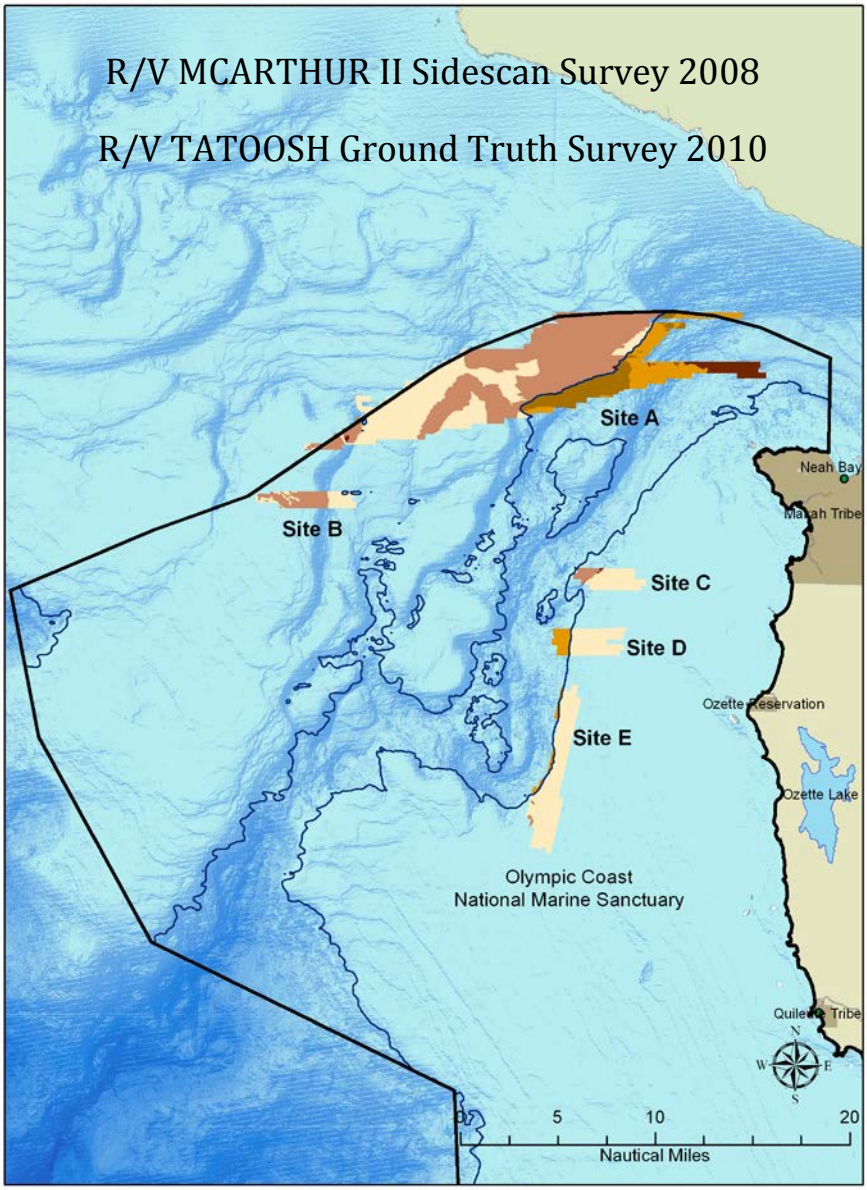
Habitat Classification of Five Sites in Northern Olympic Coast National Marine Sanctuary



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OLYMPIC COAST

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Final Report for R/V MCARTHUR II Cruise HMPR-123-2008-01 &
R/V TATTOOSH Ground Truth Survey 2010

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Introduction

The Olympic Coast National Marine Sanctuary (OCNMS) spans 2,408 square nautical miles off the coast of Washington State and comprises many habitat types from the intertidal zone to marine canyons up to 1500 meters depth. Seafloor habitat mapping and characterization is a fundamental component of research, management, ocean literacy, and resource protection at OCNMS. It provides the knowledge-base and spatial planning tools necessary to understand and manage marine resources.

Recent research has found that the Juan De Fuca Canyon and surrounding continental shelf habitats support extensive foraging grounds and migration routes for marine mammals and seabirds (Calambokidis et al. 2004). Some of these critical and fragile habitats are deep-sea coral and sponge communities that exist on some hard-bottom substrates along the shelf and canyon of OCNMS (Bowlby et al. 2005; Hyland et al., 2005). Their presence highlights the critical need to continue habitat mapping surveys (Barr 2003). This survey was undertaken to continue the focus of mapping areas surrounding the Juan De Fuca Canyon and identify habitats of interest to the research community.

The survey was conducted in two segments. Side scan sonar (SSS) was collected in five locations from the NOAA Ship MCARTHUR II from May 6-15, 2008 using Klein 3000 SSS. The science crew included two staff from OCNMS, two contracted SSS technicians, and three interns from universities around the United States. The data processing, ground truthing, sediment analysis, and final classification of habitats were conducted between 2009 and 2010 at OCNMS using CARIS and ArcGIS processing software and applying the Greene et. al. [Greene et al., 1999] seafloor classification system.

SURVEY AREAS

The survey area includes 86.4 square nautical miles across five sites northwest and southwest of Cape Flattery (Fig. 1) off the Washington State coast. The sites lie outside the 3 mile state water boundary but within the usual and accustomed fishing waters of the Makah and Quileute tribal co-trustees of the sanctuary. The northern-most Site A begins in Juan de Fuca Canyon and stretches west across the shelf south of Swiftsure Bank, covering depths from 110-320 meters. Site B maps shelf and rapid slope changes to the west of the Juan de Fuca Canyon, depths 120-180 meters. The three southern sites lie along the southeast edge of the canyon, depths 60-280 meters. Eastern edges of Sites D and E extend below the 200 meter isobath between shelf and canyon.

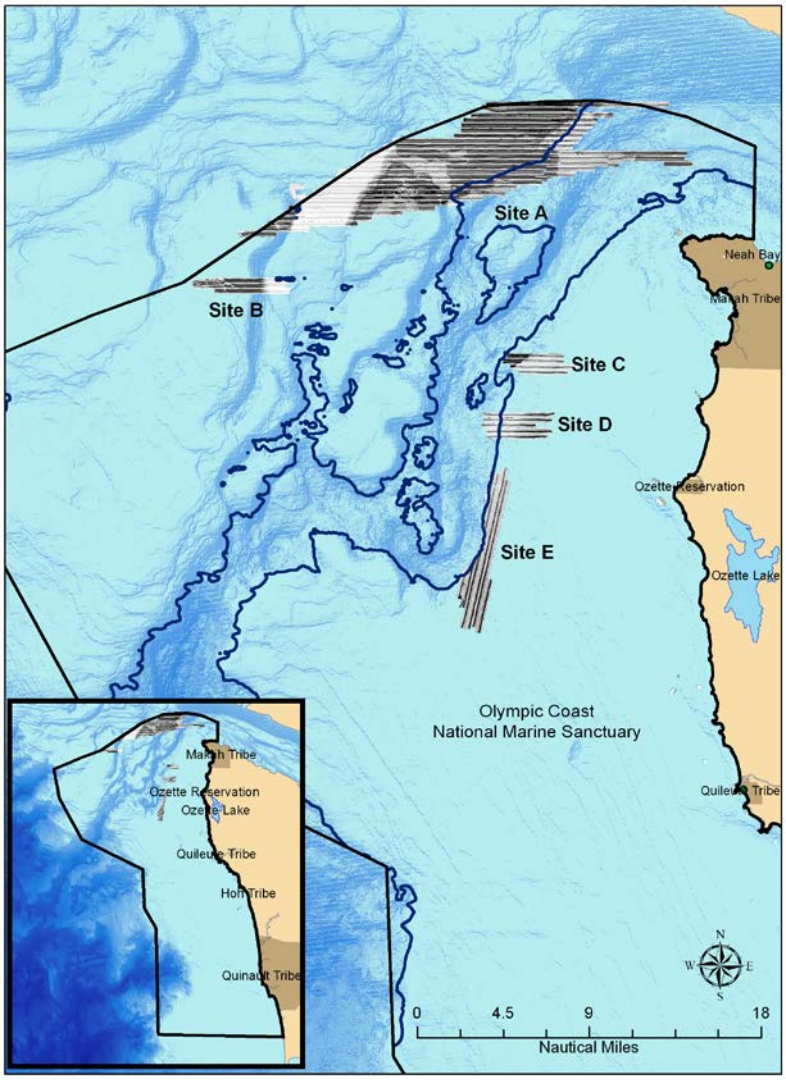


Figure 1: Five sites in Olympic Coast National Marine Sanctuary were mapped with side scan sonar in July 2008.

The outer coast of Washington is known for rough weather. During this survey period, four of the nine survey days saw winds up to 26 kt. accompanied by 8-10 ft. swells with 4-5 ft. wind waves. A summary of the daily weather and operations are in the Cruise Journal (Appendix 1). Since the SSS is a towed instrument, inconsistency caused by excessive heave, pitch, and serge in the vessel creates poor data imagery, as evidenced in some of these data.

SIDESCAN DEPLOYMENT, DATA ACQUISITION AND LOGGING

The NOAA Ship *MCARTHUR II* (Fig. 2) is a 224 ft. multipurpose oceanographic research vessel that was equipped for this survey with a Klein 3000 dual-frequency SSS (Fig. 3). The sonar was outfitted with a large wing depressor to decrease the amount of cable-out required to reach a given depth. The sonar was deployed and retrieved from the A-frame on the stern of the ship, with cabling run through a 20" sheave. Hypack software was used for survey management. SSS data were logged in Sonarpro SDF format. The SSS towfish positioning was calculated from a Trimble DSM 212 Differential Global Positioning System (DGPS) receiver set up on the fantail of the vessel using offsets to the towpoint, cable out, and course made good (CMG) corrections to compute the towfish position.

Figure 2: The NOAA Ship MCARTHUR II has been used since 2002 for a variety of research endeavors in Olympic Coast National Marine Sanctuary including seafloor mapping, marine mammal and seabird monitoring.

Figure 3: Klein 3000 dual-frequency side scan sonar with depressor.

The vessels optimum speed during data acquisition was 3 kts., however weather and sea conditions created excessive vessel motion. Heading into the seas created excessive pitching and surging or abrupt speed changes and excessive speed when the vessel was running with the seas.

DATA PROCESSING

Data from this survey were processed in CARIS® Sidescan Editor Version 7.1. Raw data files were converted and corrected for attitude, navigation error, altitude and slant range. Significant smoothing of towfish navigation was required due to the affect of the excessive vessel motion on the computed towfish position. Georeferenced Backscatter Rasters, or GeoBaRs, were created and mosaiced by site at 1 meter resolution. Sites were exported from CARIS as 24-bit, geo-referenced, compressed 3-band tif images (geotiff). In ArcMap the geotiffs were exported as 5 meter resolution grids; as grids they acquired a standardized 1-255 value colorramp. Band 1 was re-introduced into ArcMap because it carried an attribute table identifying the 255 values and their geo-referenced locations within each site. These values were considered as one of the habitat classification variables.

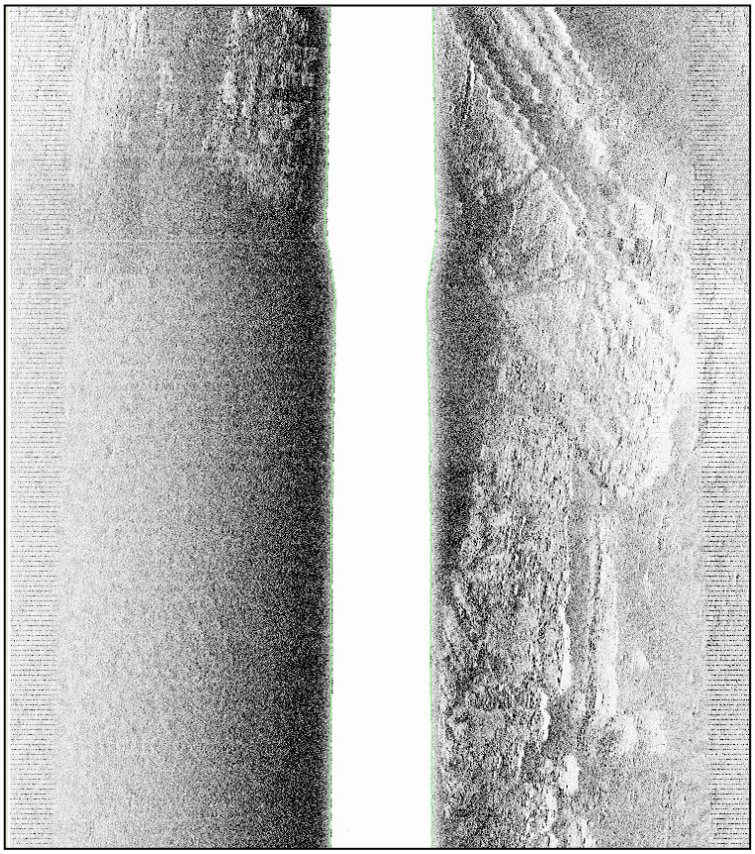


Figure 4: A waterfall editing image from CARIS Sidescan Editor showing seafloor substrate.

We determined that in these five sites there are such fine incursions of sand into mixed rocky sediments and vice versa that it is impossible to use unsupervised electronic classification to discriminate the data error from the fine sediment changes. Therefore, our seafloor habitat analysis and classification required hand-digitizing polygons with the aid of the grid values, ground truthing data, and CARIS GeoBaRs.

GROUND TRUTHING

Ground truthing is the direct verification of sediment types that are imaged by sonar. To ground truth the 2008 *MCARTHUR II* sonar data, we used a Smith-McIntyre sediment grab (Fig. 5) deployed from the OCNMS *R/V TATOOSH* in September 2010 to collect 80 sediment samples from 42 locations spread across the five survey sites. The 42 locations (Fig. 6) were pre-selected based on sonar color variation, depth, site, and grid values. Because of the sanctuary's interest in hard substrates which might promote the development of deep sea corals, the scientists focused on identifying sonar signatures within the imagery that would differentiate between hard and soft substrates and validate them with substrate samples. The intent was to gather replicates at each location. However, insufficient survey time required us to omit replicates at locations where sediments were well documented.

Figure 5: Smith-McIntyre sediment grab used on the R/V TATOOSH to collect sediment samples.

Ground truthing required a crew of 4-5 people for 10 days. For each sample, the grab was lowered vertically from the stationary boat. Contact with the seafloor triggers the grab's buckets to close. The Smith-McIntyre retrieves ~4.5 kg sediment samples from which smaller, ~1 kg, sub-samples were bagged and labeled. The 80 wet samples were first classified onboard in a wet condition. At the end of the survey they were returned to the laboratory to be dried, sieved, weighed and analyzed using a Ro-Tap sieve shaker and scale. Data from the wet and dry analysis is included with the findings for each site (Appendix 3). Invertebrates captured as part of the sampling were not kept since they were not included in the

sediment sampling protocol, however their presence was noted in the field notes and entered in the classification tables.

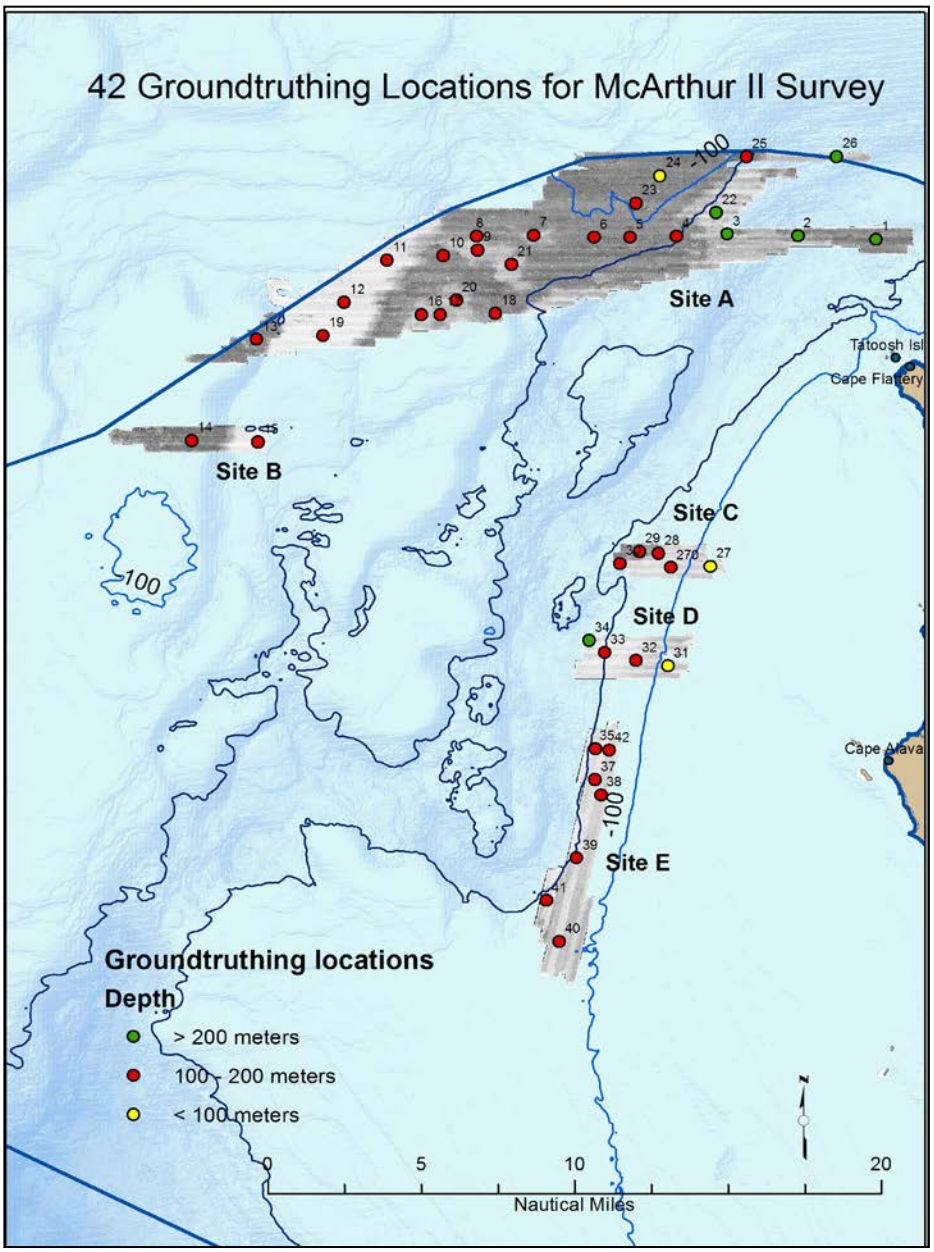


Figure 6: 42 locations were selected for ground truthing. Six locations were in shallow water < 100 meters. Fifteen were in deep water > 200 meters. The remaining 22 were in depths between -100 and -200 meters.

The dried sediments in this survey were sorted by sieving into eight categories according to the Wentworth grain size scale (Wentworth, 1922):

Cobble	64-256 mm	2.5-10 inches
Very Course Gravel	32-64 mm	1.26-2.5 inches
Course Gravel	16-32 mm	0.63-1.26 inches
Medium Gravel	8-16 mm	0.31-0.63 inches
Pebble	4-8 mm	0.157-0.31 inches
Very Course Sand	1-2 mm	0.039-0.079 inches
Course Sand	½-1 mm	0.020-0.039 inches
Mud-Silt-Clay	< 3µ	~~~~~~~~~~

CLASSIFICATION

OCNMS uses A Classification Scheme for Deepwater Seafloor Habitats to classify its mapped ocean bottom. This classification was designed for habitat interpretation determined by remotely sensed data from instruments such as SSS. The classification distinguishes marine benthic habitats and facilitates spatial displays in GIS based on the scale of the data. It is applicable across areas from 10's of kilometers to single meters. Although this classification has several levels of complexity that could be applied to the sediment grabs, we applied only two levels to the sonar data.

Megahabitat: This category is described by depth and general physiographic boundaries at 10s of km^2.

We divide the seafloor sediment types (habitats) into two megahabitats - ocean *shelf* and canyon *flanks* – with the demarcation being the 200 meter isobaths. When classifying an area of the seafloor in GIS, the code for any grid cell on the shelf is 'S' and for any grid cell on the flank is 'F'

Seafloor Induration: This category is described as substrate hardness.

Through sonar imagery and ground truthing we attempt to differentiate between three types of substrate induration – soft, hard, and mixed soft/hard. The soft includes sand, mud and silt, the hard is predominantly rock or rocky outcrops, and the mixed is generally unconsolidated cobble and gravel with coarse sand inclusions. When classifying an area as soft, hard or mixed

sediment within a GIS, the code for soft is's'; the code for mixed is 'm'; and the code for hard is 'h'.

To build a meso/macrohabitat classification using the shelf/flank (S/F) designations for the megahabitat classification and the soft/mixed/hard (s/m/h) designations for the seafloor induration we have classified each 5 meter grid cell in ArcGIS as one of the following classifications:

- (Ss) Shelf soft Soft sediment < 200 meters deep
- (Sm) Shelf mixed Mixed soft/hard sediments < 200 meters deep
- (Sh) Shelf hard Hard sediments < 200 meters deep
- (Fs) Flank soft Soft sediments > 200 meters deep
- (Fm) Flank mixed Mixed sediments > 200 meters deep
- (Fh) Flank hard Hard sediments > 200 meters deep

The Greene et. al seafloor classification scheme provides structure for a more complete habitat classification that would include seafloor slope, complexity, curvature, and rugosity , but those calculations are dependent on bathymetric data which is not a component of SSS. An expanded habitat classification of these areas may be completed by combining imagery and bathymetric data.

RESULTS AND INTERPRETATION

The habitat polygons in this classification were hand digitized using the following data:

- the sidescan images from CARIS at 1 meter resolution,
- waterfall images in CARIS for specific hard substrate identification,
- images from ArcMap at 5 meter resolution, considering a 1-253 standardized value grid,
- sediment grab data in wet and dry conditions from ground truthing, and
- contour bathymetry at 10 meter intervals to determine shelf and flank of canyons

Sediment grab data provides rich information about a single place on the seafloor and by associating the grab samples with a given reflectance we extrapolate beyond that one location. Therefore, we used the ground truthed data to determine soft, mixed or hard sediment within polygons created around areas of similar reflectance for our GIS layers. The fields in the attached sediment tables include data on wet and dry sediments, color, odor, presence or absence of biological material, and other notes from the field. These tables have been included along with each site description because they provide information on the seafloor richness and its associated habitat. A brief discussion of each site with maps and tables is included here for clarification of the classification process.

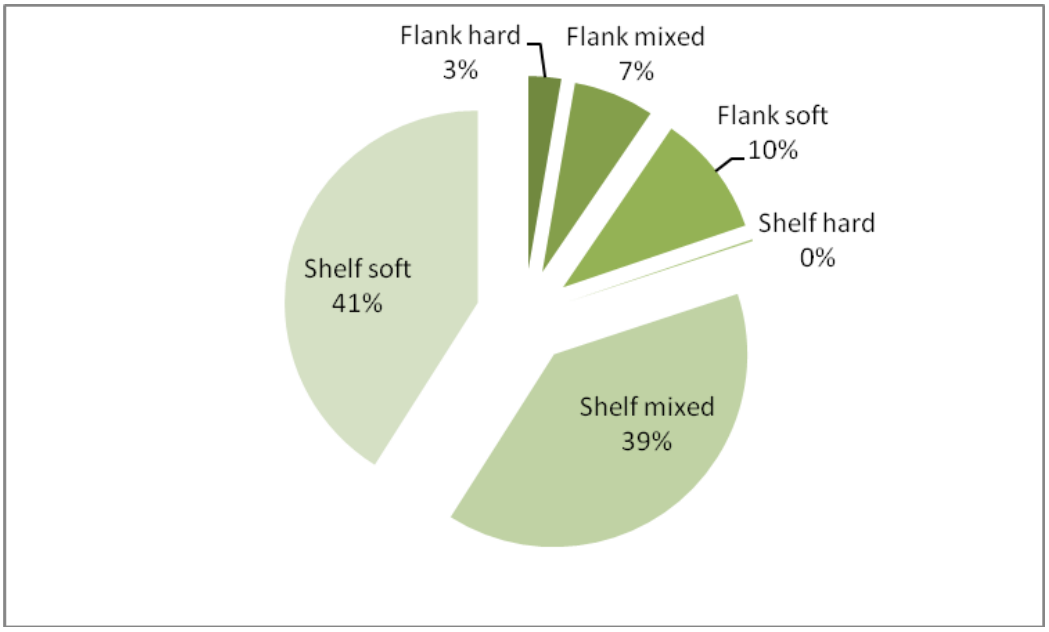
Summary Classification: All Sites

The five survey sites comprised 84.6 nm^2 which we classified into six broad seafloor sediment types (Table 1).

Table 1: Area calculations for the six habitat types

Sediment Type	Total Km^2	Total NM^2
Flank hard	8.07	4.72
Flank mixed	20.09	5.24
Flank soft	30.44	7.94
Shelf hard	0.43	1.12
Shelf mixed	115.79	3.02
Shelf hard	121.49	3.17

Figure 7: Distribution of sediment types by percentage



Site A

The largest area mapped was Site A, 221.9 km^2 (64.7 nm^2), with 76% of that area on the sloping shelf and the remainder mapping the Juan de Fuca Canyon eastern flanks. Unconsolidated hard and soft substrate composed of boulders, large and small cobble, and pebbles mixed in coarse sand comprise a great swath of that area. Changes between soft and mixed substrate types closely paralleled major changes in bathymetry, such that ridges and depressions became indicators of habitat change when classifying the seabed. Small hard substrate inclusions were difficult to identify in the ArcMap 5-meter grids, so high-resolution CARIS images were used to locate rocky outcrops and hard substrate areas were manually digitized in ArcMap. The standardized 1-255 ArcMap grid values played a secondary role as surrogates for sonar reflectivity for classifying hard, mixed and soft substrate types.

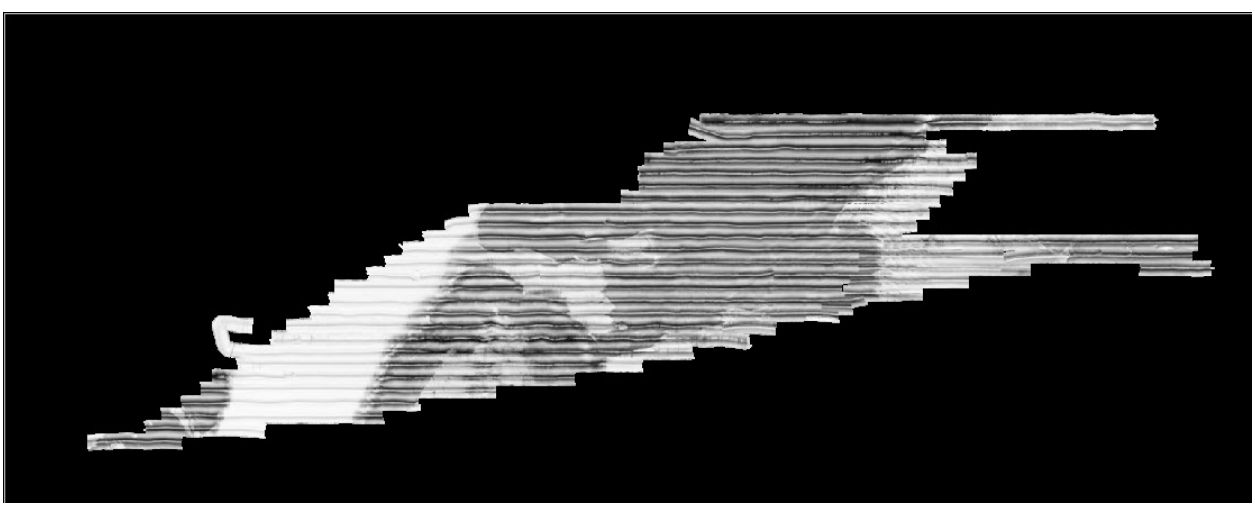


Figure 8: Site A side scan image from CARIS at 1 meter resolution

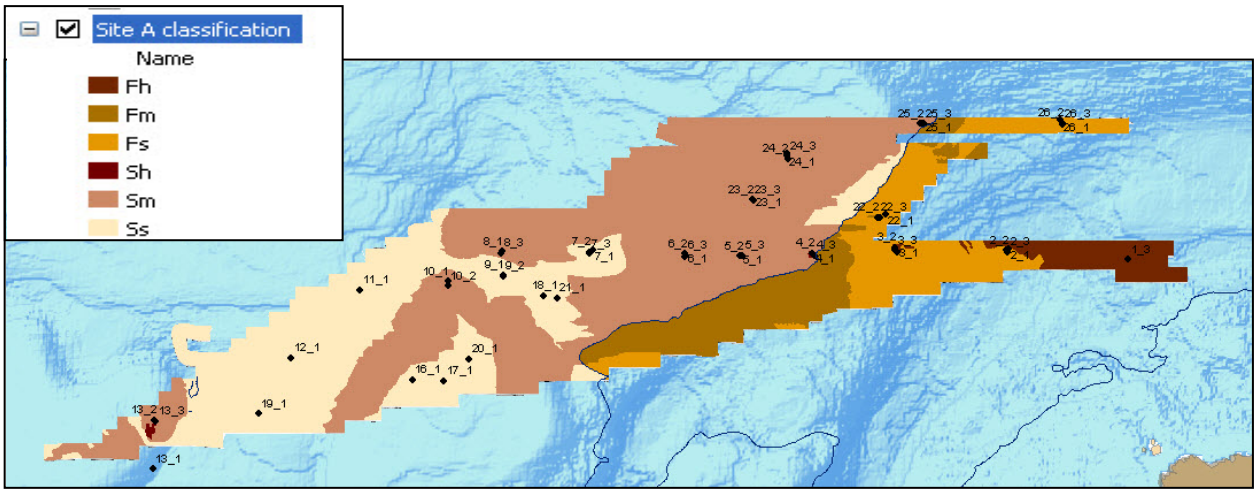


Figure 9: Site A habitat classification and location of ground truthing sites

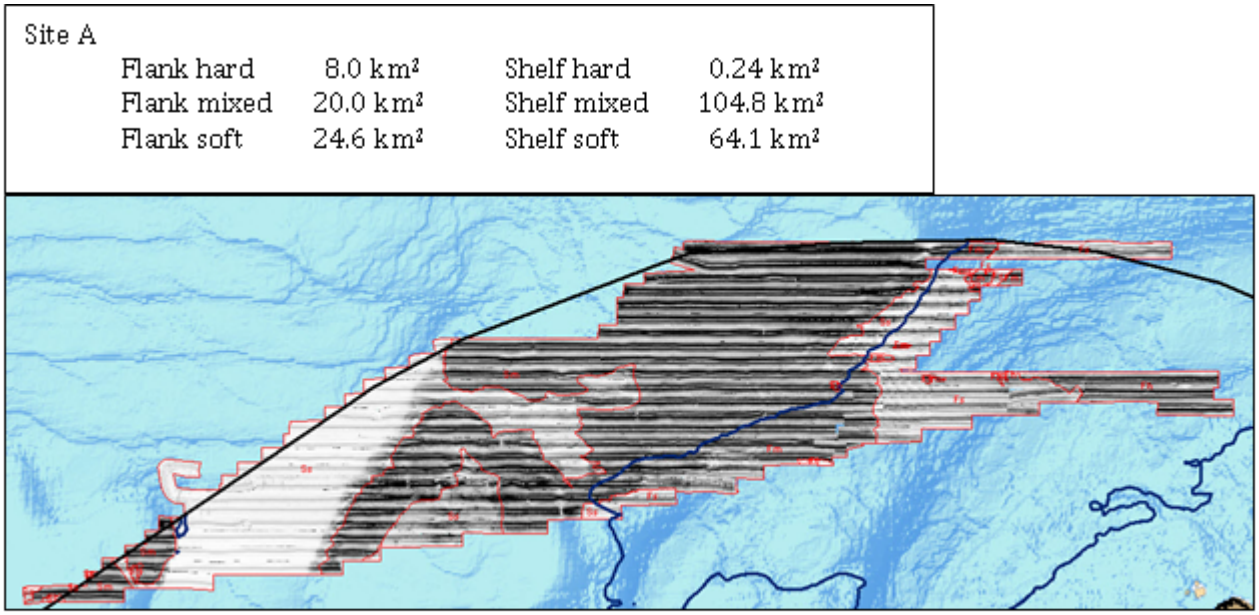


Figure 10: Site A area calculations by sediment type

Site B

Site B is an example of the importance of using multiple ground truthing sources to validate sonar data. Although this site is small, 18.1 km^2 (5.2 nm^2), it demonstrated the habitat complexity common on the outer shelf. A rapid elevation change in the middle of the site brought a parallel change in sediment types detected by 10 meter isobaths; small inclusions of soft sediment disbursed throughout the

unconsolidated mixed substrate were identified and substantiated by sediment grabs. Data error from the sonar was determined through comprehensive editing in CARIS and hand digitizing in ArcMap.

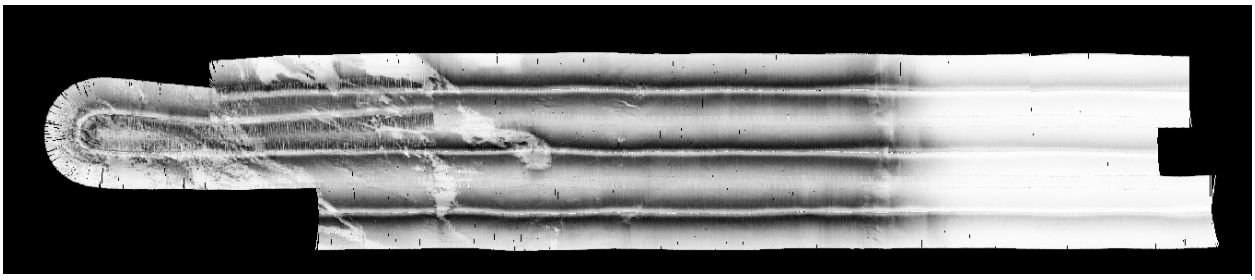


Figure 12: Site B sidescan image from CARIS at 1 meter resolution

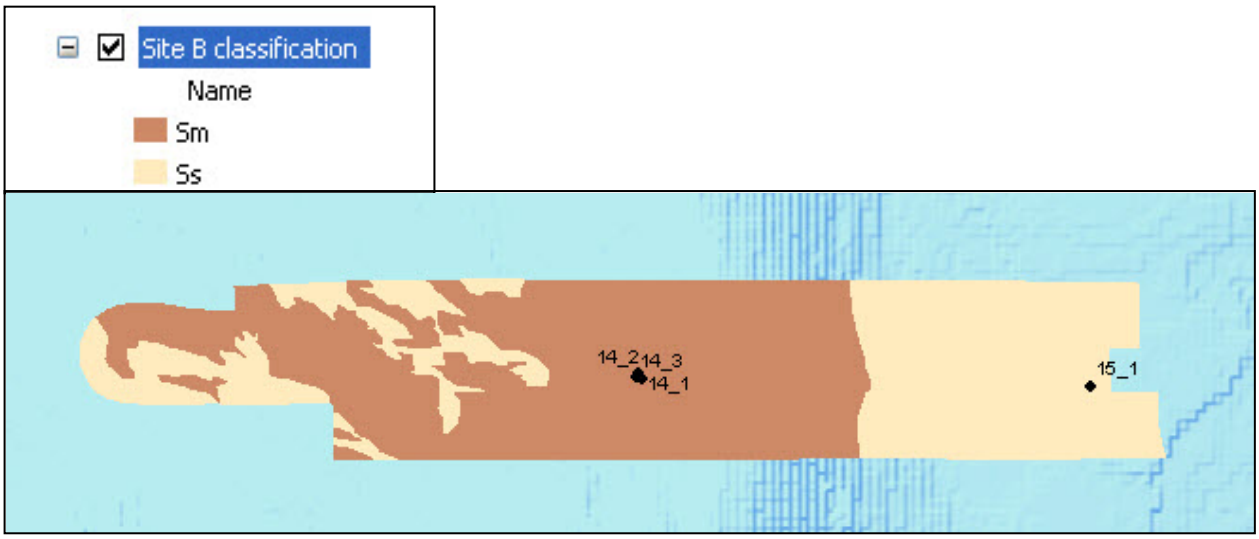


Figure 11: Site B habitat classification and location of ground truthing sites

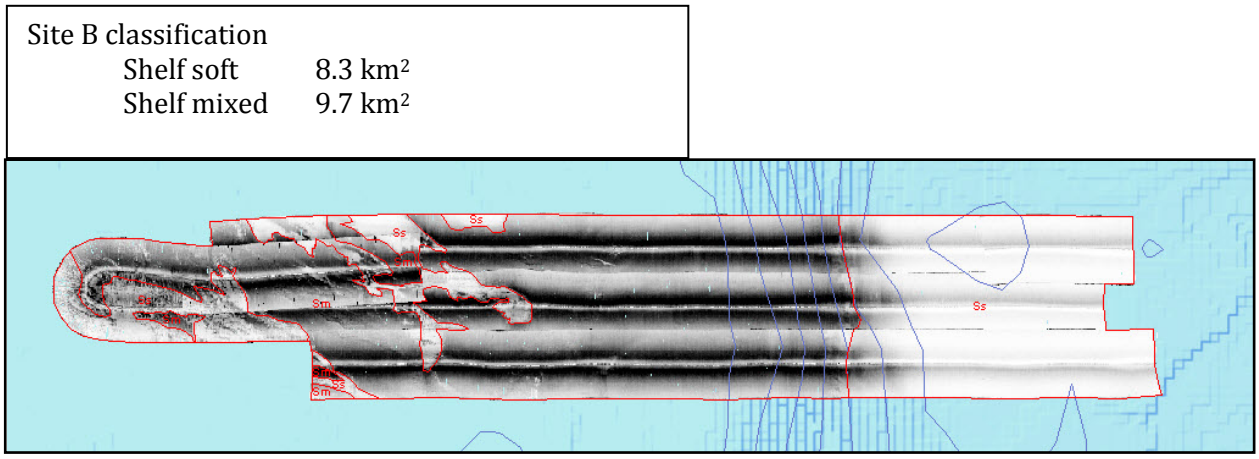


Figure 13: Site B area calculations by sediment type

Site C

Site C is a small 11.9 km^2 (3.5 nm^2) site that drops rapidly off the shelf between from -60 to -200 meters depth on the western side of the Juan de Fuca Canyon. A rocky ledge at ~180 meters depth clearly divides the site into soft, mixed and hard substrate types. The fine-resolution CARIS image was used to hand digitize the hard substrate polygons in ArcMap. Poor data quality is evident at the eastern extent of the side scan imagery.

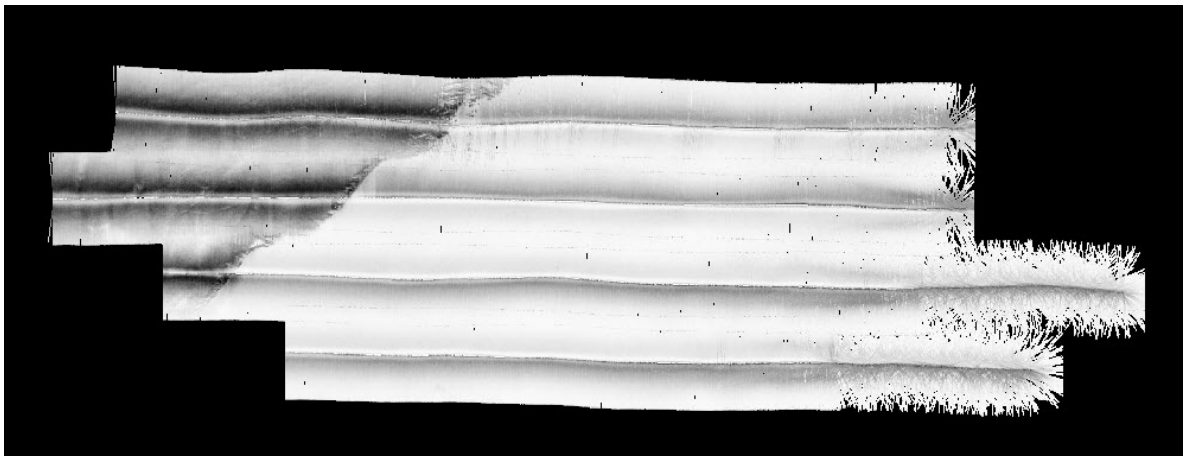


Figure 14: Site C side scan image from CARIS at 1 meter resolution shows rocks at the break between soft and mixed substrate sediments

Site C classification	
Shelf hard	0.1 km^2
Shelf mixed	2.3 km^2
Shelf soft	9.4 km^2

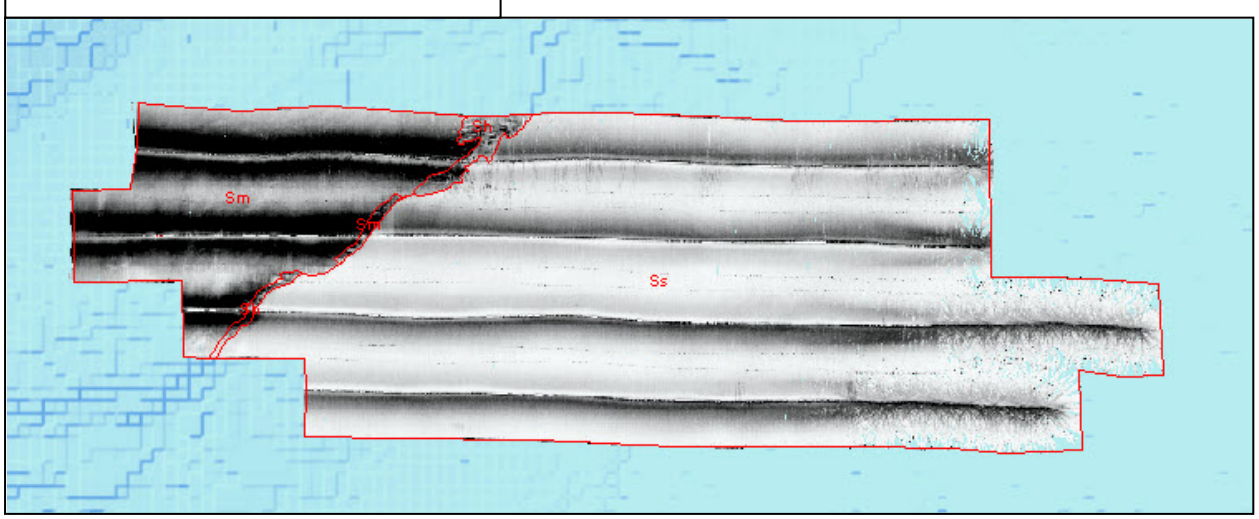


Figure 15: Site C area calculations by sediment type

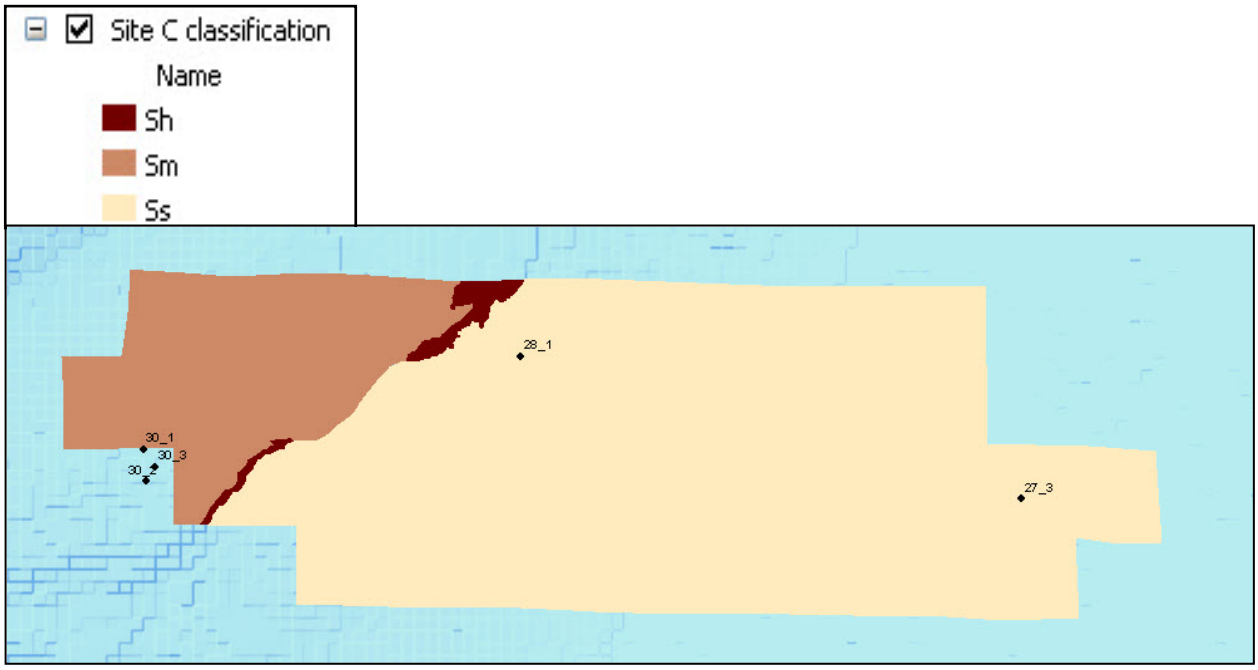


Figure 16: Site C habitat classification and location of ground truthing sites

Site D

Site D slopes eastward from 70-270 meters in depth with 23% of this small site (16.4 km^2, 4.7 nm^2) on the western flank of the Juan de Fuca Canyon. Fine resolution CARIS imagery and ground truthing indicated that this entire site is composed of soft sediments. Field notes and dry sediment analysis determined that the site sediment comprised a mud/silt combination. The consistency of the mud became stickier off the shelf and down the canyon flank.

Figure 17: Site D side scan imagery from CARIS at 1 meter resolution

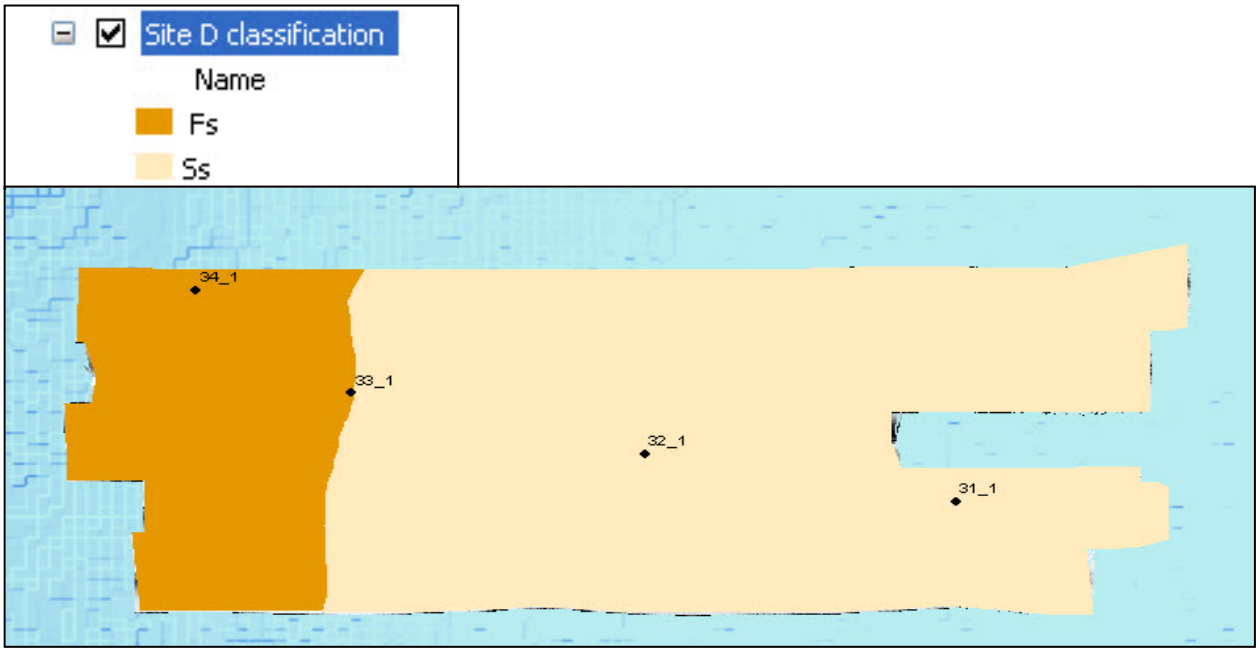


Figure 18: Site D habitat classification and location of ground truthing sites

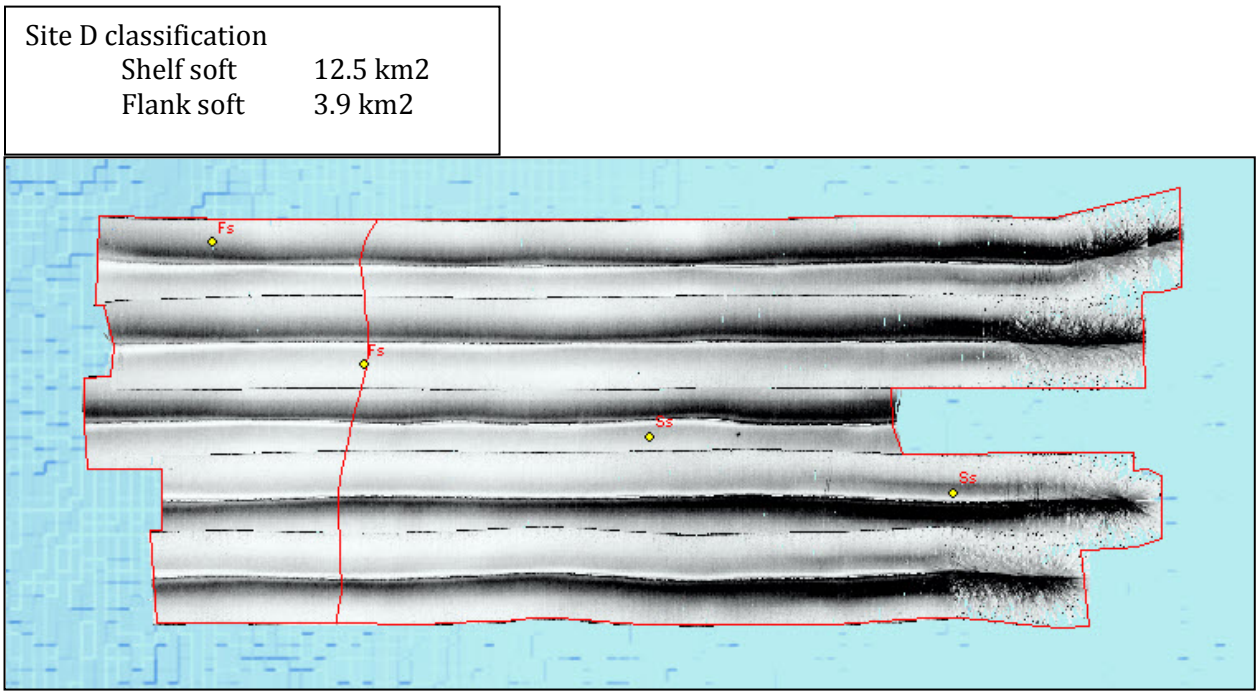


Figure 19: Site D area calculations by sediment type

Site E

Site E lies on the eastern side of Juan de Fuca Canyon along the 200 meter isobath that divides the shelf and flank. The site slopes from 80-280 meters in depth, although less than 6% of the site falls on the flank of the canyon. The site is almost exclusively soft sediment; however a small inclusion of mixed and hard sediment was identified in the CARIS 1 meter imagery. This rocky incursion was hand digitized in the ArcMap sediment classification. Mud at this site was black or green with no odor.

Site E was notable because of its absence of living organisms in the ubiquitous sticky mud that was present at each of the 14 ground truthing sites. A few worm casings and dead sea urchins were the only invertebrates recorded in the field notes.

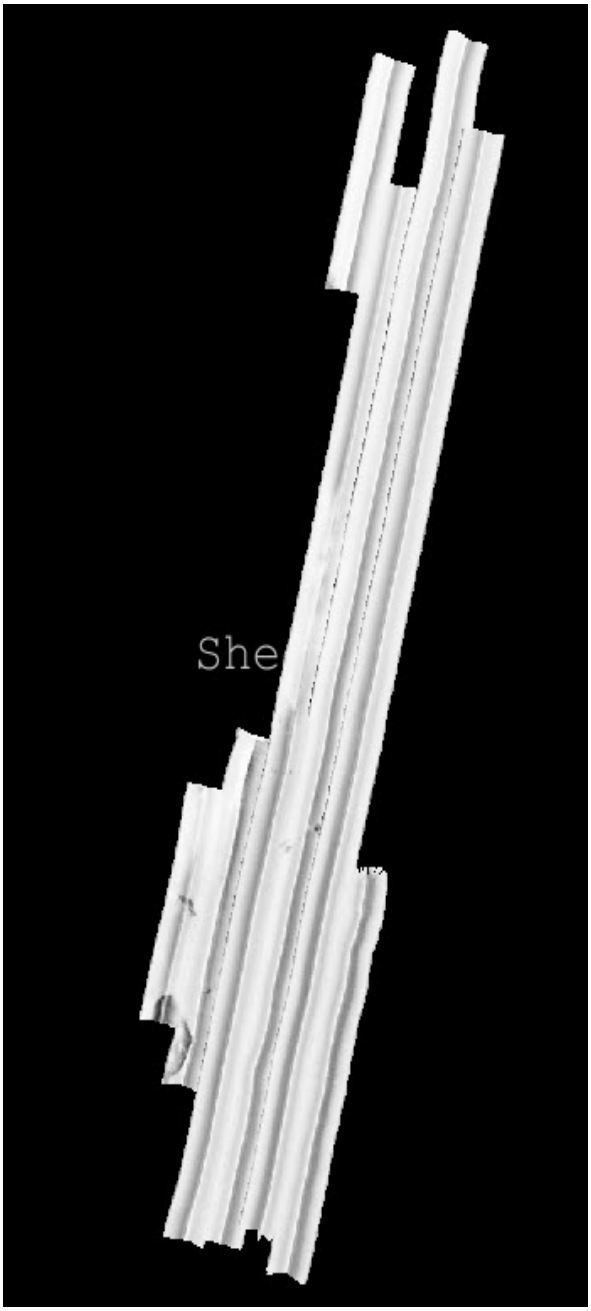


Figure 20: Site E sidescan imagery from CARIS at 1 meter resolution

Site E classification	
Flank soft	1.9 km²
Shelf hard	0.03 km²
Shelf mixed	0.3 km²
Shelf soft	30.3 km²

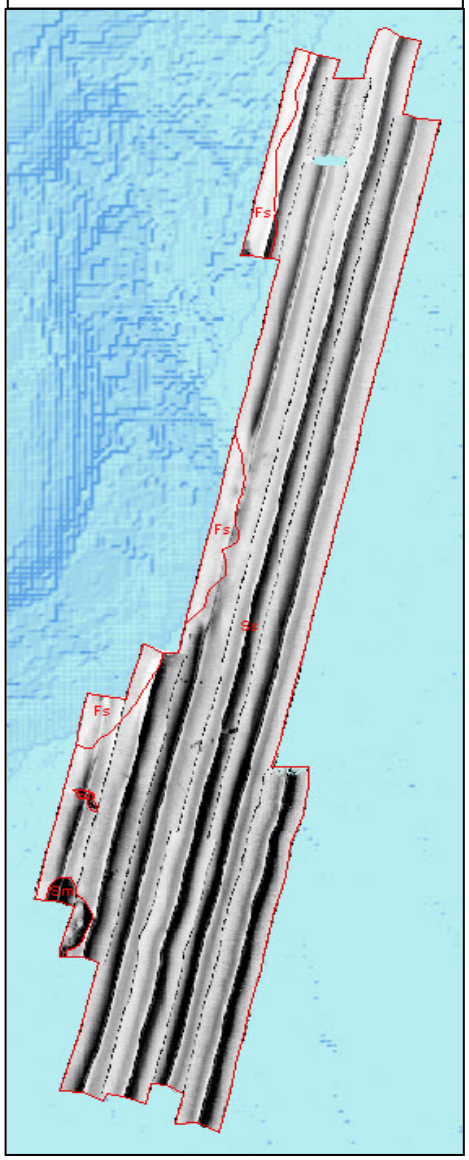


Figure 21: Site E area calculations by sediment type

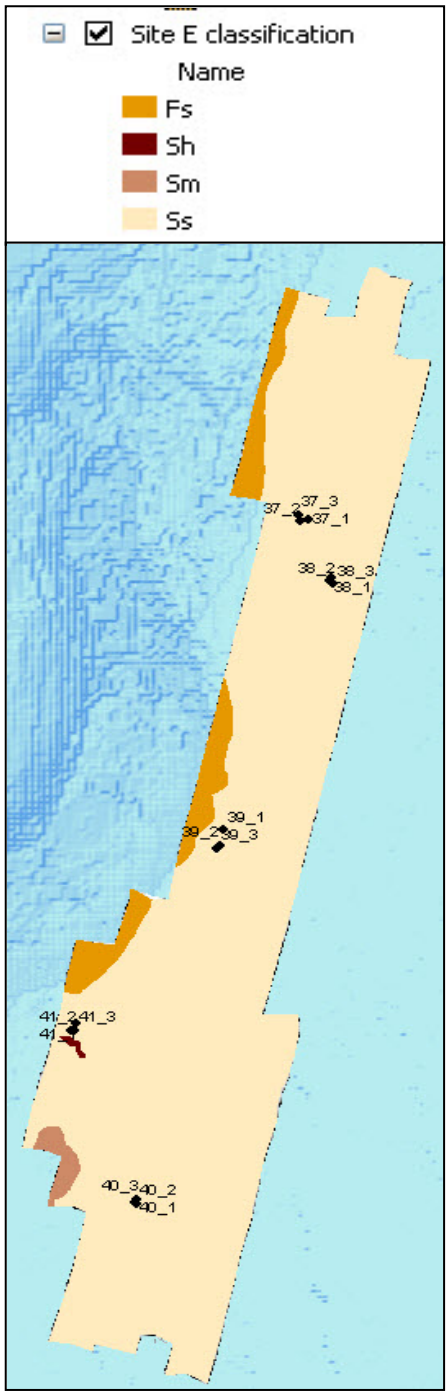


Figure 22: Site E habitat classification and location of ground truthing sites

CONCLUSIONS

The overriding objective of OCNMS is to provide a comprehensive ecosystem-wide dataset of natural and historical resources for marine management. Based on input from sanctuary partners and co-trustees, characterization of living marine resources through seafloor habitat mapping has been identified as a high-priority activity that contributes to a better understanding of ecosystem-based resource management. Under the sanctuary's new 2011 Management Plan, seafloor habitat mapping continues to be a priority mandate that will form a basis for science and policy decisions into the future.

The data from the MCARTHUR II SSS survey were processed nearly 3 years after the survey itself and no one from the original survey was available to assist with data interpretation. The available data logs were inadequate. Vessel offsets were reconstructed based on photographs for use in creating a vessel configuration file for processing. We know that several of the survey days saw very strong winds and high seas, weather that makes collection of good SSS imagery difficult at best. Despite these limitations, we were able to process the data adequately for a basic seafloor classification. Time delay in delivering these data underscores the importance of processing data concurrent with survey operations.

Using a benthic sediment sampler such as the Smith-MacIntyre to ground truth sonar has strengths and weaknesses. Scientists can analyze the physical wet and dry sediment components, compare sediment types to associated benthos, and extrapolate sediment types across a sonar image by the image reflectance type. However, the grab has its limitations on the size of sediments it can effectively pick up, cobble being the greatest. A sediment grab does not place the sample in visible spatial context the way other types of ground truthing equipment might (e.g., ROV or drop camera) where you have visibility on the seafloor. By adding lights and a camera to the Smith-MacIntyre we can increase the utility of the instrument for future ground truthing.

A comparison of the field identification of wet sediment types and the actual sediment character as determined by drying, sieving and weighing the sediment components revealed the difficulty in correctly identifying grain size by look and feel. Additional field experience would likely improve the correlation. Clearly the quantitative methodology of utilizing sieves for grain size analysis is a requirement for accurate habitat ground-truthing.

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Appendix 1: Cruise Journal

May 2 Pick up block at Fugro and interns in Seattle. MCII arrives in Port Angeles. Interns stay aboard ship.

May 3 Load gear, winch, block and cable counter frame. Dry test fish. Boom truck is delayed due to miscommunication.

May 4 Boom truck arrives early AM to hang block. Connect fish to depressor wing and go through deployment exercises. Fish loses communication with TPU. TPU fuse is blown. Fish body has .5-1 cup water inside. DEPARTURE DELAYED.

May 5 Jennifer Bright and Jim Whittaker go to Seattle to get fish NOAA Ship *Fairweather* shipped. Allison Martin and Sam Arden go to Victoria to pick up fish from NOAA Ship *Rainier*. *Rainier* fish has a good dry test.

May 6 *Fairweather* fish has good dry test. Both fish have good wet tests. DEPART PORT ANGELES. Begin survey at 2300.

May 7 Survey continues. Seas 9-11 feet, winds 20+ kts. Sonar quality is degraded by weather. Some lines are discarded for bad quality and/or poor navigation data.

May 8 Survey continues. Seas 3-6 feet, winds 5-10 kts. Sonar quality is good. 1330 winch loses power. SURVEY OPERATIONS STOPPED. We break operations to pick up parts in Neah Bay, Wa. Winch is repaired. We transit back to working grounds.

May 9 Survey resumes. Seas 2-4 feet, winds 2-7 kts. Sonar quality is good. We started surveying northern most lines in sanctuary. Slow work as traffic lane dictates survey direction.

APPENDIX 2: RELEVANT WET/DRY GROUND TRUTH SEDIMENT CODES

(Extracted from Greene et. al. 1999)

Observed Wet Sediment:
S = Sand
P = Pebble
M = Mud
GR = Gravel
B = Boulder
C = Cobble

Color:
Blk = Black
Gr = Green
G = Gray
B = Brown

Slope:
1 = Flat
2 = Sloping (1-30°)
3 = Steeply sloping (30-60°)

Complexity (estimated rugosity):
A = Very low (1-1.25)
B = Low (1.25-1.5)
C = Moderate (1.5-1.75)

Macrohabitat:
(m) = mud
(g) = gravel
(p) = pebble
(s) = sand
(b) = boulder
(c) = cobble

Biologicals:
[o] = other sessile organisms
[w] = worm tubes
[n] = anemones

APPENDIX 3: SEDIMENT TABLES

Table 2: Site A wet sediment observations from ground truthing

Drop Number	Date	Time	Depth_m	Observed Wet Sediment	Color	Notes at Sea (Site A)
2_1	9/9/2010	1330	312	MS	Gr/Blk	No comment
2_2	9/9/2010	1401	311	M	Gr/Blk	Lots of brittle star, organic matter
2_3	9/9/2010	1421	312	MS	Gr/Blk	Sticky, predominantly mud, brittle stars
3_1	9/9/2010	1450	271	MS	Gr/Blk	Urchins, worms, slippery mud
3_2	9/9/2010	1508	265	S	G	Brittle Stars
3_3	9/9/2010	1523	267	S	G	Brittle Stars
5_1	9/9/2010	1626	114	SP	Gr	Good mix of cobble, mud, living orgs, rubble, and larger gravel
5_2	9/9/2010	1636	114	SP	Gr	Well mixed cobble, mud, rubble, gravel pieces, living orgs
5_3	9/9/2010	1645	118	MP	Gr	Rubble, cobble, gravel, sticky mud, worms, living orgs well mixed
6_1	9/9/2010	1259	105	SP	B	Pebbles and cobble suspended in mud/sand mix
6_2	9/9/2010	1307	104	SP	B	Small bryzoan, worms suspended in sand/mud. Large boulders
6_3	9/9/2010	1315	103	SP	B	Small bryzoan,tiny lobsters, worms and other living organisms
7_1	9/9/2010	1346	149	S	G	A few worms
7_2	9/9/2010	1355	153	S	G	A few worms
7_3	9/9/2010	1405	153	S	G	Sand and a few worms

Drop Number	Date	Time	Depth_m	Observed Wet	Color	Notes at Sea (Site A)
8_1	9/21/2010	1510	177	CG	B Gr	Cobble, gravel with pebbles, sand, mud, boulders, rich with living orgs.
9_1	9/21/2010	1540	183	S	Blk	Black sand, brittle stars
9_2	9/21/2010	1555	182	S	Blk	Black sand, brittle stars
10_1	9/21/2010	1440	128	GS	B	Gravel, pebble, sand, mud, full of all kinds of living orgs attached to rocks
11_1	9/21/2010	1419	160	M	Gr	Smooth green mud, worms
12_1	9/21/2010	1400	169	M	Gr	Smooth green mud, urchins, worms
13_1	9/21/2010	1250	127	BS	B	Boulder, cobble in mud/sand
13_2	9/21/2010	1300	127	CS	B	All rock sizes in sand. Few living orgs.
13_3	9/21/2010	1310	126	CS	B	All rock sizes in sand/mud. Black strip in mix.
16_1	9/22/2010	1016	113	SM	Blk	Sand, mud and a few worms
17_1	9/22/2010	1003	111	S	Blk	Sand with lots of worms
18_1	9/22/2010	935	184	SM	Blk	Sand, mud, brittle stars
19_1	9/21/2010	1331	178	MP	Gr	Smooth green mud, urchins
20_1	9/22/2010	950	111	S	Blk	Sand, worms
21_1	9/21/2010	1614	183	S	Blk	Sand, brittle stars
22_1	9/9/2010	1440	235	S	G	Small gravel in sand - just a few pieces
22_2	9/9/2010	1455	234	S	G	Small Gravel - 2-3 pieces
22_3	9/9/2010	1509	233	S	G	No comments
23_1	9/9/2010	1224	100	PS	B	Cobble, mud, some living orgs
23_2	9/9/2010	1233	99	PS	B	Sticky mud, sea squirts, worms, cobble
23_3	9/9/2010	1241	100	PS	B	Cobble, mud, organisms, sea squirts

Drop Number	Date	Time	Depth_m	Observed Wet	Color	Notes at Sea (Site A)
24_1	9/9/2010	1152	89	PS	B	Mud and some sand; lots of living worms, brittle stars. Cobble.
24_2	9/9/2010	1200	89	PM	B	Cobble, worms, large & small stones, living orgs.
24_3	9/9/2010	1209	89	PM	B	No comments
25_1	9/9/2010	1105	188	PC	B	No comments
25_2	9/9/2010	1117	184	PC	B	Sand, mud, chiton, worms, crabs, other living orgs.
25_3	9/9/2010	1126	186	SP	B	Cobble (several rocks), worms, crabs, other living orgs.
26_1	9/9/2010	1000	234	SM	Gr	Brittle stars and worms
26_2	9/9/2010	1020	235	S	Gr	Brittle stars and worms
26_3	9/9/2010	1036	237	S	Gr	Brittle stars and worms
1_3	9/9/2010	1236	283	BC	B	Brittle star, worms, organic matter.
4_1	9/9/2010	1545	195	CB	B	Many organisms attached to rocks.
4_2	9/9/2010	1557	193	B	B	Rocks with organisms attached.
4_3	9/9/2010	1610	198	B	B	Simply rocks with living orgs attached.
8_3	9/21/2010	1524	178	GP	B Gr	Cobble, pebble, gravel, sand, mud, worms
10_2	9/21/2010	1455	127	GS	B	Gravel, pebble, sand, mud, full of all kinds of living orgs attached to rocks

Table 3: A breakdown and classification of dried, sieved, and weighed sediments from Site A.

Drop Number	Cobble	Very Coarse Gravel	Coarse Gravel	Medium Gravel	Pebble	Very Coarse Sand	Coarse Sand	Mud-Silt	Megahabitat	Bottom Type	Biologicals
2_1	0%	0%	0%	0%	0%	0%	0%	100%	F	s	
2_2	0%	0%	0%	0%	0%	0%	0%	100%	F	s	o
2_3	0%	0%	0%	0%	0%	0%	0%	100%	F	s	o
3_1	0%	0%	0%	0%	0%	0%	0%	100%	F	s	o
3_2	0%	0%	0%	0%	0%	0%	0%	100%	F	s	o
3_3	0%	0%	0%	0%	0%	0%	0%	100%	F	s	o
5_1	0%	0%	14%	1%	6%	31%	23%	26%	S	m	o
5_2	0%	0%	0%	4%	6%	36%	25%	29%	S	m	o
5_3	0%	0%	5%	9%	15%	30%	17%	25%	S	m	w,o
6_1	0%	6%	12%	6%	8%	27%	22%	19%	S	m	
6_2	0%	12%	7%	12%	8%	21%	27%	13%	S	m	w,o
6_3	0%	5%	36%	9%	11%	17%	9%	12%	S	m	o
7_1	0%	0%	0%	0%	0%	0%	0%	100%	S	s	w
7_2	0%	0%	0%	0%	0%	1%	8%	91%	S	s	w
7_3	0%	0%	0%	0%	0%	0%	0%	100%	S	s	w
8_1	65%	23%	1%	2%	1%	1%	1%	6%	S	h	w,o
9_1	0%	0%	0%	0%	0%	0%	0%	100%	S	s	o
9_2	0%	0%	0%	0%	0%	0%	0%	100%	S	s	o
10_1	0%	0%	5%	15%	13%	12%	10%	45%	S	m	o,w

Drop Number	Cobble	Very Coarse Gravel	Coarse Gravel	Medium Gravel	Pebble	Very Coarse Sand	Coarse Sand	Mud-Silt	Megahabitat	Bottom Type	Biologicals
11_1	0%	0%	0%	0%	0%	0%	0%	100%	S	s	w
12_1	0%	0%	0%	0%	0%	0%	0%	100%	S	s	w,o
13_1	37%	32%	1%	2%	2%	3%	6%	17%	S	h	
13_2	0%	32%	17%	14%	6%	3%	4%	24%	S	m	o
13_3	16%	25%	19%	4%	5%	4%	7%	20%	S	m	
16_1	0%	0%	0%	0%	0%	0%	0%	100%	S	s	w
17_1	0%	0%	0%	6%	7%	11%	5%	72%	S	m	w
18_1	0%	0%	0%	0%	0%	0%	0%	100%	S	s	o
19_1	0%	0%	0%	0%	0%	0%	0%	100%	S	s	o
20_1	0%	0%	0%	0%	0%	0%	0%	100%	S	s	w
21_1	0%	0%	0%	0%	0%	0%	0%	100%	S	s	o
22_1	0%	5%	0%	0%	0%	0%	0%	95%	F	m	w,o
22_2	0%	0%	0%	0%	0%	0%	0%	100%	F	s	
22_3	0%	17%	1%	0%	1%	0%	0%	82%	F	m	
23_1	0%	0%	10%	17%	19%	27%	12%	15%	S	m	o
23_2	0%	0%	28%	15%	21%	16%	7%	13%	S	m	w
23_3	0%	0%	9%	19%	22%	23%	9%	19%	S	m	o
24_1	0%	0%	5%	16%	25%	24%	10%	19%	S	m	n
24_2	0%	13%	7%	22%	19%	15%	7%	18%	S	m	w
24_3	0%	16%	2%	19%	15%	24%	8%	16%	S	m	
25_1	0%	20%	8%	11%	21%	19%	3%	18%	S	m	

Drop Number	Cobble	Very Coarse Gravel	Coarse Gravel	Medium Gravel	Pebble	Very Coarse Sand	Coarse Sand	Mud-Silt	Megahabitat	Bottom Type	Biologicals
25_2	0%	6%	34%	17%	17%	8%	3%	14%	S	m	w,o
25_3	0%	9%	4%	11%	21%	24%	4%	28%	S	m	w,o
26_1	0%	0%	0%	0%	0%	0%	0%	100%	F	s	w,o
26_2	0%	0%	0%	0%	0%	0%	0%	100%	F	s	w,o
26_3	0%	0%	0%	0%	0%	0%	0%	100%	F	s	w,o
1_3	0%	0%	0%	0%	0%	0%	0%	0%	F	h	w,o
4_1	0%	0%	0%	0%	0%	0%	0%	0%	S	h	w,o
4_2	0%	0%	0%	0%	0%	0%	0%	0%	S	h	o
4_3	0%	0%	0%	0%	0%	0%	0%	0%	S	h	o
8_3	0%	0%	0%	0%	0%	0%	0%	0%	S	m	w
10_	0%	0%	0%	0%	0%	0%	0%	0%	S	m	w,o

Table 4: Site B wet sediment observations from ground truthing

DropNo	Date	Time	Depth_m	Wet Sediment	Color	Notes at Sea (Site B)
14_1	9/21/2010	1154	119	PS	B	Pebbles, cobble, gravel, held with sand and mud, worms
14_2	9/21/2010	1207	118	GS	B	Gravel and pebbles in sand/mud mix
14_3	9/21/2010	1250	118	CS	B	Larger cobble with pebble and gravel, mud and sand
15_1	9/21/2010	1127	184	M	G	Green smooth mud, worms

Table 5: A breakdown and classification of dried, sieved, and weighed sediments from Site B.

Drop Number	Cobble	Very Coarse Gravel	Coarse Gravel	Medium Coarse Gravel	Pebble	Very Coarse Sand	Coarse Sand	Mud Silt	Megahabitat	Bottom Type	Slope	Complexity	Macrohabitat	Biologicals
14_1	0%	4%	8%	16%	13%	12%	13%	33%	S	m	1	B	msg	w
14_2	0%	3%	28%	10%	6%	5%	13%	36%	S	m	1	B	gms p	
14_3	0%	40%	17%	8%	4%	3%	7%	22%	S	m	1	B	gms p	
15_1	0%	0%	0%	0%	0%	0%	0%	100 %	S	s	1	A	m	w

Table 6: Site C wet sediment observations from ground-truthing

Drop Number	Date	Time	Depth_m	Observed wet sediments	Color	Notes at Sea (Site C)
27_3	9/9/2010	1201	72	S	Blk	No comments
28_1	9/22/2010	1145	184	M	Blk	Mud with few worms
30_1	9/22/2010	1106	178	GM	Blk	Gravel, pebble, mud, sand, cobble, worms, mostly rock stuck in mud
30_2	9/22/2010	1118	178	GM	Blk	Gravel, sticky mud, pebbles, cobble, sand, worms, rock stuck in mud
30_3	9/22/2010	1130	178	CM	Blk	All rock sizes suspended in mud with many worms

Table7: A breakdown and classification of dried, sieved, and weighed sediments from Site C.

Drop Number	Cobble	Very Coarse Gravel	Coarse Gravel	Medium Coarse Gravel	Pebble	Very Coarse Sand	Coarse Sand	Mud Silt	Megahabitat	Bottom Type	Biologicals
27_3	0%	0%	0%	0%	0%	0%	0%	100%	S	s	
28_1	0%	0%	0%	0%	0%	0%	0%	100%	S	s	w
30_1	0%	25%	19%	5%	4%	8%	7%	31%	S	m	w
30_2	0%	26%	18%	15%	10%	9%	4%	19%	S	m	w,o
30_3	45%	13%	5%	4%	3%	5%	11%	16%	S	m	w

Table 8: Site D wet sediment observations from ground-truthing

Drop Number	Date	Time	Depth_m	Observed Wet Sediment	Color	Notes at Sea (Site D)
31_1	9/22/2010	1314	90	M	Blk	No comment
32_1	9/22/2010	1301	138	M	Blk	No comment
33_1	9/22/2010	1246	205	M	Blk/Gr	Sticky mud, black stripes in green mud, urchins
34_1	9/22/2010	1228	245	M	Blk/Gr	Sticky black and green mud, urchins

Table 9: A breakdown and classification of dried, sieved, and weighed sediments from Site D.

Drop Number	Cobble	Very Coarse Gravel	Coarse Gravel	Medium Coarse Gravel	Pebble	Very Coarse Sand	Coarse Sand	Mud Silt	Megahabitat	Bottom Type	Biologicals ##
31_1	0%	0%	0%	0%	0%	0%	0%	100	S	s	
32_1	0%	0%	0%	0%	0%	0%	0%	100	S	s	
33_1	0%	0%	0%	0%	0%	0%	0%	100	F	s	o
34_1	0%	0%	0%	0%	0%	0%	0%	100	F	s	o

Table 10: Site E wet sediment observations from ground truthing

Drop Number	Date	Time	Depth_m	Observed Wet Sediment	Color	Notes at Sea (Site E)
37_1	9/20/2001	1520	147	M	Blk	Sticky mud, sand, urchins
37_2	9/20/2010	1532	150	SM	Gr/Blk	Sticky mud, sand, few worms
37_3	9/20/2010	1542	153	SM	Gr/Blk	Fine sand, green mud, silt, strips of black mud, few worms
38_1	9/20/2010	1405	131	SM	Gr	Very few living orgs in sample
38_2	9/20/2010	1417	132	SM	Gr	Very few living orgs in sample
38_3	9/20/2010	1427	130	SM	Gr	Very few living orgs in sample
39_1	9/20/2010	1311	152	M	Gr	Very few organisms in sample
39_2	9/20/2010	1323	146	Silt	Gr	Very few organisms in sample
39_3	9/20/2010	1335	147	S	Gr	Very few living organisms in sample

Drop Number	Date	Time	Depth_m	Observed Wet Sediment	Color	Notes at Sea (Site E)
40_1	9/20/2010	1200	117	SM	Blk	Sand mud very few signs of living orgs.
40_3	9/20/2010	1240	117	SM	Blk	Sand, very few signs of life
41_1	9/20/2010	1156	162	SM	Blk	Few liv orgs
41_2	9/20/2010	1707	157	SM	Blk	Very few liv orgs
41_3	9/20/2010	1240	157	SM	Blk	No comment
40_2	9/20/2010	1215	117	SM	Blk	Sand, very few signs of life

Table 11: A breakdown and classification of dried, sieved, and weighed sediments from Site E.

Drop Number	Cobble	Very Coarse Gravel	Coarse Gravel	Medium Coarse Gravel	Pebble	Very Coarse Sand	Coarse Sand	Mud Silt	Megahabitat	Bottom Type	Biologicals
37_1	0%	0%	0%	0%	0%	0%	0%	100	S	s	o
37_2	0%	0%	0%	0%	0%	0%	0%	100	S	s	w
37_3	0%	0%	0%	0%	0%	0%	0%	100	S	s	w
38_1	0%	0%	0%	0%	0%	0%	0%	100	S	s	
38_2	0%	0%	0%	0%	0%	0%	0%	100	S	s	
38_3	0%	0%	0%	0%	0%	0%	0%	100	S	s	
39_1	0%	0%	0%	0%	0%	0%	0%	100	S	s	
9_2	0%	0%	0%	0%	0%	0%	0%	100	S	s	
39_3	0%	0%	0%	0%	0%	0%	0%	100	S	s	

Drop Number	Cobble	Very Coarse Gravel	Coarse Gravel	Medium Coarse Gravel	Pebble	Very Coarse Sand	Coarse Sand	Mud Silt	Megahabitat	Bottom Type	Biologicals
40_1	0%	0%	0%	0%	0%	0%	0%	100	S	s	
40_3	0%	0%	0%	0%	0%	0%	0%	100	S	s	
41_1	0%	0%	0%	0%	0%	0%	0%	100	S	s	
41_2	0%	0%	0%	0%	0%	0%	0%	100	S	s	w
41_3	0%	0%	0%	0%	0%	0%	0%	100	S	s	
40_2	0%	0%	0%	0%	0%	0%	0%	100	S	s	