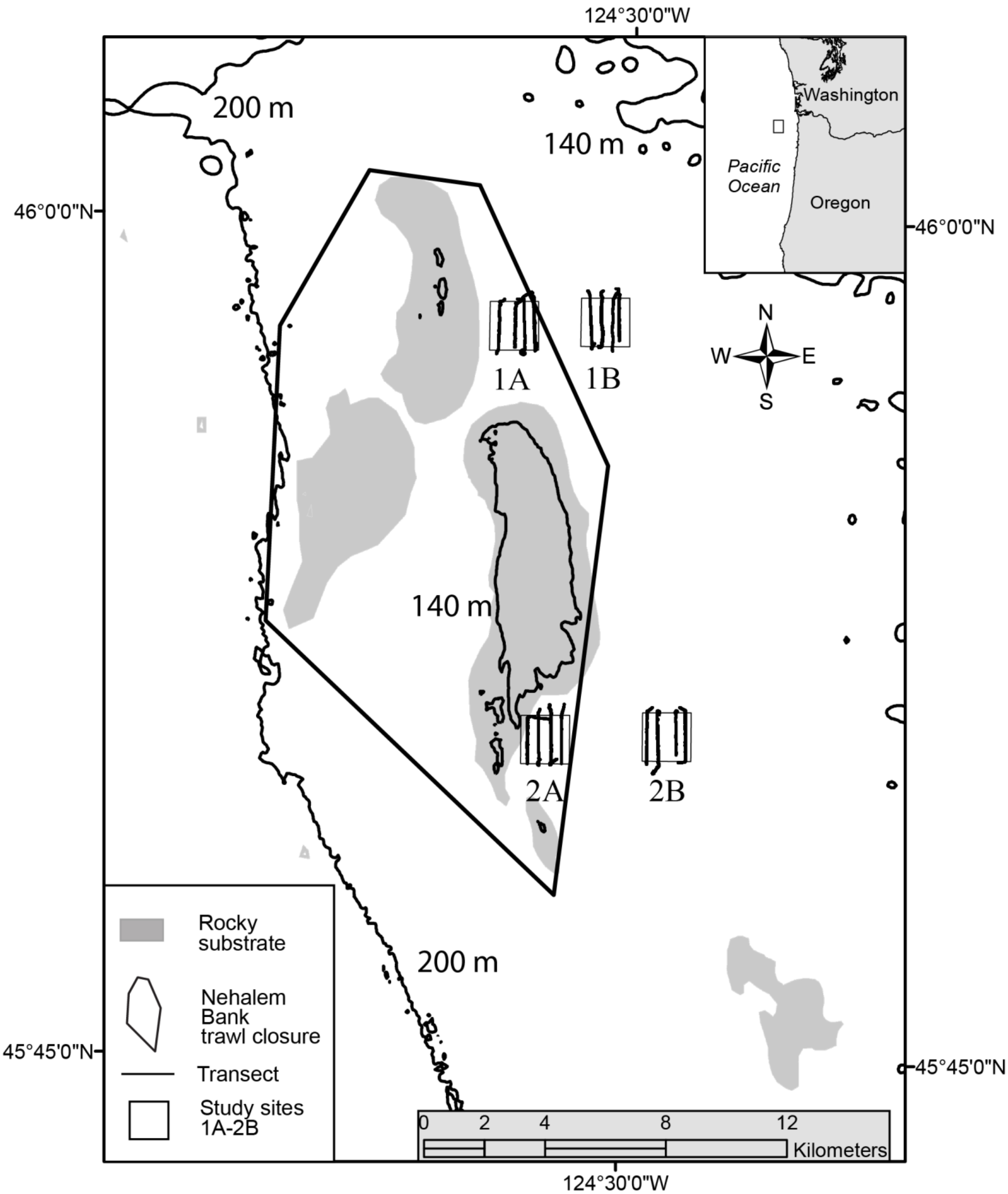

Figure 2. Map of the study area at Nehalem Bank, Oregon, showing the four study sites (1A, 1B, 2A, 2B) and transect paths surveyed with an ROV in 2013.

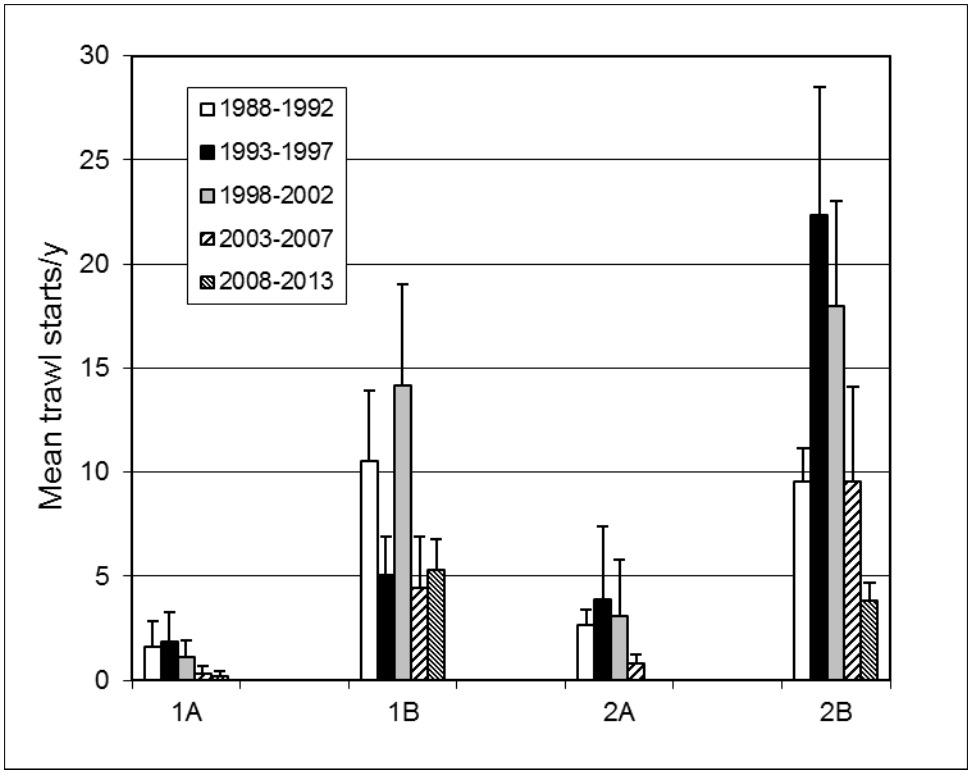

Figure 3. History of shrimp trawling (average number of logbook trawl start locations per year for five different multi-year periods) at the four ROV survey sites at Nehalem Bank, Oregon.

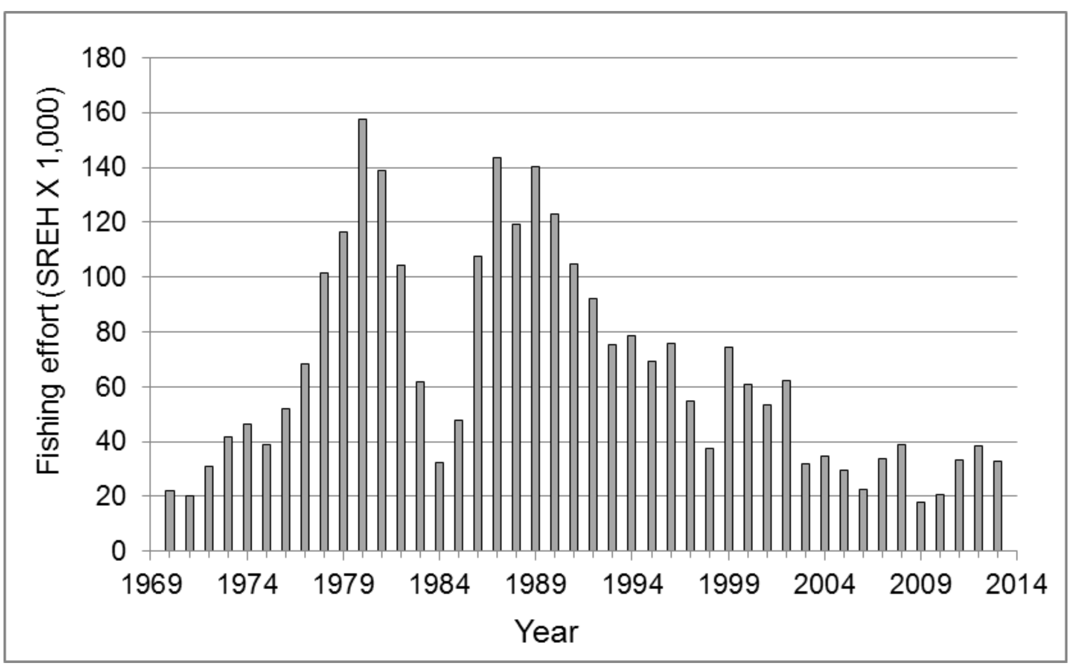

Figure 4. Time series of fishing effort (single-rig-equivalent hours X 1,000) in the Oregon trawl fishery for ocean shrimp, 1970-2013.

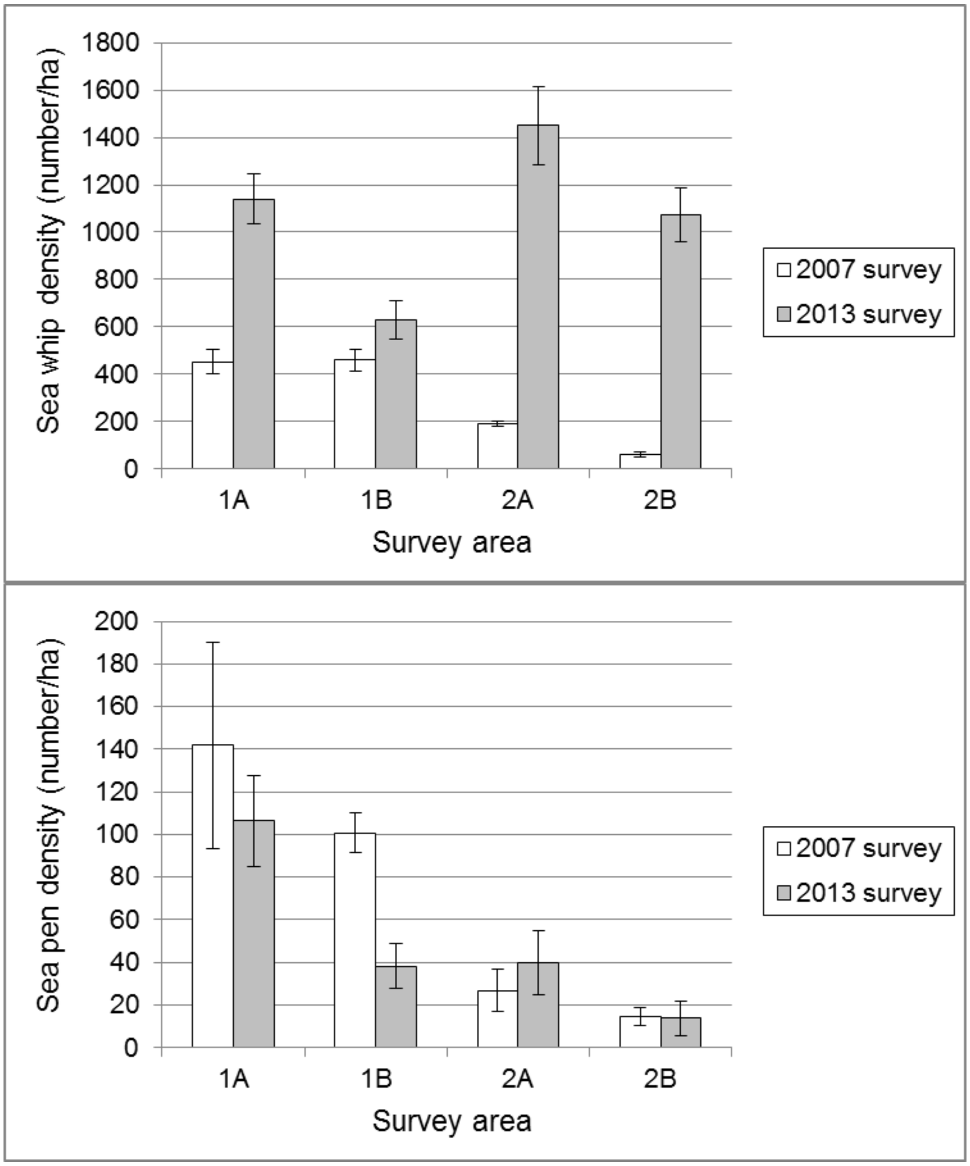

Figure 5. Comparison of mean densities (± standard error) of sea whips (*Halipterus* spp.) and sea pens (Virgulariidae) estimated from the 2007 and 2013 ROV surveys at Nehalem Bank, Oregon, by sampling site (Figures 1 and 2).

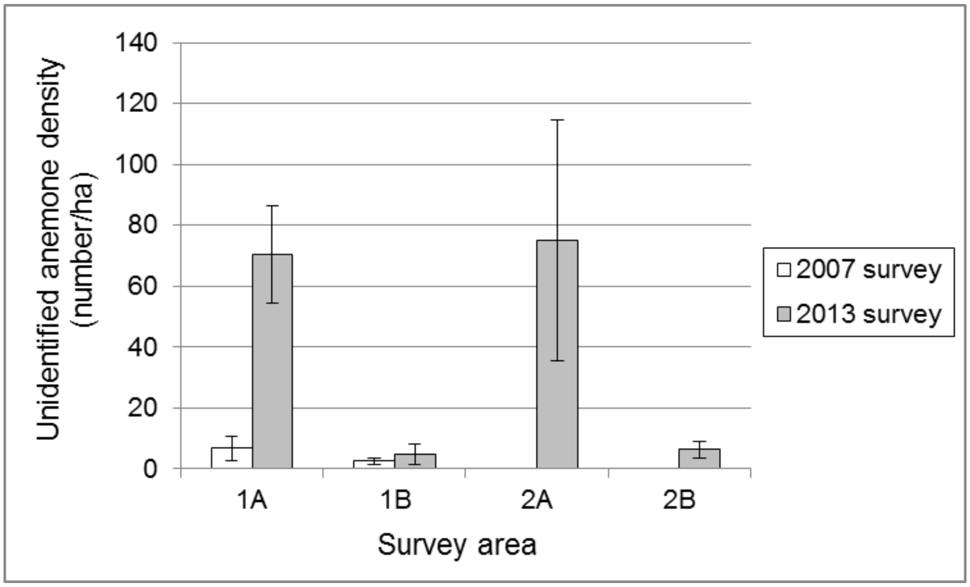

Figure 6. Comparison of mean densities (± standard error) of unidentified anemones estimated from the 2007 and 2013 ROV surveys at Nehalem Bank, Oregon, by sampling site (Figures 1 and 2).

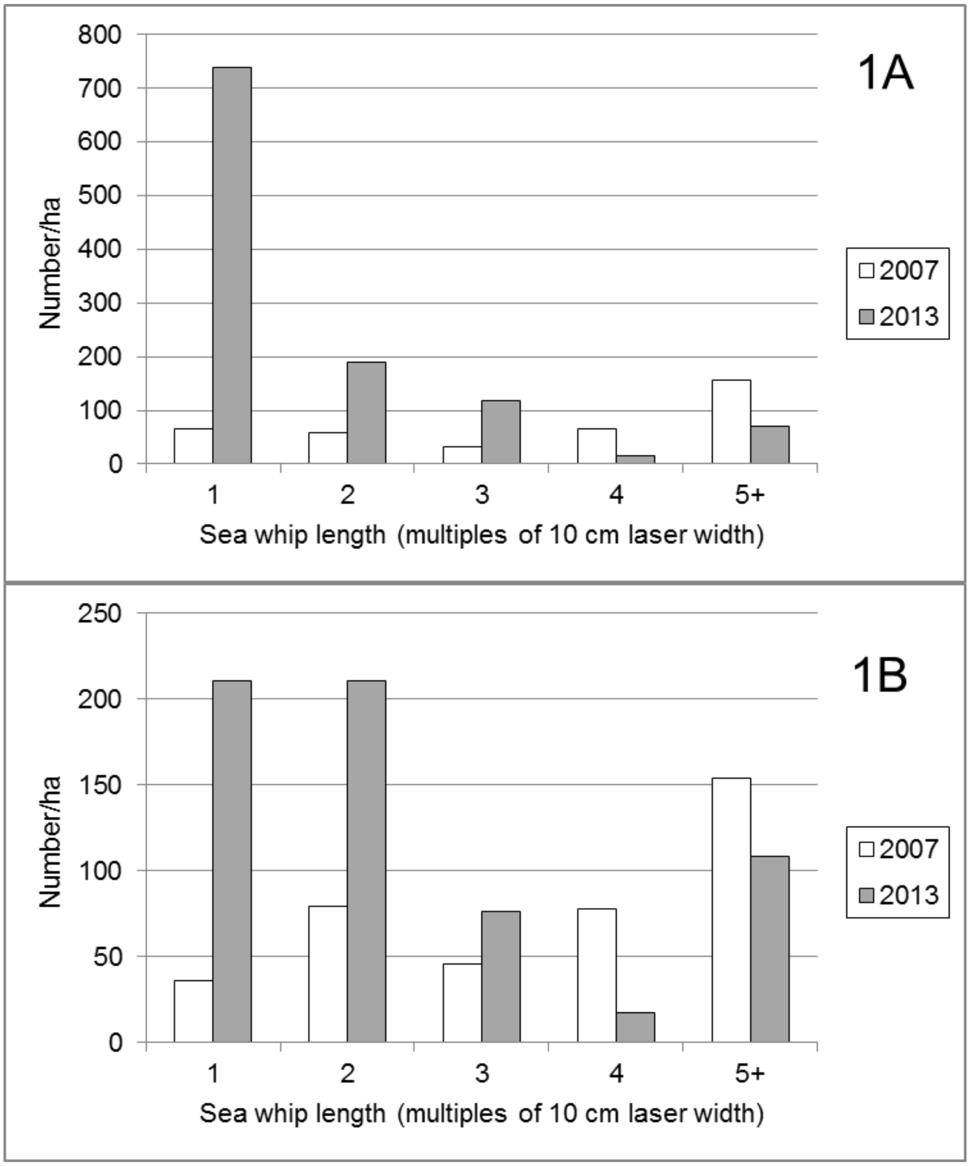

Figure 7. Comparison of sea whip length frequency data from 2007 and 2013 ROV surveys at the northern pair of sites (1A and 1B, Figures 1 and 2) at Nehalem Bank, Oregon. Data are number/ha by multiples of the 10 cm inter-laser width.

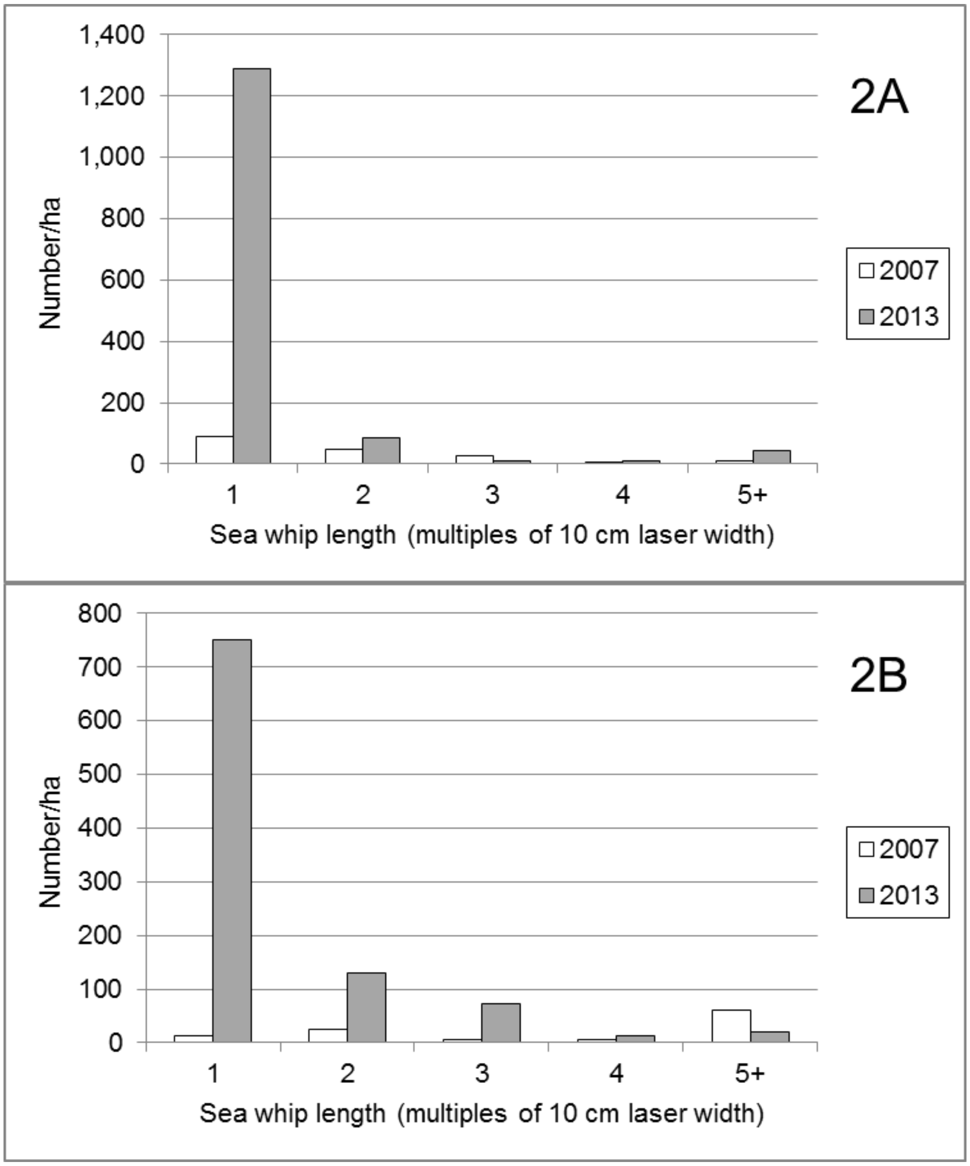

Figure 8. Comparison of sea whip length frequency data from 2007 and 2013 ROV surveys at the southern pair of sites (2A and 2B, Figures 1 and 2) at Nehalem Bank, Oregon. Data are number/ha by multiples of the 10 cm inter-laser width.

Table 1. Transect length (m) and area surveyed (ha), by sampling site and transect number (Figure 1, see text) for mud habitat areas surveyed with a remotely operated vehicle in August, 2013.

Site	Metric	Replicate				
		1	2	3	4	Total
1A						
	Transect identifier	313	321	332	333	
	Length (m)	1,118.1	1,449.0	1,174.1	1,502.6	5,243.8
	Area surveyed (ha)	0.1674	0.2072	0.1871	0.2092	0.7709
1B						
	Transect identifier	411	421	441	442	
	Length (m)	1,138.4	2,108.0	1,438.9	1,212.6	5,898.0
	Area surveyed (ha)	0.1883	0.1390	0.2020	0.1633	0.6927
2A						
	Transect identifier	541	543	544	545	
	Length (m)	1,124.8	1,263.6	1,466.5	1,541.4	5,396.4
	Area surveyed (ha)	0.1459	0.1828	0.2010	0.1916	0.7212
2B						
	Transect identifier	731	732	733	734	
	Length (m)	1,374.6	1,068.0	1,325.4	1,182.5	4,950.5
	Area surveyed (ha)	0.2085	0.1350	0.1744	0.1542	0.6720

Table 2. Transect length (m) and area surveyed (ha), by sampling site and transect number (Figure 1, see text) for mud habitat areas surveyed with a remotely operated vehicle in June, 2007.

Site	Metric	Replicate						
		1	2	3	4	5	6	Total
1A								
	Length (m)	1,742.4	1,460.6	1,971.7	2,266.3	1,806.3		9,247.4
	Area surveyed (ha)	0.2781	0.2480	0.3379	0.3569	0.2938		1.5146
1B								
	Length (m)	1,947.4	1,894.9	1,569.5	1,941.3	1,947.2		9,300.2
	Area surveyed (ha)	0.2348	0.2467	0.2264	0.2673	0.2590		1.2342
2A								
	Length (m)	1,923.9	1,782.4	2,199.7	1,925.7	1,470.1		9,301.8
	Area surveyed (ha)	0.2507	0.2467	0.2610	0.2325	0.1732		1.1639
2B								
	Length (m)	1,117.1	556.8	731.3	865.9	2,133.2	1,779.6	6,066.8
	Area surveyed (ha)	0.1209	0.0538	0.0915	0.0833	0.1606	0.2467	0.6359

Table 3. Mean densities (number/ha) and standard error (SE, nm = not meaningful) of epibenthic macroinvertebrates (Pandalid shrimp excluded) from the 2013 ROV survey of 4 mud habitat sites with different histories of trawling off the northern Oregon coast (Figure 2).

Taxon	Density (number/ha)							
	1A		1B		2A		2B	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Halipterus sp. (sea whips)	1,138.8	105.0	629.0	79.4	1,449.2	163.8	1,072.6	115.7
Virgulariidae (sea pens)	106.4	21.5	38.3	10.4	39.8	15.1	13.7	8.2
Stylasterias forreri (fish-eating star)	27.8	8.8	0.0	nm	29.5	11.4	4.7	1.7
Luidia foliolata (flat mud star)	9.1	2.5	2.8	1.6	17.2	4.0	5.2	3.4
Unidentified Asteroidea (sea stars)	6.7	6.7	0.0	nm	3.0	1.8	0.0	nm
Brisaster sp. (heart urchins)	26.5	6.5	45.0	12.4	33.4	6.3	41.6	11.6
Cancer magister (Dungeness crab)	6.6	2.7	6.1	2.5	2.7	1.5	3.1	1.8
Unidentified Ophiuroidea (basket stars)	0.0	nm	0.0	nm	0.0	nm	0.0	nm
Unidentified Galatheoidea (squat lobsters)	0.0	nm	1.8	1.8	0.0	nm	0.0	nm
Rossia sp. (bobtail squid)	17.8	4.4	12.4	5.1	14.2	2.3	21.0	5.9
Unidentified Octopododae	0.0	nm	1.3	1.3	0.0	nm	0.0	nm
Unidentified anemone	70.4	15.9	4.8	3.4	75.0	39.6	6.3	2.7
Unidentified corals (Hydrocoralia)	0.0	nm	0.0	nm	0.0	nm	0.0	nm
Unidentified Echinoidea (sea urchins)	0.0	nm	0.0	nm	0.0	nm	0.0	nm
Unidentified Holothoroidea (sea cucumbers)	0.0	nm	1.8	1.8	10.4	3.7	3.8	3.8
Unidentified invertebrates	2.5	1.5	0.000	nm	0.0	nm	0.0	nm

Table 4. Mean densities (number/ha) and standard error (SE, nm = not meaningful) of epibenthic macroinvertebrates (Pandalid shrimp excluded) from the 2007 ROV surveys of 4 mud habitat sites with different histories of trawling off the northern Oregon coast (Hannah et al. 2010, Figure 1).

Taxon	Density (number/ha)							
	1A		1B		2A		2B	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Halipterus sp. (sea whips)	452.9	51.2	459.5	46.9	188.7	10.7	60.4	11.8
Virgulariidae (sea pens)	141.8	48.6	100.8	9.2	26.9	9.7	14.5	4.1
Stylasterias forreri (fish-eating star)	21.1	3.4	28.0	6.7	19.7	3.9	28.0	7.4
Luidia foliolata (flat mud star)	28.8	4.1	9.7	1.9	27.0	3.5	7.8	2.8
Unidentified Asteroidea (sea stars)	3.3	1.0	4.2	1.9	6.8	0.8	2.0	2.0
Brisaster sp. (heart urchins)	103.6	42.9	44.8	7.1	91.9	14.2	96.4	14.9
Cancer magister (Dungeness crab)	2.9	1.4	2.5	1.0	8.9	3.7	4.5	3.1
Unidentified Ophiuroidea (basket stars)	7.9	2.9	4.9	1.6	0.0	nm	0.0	nm
Unidentified Galatheoidea (squat lobsters)	2.0	0.9	0.8	0.8	91.4	11.2	4.5	3.1
Rossia sp. (bobtail squid)	2.4	1.2	3.2	1.9	3.8	2.0	2.0	2.0
Unidentified Octopododae	0.0	nm	0.0	nm	0.0	nm	0.7	0.7
Unidentified anemone	6.7	4.0	2.5	1.0	0.0	nm	0.0	nm
Unidentified corals (Hydrocoralia)	1.4	1.4	0.0	nm	0.9	0.9	0.0	nm
Unidentified Echinoidea (sea urchins)	1.4	1.4	0.0	nm	23.0	12.7	2.0	2.0
Unidentified Holothoroidea (sea cucumbers)	0.6	0.6	0.0	nm	11.8	1.9	0.0	nm
Unidentified invertebrates	2.0	0.9	0.9	0.9	6.4	2.7	2.9	1.9

Appendix table 1. Counts of benthic macroinvertebrates (Pandalid shrimp excluded), and other seafloor features, by transect, at seafloor sampling site 1A (see text) surveyed with a remotely operated vehicle in June, 2007.

Taxon	Transect number					
	1	2	3	4	5	Total[1]
Invertebrates						
Halipterus sp. (sea whips)	143	114	132	111	173	673
Virgulariidae (sea pens)	70	62	36	19	14	201
Stylasterias forreri (fish-eating star)	6	6	6	4	9	31
Luidia foliolata (flat mud star)	6	8	10	7	12	43
Unidentified Asteroidea (sea stars)	1	1	0	2	1	5
Brisaster sp. (heart urchins)	16	8	17	45	74	160
Cancer magister (Dungeness crab)	1	1	0	0	2	4
Unidentified Ophiuroidea (basket stars)	4	3	0	1	3	11
Unidentified Galatheoidea (squat lobsters)	1	0	1	0	1	3
Rossia sp. (bobtail squid)	0	0	2	1	1	4
Unidentified Octopododae	0	0	0	0	0	0
Unidentified anemone	2	0	2	0	6	10
Unidentified corals (Hydrocoralia)	0	0	0	0	2	2
Unidentified Echinoidea (sea urchins)	0	0	0	0	2	2
Unidentified Holothoroidea (sea cucumbers)	0	0	0	1	0	1
Unidentified invertebrates	0	1	0	1	1	3
Seafloor features						
Trawl tracks	4	0	0	0	1	5
Hagfish burrows[2]	6.8	10.4	7.6	9.5	9.3	3,074

[1] Hagfish total is expanded estimate for all transects [2]Hagfish burrows/minute of video, from randomly selected 2 min subsamples

Appendix table 2. Counts of benthic macroinvertebrates (Pandalid shrimp excluded), and other seafloor features, by transect, at seafloor sampling site 1B (see text) surveyed with a remotely operated vehicle in June, 2007.

Taxon	Transect number					
	1	2	3	4	5	Total[1]
Invertebrates						
Halipterus sp. (sea whips)	134	77	121	129	103	564
Virgulariidae (sea pens)	23	27	20	35	20	125
Stylasterias forreri (fish-eating star)	5	7	6	14	3	35
Luidia foliolata (flat mud star)	3	2	2	4	1	12
Unidentified Asteroidea (sea stars)	2	2	1	0	0	5
Brisaster sp. (heart urchins)	13	5	12	10	15	55
Cancer magister (Dungeness crab)	1	1	1	0	0	3
Unidentified Ophiuroidea (basket stars)	0	2	2	1	1	6
Unidentified Galatheoidea (squat lobsters)	0	0	0	0	1	1
Rossia sp. (bobtail squid)	0	2	0	0	2	4
Unidentified Octopododae	0	0	0	0	0	0
Unidentified anemone	1	1	1	0	0	3
Unidentified corals (Hydrocoralia)	0	0	0	0	0	0
Unidentified Echinoidea (sea urchins)	0	0	0	0	0	0
Unidentified Holothoroidea (sea cucumbers)	0	0	0	0	0	0
Unidentified invertebrates	0	0	1	0	0	1
Seafloor features						
Trawl tracks	9	12	9	42	8	80
Hagfish burrows[2]	10.6	17.7	11.2	16.3	11.8	4,466

[1] Hagfish burrow total is expanded estimate for all transects [2]Hagfish burrows/minute of video, from randomly selected 2 min subsamples

Appendix table 3. Counts of benthic macroinvertebrates (Pandalid shrimp excluded), and other seafloor features, by transect, at seafloor sampling site 2A (see text) surveyed with a remotely operated vehicle in June, 2007.

Taxon	Transect number					
	1	2	3	4	5	Total[1]
Invertebrates						
Halipterus sp. (sea whips)	46	54	45	39	36	220
Virgulariidae (sea pens)	10	5	1	3	10	29
Stylasterias forreri (fish-eating star)	4	3	5	4	6	22
Luidia foliolata (flat mud star)	5	10	7	6	4	32
Unidentified Asteroidea (sea stars)	1	2	2	2	1	8
Brisaster sp. (heart urchins)	23	36	22	18	11	110
Cancer magister (Dungeness crab)	1	2	3	5	0	11
Unidentified Ophiuroidea (basket stars)	0	0	0	0	0	0
Unidentified Galatheoidea (squat lobsters)	31	26	19	22	11	109
Rossia sp. (bobtail squid)	1	1	3	0	0	5
Unidentified Octopododae	0	0	0	0	0	0
Unidentified anemone	0	0	0	0	0	0
Unidentified corals (Hydrocoralia)	0	0	0	1	0	1
Unidentified Echinoidea (sea urchins)	1	7	19	3	0	30
Unidentified Holothoroidea (sea cucumbers)	2	2	5	3	2	14
Unidentified invertebrates	4	2	1	1	0	8
Seafloor features						
Trawl tracks	0	4	0	2	0	6
Hagfish burrows[2]	2.6	9.0	5.7	6.5	4.2	2,018

[1] Hagfish burrow total is expanded estimate for all transects [2]Hagfish burrows/minute of video, from randomly selected 2 min subsamples

Appendix table 4. Counts of benthic macroinvertebrates (Pandalid shrimp excluded), and other seafloor features, by transect, at seafloor sampling site 2B (see text) surveyed with a remotely operated vehicle in June, 2007.

Taxon	Transect number						
	1	2	3	4	5	6	Total[1]
Invertebrates							
Halipterus sp. (sea whips)	5	1	7	8	13	12	46
Virgulariidae (sea pens)	2	0	1	1	5	4	13
Stylasterias forreri (fish-eating star)	2	2	0	2	8	10	24
Luidia foliolata (flat mud star)	2	0	0	1	1	3	7
Unidentified Asteroidea (sea stars)	0	0	0	0	0	3	3
Brisaster sp. (heart urchins)	8	4	8	14	15	22	71
Cancer magister (Dungeness crab)	1	1	0	0	0	0	2
Unidentified Ophiuroidea (basket stars)	0	0	0	0	0	0	0
Unidentified Galatheoidea (squat lobsters)	0	0	0	0	3	2	5
Rossia sp. (bobtail squid)	0	0	0	1	0	0	1
Unidentified Octopododae	0	0	0	0	0	1	1
Unidentified anemone	0	0	0	0	0	0	0
Unidentified corals (Hydrocoralia)	0	0	0	0	0	0	0
Unidentified Echinoidea (sea urchins)	0	0	0	1	0	0	1
Unidentified Holothoroidea (sea cucumbers)	0	0	0	0	0	0	0
Unidentified invertebrates	0	0	1	0	1	0	2
Seafloor features							
Trawl tracks	2	0	5	9	6	17	39
Hagfish burrows[2]	7.5	3.3	7.0	6.5	4.9	6.6	1,627

[1] Hagfish burrow total is expanded estimate for all transects [2]Hagfish burrows/minute of video, from randomly selected 2 min subsamples

Appendix table 5. Counts of benthic macroinvertebrates (Pandalid shrimp excluded), by transect, at seafloor sampling site 1A (see text) surveyed with a remotely operated vehicle in August, 2013.

Taxon	Transect number				
	313	321	332	333	Total
Invertebrates					
Halipterus sp. (sea whips)	190	176	251	257	874
Virgulariidae (sea pens)	22	31	10	19	82
Stylasterias forreri (fish-eating star)	4	4	10	3	21
Luidia foliolata (flat mud star)	1	1	3	2	7
Unidentified Asteroidea (sea stars)	0	0	5	0	5
Brisaster sp. (heart urchins)	2	9	5	5	21
Cancer magister (Dungeness crab)	2	2	0	1	5
Unidentified Ophiuroidea (basket stars)	0	0	0	0	0
Unidentified Galatheoidea (squat lobsters)	0	0	0	0	0
Rossia sp. (bobtail squid)	3	5	1	5	9
Unidentified Octopododae	0	0	0	0	0
Unidentified anemone	14	7	20	12	41
Unidentified corals (Hydrocoralia)	0	0	0	0	0
Unidentified Echinoidea (sea urchins)	0	0	0	0	0
Unidentified Holothoroidea (sea cucumbers)	0	0	0	0	0
Unidentified invertebrates	0	0	1	1	2
Seafloor features					
Trawl tracks	0	2	2	5	9
Hagfish burrows	1,680	1,486	2,426	1,731	7,323

Appendix table 6. Counts of benthic macroinvertebrates (Pandalid shrimp excluded), and other seafloor features, by transect, at seafloor sampling site 1B (see text) surveyed with a remotely operated vehicle in August, 2013.

Taxon	Transect number				
	411	421	441	442	Total
Invertebrates					
Halipterus sp. (sea whips)	82	107	151	92	432
Virgulariidae (sea pens)	3	9	6	7	25
Stylasterias forreri (fish-eating star)	0	0	0	0	0
Luidia foliolata (flat mud star)	0	0	1	1	2
Unidentified Asteroidea (sea stars)	0	0	0	0	0
Brisaster sp. (heart urchins)	2	8	9	11	30
Cancer magister (Dungeness crab)	0	1	1	2	4
Unidentified Ophiuroidea (basket stars)	0	0	0	0	0
Unidentified Galatheoidea (squat lobsters)	0	1	0	0	1
Rossia sp. (bobtail squid)	2	2	5	0	9
Unidentified Octopododae	1	0	0	0	1
Unidentified anemone	0	2	1	0	3
Unidentified corals (Hydrocoralia)	0	0	0	0	0
Unidentified Echinoidea (sea urchins)	0	0	0	0	0
Unidentified Holothoroidea (sea cucumbers)	0	1	0	0	1
Unidentified invertebrates	0	0	0	0	0
Seafloor features					
Trawl tracks	20	33	36	31	120
Hagfish burrows	1,678	1,712	1,553	1,647	6,590

Appendix table 7. Counts of benthic macroinvertebrates (Pandalid shrimp excluded), and other seafloor features, by transect, at seafloor sampling site 2A (see text) surveyed with a remotely operated vehicle in August, 2013.

Taxon	Transect number				
	541	543	544	545	Total
Invertebrates					
Halipterus sp. (sea whips)	258	185	282	309	1,034
Virgulariidae (sea pens)	12	2	7	6	27
Stylasterias forreri (fish-eating star)	9	2	6	3	20
Luidia foliolata (flat mud star)	4	2	4	2	12
Unidentified Asteroidea (sea stars)	1	0	1	0	2
Brisaster sp. (heart urchins)	6	3	9	6	24
Cancer magister (Dungeness crab)	0	1	0	1	2
Unidentified Ophiuroidea (basket stars)	0	0	0	0	0
Unidentified Galatheoidea (squat lobsters)	0	0	0	0	0
Rossia sp. (bobtail squid)	3	2	3	2	10
Unidentified Octopododae	0	0	0	0	0
Unidentified anemone	28	3	9	9	49
Unidentified corals (Hydrocoralia)	0	0	0	0	0
Unidentified Echinoidea (sea urchins)	0	0	0	0	0
Unidentified Holothoroidea (sea cucumbers)	0	3	3	2	8
Unidentified invertebrates	0	0	0	0	0
Seafloor features					
Trawl tracks	0	1	1	1	3
Hagfish burrows	1,130	917	1,694	1,600	5,341

Appendix table 8. Counts of benthic macroinvertebrates (Pandalid shrimp excluded), and other seafloor features, by transect, at seafloor sampling site 2B (see text) surveyed with a remotely operated vehicle in August, 2013.

Taxon	Transect number				
	731	732	733	734	Total
Invertebrates					
Halipterus sp. (sea whips)	183	122	182	175	662
Virgulariidae (sea pens)	1	5	0	2	8
Stylasterias forreri (fish-eating star)	1	0	1	1	3
Luidia foliolata (flat mud star)	3	0	0	1	4
Unidentified Asteroidea (sea stars)	0	0	0	0	0
Brisaster sp. (heart urchins)	3	7	9	5	24
Cancer magister (Dungeness crab)	1	1	0	0	2
Unidentified Ophiuroidea (basket stars)	0	0	0	0	0
Unidentified Galatheoidea (squat lobsters)	0	0	0	0	0
Rossia sp. (bobtail squid)	1	4	4	3	12
Unidentified Octopododae	0	0	0	0	0
Unidentified anemone	1	1	0	2	4
Unidentified corals (Hydrocoralia)	0	0	0	0	0
Unidentified Echinoidea (sea urchins)	0	0	0	0	0
Unidentified Holothoroidea (sea cucumbers)	0	0	2	0	2
Unidentified invertebrates	0	0	0	0	0
Seafloor features					
Trawl tracks	0	0	1	3	4
Hagfish burrows	1,002	987	1,073	689	3,751

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