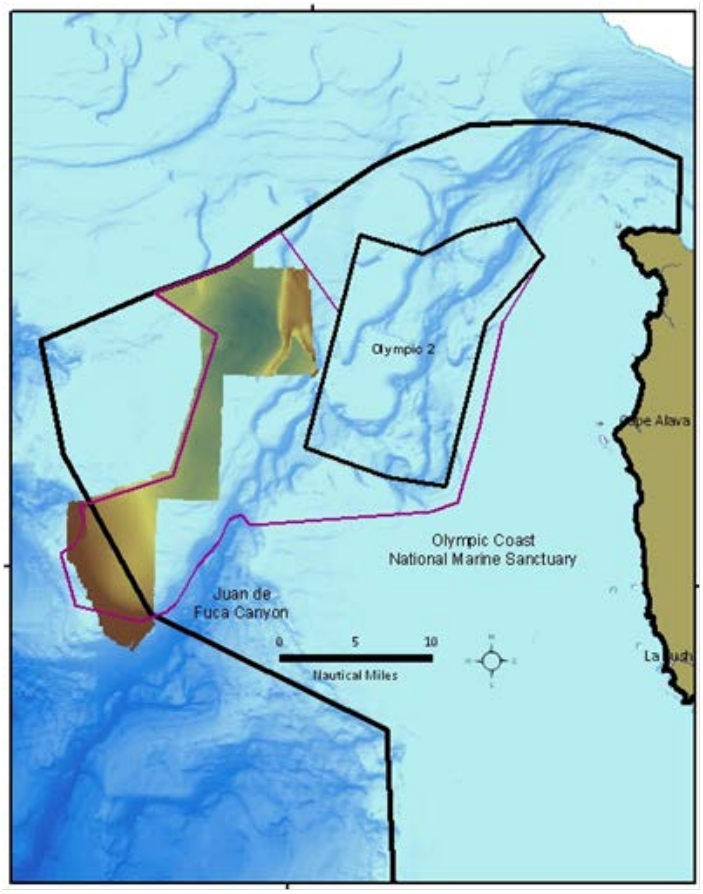
Multibeam Mapping of Potential Deep-Sea Coral Habitats Near Olympic 2 EFH
Final Report, 2014

Derived from: Preliminary Report Prepared for NOAA
Coral Reef Conservation Program, 2011
Ground Truthing and Habitat Classification, 2014



Nancy Wright, Chris Romsos

*NOAA, Olympic Coast National Marine Sanctuary
**OSU, College of Ocean and Atmospheric Sciences

Note: The original HMPR-128-2011-02 report was entitled *Multibeam Mapping of Potential Deep-Sea Coral Habitats Around Olympic 2 EFH*. It was submitted to the Pacific Fisheries Management Council (PFMC) and Coral Reef Conservation Program (CRCP) in December 2011 as partial documentation of substrate conditions in a geographic area proposed for expansion of Essential Fish Habitat. Ground truthing could not be conducted until 2012. This updated 2014 report includes ground truthing data and habitat classification for the surveyed area. It is the final report for this survey.

Acknowledgements: Dr. Chris Goldfinger, Morgan Erhardt, staff from the Oregon State University College of Oceanic and Atmospheric Sciences, crew from the R/V *Pacific Storm*, 2011. George Galasso, Rick Fletcher, crew of the R/V *Tatoosh* 2012.

Citation: Wright, N. and C. Romsos. 2014. Multibeam Mapping of Potential Deep-Sea Coral Habitats around Olympic 2 EFH. Updated with Ground Truthing and Habitat Classification. Report to NOAA Coral Reef Conservation Program. Olympic Coast National Marine Sanctuary Survey HMPR-128-2011-02. pp. 18

Background

Olympic 2 is a 211 mi^2 groundfish conservation area adjacent to the Juan de Fuca Canyon designated in 2006 using an essential fish habitat (EFH) model (PFMC 2005) that combined bathymetry, sidescan sonar, substrate samples, and seismic reflection as geological determinants in the designation process. Although Olympic Coast National Marine Sanctuary (OCNMS) had surveyed the Olympic 2 area at the time of its designation, seafloor data from OCNMS surveys were not used in the designation process. OCNMS began collecting sidescan and multibeam sonar data in 2001 using both ROV and drop-camera video to groundtruth seafloor habitats. By 2009, more than 770 mi^2 of seafloor habitat around Olympic 2 had been surveyed, groundtruthed, classified and published as part of the OCNMS mapping initiative (Fig. 1). Twenty-one benthic mapping surveys over eight years were conducted by OCNMS staff and collaborators to create the scientific foundation from which OCNMS prioritizes and conducts its coral and sponge community research and monitoring programs. OCNMS coral and sponge community investigations are targeted at sites where hard substrate has been identified.

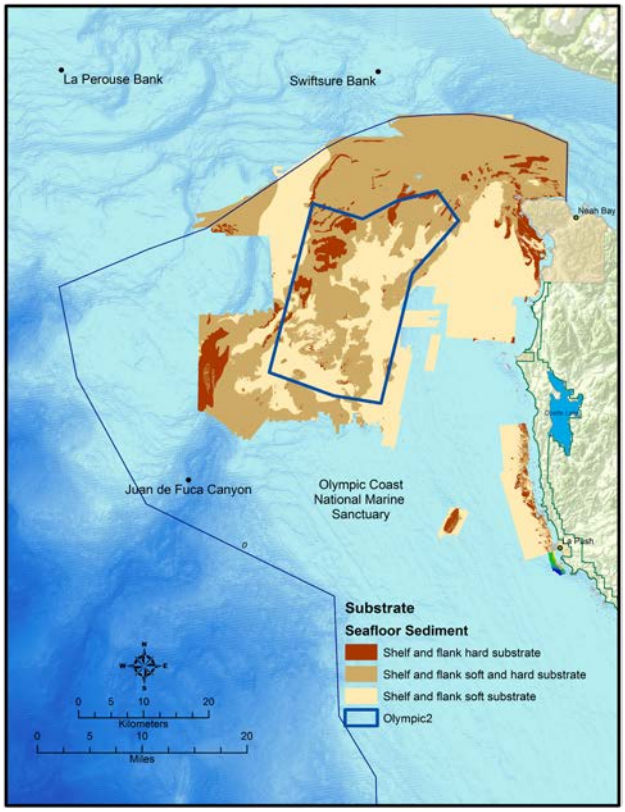


Figure 1: Classified seafloor substrate map from OCNMS surveys conducted between 2001 and 2009 near Olympic 2 groundfish conservation area.

Since 2009 OCNMS has collected an additional 160 mi^2 of multibeam data used in seafloor habitat classification, providing bathymetric and backscatter data and the ability to produce geomorphic derivatives, such as slope, aspect, curvature, and rugosity values. These data continue to inform the management of research, monitoring and resource protection programs for OCNMS on the Washington outer coast.

Coral Reef Conservation Program (CRCP) Mapping Initiative

NOAA's Coral Reef Conservation Program (CRCP) developed a three-year exploration and research priority plan for the West Coast that commenced in 2010 (NOAA, 2011). In Olympic Coast National Marine Sanctuary, the research has focused in and around Olympic 2 where coral and sponge communities have been located since ROV surveys of mapped seafloor began in 2006.

In 2007, the Pacific Fishery Management Council began consideration of a boundary expansion for Olympic 2. Part of the proposed expansion area had never been acoustically mapped nor surveyed visually in a comprehensive manner to quantitatively assess the characteristics of the seafloor or the abundance, distribution, and condition of deep-sea coral and sponge habitats. Because high-resolution seafloor habitat data was lacking for the proposed expansion area, CRCP funded an acoustic survey to fill the data gaps regarding the presence or absence and spatial distribution of hard substrate in the proposed EFH expansion area. The area of the proposed Olympic 2 expansion area that was not acoustically mapped included 174 mi^2 of shallow (primarily 100-200 meter deep), lightly sloped (0-5°) continental shelf which lies between the northwestern flank of the Juan de Fuca Canyon and Nitinat Canyon, west of Olympic 2 (Fig. 2). The purpose of this survey was to provide seafloor maps to support a subsequent ROV survey which would investigate the presence of coral and sponge communities on hard substrate in this unmapped area.

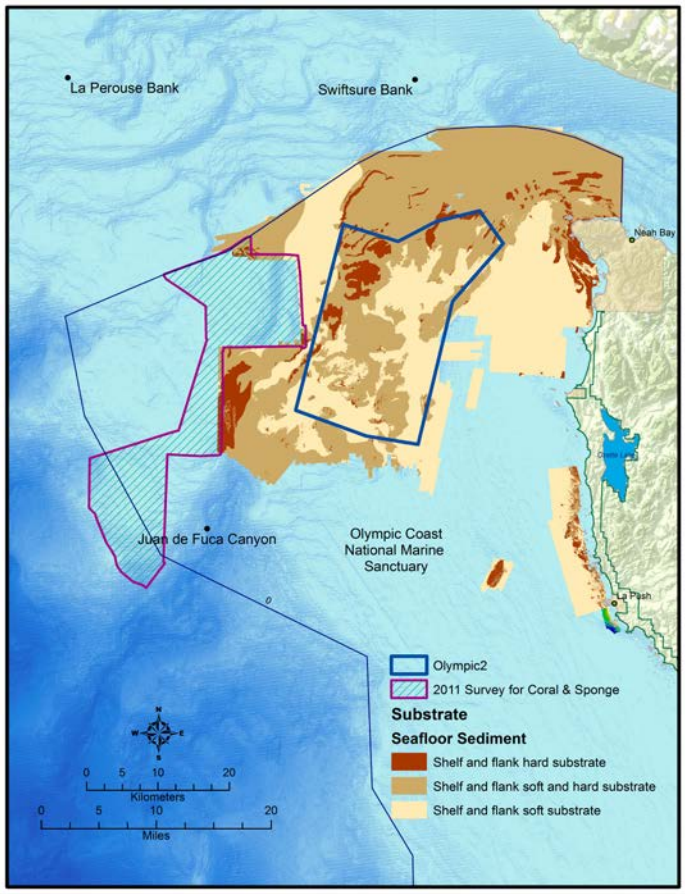


Figure 2: Extent of proposed Olympic 2 EFH boundary expansion (purple outline), with unmapped seafloor in green hatched area.

2011 OSU/OCNMS Multibeam Mapping Survey

From July 13 to July 23, 2011, the Oregon State University (OSU) Seafloor Mapping Lab and Olympic Coast National Marine Sanctuary conducted a multibeam sonar survey of 174 mi^2 in the unmapped area identified as a data gap by CRCP and the Pacific Fisheries Management Council's EFH Review Committee considering expansion of Olympic 2 boundaries. Mapping the substrate of this area with multibeam sonar was a basic first step towards confirming the likelihood of deep-sea coral habitat (e.g., hard substrate) presence in the area. Map products from acoustic surveys would assist with identification of areas to be visually surveyed later by ROV.

The objectives of the multibeam survey were:

- Conduct multibeam mapping of areas west and northwest of the Juan de Fuca Canyon;
- Produce high resolution maps of bathymetry and backscatter;
- Characterize key features of surveyed substrates, such as complexity, hardness, rugosity, and slope; and
- Identify high-confidence targets for visual surveys of deep-sea coral and sponges in areas adjacent to the Juan de Fuca Canyon.

The survey area lies on the continental shelf 0-3 miles north and west of Juan de Fuca Canyon, 4-11 miles east and south of Nitinat Canyon, and 20 miles south of La Perouse and Swiftsure Banks. It lies in the western-most extent of the proposed Olympic 2 EFH expansion area. The elongated shape of the survey was determined by previously mapped areas on the east side, by the outer boundary of the proposed EFH expansion area on the west and southwest boundaries, and by the U.S. border on the north. For convenience, we partition the survey into three sections; north, central and south. Each section showed unique variations in depth, slope and sediment profiles (Fig. 3).

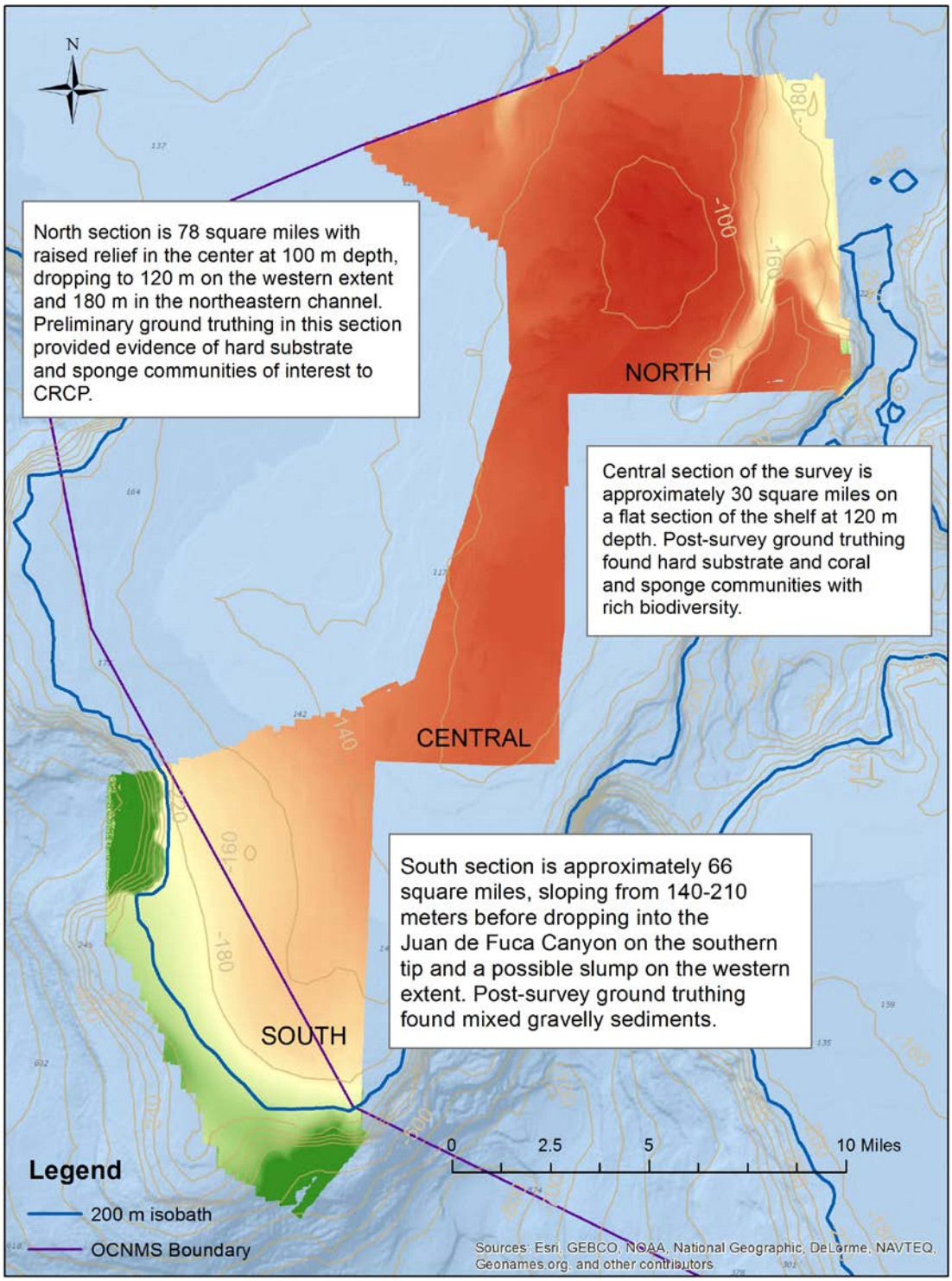


Figure 3: The objective of the survey was to fill gaps in knowledge about hard substrate and coral/sponge community habitats along the western edge of existing seabed data. The elongated shape of the survey was determined by existing surveys and EFH expansion possibilities that were proposed to the Pacific Fisheries Management Council in 2007.

2011 Multibeam Data Collection on the R/V *Pacific Storm*

The multibeam survey was conducted on the R/V *Pacific Storm* (Fig. 4), an 84' steel hull converted fishing vessel. Navigation was collected with a Navcom Starfire 3050 subscription satellite-based carrier wave differential GPS, with ~15 cm horizontal accuracy. Motion control was maintained via an Applanix Pos MV inertial/GPS attitude system. Sonar data were collected with a Reson 8101ER MBES, acquired with Hypack/Hysweep software in .hsx format, and processed at 8 meter pixel resolution using CARIS software. The backscatter was processed in Fledermaus FMGeocoder Toolbox Ver. 7.3 software. The final seafloor classification and map products were created in ArcMap 10. Groundtruth samples were collected using a Shipek grab sampler at 19 strategic sites to verify the acoustic data. Additional groundtruth samples from USGS SEABED Surveys, R/V *Tatoosh* sidescan surveys, and fiber optic monitoring surveys in the area were added to support the sediment samples collected during the *Pacific Storm* survey.

Figure 4: The R/V *Pacific Storm*

2012 Ground Truthing Survey on the R/V *Tatoosh*

During the 2011 *Pacific Storm* survey, the crew took opportunistic sediment grab samples with a Shipek style sampler on the uplifted areas of the north section. Several of the physical samples brought up living sponges attached to siltstone and mudstone. For that reason, a preliminary seafloor characterization was developed for the north section of the survey and presented to the Coral Reef Conservation Program as data that are relevant to the possible expansion of Essential Fish Habitat near Olympic 2 in the December 2011 report (Wright and Romsos 2011). However, those ground truthing data points were insufficient for habitat classification of the entire survey area. In July 2012 the crew of the R/V *Tatoosh* collected 40 additional sediment samples and several hundred seafloor photos in the north, central, and south sections of the survey to validate the sonar imagery, to determine seafloor texture, and to provide a complete habitat classification.

OCNMS has developed a ground truthing method that uses a Smith-MacIntyre sediment grab with an attached, self-contained underwater video camera (Fig. 5). This combination provides a hands-on sample of seafloor sediment with a video of the area around the sample to provide visual context that complements the grain size analysis. From each Smith-MacIntyre grab we save 500-1000 g seafloor material, dry it in the laboratory, and sieve it to levels of coarseness from cobble to clay based on the Wentworth grain size scale (Wentworth 1922). This provides a textural foundation for habitat characterization.

Figure 5: A spring-loaded Smith-MacIntyre grab with a self-contained underwater camera mounted on the grab's frame.

Ground truthing sites were selected using the backscatter imagery from the original 2011 multibeam survey (Fig. 6). Backscatter generally provides good imagery for seafloor 'induration' or hardness, an important measure of potential habitat for corals and sponges. An emphasis was placed on getting seabed samples and photos from areas presumed to be hard substrate such as the uplifted anticline of the north section where sponges had been seen during the 2011 survey. A second area of importance was the western extent of the central section which appeared to have hard substrate. Some areas of the survey were more challenging to ground truth because of the depth (>200 m) and the distance from shore (>50 miles) which were limiting factors for the ground truthing survey. This included the channel extending south from Swiftsure Bank and the area outside the sanctuary deeper than 180 meters. Ideally, a grid of replicate sites would have been surveyed, but sea state, weather, and time limited the number of samples that could be collected in each of the benthic habitat types.

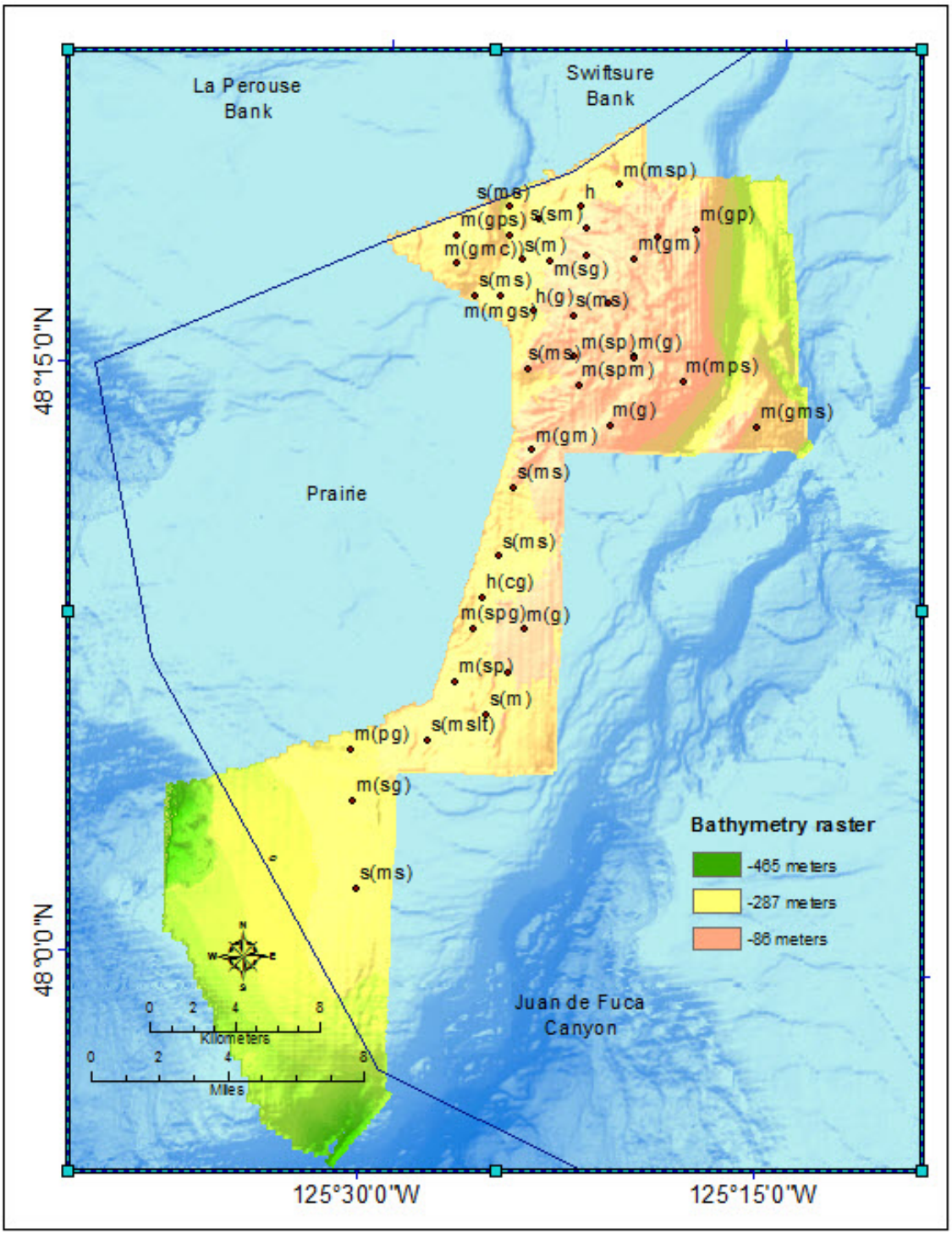


Figure 6: Substrate types were determined at each groundtruthing site by sieving and weighing the sediments and analyzing the associated photography. The substrate-type codes are taken from the Greene et al. classification scheme. Outside the parenthesis h= hard substrate; s=soft substrate (sand or mud); m=mixed hard/soft substrate (cobble or gravel in a sand/mud base). Inside the parenthesis: m=mud; p=pebble; s=sand; g=gravel; c=cobble. Sediments are listed in order of their predominance in the soil sample.

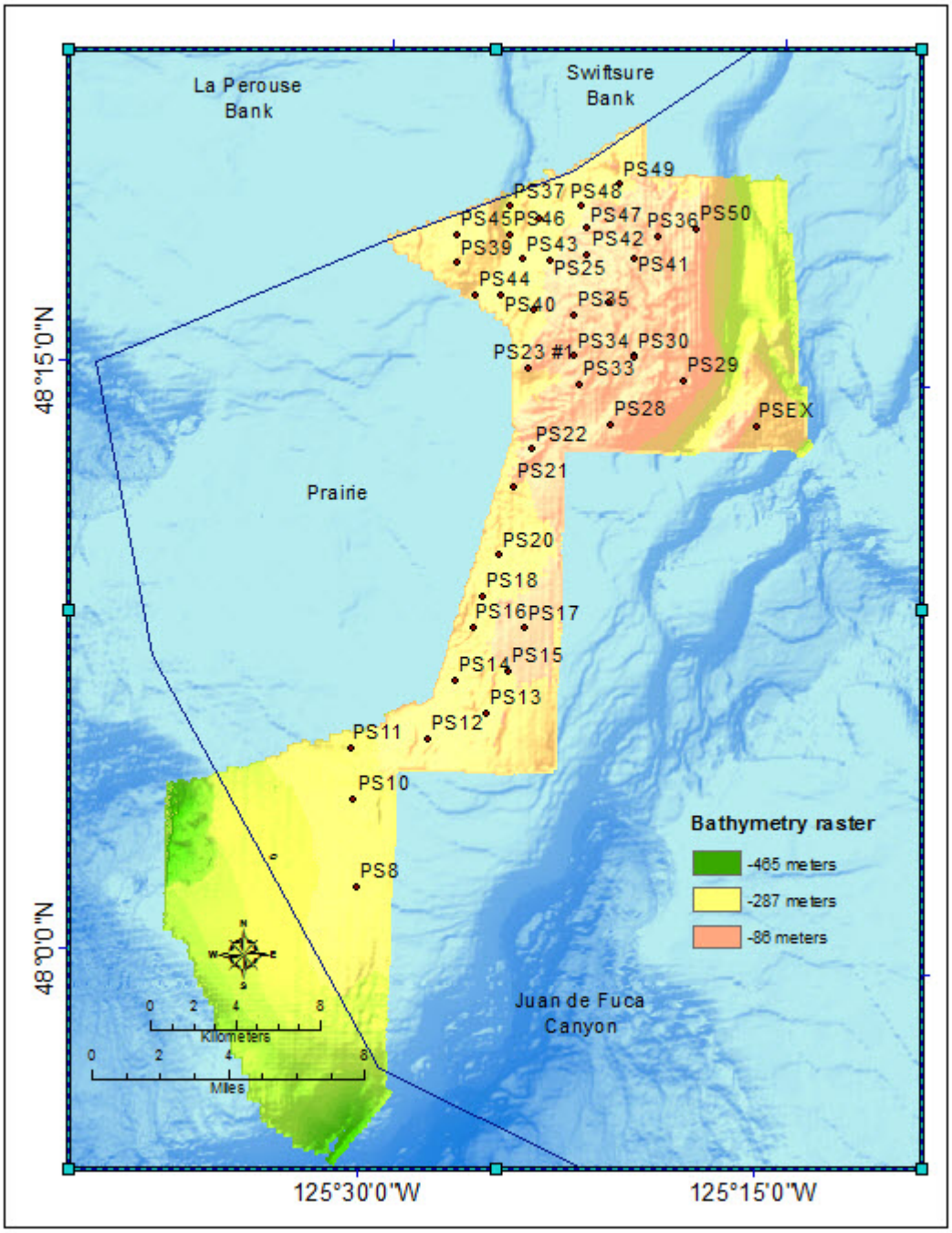


Figure 7: Groundtruthing site numbers.

Table 1: Ground truth samples are collected at sea and returned to the lab for drying, sieving and weighing to determine the sediment composition.

Site Number	Date	Depth in Meters	Latitude	Longitude	Percent Cobble	Percent Very Coarse Gravel	Percent Coarse Gravel	Percent Coarse Gravel	Percent Pebble	Percent Very Coarse Sand	Percent Sand	Percent Mud or Silt	Seabed Type
PS10	8/22/2012	152	48.06747	-125.5094		0.124	0.092	0.204	0.204	0.268	0.049	0.058	m(sg)
PS11	8/22/2012	145	48.08892	-125.5124				0.276	0.346	0.227	0.068	0.083	m(pg)
PS12	8/22/2012	129	48.09422	-125.4634			0.104	0.222	0.272	0.268	0.081	0.053	s(mslt)
PS13	8/21/2012	118	48.10583	-125.4269							0.002	0.998	s(m)
PS14	8/21/2012	124	48.11903	-125.4474									m(sp)
PS15	8/21/2012	114	48.12407	-125.4139			0.037	0.208	0.203	0.34	0.122	0.089	m(spg)
PS16	8/22/2012	116	48.14213	-125.4369		0.306	0.079	0.136	0.135	0.165	0.054	0.124	m(spg)
PS17	8/22/2012	112	48.14227	-125.4049		0.129	0.324	0.22	0.116	0.135	0.033	0.043	m(g)
PS18	8/21/2012	121	48.15547	-125.4313	0.772	0.228							h(cg)
PS20	8/21/2012	122	48.17298	-125.422						0.013	0.065	0.922	s(ms)
PS21	8/21/2012	116	48.20258	-125.4138				0.008	0.012	0.136	0.152	0.692	s(ms)
PS22	8/21/2012	113	48.21847	-125.4032		0.236	0.075	0.036	0.042	0.305	0.113	0.193	m(gm)
PS23	8/8/2012	115	48.25323	-125.4077			0.079	0.007	0.013	0.054	0.122	0.726	s(ms)
PS24	8/8/2012	115	48.27757	-125.4048		0.926	0.054	0.019	0.001				h(g)
PS25	8/7/2012	116	48.29873	-125.3953		0.107	0.034	0.017	0.093	0.563	0.09	0.096	m(sg)
PS28	8/21/2012	104	48.22993	-125.3543		0.129	0.324	0.22	0.116	0.135	0.033	0.043	m(g)
PS29	8/8/2012	106	48.2496	-125.3087			0.062	0.098	0.181	0.318	0.052	0.288	m(mps)
PS30	8/8/2012	101	48.25937	-125.34		0.091		0.031	0.299	0.46	0.073	0.046	m(sp)
PS30b	8/2/2012	101	48.25902	-125.3403									m(g)
PS32	8/2/2012	100	48.2816	-125.3575		0.047	0.048	0.038	0.042	0.415	0.19	0.221	s(sm)
PS33	8/8/2012	105	48.24677	-125.3746			0.01	0.044	0.13	0.561	0.147	0.108	m(spm)
PS34	8/8/2012	110	48.2586	-125.3781		0.077	0.152	0.157	0.057	0.107	0.161	0.288	m(msg)
PS35	8/8/2012	107	48.2763	-125.3795				0.04	0.073	0.19	0.13	0.566	s(ms)
PS36	8/7/2012	104	48.31065	-125.3277			0.236	0.238	0.135	0.116	0.089	0.186	m(gps)
PS37	8/8/2012	155	48.32143	-125.4219							0.109	0.891	s(ms)
PS38	8/7/2012	128	48.3171	-125.4038			0.055	0.025	0.017	0.054	0.094	0.755	s(ms)
PS39	8/8/2012	127	48.29685	-125.4546								0	m(gmc))
PS40	8/8/2012	125	48.28387	-125.4259		0.047	0.121	0.071	0.072	0.095	0.109	0.485	m(mgs)
PS41	8/2/2012	100	48.30092	-125.3417		0.164	0.295	0.095	0.037	0.052	0.115	0.241	m(gm)
PS42	8/7/2012	108	48.30183	-125.3718			0.059	0.1	0.125	0.279	0.201	0.236	m(smp)
PS43	8/8/2012	128	48.29918	-125.4134							0.07	0.93	s(m)
PS44	8/8/2012	134	48.28327	-125.4422						0.003	0.101	0.896	s(ms)
PS45	8/8/2012	129	48.309	-125.4551			0.236	0.238	0.135	0.116	0.089	0.186	m(gps)
PS46	8/8/2012	140	48.3093	-125.4218			0.236	0.238	0.135	0.116	0.089	0.186	m(gps)
PS47	8/7/2012	110	48.31335	-125.3729								1	s(sm)
PS48	8/7/2012	117	48.32242	-125.3762	1								h
PS49	8/7/2012	116	48.33235	-125.3527				0.054	0.154	0.121	0.039	0.632	m(msp)
PS50	8/7/2012	111	48.31422	-125.303		0.175	0.097	0.286	0.211	0.112	0.051	0.068	m(gp)
PS8	8/22/2012	159	48.03007	-125.5054						0.027	0.008	0.966	s(ms)

Northern Section: Bathymetry

The northern section is centered at 48°16'30"N / 125°20'20"W. The most striking feature of the northern section is a central outcrop of ~35 m bathymetric relief (Fig. 8). This broad, low relief area, northwest of Juan de Fuca Canyon is an uplifted anticlinal structure trending NE-SW, with strike ridges of exposed hard substrate that wrap around the nose of a NE plunging anticline, creating a pattern of hard ridges with 3-5 m relief. The active anticline appears to control the SW trend of the Juan de Fuca Canyon which is 150-170 m deep adjacent to the uplifted bank. The unique features of the uplift and the deeply incised adjacent canyon were reasons to focus ground truthing effort in the north.

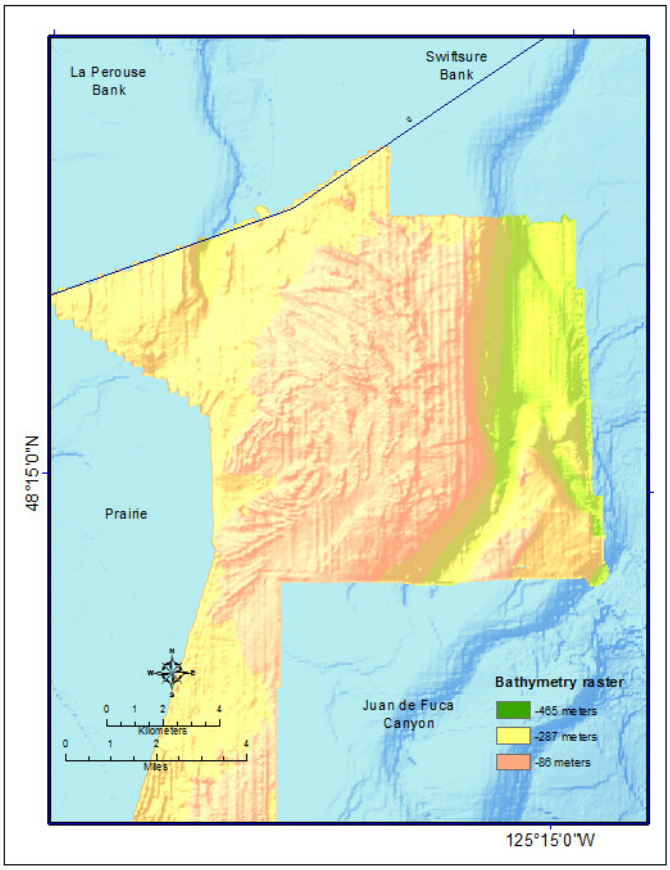


Figure 8: Bathymetry from the north section showed a unique uplifted anticline, a deeply incised canyon extending from Swiftsure Bank and a second smaller canyon extending from La Perouse Bank.

North Section: Backscatter

The multibeam backscatter for the northern section (Fig. 9) indicates hard or compacted substrate mixed with gravel beds, semi-lithified sediments, and coarse to fine sand. The uplifted hard ridges were sampled opportunistically during the survey; grab samples recovered consolidated siltstones and mudstones with attached living sponges. In 2011 additional samples from USGS and OCNMS were added for ground truthing, showing that on the backscatter mosaic, the relatively light areas correspond to narrow ridges in the bathymetry. Overlaid on this bedrock are thin deposits of glacial outwash, rounded gravels, coarse sands, and shell hash, which fill the narrow gullies between the bedrock ridges. This overlay material comprises the bright areas on the backscatter imagery. These deposits are also formed into several terminal moraines or glacial push ridges draped over the bedrock framework of exposed siltstone. Therefore the gravels are likely glacial deposits and not of local origin. The initial findings were reported in Wright and Romsos (2011). Additional ground truthing in 2012 revealed that

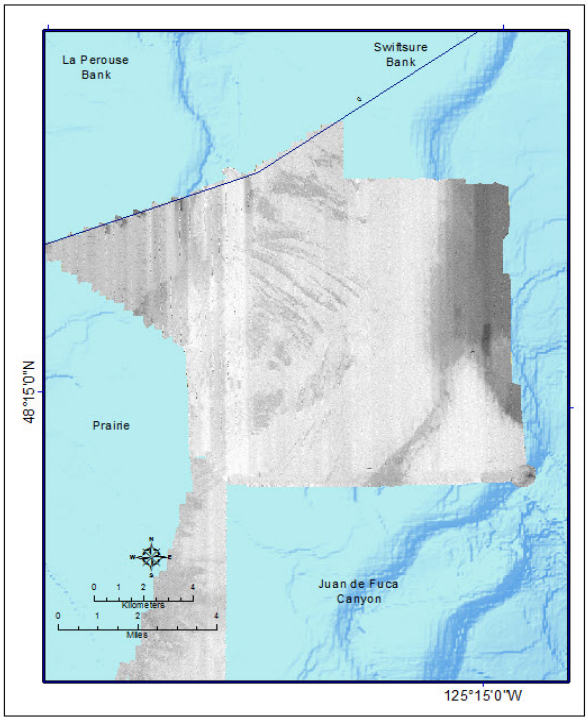


Figure 9: North section backscatter reveals the circular pattern of the uplifted hard substrate, comprised of a mudstone formation where sponge was located during a random sediment grab.

both the mudstone and the mixed sand and gravel overlay are benthic habitats rich with biodiversity that includes corals, sponges, bivalves, worms, stars, and a suite of other invertebrates.

Central Section: Bathymetry

Partial evidence of another uplifted anticlinal structure is seen along the western extent of the central section of the survey (Fig. 10). A pattern similar to the northern uplift, with hard ridges of 3-5 m relief, is apparent; however the western continuation of the structure is unmapped and therefore undetermined. The uplift lies directly along the 120 m isobath. No opportunistic sediment grabs were conducted in the central section during the 2011 survey, however 11 sediment samples and 61 video images were taken during the 2012 ground truthing survey in order to build the benthic habitat classification. The video reveals boulders covered with sponges and other sessile invertebrates. With the exception of the low relief uplift and a small portion of the southwest corner, the entirety of the central section lies on a shelf plateau at 120 m, showing little variation in depth or slope.

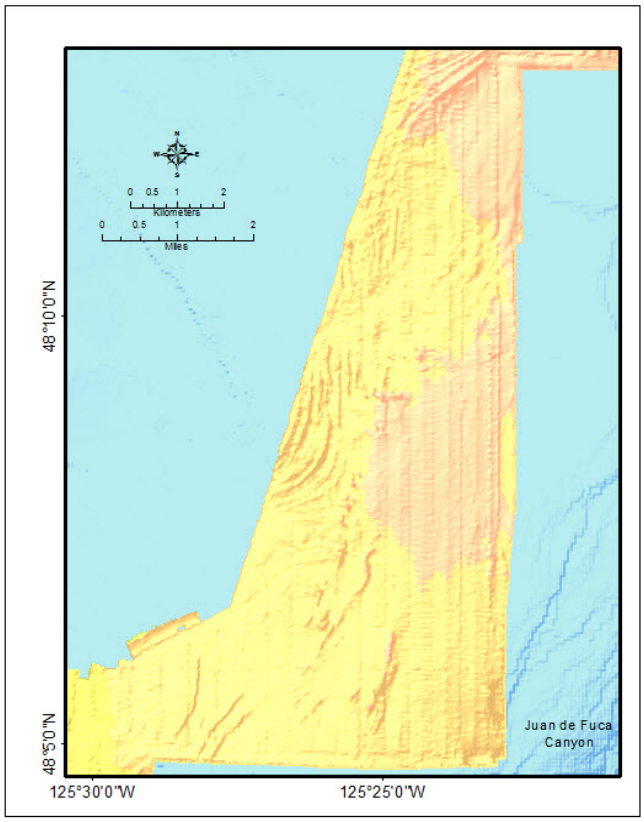


Figure 10: Central section bathymetry

Central Section: Backscatter

Backscatter from the central section (Fig. 11) reveals that hard substrate is the predominate feature along the western survey boundary. The extent of hard substrate is not apparent in the low relief bathymetry. Sediment grabs and underwater video showed hard substrate in the area of brighter reflectance. Ground truthing included photos of large boulders covered with silt, sand, and sessile invertebrates. Occasionally there were larger rock outcrops. The darker reflectance in the backscatter is a substrate of cobble and gravel in a sand/mud base, rich with fish, benthic invertebrates, small corals and sponges.

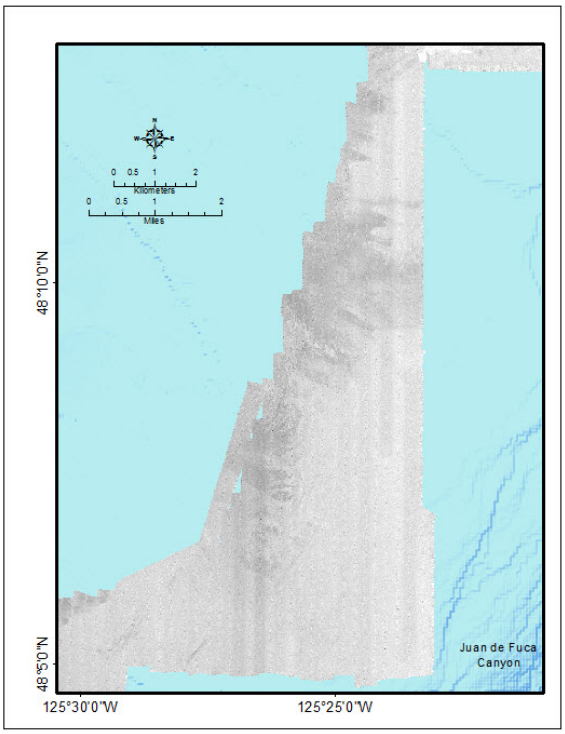


Figure 11: Central section backscatter shows the extent of hard substrate (darker area) along the western side of the survey.

South Section: Bathymetry

A relatively flat, minimally sloping area of the south section lies on the shelf up to the 200 m isobath and exhibits little structural variation (Fig. 12) based on the bathymetry. Evidence of a possible slump is seen on the northwestern extent where the shelf drops from 200 to 400 meters. The survey boundary on the south is the Juan de Fuca Canyon where evidence of steep canyon walls can be seen. The entire southwestern extent of this survey section is outside OCNMS and off the continental shelf.

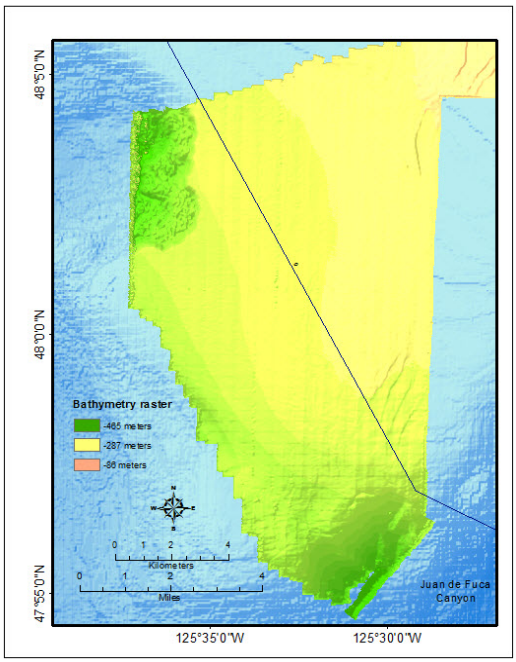


Figure 12: South section bathymetry

South Section: Backscatter

Backscatter from the south section (Fig. 13) shows little variability in substrate — the near uniformity in darker colors reflecting the mixed combination of pebbles, gravel, sand, and mud. Brighter areas to the NW and S are a result of angular response from the

multibeam as the survey captured depth variations along the canyon edge. Ground truthing in the south section provides evidence of fine scale variation in substrate characteristics such as changes in grain size ratios.

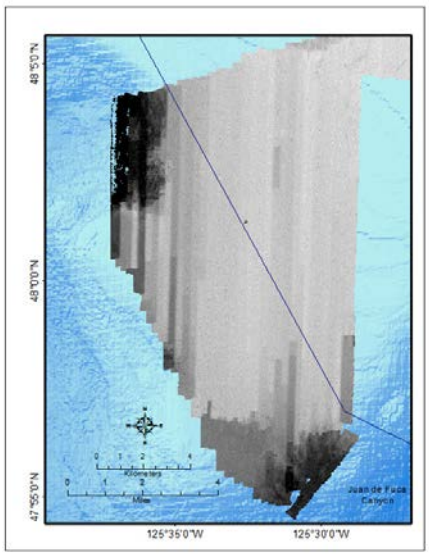


Figure 13: South section backscatter. Light color shows deep area on canyon walls. Dark area shows mixed gravels, sand, and mud. Striping is a result of survey data collection methods.

Habitat Classification

OCNMS uses a marine classification scheme by Greene *et al*. (1999) that structures seafloor habitat information at mega-, meso-, and micro- spatial scales and includes bathymetry, induration, seafloor slope, seafloor complexity, and presence of benthic biology in a geospatial context. A variety of sensors and data collection tools are employed to meet the specifications of each data scale. Megahabitats — 10s of kilometers in size — are 'mapped' by the multibeam sonar products of bathymetry and backscatter. Meso-, macro-, and microhabitats — meters to kilometers in size — are best characterized by a combination of remote sensors and localized ground truthing tools such as sediment grabs & cores, rock samples, and seafloor video & still imagery. For this survey, visual interpretation of backscatter was used to identify areas on the seafloor with similar textural patterns or acoustic themes using a process described by Fonseca (2009). Ground truth sites were selected from those themes, and hand-digitized polygons identifying unique seafloor sediment categories generally followed the boundaries of the backscatter acoustic themes.

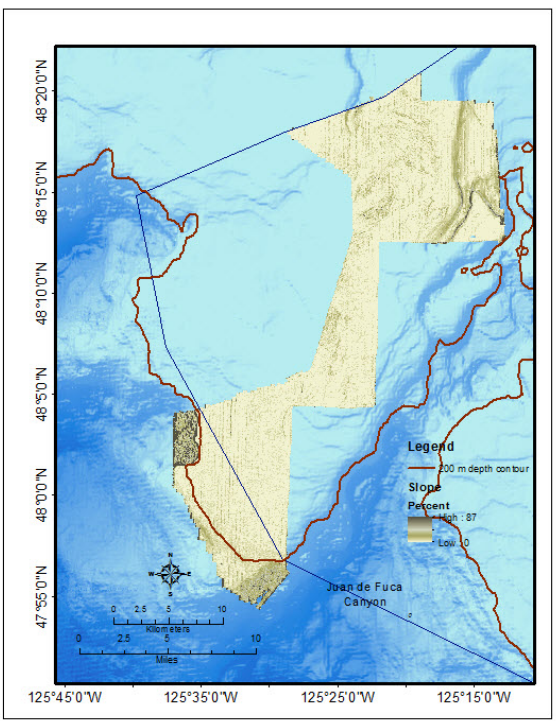


Figure 14: Slope mapped at 8 m resolution shows a primarily flat seafloor with increased slope off the shelf and at the rigidly incised Swiftsure bank channel in the northeast.

Depth, Slope, and Seafloor Complexity

Megahabitat is the broadest scale of habitat delineation in the Greene *et al*. classification scheme.

In the Pacific Northwest, it divides the seafloor into shelf and flank communities at the 200 m isobath. Eighty-nine percent of this survey was conducted on the continental shelf in ocean depths less than 200 m. Canyon areas off the shelf —from 200 to 465 m — were mapped along the flank of the Juan de Fuca Canyon and along a canyon-head/scarp (age unknown) occurring at the western shelf break. From bathymetry, derivative products of slope and seafloor complexity were calculated by a set of geospatial tools called Benthic Terrain Modeler (BTM) (Wright *et al.* 2012). Slope was calculated in degrees at 8 m resolution and broadly characterized from flat to vertical or overhanging scarps. The surveyed area of the shelf is primarily flat, less than 1° slope, across 68% of the mapped area. The slope increases from 1° to 30° between the shelf and the upper ridge of the Juan de Fuca Canyon, and again along the deeply incised channel derived from Swiftsure and La Perouse Banks. Erratic slope changes are also seen along the rough edges of the rocky outcrops in the north and central sections. Steeply sloping and vertical inclines are found in the survey, but they are limited to small areas on the canyon walls and comprise less than 1% of the mapped area.

Seafloor complexity is often described as the ratio of surface area to planimetric (linear) area. Using BTM in GIS software, terrain ruggedness is a more complex calculation using slope and aspect (Sappington *et al*. 2007) in neighborhood statistics which evaluate the characteristics of each 8 m cell based on variations in the cells around it. BTM calculations provide measures that fit the Greene et al. classification. Ruggedness is then reported as resultant standard deviation units of very low complexity (-1) to very high complexity (3+) on the Greene *et al*. classification scheme. Very low and low complexity is common in areas where sand and mud create the base material holding small pebbles, gravels and cobbles; this complexity comprise 163.9 mi^2 (95.4%) of the survey area. Moderate and high complexities are seen on the ridges of the rocky outcrops. Very high complexity is reflected in the canyons off Juan de Fuca and the western shelf break; however those data may be an artifact of modeling complexity on such steep slopes and not always a reflection of the actual substrate condition.

Since the primary goals of this survey were to 1) characterize key features of surveyed substrates, such as complexity, hardness, rugosity, and slope; and 2) identify high-confidence targets for visual surveys of deep-sea coral and sponges in areas adjacent to the Juan de Fuca Canyon, we used backscatter imagery coupled with ground truthing samples and underwater video to identify areas of hard substrate that would support structure-forming habitat such as corals and sponges. We found that many of the areas of hard substrate were patchy, low relief ridges interspersed with mixed gravels or sand, such as the anticline found in the north section. Most individual occurrences of a rock ridges fell below reasonable mapping units of 20-40 m^2. To create a generalized benthic habitat map, we used a

visual interpretation of benthic texture that generally followed the backscatter acoustic theme coupled with ground truthing and video, then hand-digitized polygons and labeled them with unique meso- and macrohabitat modifiers, level of induration, geologic attributes, and biologic attributes. The result is a relatively coarse resolution benthic habitat map. The finer resolution detail of seafloor complexity and induration required for identifying unique coral and sponge communities still exists in the base raster data and can be mined as necessary for future ROV surveys.

Overall Seafloor Complexity and the Principle Components Analysis (PCA)

Slope and depth were added to a suite of other metrics derived from the bathymetric data to characterize the complexity and surface of the seafloor across the entire mapped area. These metrics included 1) depth, 2) mean depth, 3) standard deviation of depth, 4) curvature, 5) plan curvature, 6) profile curvature, 7) rugosity, 8) slope, and 9) slope of slope. The importance of these metrics for seafloor complexity analysis has been fully described in *Moderate-Depth Benthic Habitats of St. John, U.S. Virgin Islands* (Costa *et al.* 2009). The metrics were used to identify information that uniquely described the complexity and structure of the seafloor. The data were stacked as rasters in ArcGIS 10 and processed in a Principle Components Analysis (PCA) to identify uncorrelated components that might capture variation in seafloor detail while eliminating correlated or redundant information. Details of the PCA are shown in Table 1. The PCA reduced the dimensionality of the dataset by removing information that was redundant across the 9 rasters, resulting in two primary indicators of seafloor complexity – depth and curvature. The suite of depth characteristics (i.e., depth, mean depth, and standard deviation of depth) explained 99.23% of the variance on the seafloor. This means that for this geographic footprint, only depth is a constant, explanatory variable. The suite of curvature values (curvature, profile curvature, and plan curvature) explained an insignificant 0.77%. The standard deviation of depth was highly correlated with surface rugosity (r=0.93) and slope (r=0.77), rendering rugosity, slope, and slope of slope unnecessary in the model. Surface curvature is negatively correlated with the profile curvature of the mapped area indicating that the curve of the seafloor lies perpendicular to the slope, which runs from La Perouse and Swiftsure Banks to Juan de Fuca Canyon and off the shelf.

Table 1: Principle Component Analysis for northern, central and southern mapped areas. Depth and curvature explain the significant variation in the seafloor complexity.

Input Raster Data	**Eigen values**	**% variance explained by data**	**cumulative variance**
Depth	1300.192	91.32	91.32

Mean Depth	98.796	6.94	98.26
Standard Deviation of Depth	13.747	0.97	99.23
Surface Curvature[1]	7.209	0.51	99.73
Surface Profile Curvature[2]	3.255	0.23	99.96
Surface Plan Curvature[3]	0.533	0.04	100.00
Surface Rugosity[4]	0.007	0	0
Slope[5]	0.000	0	0
Slope of the Slope[6]	-0.001	0	0
Total variation		100.00	

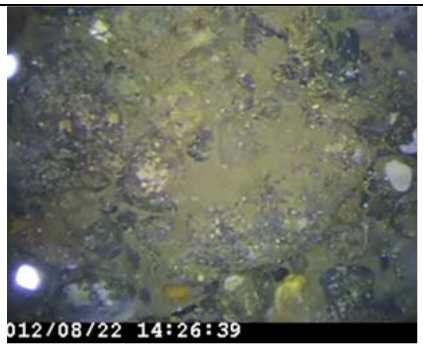
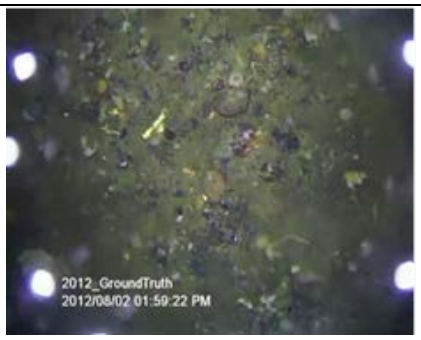
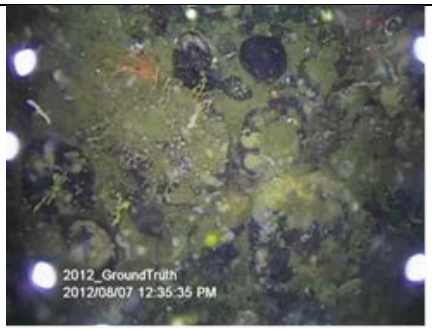
Because of its apparent unique geomorphology, we also conducted a PCA of the north section (separate from the central and south). We found that the same suite of depth values account for 99.22% of the variance in seafloor characteristics in the north; essentially the same values as the PCA run for the entire survey area, despite the unique outcrop and canyon features seen in the north, indicating that depth is the single explanatory variable for seafloor character in this area. Curvature values still account for an insignificant 0.78% of the variance. As with the PCA for the north-central-south area together, the standard deviation of depth is strongly correlated with rugosity (r=0.89) and slope (0.84) and with the slope of the slope (0.56). Curvature is negatively correlated with the profile curvature (-0.92) and strongly correlated with the plan curvature (0.90) indicating that the curve of the seafloor lies perpendicular to the slope. Rugosity, slope and slope of slope are all strongly correlated, but they have been rendered unnecessary in the model by the inclusion of the standard deviation of depth.

Habitat Types and GIS Codes:

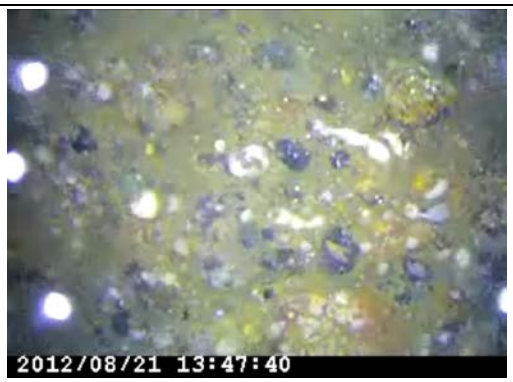
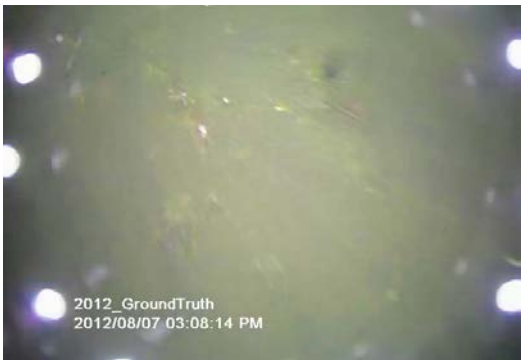
Using the Greene *et al*. classification scheme and GIS codes, ten discrete benthic habitat types were characterized in this survey area. Key to the specific codes is provided in Table 2. Megahabitat is first characterized as shelf or flank (S/F) followed by substrate induration (hard(h), mixed(m), or soft(s)). In parentheses are the sediment types in order of predominance, followed by the macrohabitat description. The underscore/lower-case letter is a modifier for the sediment texture, followed by the slope category number (1-5) and the complexity (A-E).

[1] Rate of change in curvature across the surface highlighting ridges, crests and valleys
[2] Curvature of the surface in the same direction as the slope of the 3 x 3 neighborhood cells
[3] Curvature of the surface perpendicular to the slope direction of the 3 x 3 neighborhood cells
[4] Ratio of surface area to planar area of the 3 x 3 cell neighborhood ((from Benthic Terrain Modeler (Jenness 2002)
[5] In degrees, maximum rate of change in slope between cell and 8 neighbors
[6] Degrees of degrees, maximum rate of maximum slope change between cells

Table 2: Habitat types and photos of sediment from 2012 ground truthing

Habitat Descriptions from Ground Truthing	Photos Samples from Ground Truthing
1. A mixed combination of differentially eroded sediment, moderately complex gravels with a wash of mud and sand, found primarily on the sloping shelf break and flanks of the canyon. Classification code: Fm(gms)c_d3B:	
2. A conglomerate of low complexity comprised primarily of mud, then sand, and then gravels of varying sizes found on the ridge of Juan de Fuca Canyon and the shelf break. Classification code: Fm(msg)c_b2B	
3. A moderately complex, consolidated mixture of primarily cobble and gravel in a sand matrix, found in a channel derived from La Perouse Bank, rich with invertebrate biodiversity. Classification code: Sm(cgs)g_c1B	

4. The hard (h) boulder and cobble (bc) outcrop along the western extent of the Central Section survey on the shelf (S) showing evidence of an interface (i) with exposed (e) granite, at sloping angles (2) and moderate complexity (C). Classification code: Sh(bc)e_i2C.	
5. A hard mound of moderately complex consolidated [mudstone, siltstone, sandstone, or conglomerate] mud and sand, found on the shelf at 1-30 degree slope. This is the hard mudstone outcrop of the Northern Section. Photos and physical samples showed existing sponges and suitable sponge habitat. Classification code: Sh(ms)m_c2C.	
6. The most common seafloor habitat across the survey area comprises low complexity, unconsolidated, gravels of different sizes in a mud and sand matrix, rich with brittle star, worms, bivalves, small corals and sponges, and other invertebrates. Classification code: Sm(gms)f_u1B.	

7. A low complexity conglomerate of cobble, gravel and a deep sand wash found in the Swiftsure Bank Channel. Classification code: Sm(cgs)g_c2B.	
8. A low complexity sediment on the flat shelf area southeast of the Swiftsure Channel, comprised of mixed sediment — primarily mud and sand with gravel/pebble inclusions — in a bimodal complex. Classification code: Sm(msg)f_b1B.	
9. The largest part of the Southern section is a complex of gravel and pebbles interspersed in a mud and sand matrix with shell hash and invertebrates. Classification code: Sm(msg)f_b2B.	
10. This single area of truly soft sediment is a small extent of a much larger area to the northeast comprised of flat, soft, shelf, sediments of mud and clay. Classification code: Ss(mcl)f_c1B.	

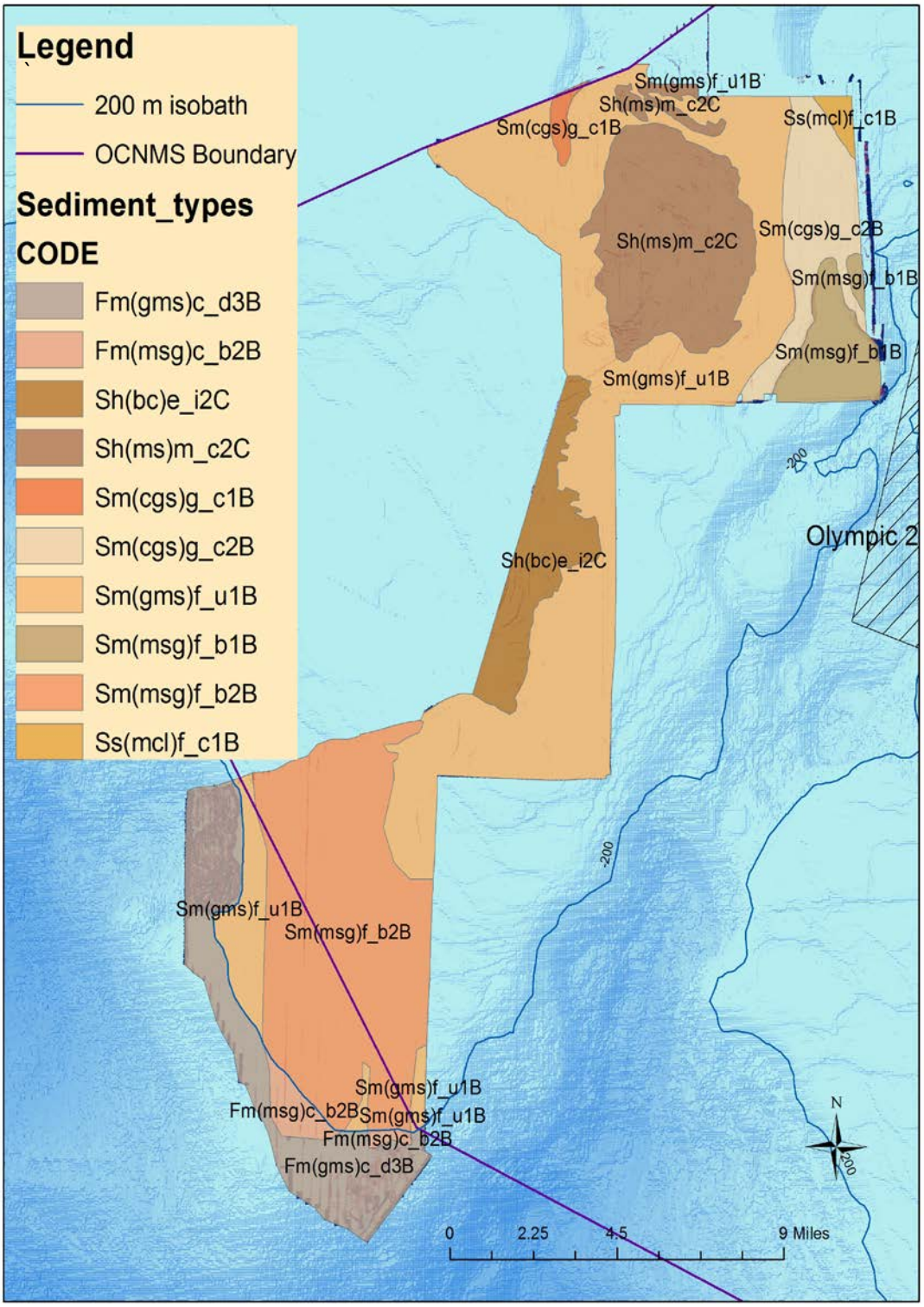


Figure 6: Benthic habitat classification for 2011 CRCP survey

Table 3: Habitat classification categories from Greene *et al*. with calculated areas

1. Megahabitat: Based on canyon flank (F) > 200 meters orshelf (S) < 200 meters	S: Shelf F: Flank		147.3 mi^2 (381.5 km^2) 18.5 mi^2 (47.9 km^2)
2. Seafloor Induration: Substrate hardness in categories of hard, mixed hard/soft, or soft.	Hard (h) 30.7 mi^2 (79.6 km^2)	Mixed hard/soft (m) 134.2 mi^2 (347.5 km^2)	Soft (s) 0.9 mi^2 (2.2 km^2)
3. Meso/Macrohabitats: Seafloor features ranging from 1m to 1 km.	(f): Flats (m): mound, depression (c): canyon (g): gully, channel (e): exposed bedrock		105.9 mi^2 (274.5 km^2) 21.4 mi^2 (55.6 km^2) 18.5 mi^2 (47.9 km^2) 10.6 mi^2 (27.3 km^2) 9.3 mi^2 (24.1 km^2)
4. Modifiers Texture or lithography of seafloor.	(u): Unconsolidated sediment (b): Bimodal-mixed gvl, cbl, pbl (c): Consolidated sediment (d): Differentially eroded (i): Interface-lithographic		62.4 mi^2 (161.7 km^2) 45.0 mi^2 (116.6 km^2) 32.8 mi^2 (85.1 km^2) 16.2 mi^2 (42.0 km^2) 9.3 mi^2 (24.1 km^2)
5. Seafloor Slope Calculated from bathymetry rasters at 8m resolution. Codes: (1), (2), (3), (4), (5)	(1): Less than 1° slope: (2): 1° - 30° slope: (3): 30° - 60° steeply sloping: (4): 60° - 90° vertical: (5): >90° overhang		104.8 mi^2 (271.4 km^2) 65.0 mi^2 (168.3 km^2) 0.82 mi2 (2.14 km^2) <1 m^2 (1.13 km^2) None
6. Seafloor Complexity Calculated from bathymetry, slope and aspect rasters at 8m resolution.	A: Very Low Complexity B: Low Complexity C: Moderate Complexity D: High Complexity E: Very High Complexity		None 164.0 mi^2 (424.7 km^2) 2.5 mi^2 (6.4 km^2) 1.2 mi^2 (3.1 km^2) 4.0 mi^2 (10.6 km^2)
7. Macro- Microhabitats Fine-scale habitats from video, described within survey bounds.	(b) boulder (c) cobble (d) deformed, faulted, folded (e) exposed bedrock		(g) gravel (m) mud, silt, clay (p) pebbles (s) sand
8. Biologic attributes Ground truth notes and video include this benthic biology	[a] algae [b] bryozoans [d] detritus [e] echinoderms		[f] fish [n] anemones [o] other sessile organisms [w] worms, worm tubes

Note: Slight variation in area exists due to area calculations done in GIS raster vs. polygon.

Conclusion

To meet the original goals of the 2011 R/V *Pacific Storm* survey and identify high-confidence targets for visual surveys of deep-sea corals and sponges near the Juan de Fuca Canyon, a subsequent 2012 R/V *Tatoosh* ground truthing survey and the development of this habitat characterization report were required. With these data it is possible to understand the relationship between the canyon and the varied substrates of the surrounding plateaus, channels, and rocky or rigid features. Eighteen percent of the area is hard substrate and some of the rock or mudstone features of that area host individual corals or sponges, as evidenced in the ground truthing still photos. Within the larger area (81%) that is mixed cobble, gravel and sand, video of some substrates reveals boulder outcrops and rich communities of biodiversity. Broad areas of primarily mud and sand comprise much of the southern section. Further surveys with an ROV would be required to determine the exact location, presence and/or absence, species identification, community size, and health of corals and sponges communities in this survey area.

Citations

Costa, B.M., L.J. Bauer, T.A. Battista, P.W. Mueller and M.E. Monaco. 2009 Moderate-Depth Benthic Habitats of St. John, U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS 105. Silver Spring, MD 57 pp

Fonseca, L.; Brown, C.; Calder, B.; Mayer, L.; Rzhanov, Y. 2009. Angular range analysis of acoustic themes from Stanton Banks Ireland: A link between visual interpretation and multibeam echosounder angular signatures. Appl. Acoust. 70, 1298–1304.

Greene, H.G., M.M. Yoklavich, R.M. Starr, V.M. O'Connell, W.W. Wakefield, D.E. Sullivan, J.E. McRea, Jr., G.M. Cailliet. 1999. A classification scheme for deep seafloor habitats. Oceanologica Acta. 22(6):663

Greene H.G. Appendix I. Explanation for Habitat Classification Code. Modified after Greene et al. 1999.

NOAA, 2010. Strategic Plan for Deep-Sea Coral and Sponge Ecosystems. Research, Management, and International Cooperation. NOAA Technical Memorandum CRCP 11.

Pacific Fishery Management Council, 2005. Pacific Coast Groundfish Fishery Management Plan for the California, Oregon, and Washington Groundfish Fishery. Appendix B Assessment Methodology for Groundfish Essential Fish Habitat. pp 52.

C K Wentworth, "A scale of grade and class terms for clastic sediments", J. Geology V. 30, 377-392 1922).

Wright, N. and C. Romsos. 2011. Multibeam Mapping of Potential Deep-Sea Coral Habitats around Olympic 2 EFH. Prepared for NOAA, Coral Reef Conservation Program. Olympic Coast National Marine Sanctuary Survey HMPR-128-2011-02. pp. 15