Multibeam Mapping of Potential Deep-Sea Coral Habitats Around Olympic 2 EFH

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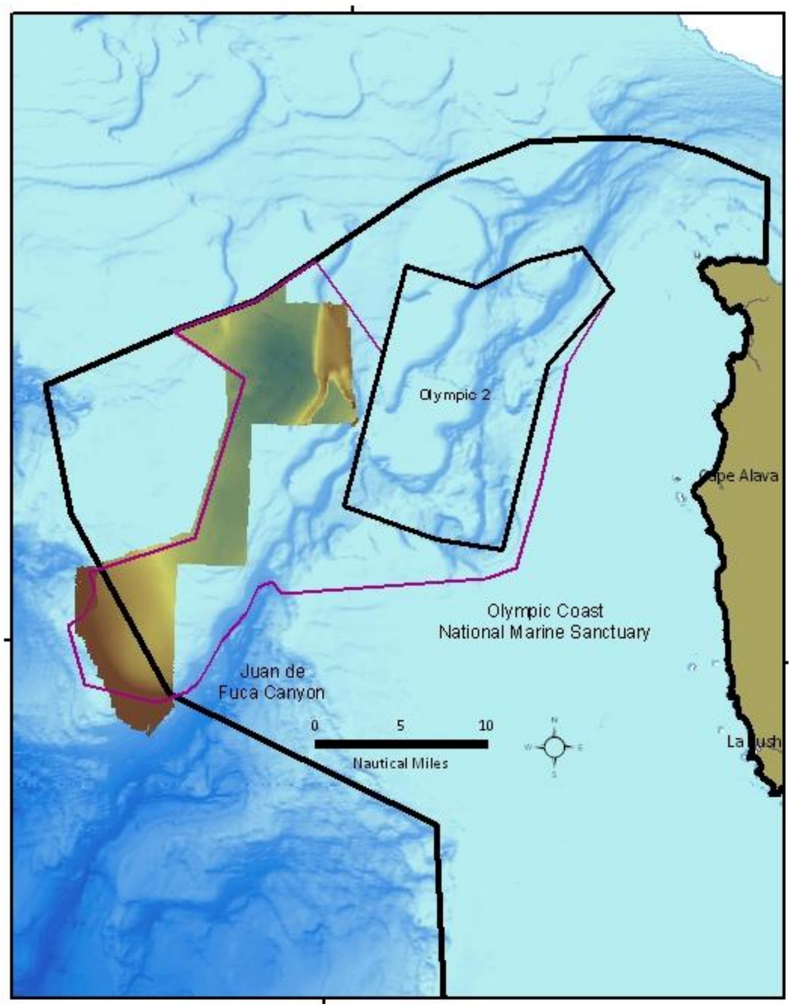

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Background

Olympic 2 is a 160 nm^2 groundfish conservation area adjacent to the Juan de Fuca Canyon designated in 2005 using an essential fish habitat (EFH) model (PFMC 2005) that combined bathymetry, sidescan sonar, substrate samples and seismic reflection as geological elements 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 908 nm^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.

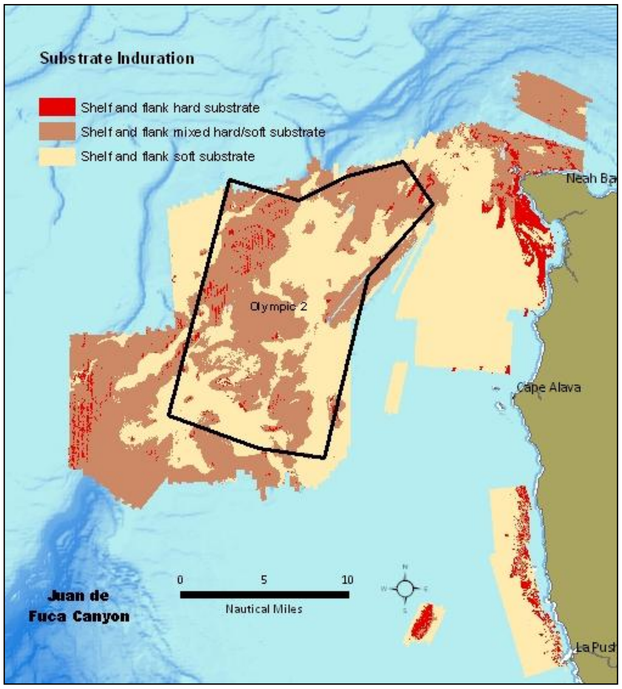


Figure 1: Classified **s**eafloor substrate map from OCNMS surveys conducted between 2001 and 2009 near Olympic 2 groundfish conservation area

Since 2009 OCNMS has collected an addition 704 nm^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.

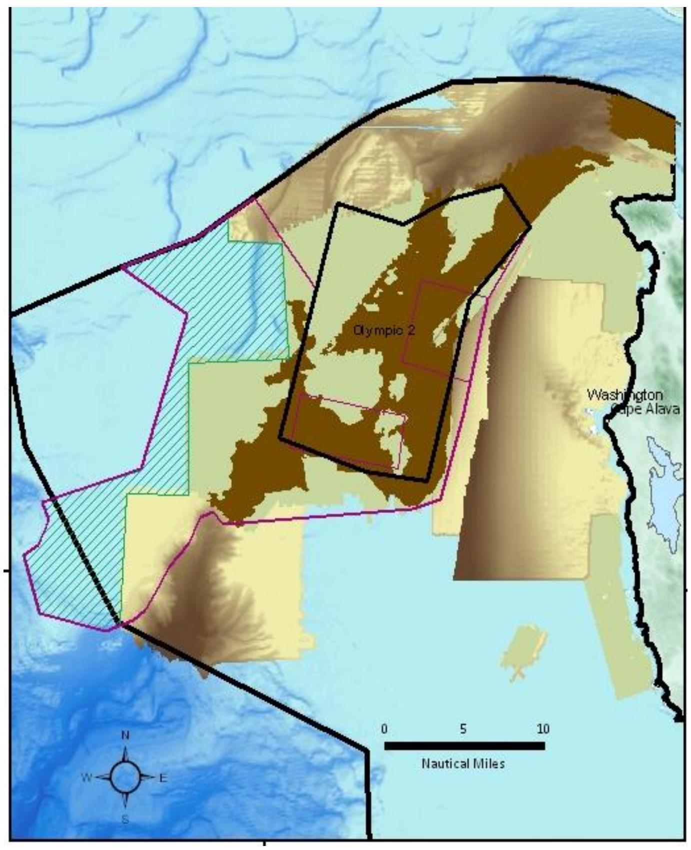


Figure 2: Extent of proposed Olympic 2 EFH boundary expansion (purple outline), with unmapped seafloor in green hatched area.

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 ~128 nm^2 of shallow (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.

2011 OSU/OCNMS Multibeam Mapping Survey on the R/V *Pacific Storm*

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 ~128 nm^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) in this area. Map products from acoustic surveys would assist with identification of areas to be visually surveyed later by ROV to identify the presence of deep-sea coral.

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 nm north and west of Juan de Fuca Canyon, 3-8 nm east of Nitinat Canyon, and 15 nm south of La Perouse and Swiftsure Banks. It lies in the westernmost extent of the proposed Olympic 2 EFH expansion area.

Data Collection

This multibeam survey was conducted on the R/V *Pacific Storm*, an 84' steel hull converted fishing vessel. The main cabin area had been extended 18' onto the back deck for a computer dry lab where the survey technicians conducted multibeam surveys 24 hrs daily. Navigation was collected with a Navcom Starfire 3050 subscription satellite-based carrier

Figure 3: The R/V *Pacific Storm*

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 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, 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.

Bathymetry and Slope

The greater mapped area lies between -86 and -250 meters depth with 0-5° slope on the shelf northwest of Juan de Fuca Canyon (Fig. 4). One exception to the flat, gently sloping character is an area along the southwestern edge that drops abruptly from 5° to 87°, where the significant slope change may indicate a slump or slide of unknown age. Another exception is on the southern tip where slope shows less dramatic change from 5° to 15° between the shelf and the upper ridge of the Juan de Fuca Canyon. Slope change from 5°-9° in the northern section reflects rugosity along the edges of a central rocky outcrop.

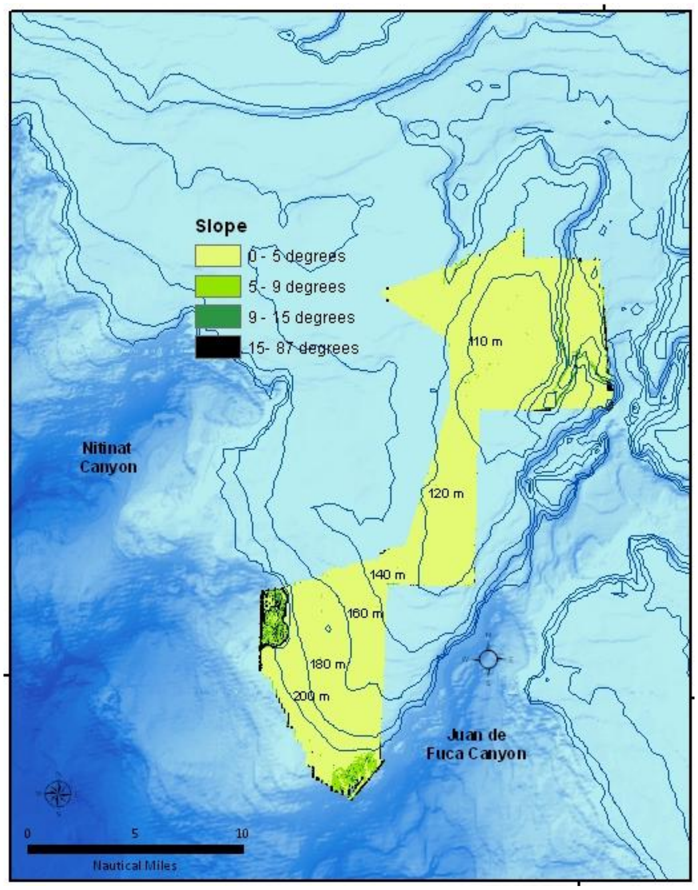


Figure 4: Mapped area has slope of 0-5° except at canyon and channel flanks.

The eastern side of the northern section picks up a length of canyon approximately -170 m deep that is a continuation of multiple linked seafloor channels running between La Perouse and Swiftsure Banks south to the Juan de Fuca Canyon. Depth in the central section drops evenly from -100 to -130 meters, and depth in the southern section, including the area off the shelf, drops from -130 to -466 m.

Complexity and Structure of the Seafloor

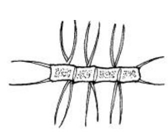
Slope and depth were added to a suite of metrics derived from the bathymetric data to characterize the complexity and surface of the seafloor across the entire mapped area. These metrics included 1) depth, 2) mean depth, 3) standard deviation of depth, 4) curvature, 5) plan curvature, 6) profile curvature, 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.

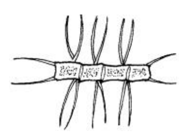
Table 1: Principle Component Analysis for northern, central and southern mapped areas. Depth and curvature explain the significant variation in the seafloor complexity.

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	

[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

The PCA reduced the dimensionality of the dataset by removing information that was redundant across the 9 rasters, resulting in 2 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.





Northern Section: Hard Substrate and the Presence of Sponges

The primary purpose of the 2011 CRCP multibeam mapping endeavor was to identify seafloor areas with hard substrate having the potential for coral and sponge community development. Only the northern section showed evidence of hard substrate; the central and southern sections showed little indication of seafloor complexity or variability. The data from the multibeam imagery for the central and southern areas showed consistently unconsolidated sandy mud. Because the northern section has hard substrate, and this fit the purpose of the survey, it is important to analyze the seafloor characteristics of the northern section separate from the larger mapping section. It warrants special attention when considering expansion of the EFH.

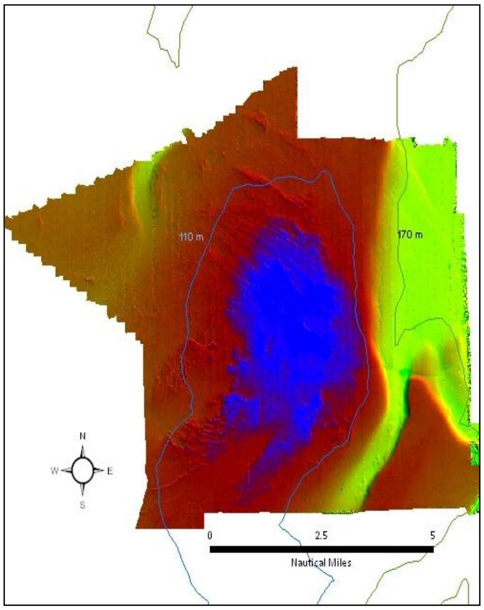


Figure 5: Northern section central outcrop (blue) with channel (green).

The most striking feature of the northern section is a shallow central outcrop of ~35m bathymetric relief (Fig. 5). 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.

Using PCA to analyze the geomorphic drivers of the northern section (separate from the central, and southern), we found the suite of depth values account for 99.22% of the variance in seafloor characteristics. These values are essentially the same 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 (Table 2). 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.

Table 2: Principle Components Analysis (PCA) for the northern section only.

Input Raster Data	Eigenvalues	% Variance explained by data	Cumulative variance
Depth	565.24	92.98	92.98
Mean Depth	22.62	3.728	96.70
Standard Deviation of Depth	15.31	2.52	99.22
Surface Curvature	2.31	0.38	99.60
Surface Profile Curvature	1.56	0.26	99.85
Surface Plan Curvature	0.76	0.13	99.98
Surface Rugosity	0.11	0.02	100
Slope	0	0	0
Slope of Slope	0	0	0

Northern Section: Backscatter

Backscatter data from the survey were collected as .hsx files in Hypack/Hysweep. Hysweep was used to convert the .hsx format files to .gsf, a format-readable by Fledermaus Geocoder. In the multibeam backscatter, only the northern area showed evidence of hard or compacted substrate mixed with gravel beds, semi-lithified sediments, coarse and fine sand. The northern area exhibits a large central outcrop with bathymetric relief of ~35 m. Overall, the 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 in a boomerang shape pointing toward the ENE. These ridge areas are mixed with gravel beds, semi-lithified sediments, and coarse and fine sand. The uplifted hard ridges were sampled opportunistically during the survey, and grab samples recovered consolidated siltstones and mudstones with attached living sponges. Additional samples from USGS and OCNMS from other surveys were added for groundtruthing, showing that on the backscatter mosaic, the relatively dark 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 that are draped over the bedrock

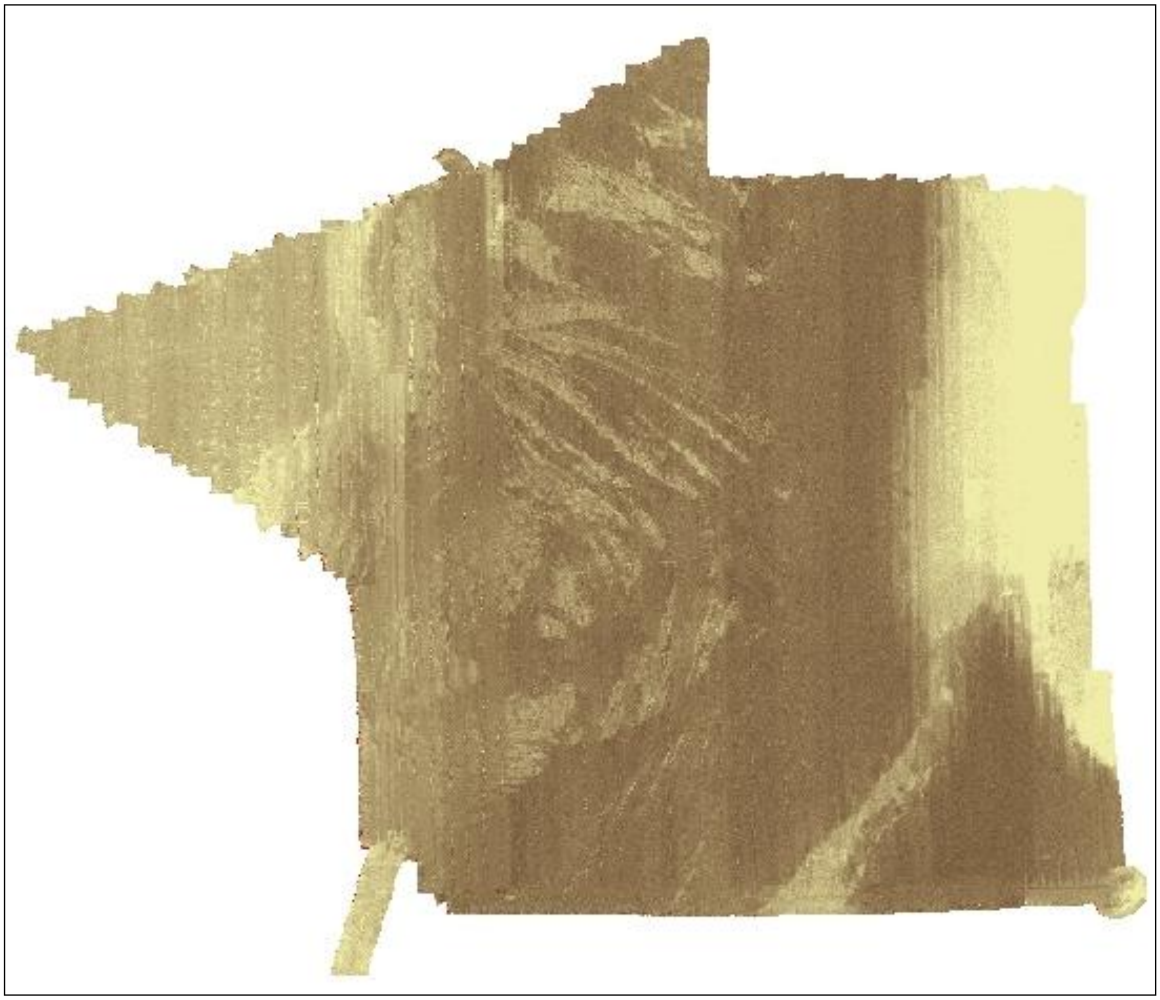


Figure 6: Backscatter from northern section multibeam sonar.

framework. Other darker areas surrounding the uplifted bank are likely coarse sand in deeper areas, though these areas were not sampled. The gravels and sands are brighter reflectors as they form a good specular reflection with the 240 kHz Reson sonar, and because these gravels are likely transported harder rock material than the soft, exposed siltstone bedrock material.

Northern Section: Habitat Classification

OCNMS uses the *Classification Scheme for Deep Seafloor Habitats* (Greene et. al, 1999) to build complete classifications for surveyed and groundtruthed benthic habitats. This scheme includes information about meso and macro habitats, size distribution of sediments, and sediment texture. The area mapped under this CRCP initiative does not have adequate groundtruth data to build a full classification scheme. In order to provide baseline information for the CRCP analysis, and to guide future ROV surveys, this preliminary habitat classification has been built in ArcGIS 10 using six valid groundtruthing points in a Maximum Likelihood supervised classification scheme. Only three classes of substrate were specified – soft substrate, hard substrate, and mixed soft/hard substrate.

During the course of the 2011 CRCP survey of the northern section, the crew took opportunistic sediment grab samples with a Shipek grab sampler on the dark, uplifted areas in the backscatter. Several of these physical samples brought up living sponges attached to siltstone and mudstone. To build the habitat classification, two of the groundtruth sample for hard substrate came from the CRCP survey. However, these samples were not random and therefore did not give a broad picture of the benthic substrate variability. Therefore, two samples for the soft sediments and two for the mixed sediments were selected from previous USGS and OCNMS surveys. These samples were adequate to guide the supervised classification model in ArcGIS.

Not all backscatter data collected in the northern section could be classified using the groundtruthing available from the CRCP, USGS, and Tatoosh surveys. During the first day of the survey on the western extent of the northern area, the Reson MBES settings were too high for reliable backscatter interpretation. Although the backscatter image (Fig. 6) gives evidence of actual seafloor complexity, approximately 20% of the data collected on the western side of this section cannot be classified without additional groundtruthing to mitigate for the incorrect settings in the original MBES data collection.

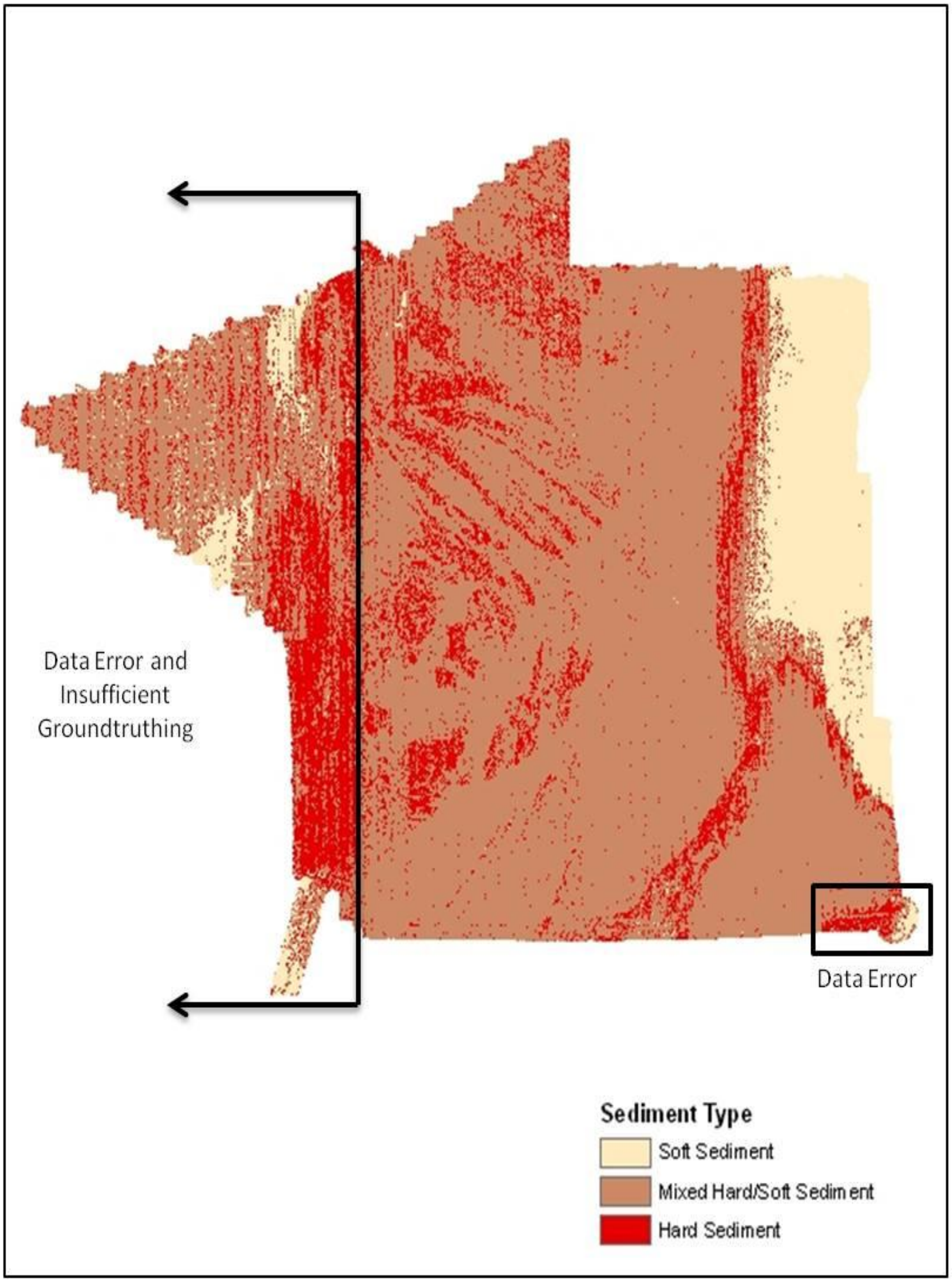


Figure 7: Northern section classified backscatter shows canyons with soft sediment (pink) east and west of the hard ridges of the central outcrop (red). The mottled mix of sandy-gravels (brown) constitutes the base material for the section. The area west of the black line cannot be correctly classified without additional groundtruthing, although bathymetric data verifies the presence of the canyon.

Descriptive Characterization of North-Central-South Sections of CRCP Mapping Initiative

The CRCP multibeam mapping initiative included a ~128 nm^2 geographic area with three contiguous sections – north, central and south. Backscatter from the southern and central sections revealed primarily unconsolidated substrate with little geomorphic relief that would indicate the presence of hard substrate (Figs 8 & 9). OCNMS and OSU staff have identified substrate variation on the far western boundary of the central region where future ROV surveys might investigate a seafloor anomalies not necessarily linked to hard substrate. Groundtruthing should be conducted in the central and southern sections in order to produce a habitat classification; however the initial review of the backscatter for these areas indicates there is no evidence of hard substrate in either area.

The northern section is the only area where hard substrate has been positively identified in the backscatter and in groundtruthed samples where mudstone, siltstone and living sponges were collected by a Shipek grab sampler. Only 80% of the northern section could be classified with the available groundtruthing. It produced a basic classification where 12.3% of the area is soft sand/mud/silt (primarily in the channel bottom); 74.5% is mixed, unconsolidated sand/gravel that forms the ubiquitous seafloor north of the Strait of Juan de Fuca, and; 13.2% is comprised of siltstone and mudstone (comprising the circular outcrop and lip of the channel). The extent of the sponge community and the presence of corals have not yet been established. This is a preliminary classification. Additional groundtruthing for a complete seafloor habitat classification is required, and ROV research surveys would reveal the presence or absence and condition of coral and sponge communities on the semi-exposed bedrock ridges.

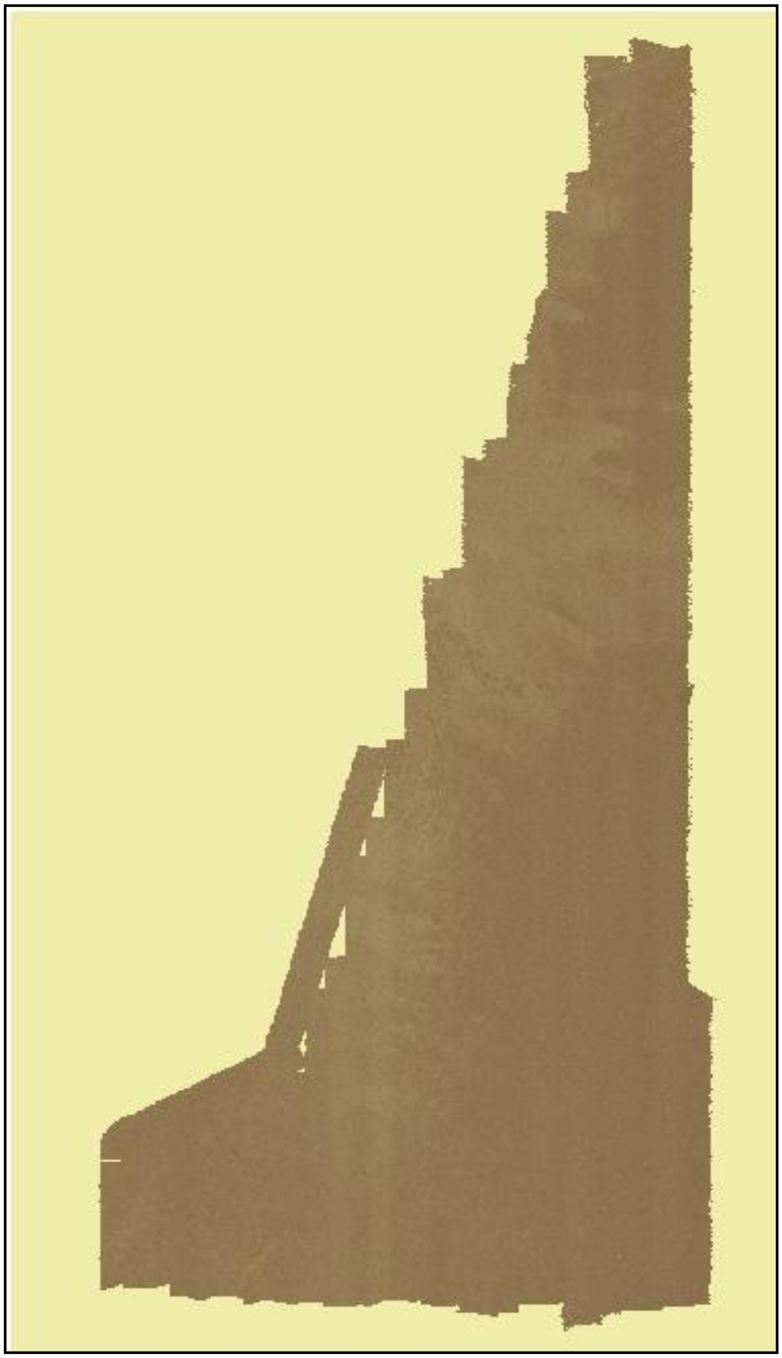


Figure 8: Central section backscatter reveals substrate variability on western extent.

Figure 9: Southern section backscatter shows variation in sediment at shelf-canyon transition zones.

Citations

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