

**Survey report of NOAA Ship McArthur II cruises  
AR-04-04, AR-05-05 and AR-06-03:  
Habitat classification of side scan sonar imagery  
in support of deep-sea coral/sponge explorations  
at the Olympic Coast National Marine Sanctuary**

**U.S. Department of Commerce**  
National Oceanic and Atmospheric Administration  
National Ocean Service  
Office of Ocean and Coastal Resource Management  
**National Marine Sanctuary Program**



May 2007

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## **COVER**

Image of the Klein System 3000 side scan sonar used to image the seabed during the three separate mapping cruises, shown here with a KwingII depressor.

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## **ABSTRACT**

Habitat mapping and characterization has been defined as a high-priority management issue for the Olympic Coast National Marine Sanctuary (OCNMS), especially for poorly known deep-sea habitats that may be sensitive to anthropogenic disturbance. As a result, a team of scientists from OCNMS, National Centers for Coastal Ocean Science (NCCOS), and other partnering institutions initiated a series of surveys to assess the distribution of deep-sea coral/sponge assemblages within the sanctuary and to look for evidence of potential anthropogenic impacts in these critical habitats. Initial results indicated that remotely delineating areas of hard bottom substrate through acoustic sensing could be a useful tool to increase the efficiency and success of subsequent ROV-based surveys of the associated deep-sea fauna. Accordingly, side scan sonar surveys were conducted in May 2004, June 2005, and April 2006 aboard the NOAA Ship *McArthur II* to: (1) obtain additional imagery of the seafloor for broader habitat-mapping coverage of sanctuary waters, and (2) help delineate suitable deep-sea coral/sponge habitat, in areas of both high and low commercial-fishing activities, to serve as sites for surveying-in more detail using an ROV on subsequent cruises. Several regions of the sea floor throughout the OCNMS were surveyed and mosaicked at 1-meter pixel resolution. Imagery from the side scan sonar mapping efforts was integrated with other complementary data from a towed camera sled, ROVs, sedimentary samples, and bathymetry records to describe geological and biological (where possible) aspects of habitat. Using a hierarchical deep-water marine benthic classification scheme (Greene et al. 1999), we created a preliminary map of various habitat polygon features for use in a geographical information system (GIS). This report provides a description of the mapping and groundtruthing efforts as well as results of the image classification procedure for each of the areas surveyed.

## **KEY WORDS**

Benthic, habitat mapping, sediment classification, side scan sonar, textural analysis, deep-sea coral, essential fish habitat, Olympic Coast National Marine Sanctuary

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## INTRODUCTION

The offshore shelf and canyon habitats of the Olympic Coast National Marine Sanctuary (OCNMS) are areas of high primary productivity and biodiversity important to groundfish fisheries. Additionally, documentation of bioherms discovered off the nearby western Canadian continental shelf (Conway et al. 1991; Conway 1999; Conway et al. 2005; Jamieson et al. 2005) provided evidence that such fauna also likely existed in the waters off the Washington coast. These habitats are of tremendous value for their inherent biodiversity and as sites of recruitment for commercially important fishes. However slow growth rates, ease of disturbance, and long life spans make these communities extremely susceptible to destruction from anthropogenic disturbances such as bottom trawling and cable trenching, which have been shown to impact benthic communities by altering structure (Bergman et al. 1990; Auster et al. 1996; Brancato 2004; Brancato and Bowlby 2005) and removing benthic fauna (Brown et al. 2000).

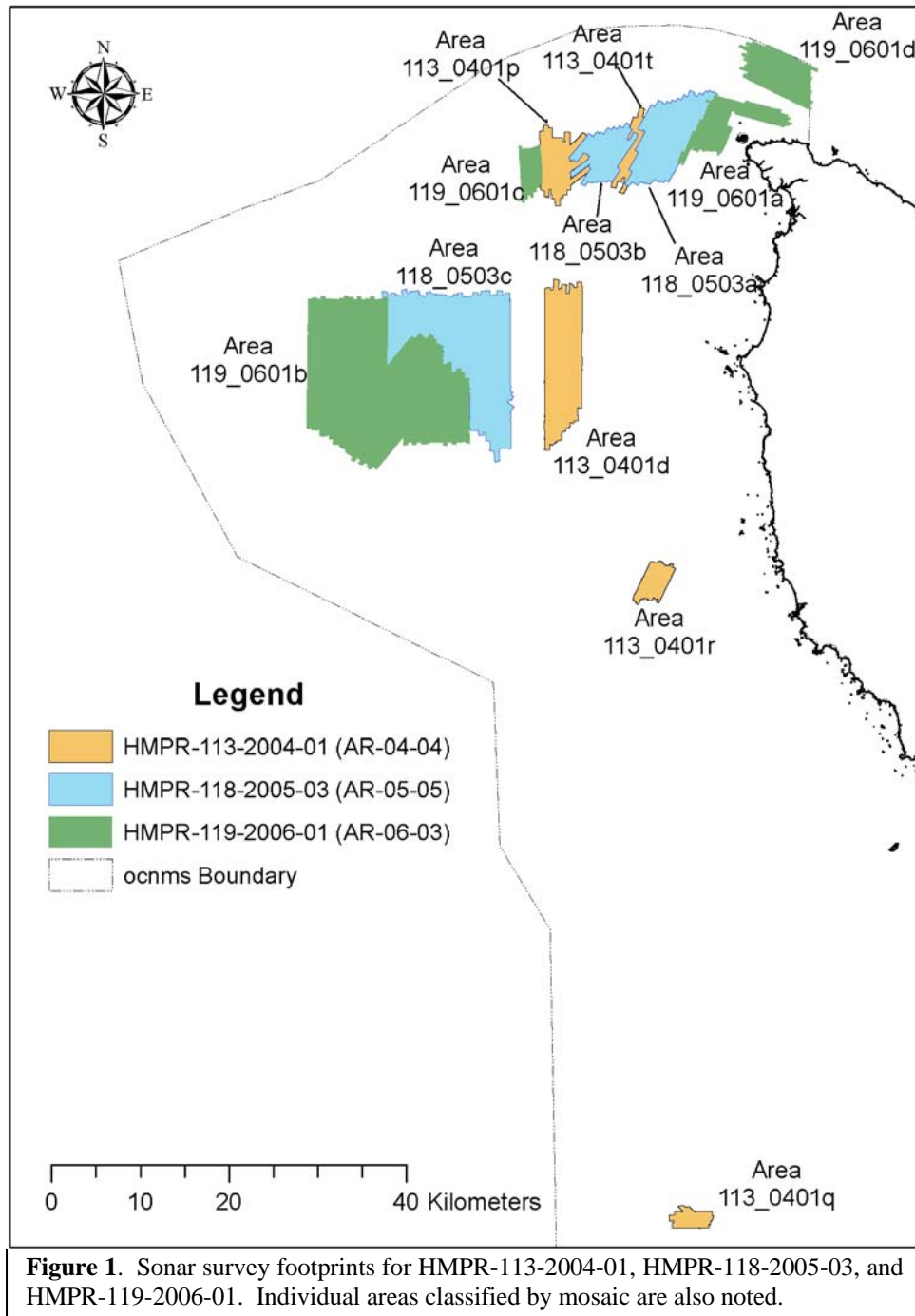
Potential effects of fishing and other commercial operations in such critical habitats, and the need to define appropriate strategies for the protection of these resources have been identified as a high-priority management issue for the sanctuary (Gittings et al. 2002). As a result, a team of OCNMS, NCCOS, and partnering scientists have conducted a series of submersible surveys since 2000 to evaluate benthic recovery from cable trenching, study the differences in benthic communities in relation to fishing intensity, and to document the presence of deep-sea coral/sponge assemblages at the OCNMS (Brancato 2004; Bowlby et al. 2005; Hyland et al. 2005). Although sampling coverage has been limited, results are significant in demonstrating the presence of deep-sea coral species in these waters (Brancato 2004; Bowlby et al. 2005; Hyland et al. 2005). Patches of rare stony corals, later confirmed as *Lophelia pertusa*, were discovered in an area that was defined as hard substrate by previous acoustic surveys.

It appeared that remotely delineating areas of hard bottom substrate through acoustic sensing could be a useful tool to increase the efficiency and success of subsequent ROV explorations for photographically documenting the presence and condition of deep-sea coral and sponge communities. As a result, side scan sonar surveys were conducted in May 2004, June 2005, and April 2006 aboard the NOAA Ship *McArthur II* to obtain additional side scan sonar imagery of the seafloor for broader habitat mapping coverage of sanctuary waters and to help delineate locations of suitable deep-sea coral/sponge habitat for revisiting and surveying in more detail using an ROV on subsequent cruises.

Several regions of the sea floor throughout the OCNMS were surveyed and mosaicked at 1-meter pixel resolution. We integrated video from a towed camera sled, ROVs, sedimentary samples, bathymetry data, and the side scan sonar mapping to describe geological and biological (where possible) aspects of habitat. With a hierarchical deep-water marine benthic classification scheme (Greene et al. 1999), we then created and attributed polygon features for use in a geographical information system (GIS). This report provides a description of the mapping and groundtruthing efforts as well as results of the image classification procedure for each of the areas surveyed.

## SURVEY AREA

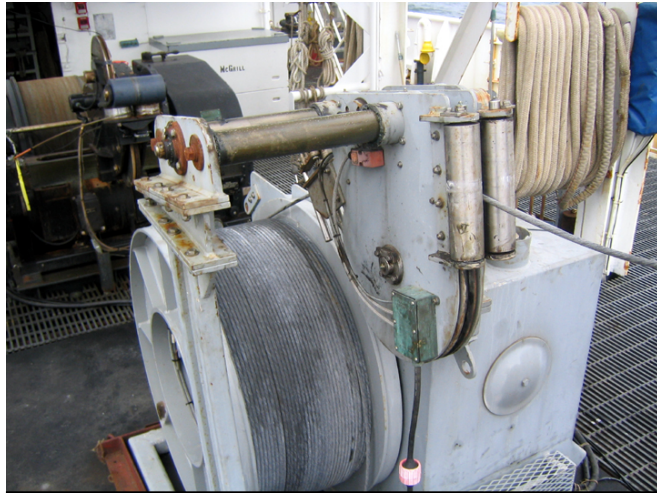
OCNMS conducted approximately 137 km<sup>2</sup>, 237 km<sup>2</sup>, and 341 km<sup>2</sup> of seafloor mapping surveys aboard the NOAA Ship *McArthur II* during cruises AR-04-04, AR-05-05, and AR-06-03, respectively (Figure 1). Survey records were obtained from May 22 - 31 in 2004, June 19-23 in 2005, and April 7-15 during 2006. Water depths ranged between 50 and 400 meters throughout the survey area. With the addition of these sonar records, approximately 26 percent of the benthic habitat within sanctuary waters has now been mapped using contemporary acoustic methods.



**Figure 1.** Sonar survey footprints for HMPR-113-2004-01, HMPR-118-2005-03, and HMPR-119-2006-01. Individual areas classified by mosaic are also noted.

## SONAR ACQUISITION AND DATA LOGGING

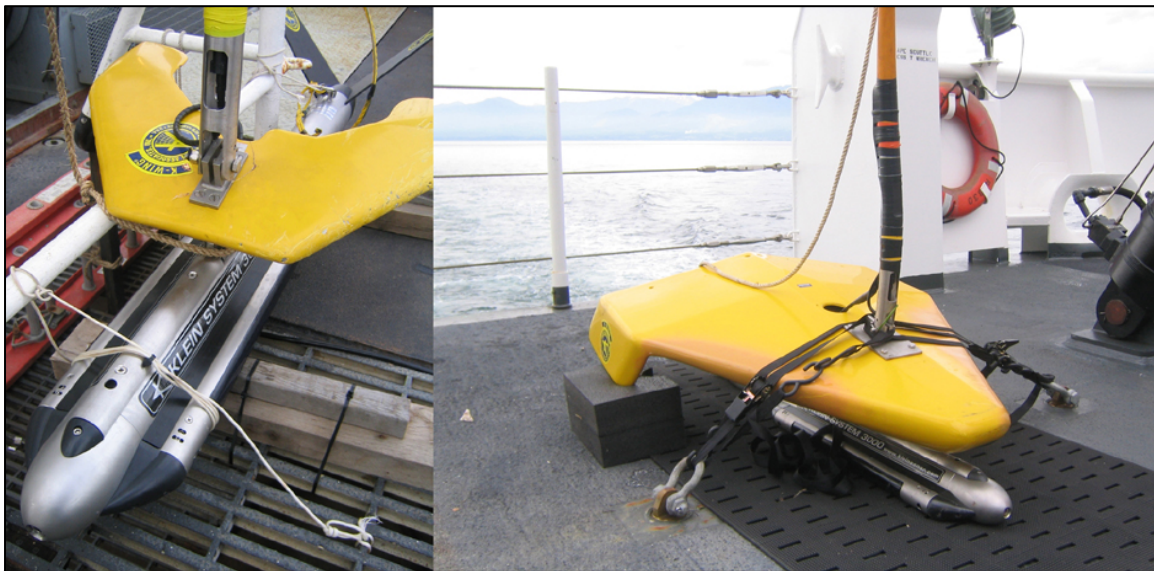
For all three cruises, the NOAA research vessel *McArthur II*, measuring 68.3 meters in length, was used as the survey platform. We acquired ship positioning with a Trimble DSM 212L differential GPS (DGPS) and controlled line planning through Hypack Max software. We estimated towfish position through use of a Red Lion digital cable counter mounted on the winch level wind (Figure 2).



**Figure 2.** Magnetic cable counter (green box) shown mounted to the level wind block. This device logged cable out data to assist with estimating towfish position.

We used a Klein System 3000 digital side scan sonar for acquiring the acoustic imagery. Only the 100 kHz

sonar channels were used for creating mosaics. The sonar system has a horizontal beam width of  $1.0^\circ$  at 100 kHz with a vertical beam width measuring  $40^\circ$ . Depressors were used to help drive the towfish to greater depths while deploying the least amount of cable in an effort to minimize layback offset and towfish positioning error. However, due to the deep water depths typically being surveyed (up to 400 m), a larger wing depressor was used after the 2004 survey to create a greater hydrodynamic force that would drive the towfish more effectively and thus reduce the cable needed to reach a given depth (Figure 3).



**Figure 3.** Klein System 3000 side scan sonar shown configured with the shallow-water KwingI depressor (left) and with the heavier KwingII depressor (right). Cruise AR-04-04 was conducted using the configuration shown on the left while cruises AR-05-05 and AR-06-03 were operated using the setup shown to the right.

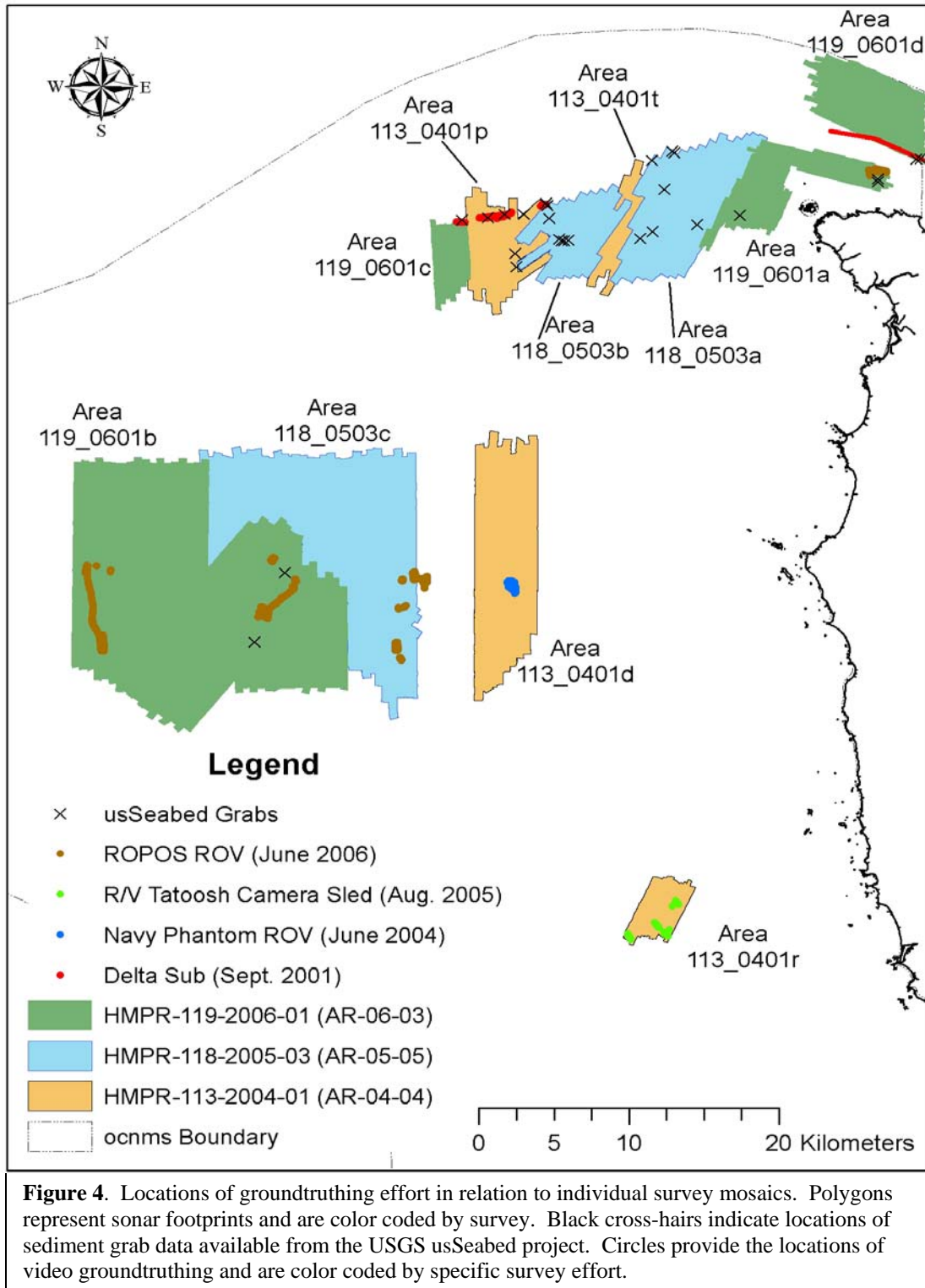
A 300-meter range scale was used in all survey areas except in areas 119\_0601c and 119\_0601d, where a 200-meter range was used, and in areas 113\_0401r and 119\_0601a where a 150-meter range scale was used. The areas surveyed with the 300-meter range scale were designed around 500-meter line-spacing plans, while the various areas surveyed with the 200-meter and 150-meter range scale were designed around 350 and 200-meter line-spacing plans respectively. We maintained vessel speed at between 3 and 3.5 knots for all operations. Sonar imagery was logged as 16 bit data with 2,048 samples per channel using Triton Imaging, Inc. (TII) Isis Sonar and recorded as eXtended Triton Format (XTF).

## **SONAR DATA PROCESSING AND IMAGE CLASSIFICATION**

The navigation data were smoothed in Isis Sonar using a combination of a Kalman filter and an 11-point moving average filter. We accomplished slant range correction and bottom tracking in Isis Sonar, in addition to the application of time-varied gain and beam angle compensation curves. We imported individual line mosaics into TII's DelphMap, merged them into separate mosaics for each survey block and then exported them as geotiff images. Image homogeneity and entropy were calculated for each mosaic using custom designed software (Cochrane and Lafferty 2002). Mosaics from the side scan packets, entropy and homogeneity images were all layer stacked in Erdas Imagine to create multi-spectral images. A supervised classification was performed using a maximum likelihood decision rule to produce a final classified image (Intelmann et al. 2006; Intelmann and Cochrane 2006) consisting of three broad sediment classes comprised of hard (rock or boulder), soft (sand, silt, clay or mud), and mixed (harder sediment such as gravel, pebble, cobble and boulder mixed with soft sediment). Adobe Photoshop was then used to edit misclassified data such as those occurring at nadir or in other various areas such as misclassified side lobes or shadows. Raster images were then smoothed with a low pass filter and converted to Features in ArcGIS where video groundtruthing was further used to enhance classification by describing microhabitat in more detail and adding roughness components and biological information where available (Greene et al. 1999).

## **GROUNDTRUTHING**

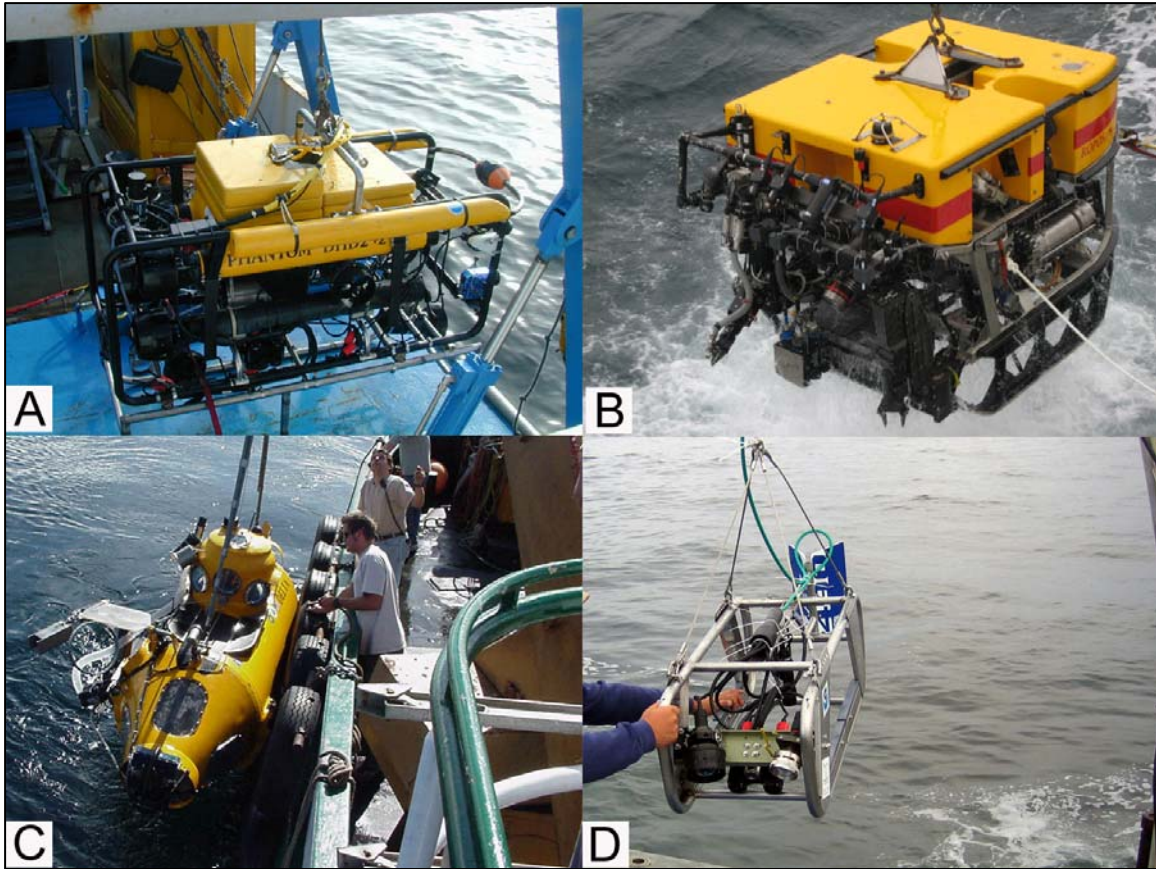
Video data acquired during four separate OCNMS missions and grab samples extracted from the usSeabed project (Reid et al. 2006), provided some degree of groundtruthing validation for all of the sonar mosaics except 113\_0401t (Figure 4). In September 2001, the *Delta* submersible (Figure 5C) was deployed from the *R/V Auriga* in an effort to monitor benthic recovery processes after installation of two fiber optic cables that intersected sanctuary waters. Video from the *Delta* operations was used to help with classification of survey areas 113\_0401p and 119\_0601c. In June 2004, the US Navy's Phantom DHD2+2 ROV (Figure 5A) was deployed from the NOAA Ship *McArthur II* to conduct the pilot survey of deepwater coral/sponge assemblages at OCNMS (Hyland et al. 2005). Although positioning of the ROV was less than desirable due to the Trackpoint II and Winfrog acquisition filtering setup, the imagery from this operation was still quite



**Figure 4.** Locations of groundtruthing effort in relation to individual survey mosaics. Polygons represent sonar footprints and are color coded by survey. Black cross-hairs indicate locations of sediment grab data available from the USGS usSeabed project. Circles provide the locations of video groundtruthing and are color coded by specific survey effort.

useful as a groundtruthing tool and to further classify the sonar imagery according to Greene et al. 1999. In August 2005, we used a custom designed camera sled (Figure 5D)

to acquire underwater videography for validating several shallow-water sonar surveys, including data from the “Quileute rock pile”, which was the shallow-water area 113\_0401r. And finally, in May/June 2006, the Canadian Scientific Submersible Facility’s (CSSF) ROPOS ROV (Figure 5B), under contract to Canpac, was deployed from the NOAA Ship *McArthur II* as a follow-up effort to the 2004 coral/sponge exploration. The IXSEA GAPS system that was used for underwater positioning of the ROPOS provided the most reliable positioning information for any of the groundtruthing efforts. Video from the ROPOS survey was used to groundtruth mosaics 118\_0503c, 119\_0601a and 119\_0601b. Additionally, the greater stability of the ROPOS, along with higher quality underwater positioning and video equipment, permitted selected clips of video to be mosaicked into plan-perspective images by co-registering adjacent video frames into a single mosaic on a basis of pair-wise transformations (Rzhanov et al. 2006) that were ultimately georeferenced to provide more thorough sonar interpretation. Although not available in every survey block, the usSeabed project (Reid et al. 2006) provided many samples as further weight of evidence for the video and sonar interpretation.



**Figure 5.** Groundtruthing platforms. Several operations between 2001 and 2006 provided useful video imagery of the seafloor for groundtruthing validation and permitted more descriptive habitat characterization in certain areas. Data was acquired from a wide variety of platforms including two ROVs, the Navy’s Phantom DHD2+2 in June 2004 (inset A) and the CSSF ROPOS (inset B) in June 2006, the Delta manned-submersible vehicle (inset C) in September 2001, and a custom-designed towed-camera sled (inset D) in August 2005.

## SURVEY RESULTS AND INTERPRETATION

We acquired over 335 linear km of survey lines aboard the NOAA Ship *McArthur II* in 2004 (Table 1), 523 km of sonar survey lines in 2005, and over 803 km during the 2006 mapping effort. Between the three cruises nearly 273 hours of actual logged sonar records were acquired.

**Table 1.** Below are the survey effort statistics for HMPR-113-2004-01 (AR04-04), HMPR-118-2005-03 (AR-05-05) and HMPR-116-2005-01 (AR-06-03). Data were acquired aboard the NOAA Ship *McArthur II* using a Klein 3000 side scan sonar. Five areas were surveyed in 2004, three in 2005, four in 2006. Area is presented in square kilometres, length of linear track lines in kilometres, and hours of actual logged sonar packets in hours, minutes, and seconds.

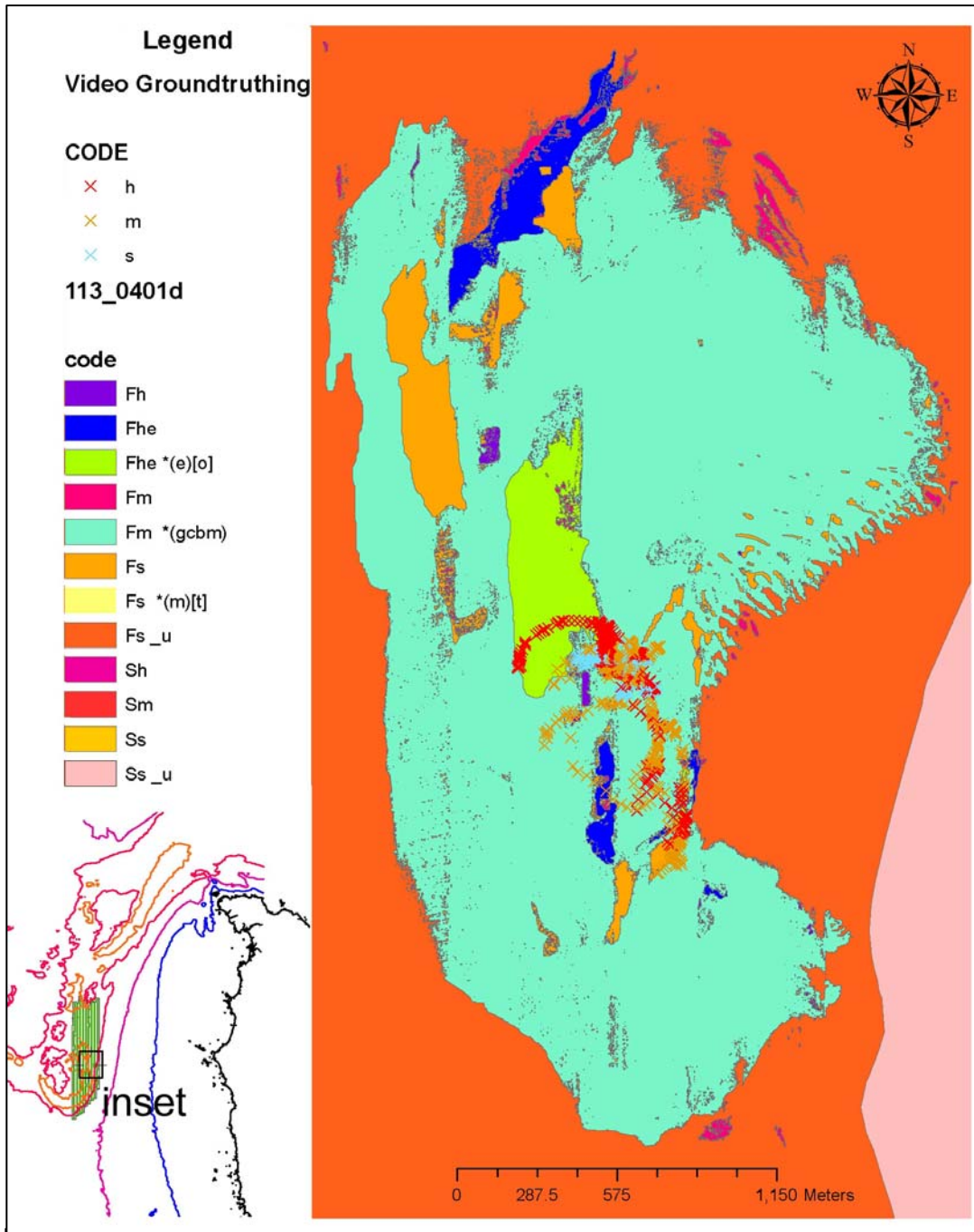
Year	Block	Date	Area (km <sup>2</sup> )	Tracks (km)	Hours (h:m:s)
2004	113_0401d	May 25-28	69.6	150.4	23:42:49
	113_0401p	May 28-30	30.8	70.0	10:39:45
	113_0401q	May 22	8.7	24.9	3:57:35
	113_0401r	May 24-25	13.3	64.3	10:20:30
	113_0401t	May 31	15.2	26.0	5:23:13
<b>Total</b>			<b>137.6</b>	<b>335.6</b>	<b>54:03:52</b>
2005	118_0503a	June 16-17	57.9	121.1	19:07:43
	118_0503b	June 18-19	29.1	63.7	9:50:35
	118_0503c	June 19-23	149.9	338.2	53:31:21
<b>Total</b>			<b>236.9</b>	<b>523.0</b>	<b>82:29:39</b>
2006	119_0601a	April 7-8	34.4	139.8	24:45:21
	119_0601b	April 9-13	253.2	516.5	85:56:27
	119_0601c	April 13	13.3	37.9	7:19:29
	119_0601d	April 14-15	37.8	109.7	18:20:23
<b>Total</b>			<b>33.62</b>	<b>803.9</b>	<b>136:21:40</b>

The Appendices present all side scan sonar mosaics, the full-scale attributed polygon layers showing the distribution of truncated habitat codes (due to the large number of possible categories when displaying the full habitat code) and matrix tables providing the descriptions of the habitat classification (with exception of slope, complexity, and microhabitat) per Greene et al. (1999) for each of the areas surveyed during cruises AR-04-04, AR-05-05 and AR-06-03.

### HMPR-113-2004-01 (Cruise AR-04-04)

Survey block 113\_0401d is located along the eastern edge of the Juan de Fuca Canyon wall and was characterized as over 90 percent soft (s), silty substrate (Table 2). There was one significant area of harder substrate (shown in Figure 6) at the base of the canyon slope in the southern portion of the survey area that consisted of mostly gravel, cobbles, and mixed boulders along with an exposed bedrock scarp. Several patches of *Lophelia pertusa* coral were later identified in a boulder field along the eastern edge of this rock

ledge through video captured by ROV (Hyland et al. 2005). No contemporary high resolution multibeam data existed in the 113\_0401d survey area, and as such, slope and



**Figure 6.** Example of habitat classification results for a selected region of the side scan sonar survey area 113\_0401d acquired during the NOAA Ship *McArthurII* cruise AR-04-04. Location of inset region is shown as the black hashed polygon at lower left where the individual sonar track lines are shown in green. Contours of large scale map range from -50 meters (blue line) to -400 meters depth (yellow line). Colored cross hairs (X) define bottom hardness as interpreted through video, where h=hard, s=soft, and m=mixed sediment. Polygons codes are taken from Greene et al (1999); where F=flank, S=continental shelf megahabitat, h=hard, m=mixed, s=soft bottom hardness, e=exposed bedrock, \_u=unconsolidated sediment modifier. Letters following asterisks are determined from video observations and refer to microhabitat classification where g=gravel, c=cobble, m=mud, t=tube worms, o=other sessile organisms.

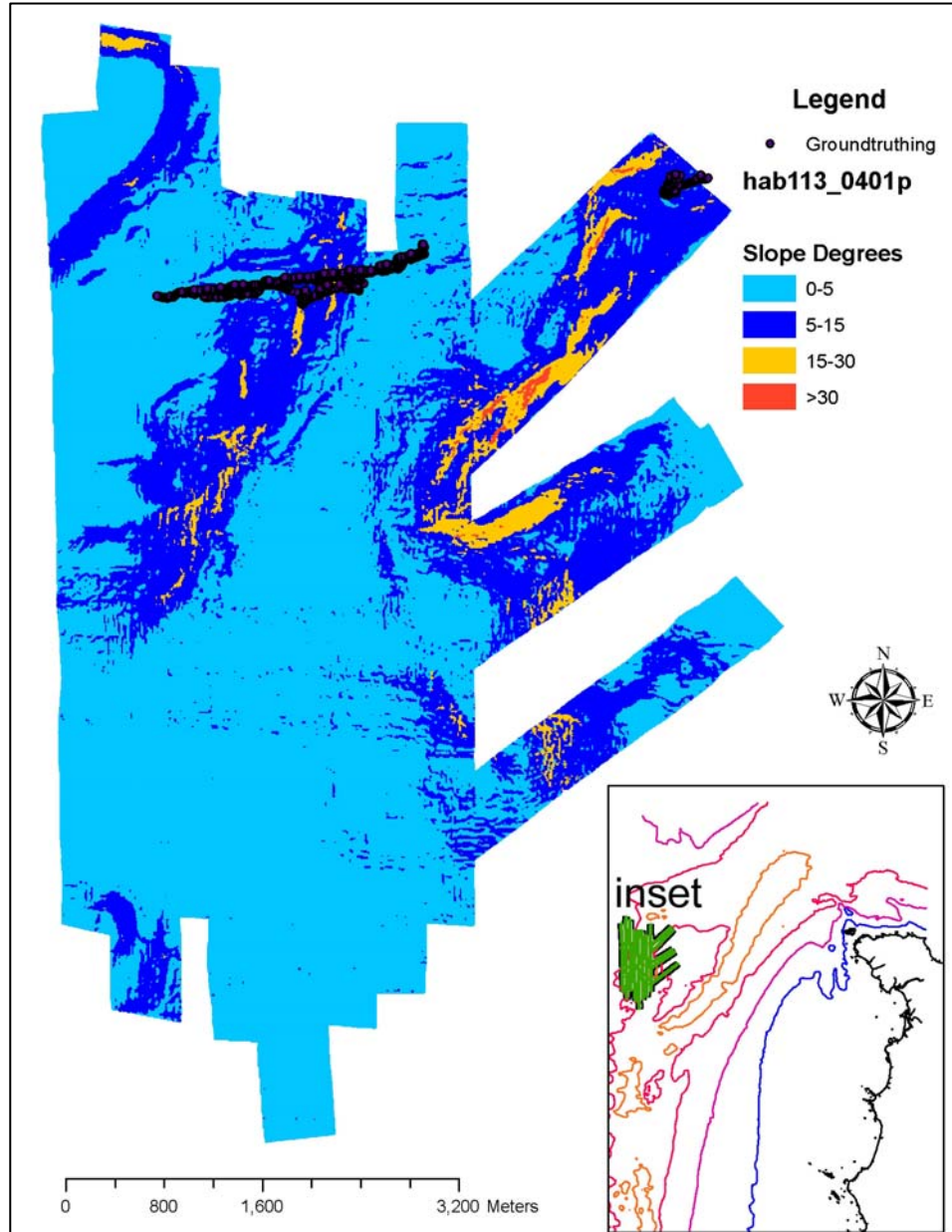


**Table 2.** Distribution of bottom hardness for each sonar mosaic classified from survey HMPR-113-2004-01. See Figure 1 for area locations. Bottom hardness codes are hard (h), mixed (m) and soft (s) – see previous section for description of classes. Area is presented in square meters (top value) and percentage of each individual mapped area (bottom bold value in the matrix).

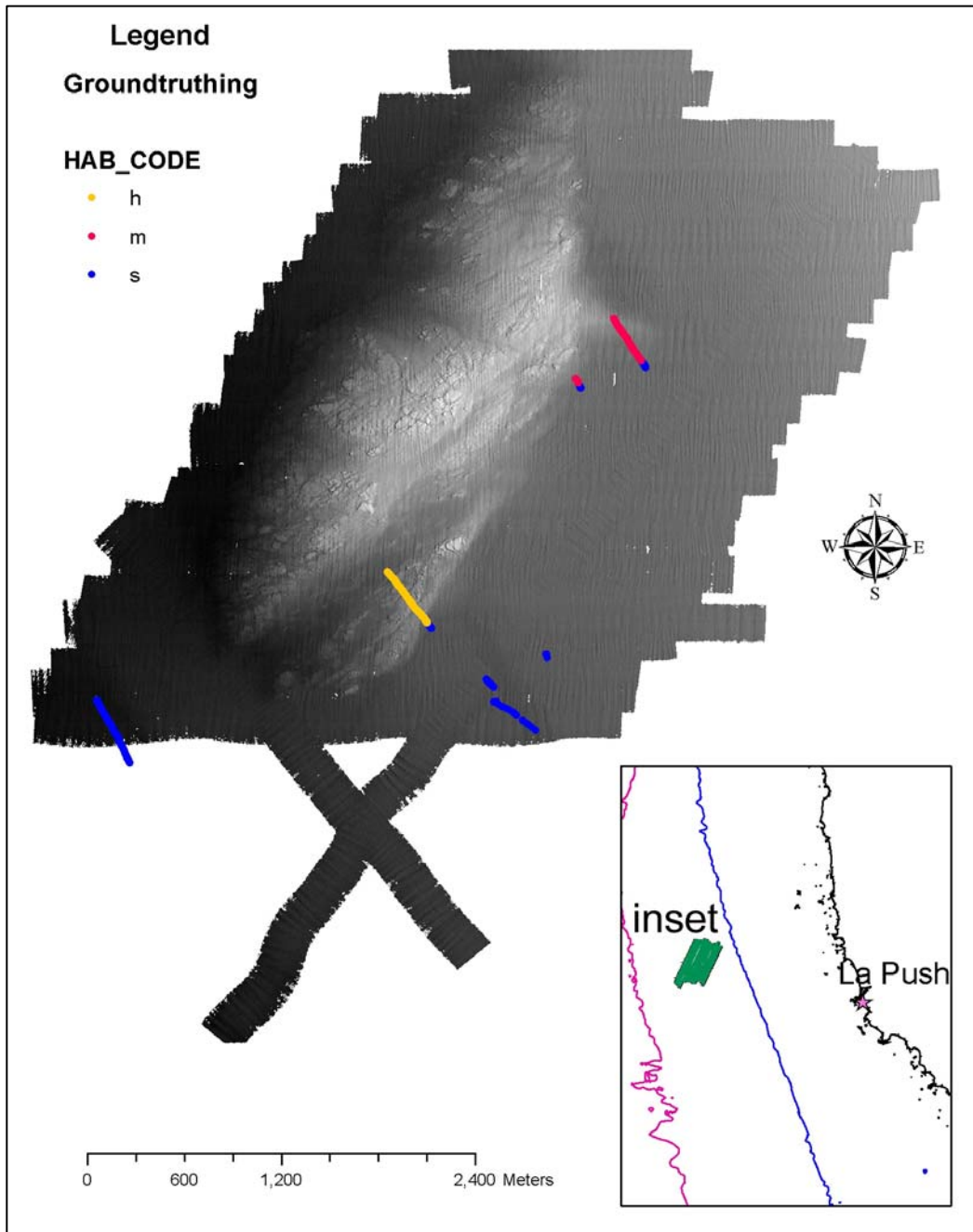
Cruise	Survey Block	h	m	s
AR-04-04	113_0401d	482,945.0 <b>0.69</b>	5,884,356.0 <b>8.45</b>	63,250,477.0 <b>90.85</b>
	113_0401p	92,514.0 <b>0.00</b>	15,932,845.3 <b>51.86</b>	14,693,506.7 <b>47.83</b>
	113_0401q	1,207,432.0 <b>13.8</b>	274,922.0 <b>3.15</b>	72,411,394.0 <b>82.97</b>
	113_0401r	3,989,073.0 <b>30.0</b>	1,739,324.1 <b>13.08</b>	7,567,162.9 <b>56.91</b>
	113_0401t	366,082.0 <b>2.42</b>	9,835,471.0 <b>65.10</b>	4,900,729.0 <b>32.44</b>

complexity fields have not been populated at this time. There were only a few areas of hard bottom in area 113\_0401p, which occurred in the high slope areas shown in Figure 7. Slightly more than half of the 113\_0401p mosaic was classified as mixed sediment (Table 2) with the video groundtruthing indicating this as being cobble and gravel mixed with sand, although several areas of mixed boulder fields were also noted. Large areas of homogeneous seafloor were classified as mud based on a limited amount of video coverage. Area 113\_0401q, the southern-most area in the sanctuary surveyed during the three cruises, covered only a relatively small region (roughly 8 km<sup>2</sup>) at the head of Quinault Canyon. Textural classification of this imagery suggested that 83 percent of the seafloor in this area was soft sediment, although there was a significant band of bedrock following the contours of the canyon wall. Video groundtruthing of this rock wall was attempted during 2004 using the Phantom DHD2+2 ROV, but unfortunately only a mere glimpse of the wall was captured due to swift currents which made it difficult to keep this small ROV on station. Located entirely on the continental shelf, the area known as the Quileute “rock pile” was also surveyed during AR-04-04 (113\_0401r). Side scan imagery for this area was classified as 30 percent rock outcrop and 57 percent soft sediment (Table 2). Mixed sediment was identified along the periphery of the outcrop and interspersed throughout the main rock feature. Figure 8 provides a shaded relief model of the “rock pile” feature and locations where groundtruthing video was acquired using a towed camera sled during August 2005 from the *R/V Tatoosh*. The multibeam bathymetry data available for this area was collected in October 2001 using an Elac 1050D echosounder onboard the NOAA Ship *Rainier*. Mosaic 113\_0401t was located about 12 km directly west of Cape Flattery and consisted of just four lines of side scan

data to fill a gap between two other previously surveyed areas. This area was also previously surveyed with multibeam bathymetry in October 2002. Although just 2 percent of this mosaic was classified as hard sediment (Table 2), a prominent exposed outcrop greater than one kilometer in length can be found in the southern portion of the imagery (see Appendix).



**Figure 7.** Habitat classification of mosaic 113\_0401p based on slope criteria. Slope classes are modified from Greene et al. (1999). High slope areas are shown in orange and are classified as hard bottom. Purple spheres show the location of video groundtruthing captured in September 2001 using the Delta submersible manned-vehicle. The inset image shows the survey location in relation to Cape Flattery. Bathymetry contours on large scale map range from -50 meters (blue line) to -400 meters (yellow line) depth. Slope data were calculated from multibeam data collected in 2002 using an Elac 1050D echosounder onboard the NOAA Ship *Rainier*.



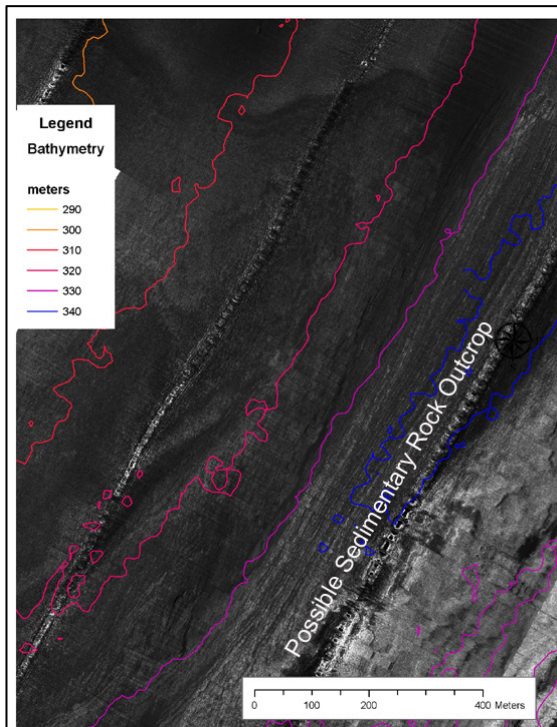
**Figure 8.** Shaded relief model featuring the Quileute “rock pile” offshore from LaPush, WA. Colorized spheres show the location of video groundtruthing captured in August 2005 using a custom-designed camera sled towed from the *R/V Tatoosh*. The ripple-like features visible in the flat areas of the multibeam data are heave artifacts resulting from motion sensor timing latency issues.

HMPR-118-2005-03 (Cruise AR-05-05)

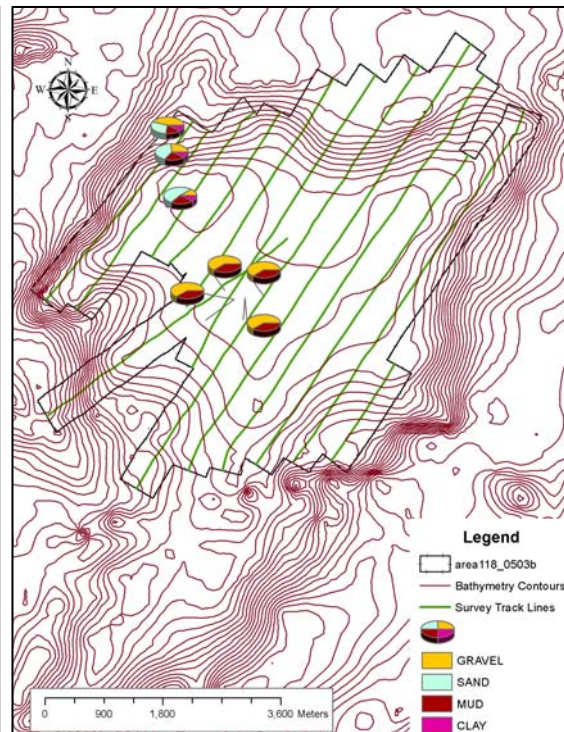
Three different areas were surveyed during the month of June 2005. Block 118\_0503a was located just 5 km offshore of Tatoosh Island. Being so near the entrance to the Strait of Juan de Fuca, this proved to be an extremely challenging area to conduct side scan sonar operations due to the water depth and extreme tide-induced currents that caused excessive movement of the towfish, even when using the large KwingII depressor. The imagery suffered significant degradation due to both pitch and roll of the towfish. Even though previous multibeam bathymetry data was acquired in this area during 2002 and 2003, sonar interpretation had to be made without any video groundtruth validation. Although 12 grab samples were available for this area from the usSeabed database (Reid et al. 2006), they provided little assistance with enhancing interpretation. The hummocky terrain that occurs throughout a good portion of the mosaic makes it even more difficult to distinguish shadows from soft sediment. Although results of the textural classification suggested that only 5 percent of this area was characterized as hard bottom (Table 3), video groundtruthing is needed to refine the habitat classification of this mosaic. Several uncertain features need to be examined in more detail to increase confidence in the classification, such as the linear features visible in Figure 9 that resemble typical wood grain-like sedimentary rock outcrops. Similar to area 118\_0503a, no video groundtruthing was available for mosaic 118\_0503b. However, since this area covered the top of a plateau (Figure 10) and the side scan sonar records were typical of mixed sediment class, the few grab samples available from the usSeabed database provided ample assurance for classification. The mosaic was characterized by minimal hard bottom (< 1 percent) with the majority of pixels falling into the mixed sediment class (Table 3). Area 118\_0503c was another difficult area to survey with towed side scan sonar due to the steep canyon walls. Survey lines had to be run in multiple directions to safely acquire data without smashing the towfish into the seafloor. Many lines could only be accomplished by flying the towfish in a down slope direction. Several rock outcrops occurred in this area, however the mosaic was essentially classified as half soft sediment and half mixed sediment (Table 3).

**Table 3.** Distribution of bottom hardness for each sonar mosaic classified from survey HMPR-118-2005-03. See Figure 1 for area locations. Bottom hardness codes are hard (h), mixed (m) and soft (s) – see previous section for description of classes. Area is presented in square meters (top value) and percentage of each individual mapped area (bottom bold value in the matrix).

Cruise	Survey Block	h	m	s
AR-05-05	118_0503a	2,889,857.0 <b>5.00</b>	26,048,737.6 <b>45.09</b>	28,836,707.5 <b>49.91</b>
	118_0503b	165,997.0 <b>0.57</b>	25,633,750.9 <b>88.39</b>	3,200,722.0 <b>11.04</b>
	118_0503c	3,683,781.4 <b>2.46</b>	80,263,060.0 <b>53.53</b>	65,996,188.6 <b>44.01</b>



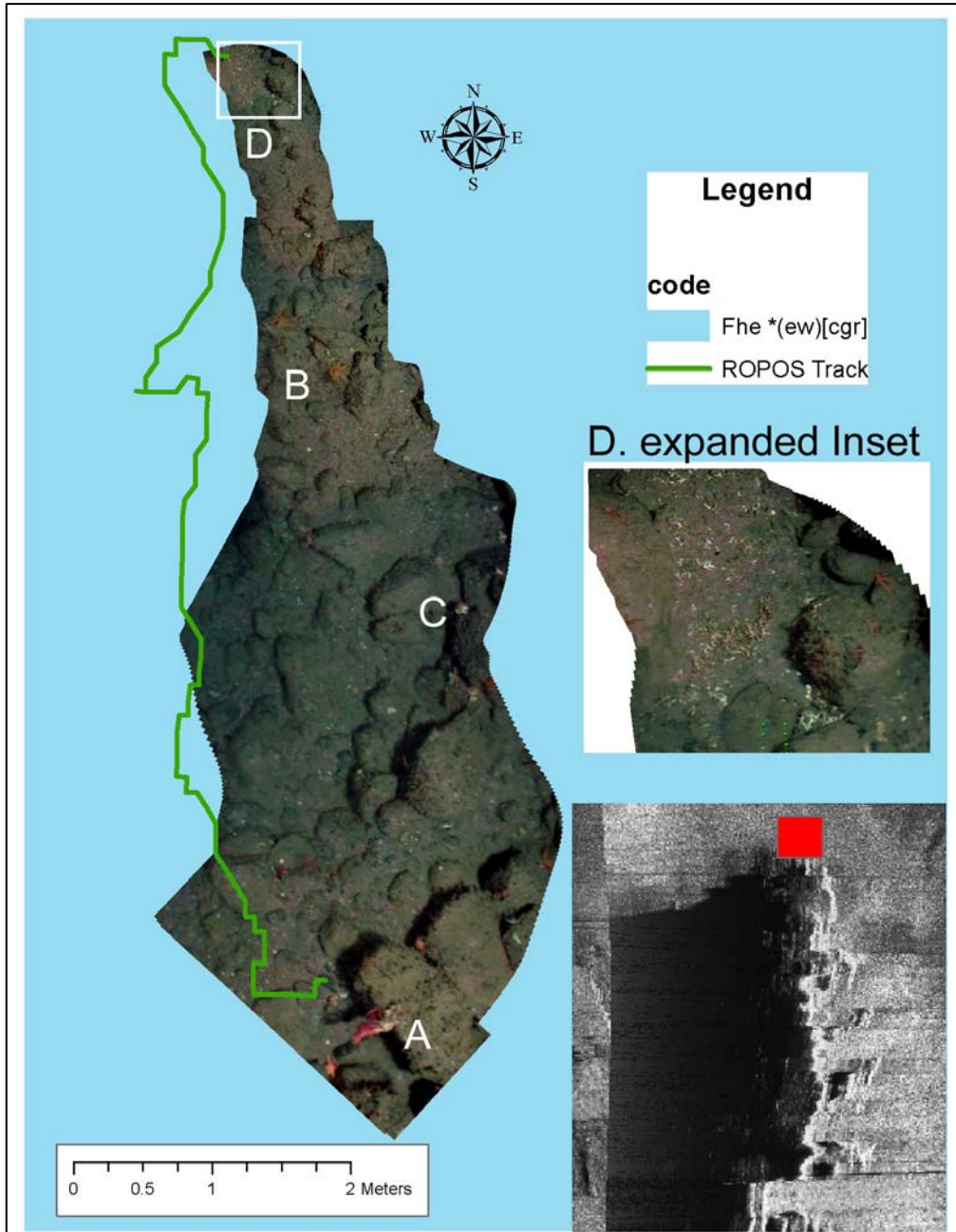
**Figure 9.** Example of an uncertain feature requiring further video groundtruthing for better confirmation. Note the linear striations paralleling the 340-meter contour (blue line), which resemble sedimentary rock layering.



**Figure 10.** Area118\_0503b footprint (black outline) shown with sonar track lines (green) and results of sediment grabs. Note the large percentage of gravel in each grab, and the top of plateau evident from the red contour lines.

In June 2006, over 22 hours of video was acquired in the same area covered by mosaic 118\_0503c using the ROPOS ROV aboard the NOAA Ship *McArthur II*. These video data were of high quality, assisting greatly with validation of the sonar records collected during AR-05-05. Using software designed at the Center for Coastal Ocean Mapping (CCOM), University of New Hampshire (UNH), 29 small clips of video acquired at selected locations throughout this survey area were mosaicked into seamless images and later georeferenced to provide a clearer context of the sediment structure thereby facilitating sonar validation and habitat classification to a greater extent than would be possible through simple video still frame extractions. The video mosaics, for example, were useful in correcting the maximum likelihood classification in several areas where apparent shadows were actually small pockets of soft sediment. Such small scale pockets would not be notable from an individual still-frame extraction, but become immediately apparent through the broader perspective provided by a mosaicked video stream. Additionally, with use of the 300-meter range scale, less rugose boulder fields are often misclassified as mixed sediment due to the associated slower ping rates that produce lower resolution imagery. The data in Figure 11 provide a good example of a region where the flank of a rock outcrop was initially classified as mixed sediment hardness, but through use of the video mosaicking technique, it became apparent that the bottom of this

gully was actually filled with boulders, providing substrate for gorgonians and *Lophelia pertusa*.



**Figure 11.** Selected clip of mosaicked video showing a hard-bottom boulder patch with a visible gorgonian (A), crinoids (B), sponges (C), and *Lophelia pertusa* (D - inside white box and shown in expanded inset). The CCOM UNH process takes into account both scaling and rotation factors and uses pair-wise transformations to seamlessly stitch individual video frames. A rock outcrop is clearly visible in the side scan sonar record shown in the bottom inset. The red box (measuring 35 meters in width) shows the relative position of the classified polygon feature, overlain with an 11-meter long strip of mosaicked video. The green line represents the navigational path of the ROPOS ROV. This particular polygon (blue) was classified (see code) as flank, hard exposed wall, with cobble, gravel, and rockfish being present.

HMPR-119-2006-01 (Cruise AR-06-03)

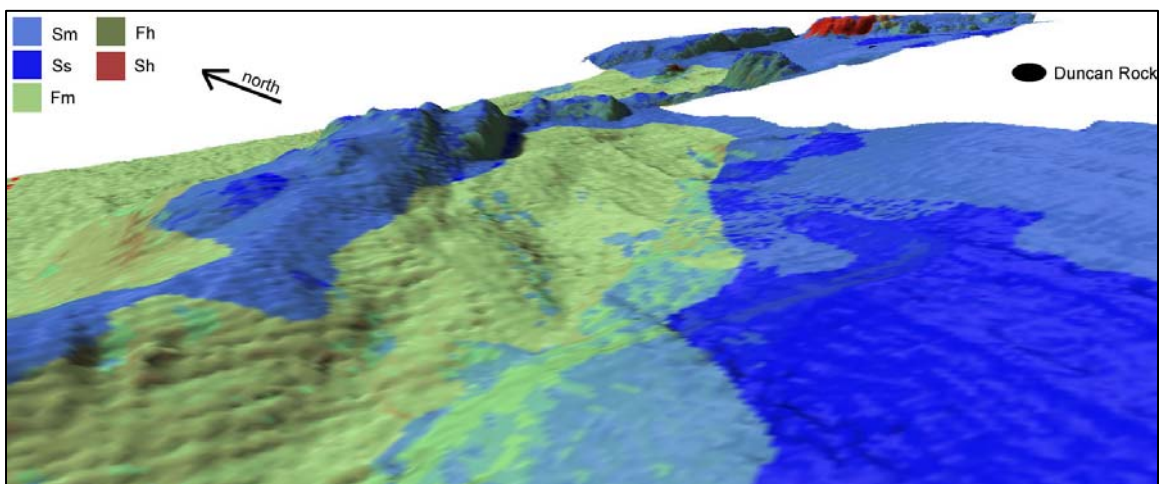
Area 119\_0601a was located offshore of Cape Flattery. In general, the northern half of the mosaic was classified as mixed sediment consisting of gravel, pebble, cobble and scattered boulders while the southern portion of the area was soft sand and mud. There were two main features of hard bottom evident in the side scan sonar and bathymetry data. One band of rock outcropping paralleled Chibahdehl Rocks approximately one mile offshore, while the other occurred just off Duncan Rock and continued in a northwesterly direction for nearly 3 kilometers (Figure 12).

No high-resolution multibeam bathymetry data have been acquired at survey area 119\_0601b. The western edge of this survey area was defined as large boulders and cobbles, with the video data revealing minimal encrustation but having high densities of large ling cod. Several patches of sediment waves were also visible in the side scan sonar and video records, indicating swift currents are present in this region of the Juan de Fuca canyon. The soft sediment classified in the eastern side of the area is a very fine silt/mud. Several gorgonians were found on boulders along the southeastern edge of the mosaic, and sediment covered pebble and cobble existed throughout.

Very little hard bottom was classified in mosaics 119\_0601c or 119\_0601d (Table 4), thus suggesting a low likelihood of habitat suitable for coral or sponge communities. In fact, area 119\_0601d, located at the very eastern edge of the sanctuary boundary in the Strait of Juan de Fuca, was over 90 percent flat bottom (< 5 percent slope) and was classified as almost entirely mixed pebble with cobble but having a small area of soft sediment and a few scattered areas of hard rock. Several submarine cables were also identifiable in the sonar imagery.

**Table 4.** Distribution of bottom hardness for each sonar mosaic classified from survey HMPR-119-2006-01. See Figure 1 for area locations. Bottom hardness codes are hard (h), mixed (m) and soft (s) – see previous section for description of classes. Area is presented in square meters (top value) and percentage of each individual mapped area (bottom bold value in the matrix).

Cruise	Survey Block	h	m	s
AR-06-03	119_0601a	2,205,347.0 <b>6.41</b>	17,188,222.2 <b>50.0</b>	14,967,752.8 <b>43.6</b>
	119_0601b	8,614,082.1 <b>3.40</b>	172,527,478.3 <b>68.1</b>	72131056.6 <b>28.47</b>
	119_0601c	13,059.0 <b>0.09</b>	6,842,935.9 <b>51.46</b>	6,442,094.9 <b>48.44</b>
	119_0601d	220,125.3 <b>0.58</b>	36,864,423.6 <b>97.65</b>	664,909.0 <b>1.76</b>



**Figure 12.** Example of habitat classified attributed polygon data draped over shaded relief bathymetry data in area 119\_0601a. The hard exposed rock outcrop visible in the foreground is the northwesterly trending rock band off of Duncan Rock. Sun illumination is modeled using a 315 degree azimuth, 17 degree vertical angle, and 2x vertical exaggeration. S=Shelf, F=Flank, m=mixed, s=soft, h=hard.

## SUMMARY

The side scan sonar imagery acquired during research cruises AR-04-04, AR-05-05, and AR-06-03 provided valuable information to broaden our knowledge of seafloor substrate distribution in OCNMS waters. Another underlying objective of the sonar imagery acquisition was to provide supporting data for conducting subsequent video explorations with hopes of identifying deep-sea coral/sponge communities. A literature search indicated that most prior records of deep-sea coral, especially in neighboring western Canadian waters, are at depths of about 100-500 meters (Alfonso and McAllister 2000; Jamieson et al. 2005). As such, the present survey work at OCNMS was conducted in water depths from 100 to 400-meters. Also, areas within the sanctuary deeper than 400 meters are located in very steep canyons where it is quite difficult to maintain quality side scan sonar records due to both towfish movement and the underwater positioning and winch limitations. At these water depths, some type of wing-depressor was needed for all operations, although it was determined that a larger and heavier wing depressor produced the best imagery by creating increased hydrodynamic forces and greater downward pressure on the towfish in addition to reducing the amount of cable paid out which ultimately increased positional certainty under the layback algorithm.

In general, we chose to use a 300-meter range scale for most of the survey operations. This allowed us to cover as much area as possible with a given line while still being able to delineate hard rocky areas from mixed substrate and soft muddy bottom, even when pinging at just 2.5 times per second. This range scale additionally allowed us to fly the towfish at altitudes approaching 60-meters which was imperative in the canyon areas to avoid damaging the sonar by contact with the seafloor.



It is important to note that the small coral colonies that were found are not capable of being identified from side scan sonar imagery itself when using the frequency and range scales as described in this report. Instead, structures on the sea floor were identified that fit the requirements of coral growth, such as depth, rugosity and substrate type. Such use of acoustic meso-scale sampling proved to be a highly successful means for delineating hard bottom substrate suitable as habitat for deep-sea coral/sponge assemblages. Through examination of three years of deep-towed, side scan sonar mosaics, 48 sites were selected to investigate in greater detail using the ROPOS ROV during the subsequent June 2006 survey. Of these 48 selected sites, 15 were actually visited and 14 (93 percent) produced some sighting of coral or sponge.

Thus it is evident that having a more thorough understanding of the distribution and location and benthic substrates can lead to more efficient ROV operations by increasing the chances of success at finding a target object dependent upon a specific sediment association. This becomes increasingly important when considering the cost associated with an ROV deployment in deep water.

## ACKNOWLEDGMENTS

These surveys would not have been possible without the side scan winch and various peripherals made available by the staff of the USGS's Marine Facility in Redwood City, CA, or towfish from the NOAA Ship *RAINIER* and the Office of Coast Survey. The authors would also like to thank NOAA's National Undersea Research Program for partially funding the 2006 survey, and Nicholas Perry, Danny Shaylor, Peter Noto, James Whitaker, and Tim Jamison for assisting with sonar data acquisition.

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## APPENDIX

### Appendix 1. Isis Processing Parameters

#### HMPR-113-2004-01

Lateral Offset: -4.26m

Layback Offset: 13.7m

Heading= use Gyro with offset of 23 degrees

Mosaic resolution: 1.0m

Apply BAC

TVG: start at first return

$$\text{Curve} = 1.4 + 0.022 + (-2)$$

#### HMPR-118-2005-03

Lateral Offset: -3.3m

Layback Offset: 12.5m

Heading= use CMG

Mosaic resolution: 1.0m

Apply BAC

Duration Distance=294m

TVG: start at first return

$$\text{Curve} = -2 + 0.09 + 1$$

Threshold=5

#### HMPR-119-2006-01

Lateral Offset: -3.3m

Layback Offset: 12.5m

Heading= use CMG

Mosaic resolution: 1.0m

Apply BAC

TVG: start at first return

$$\text{Curve} = -2 + 0.09 + 1$$

Threshold=5

Duration Distance 119\_0601a=145m

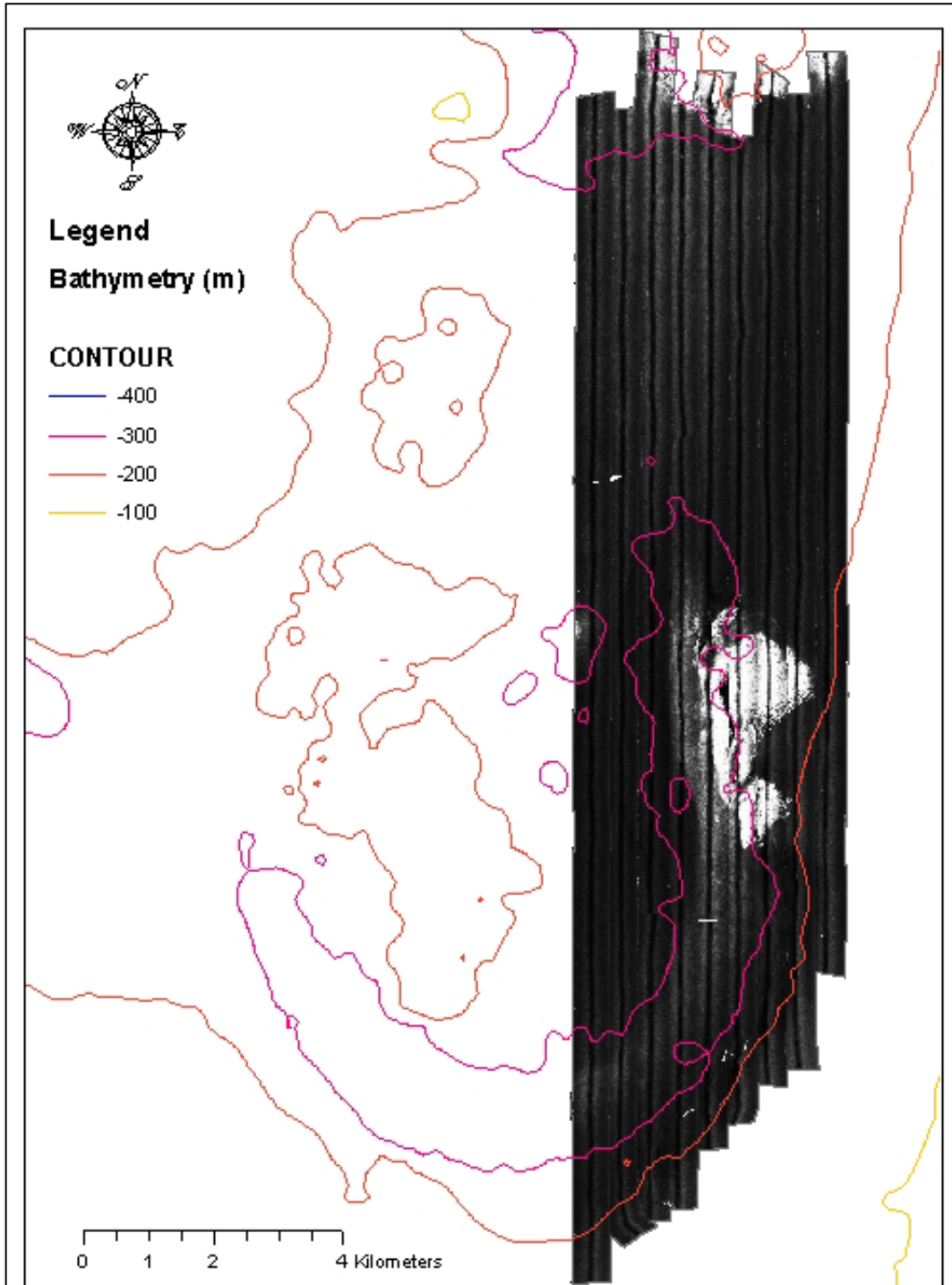
119\_0601b=294m

119\_0601c=194m

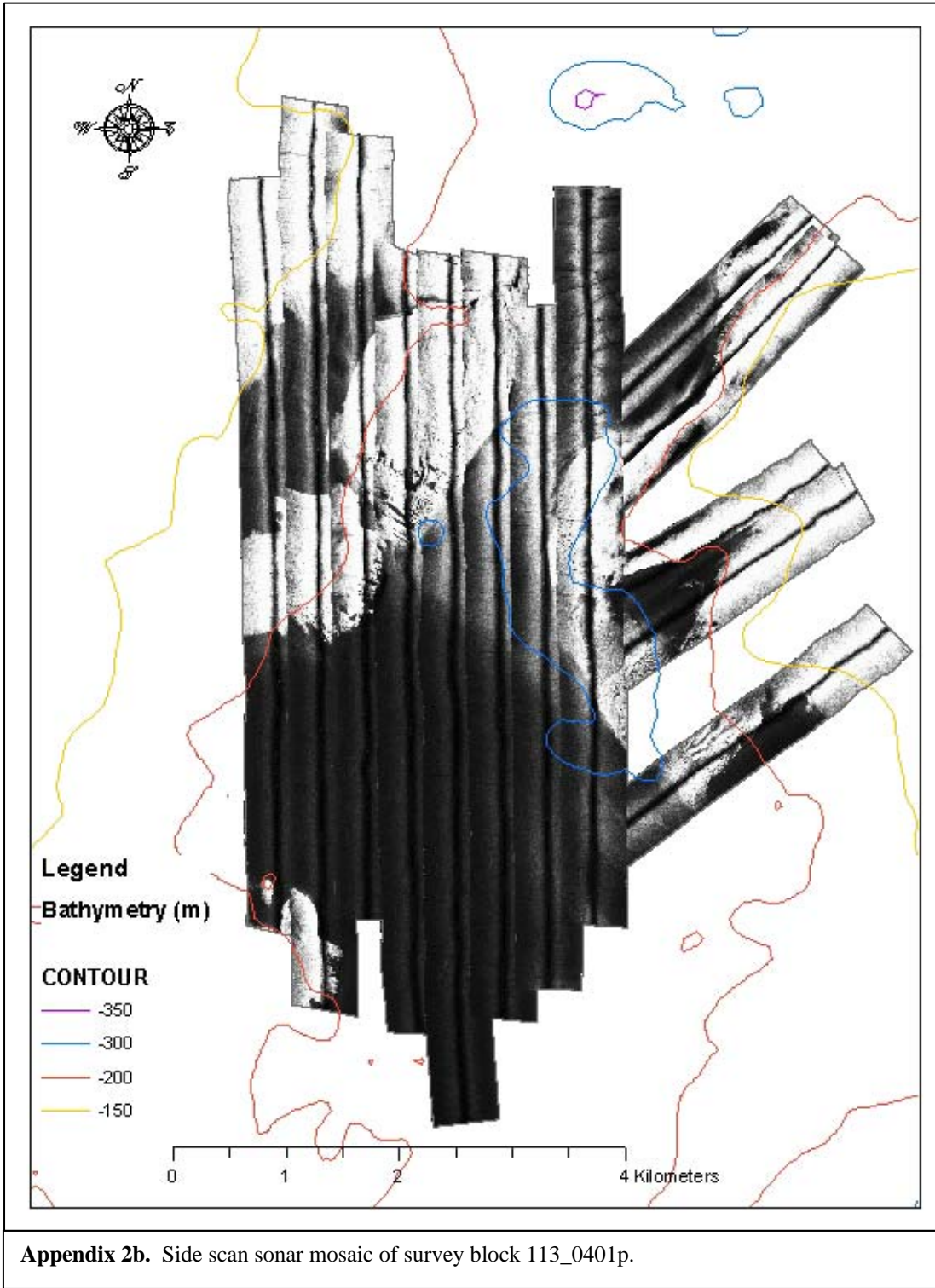
119\_0601d=194m

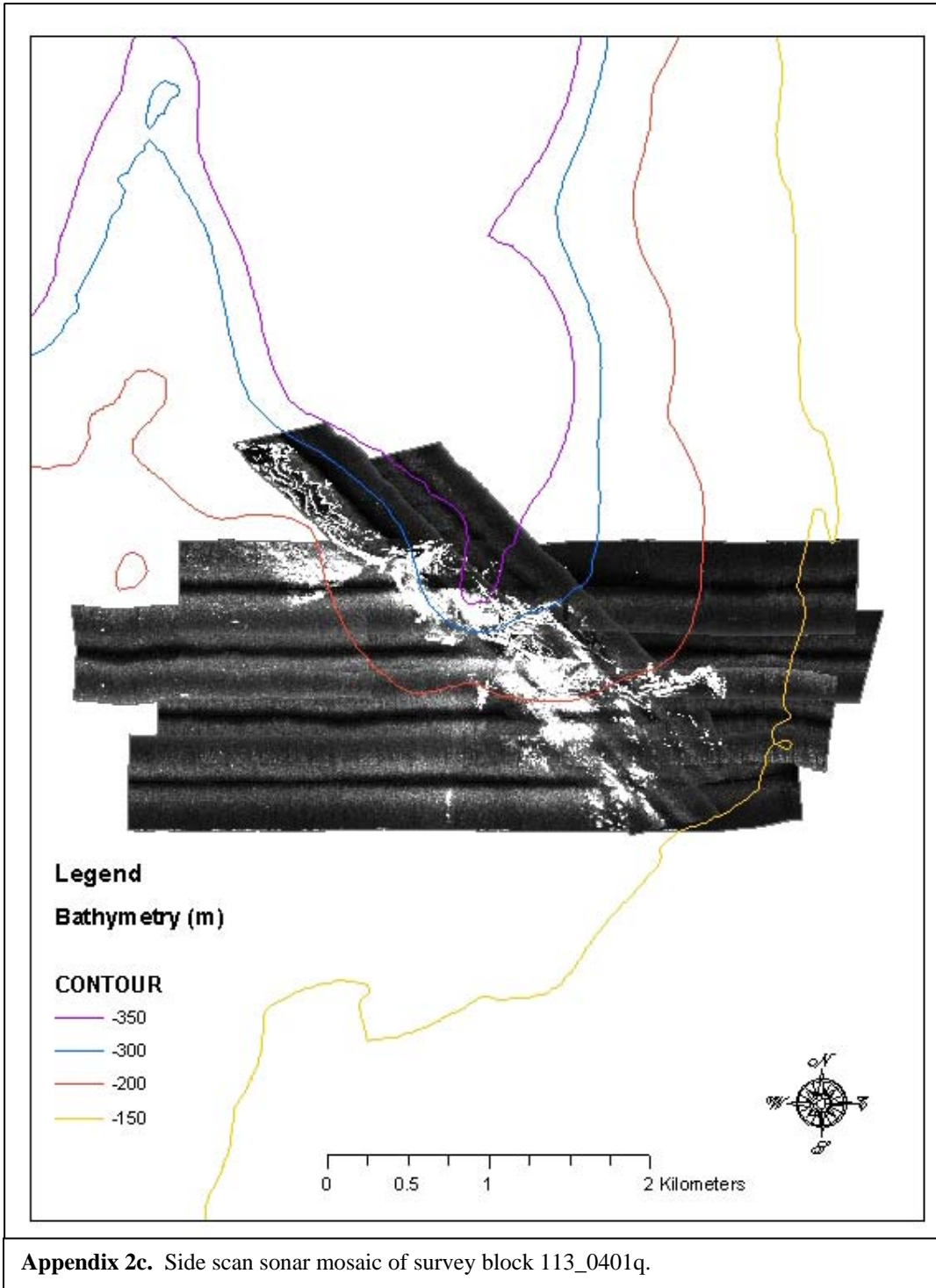
## Appendix 2. Side Scan Sonar Imagery

See Figure 1 for perspective of survey locations in relation to OCNMS boundary.

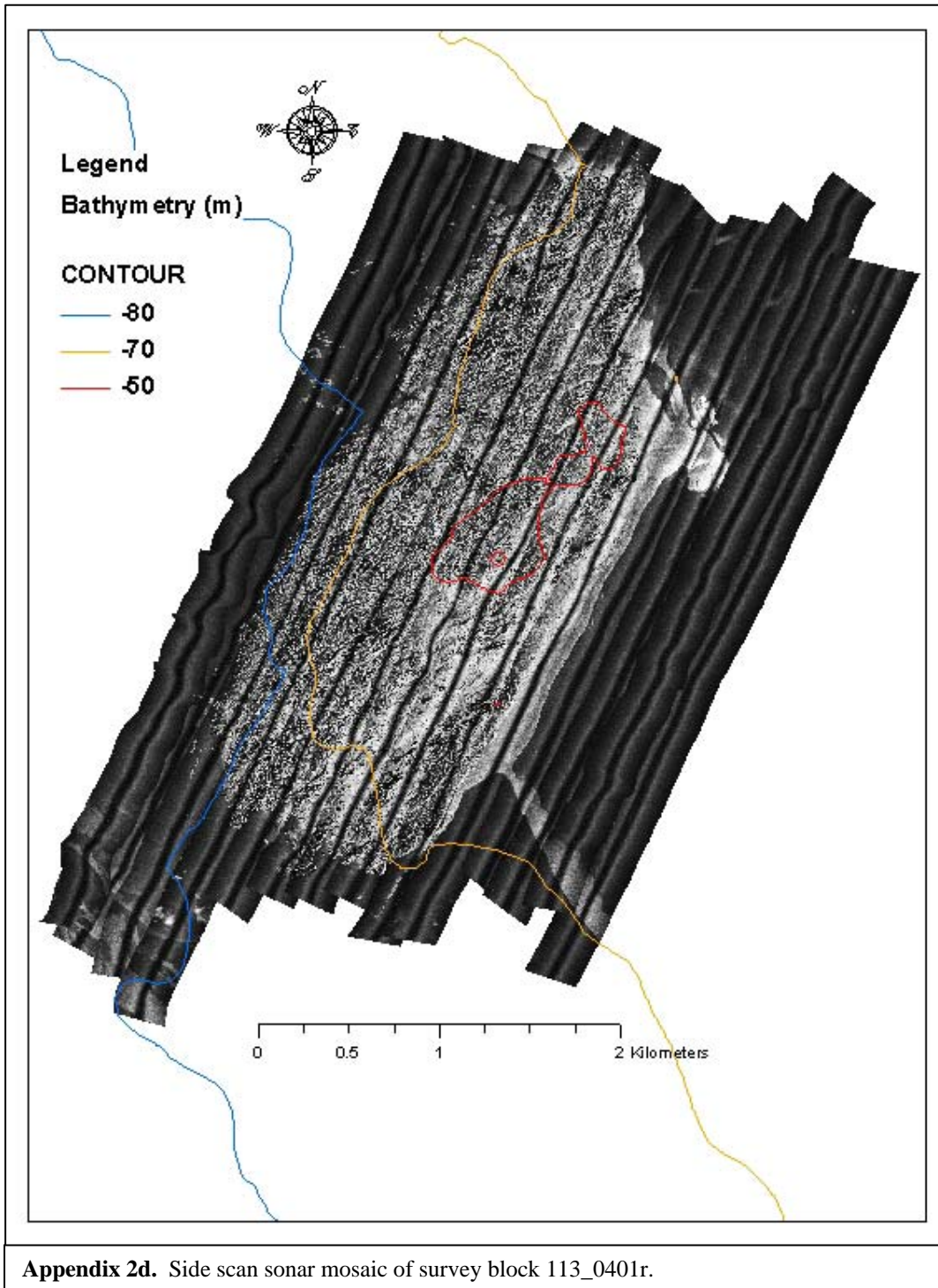


Appendix 2a. Side scan sonar mosaic of survey block 113\_0401d.



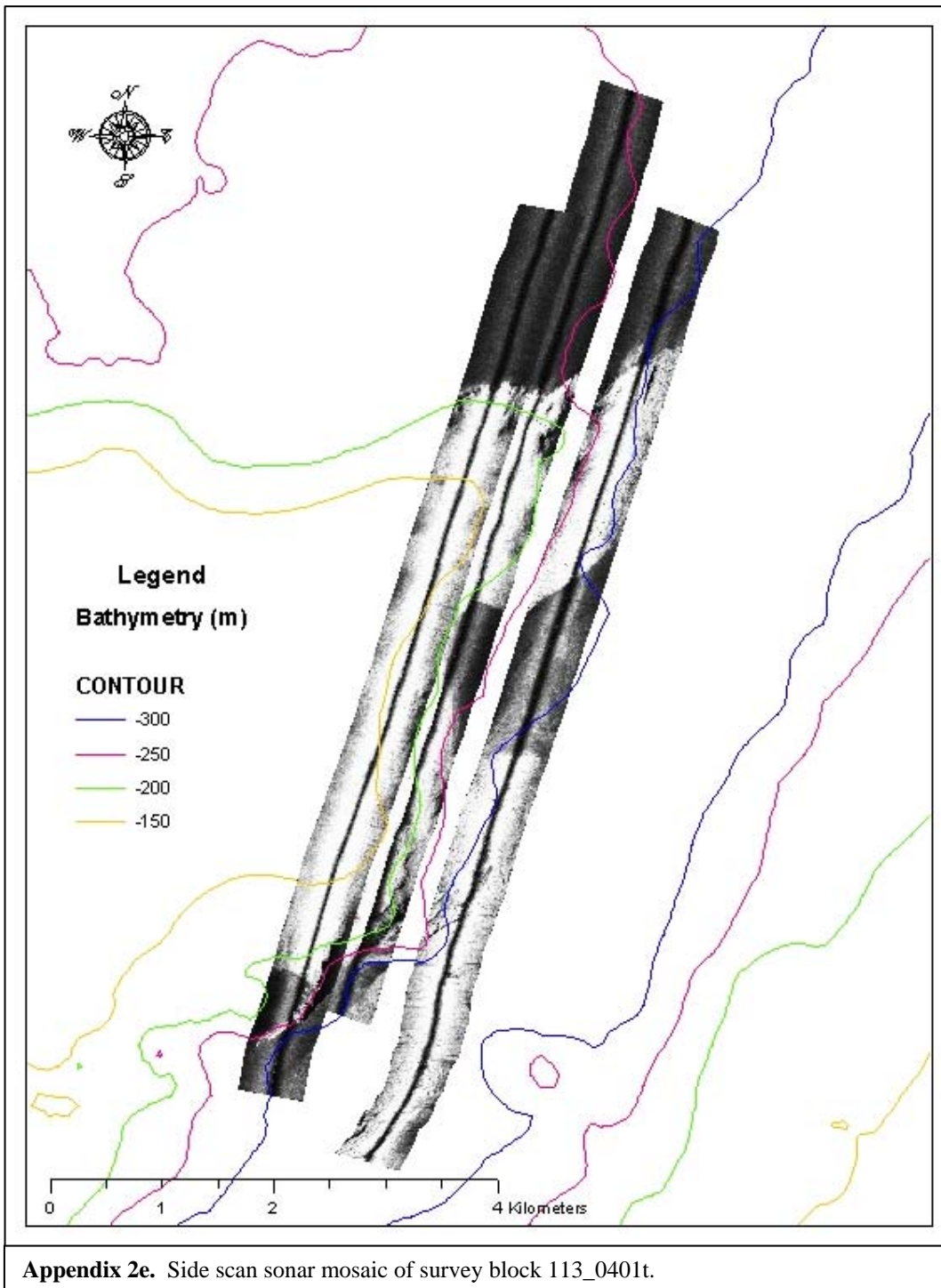


**Appendix 2c.** Side scan sonar mosaic of survey block 113\_0401q.

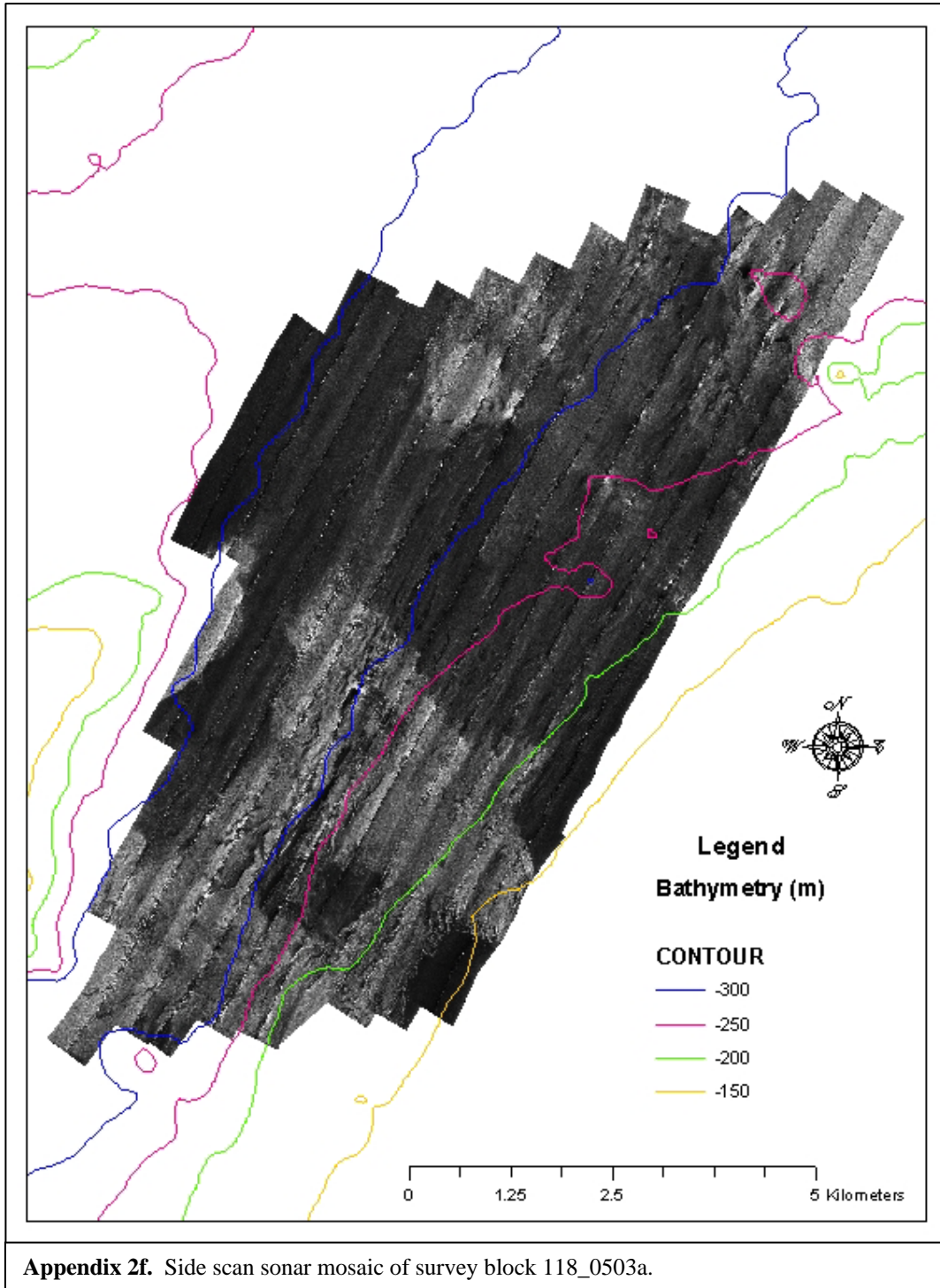


**Appendix 2d.** Side scan sonar mosaic of survey block 113\_0401r.

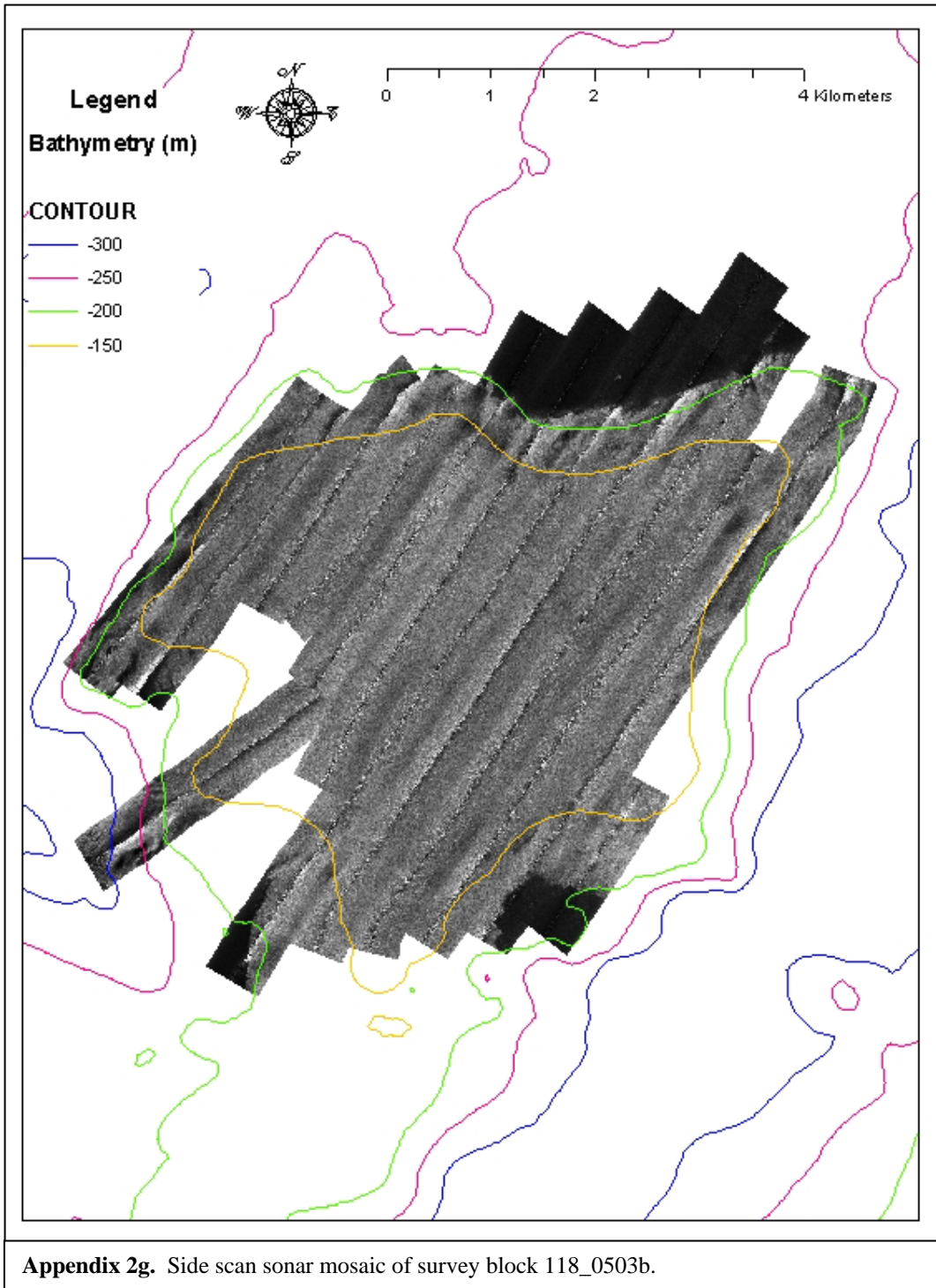




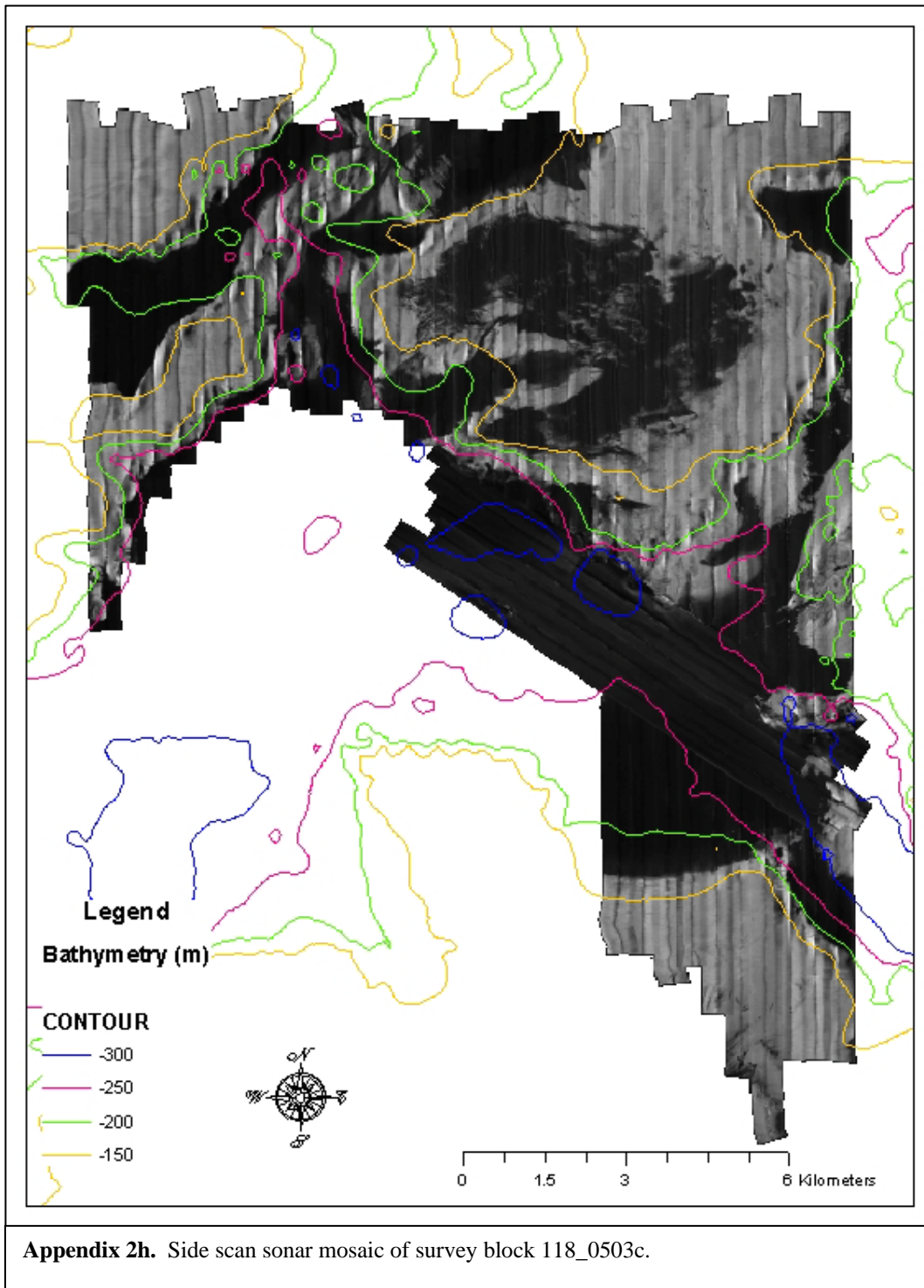
**Appendix 2e.** Side scan sonar mosaic of survey block 113\_0401t.

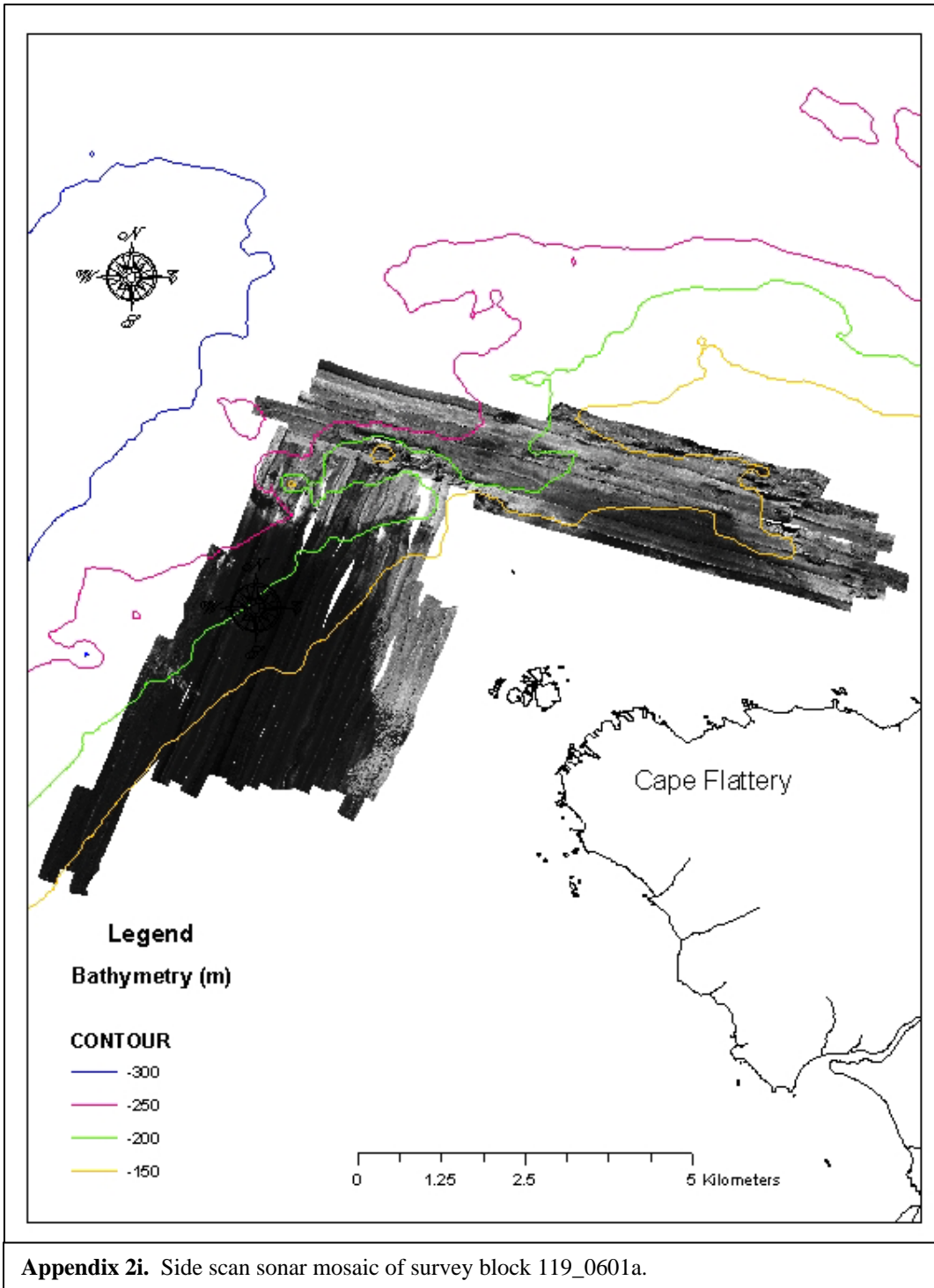


**Appendix 2f.** Side scan sonar mosaic of survey block 118\_0503a.

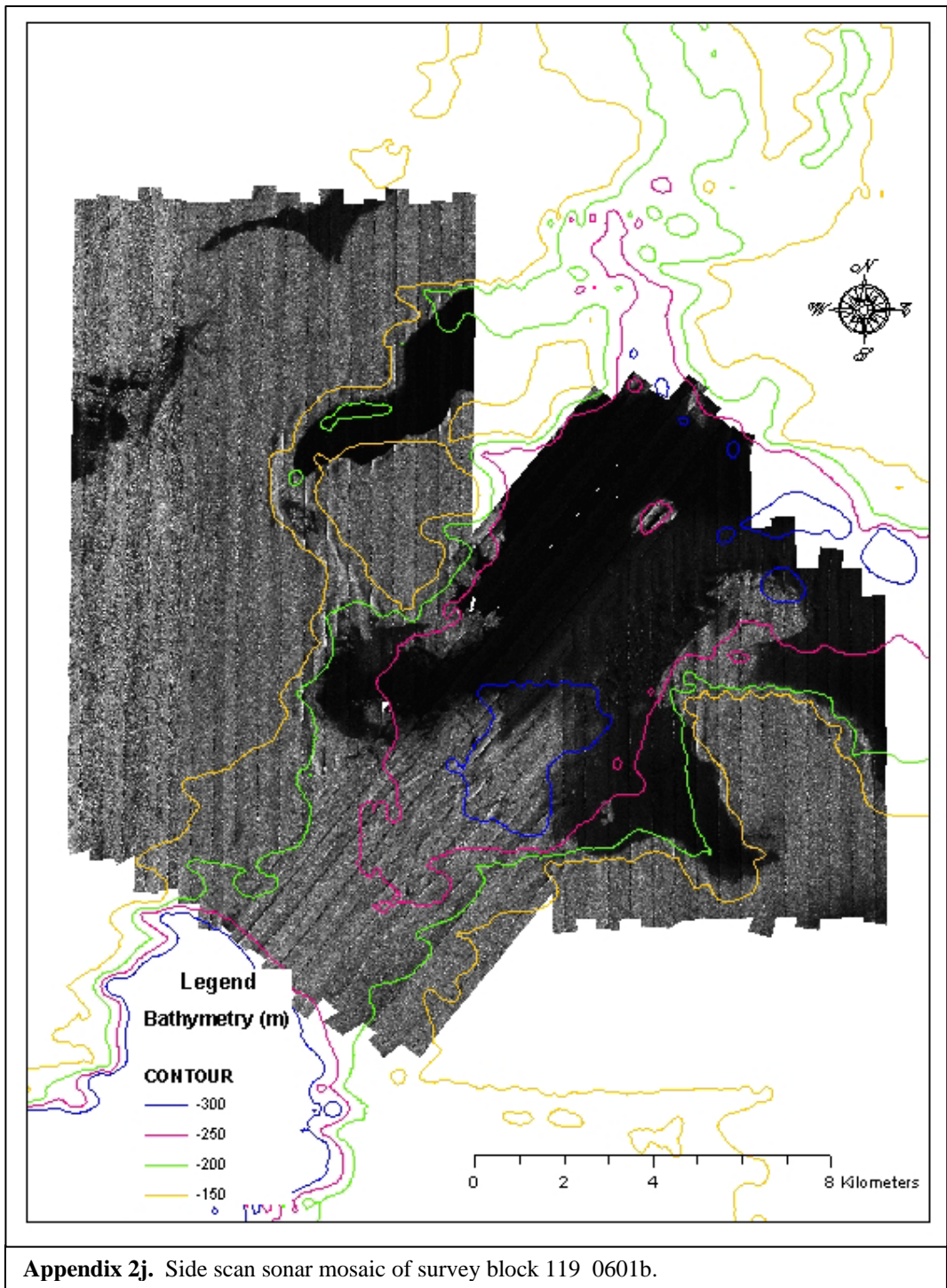


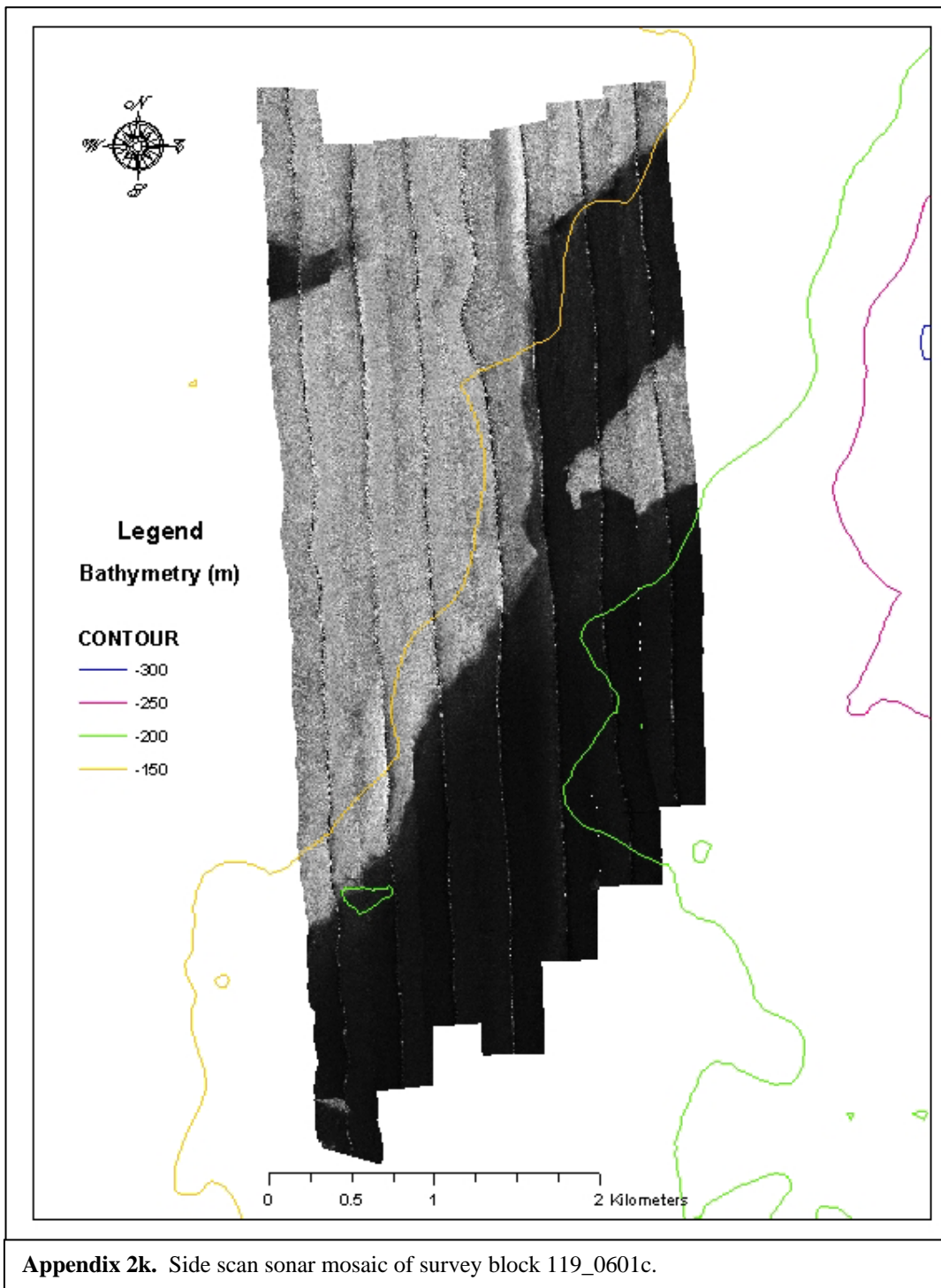
**Appendix 2g.** Side scan sonar mosaic of survey block 118\_0503b.

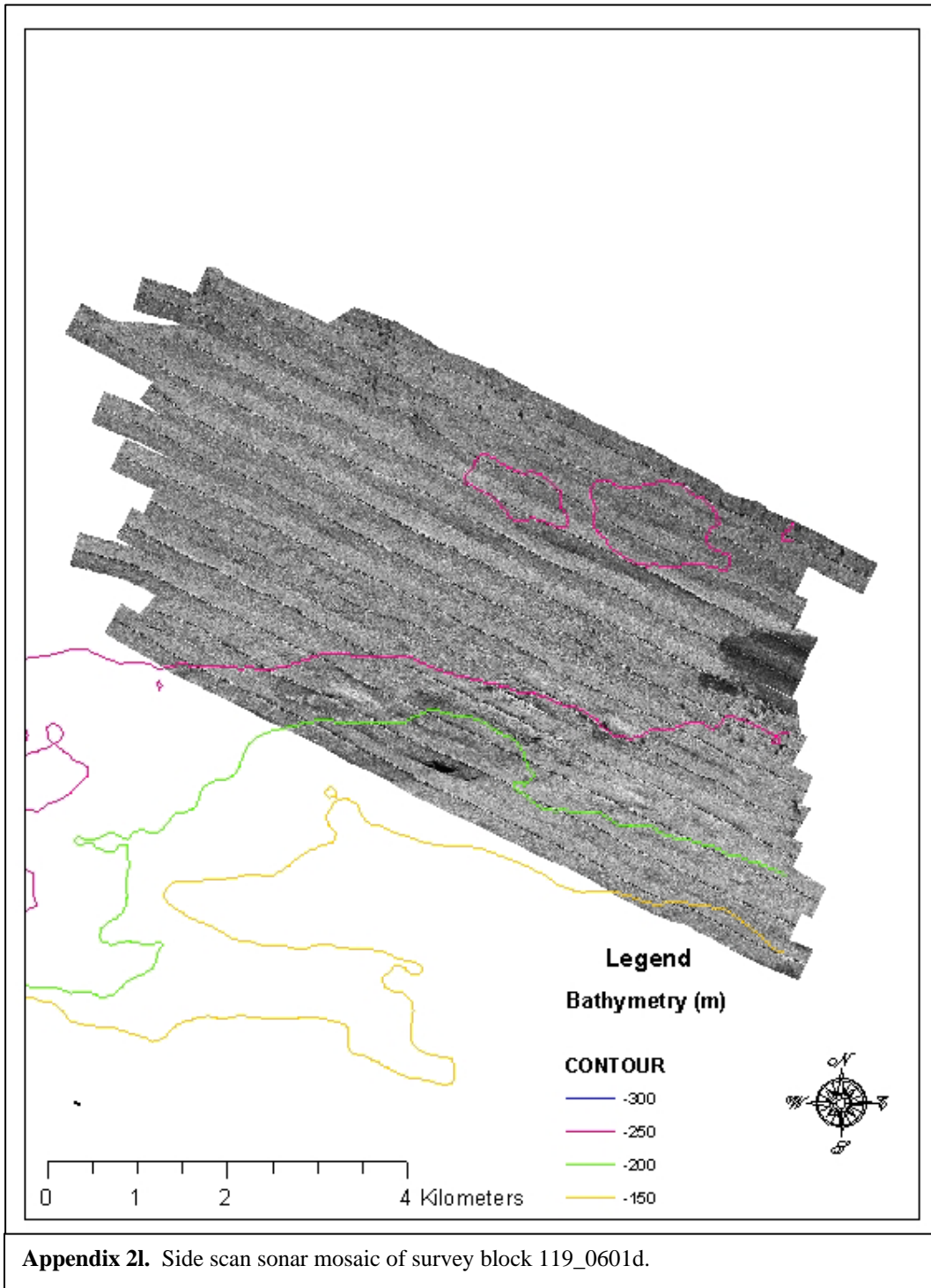




**Appendix 2i.** Side scan sonar mosaic of survey block 119\_0601a.





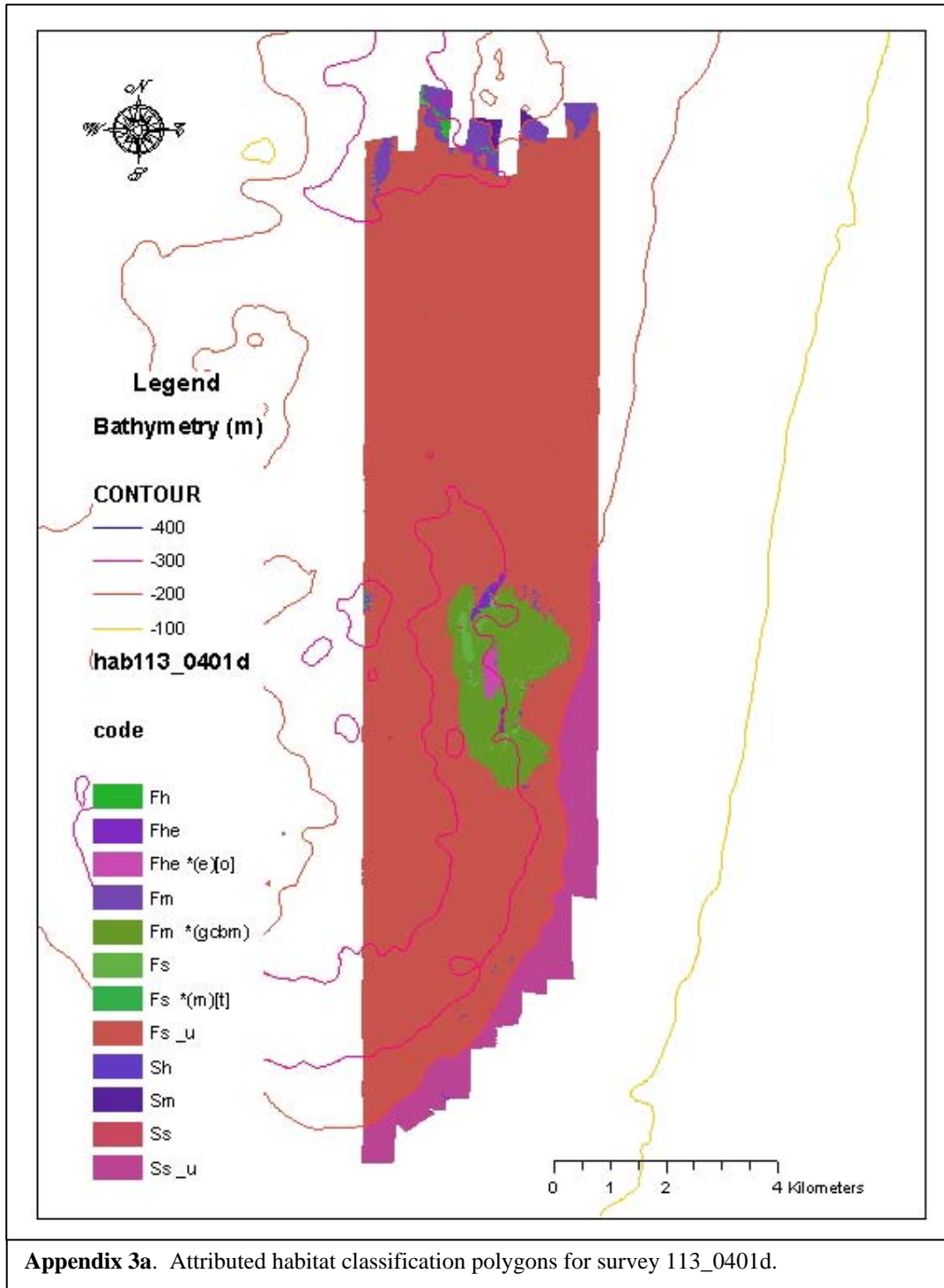


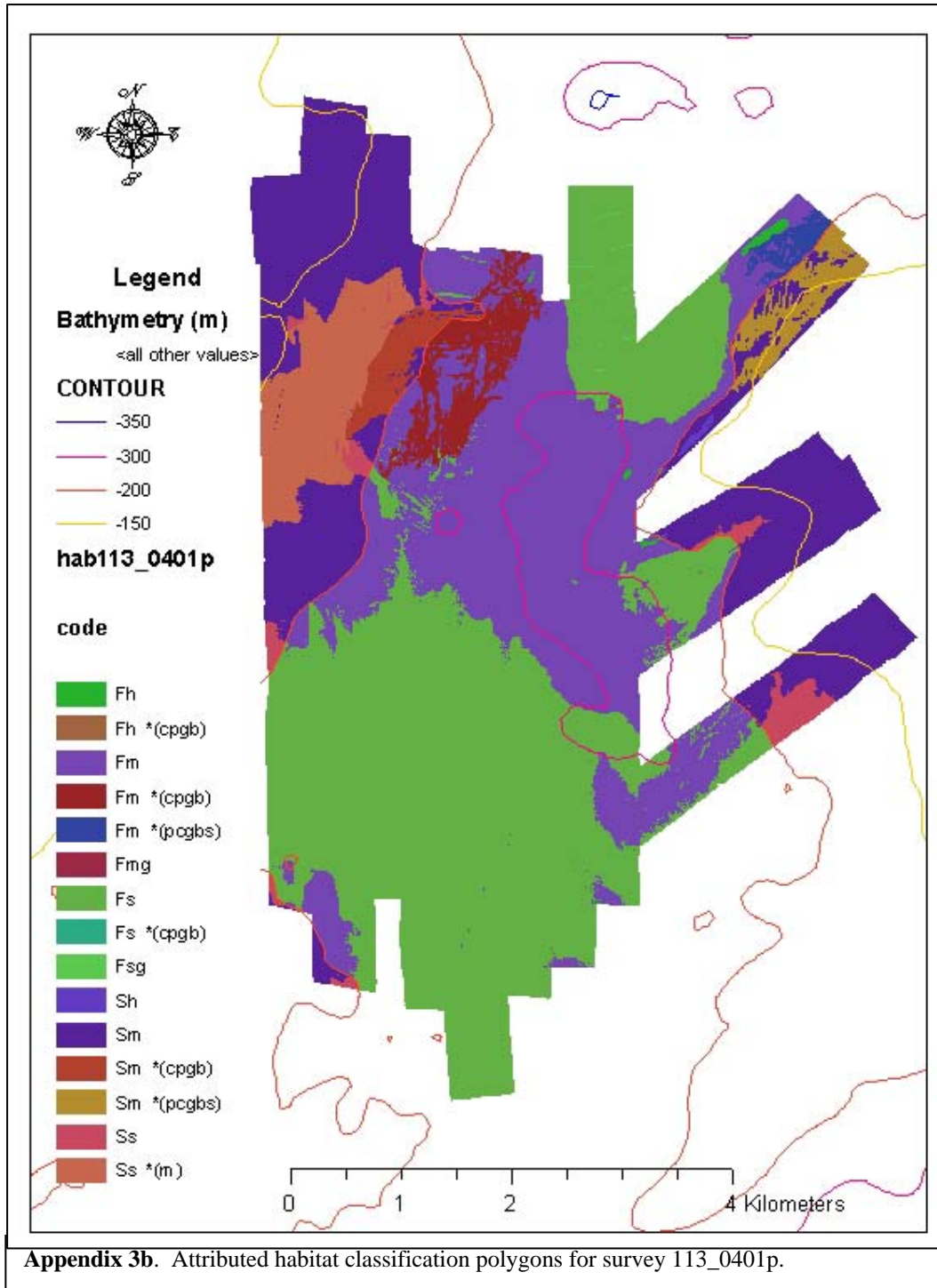
**Appendix 2I.** Side scan sonar mosaic of survey block 119\_0601d.

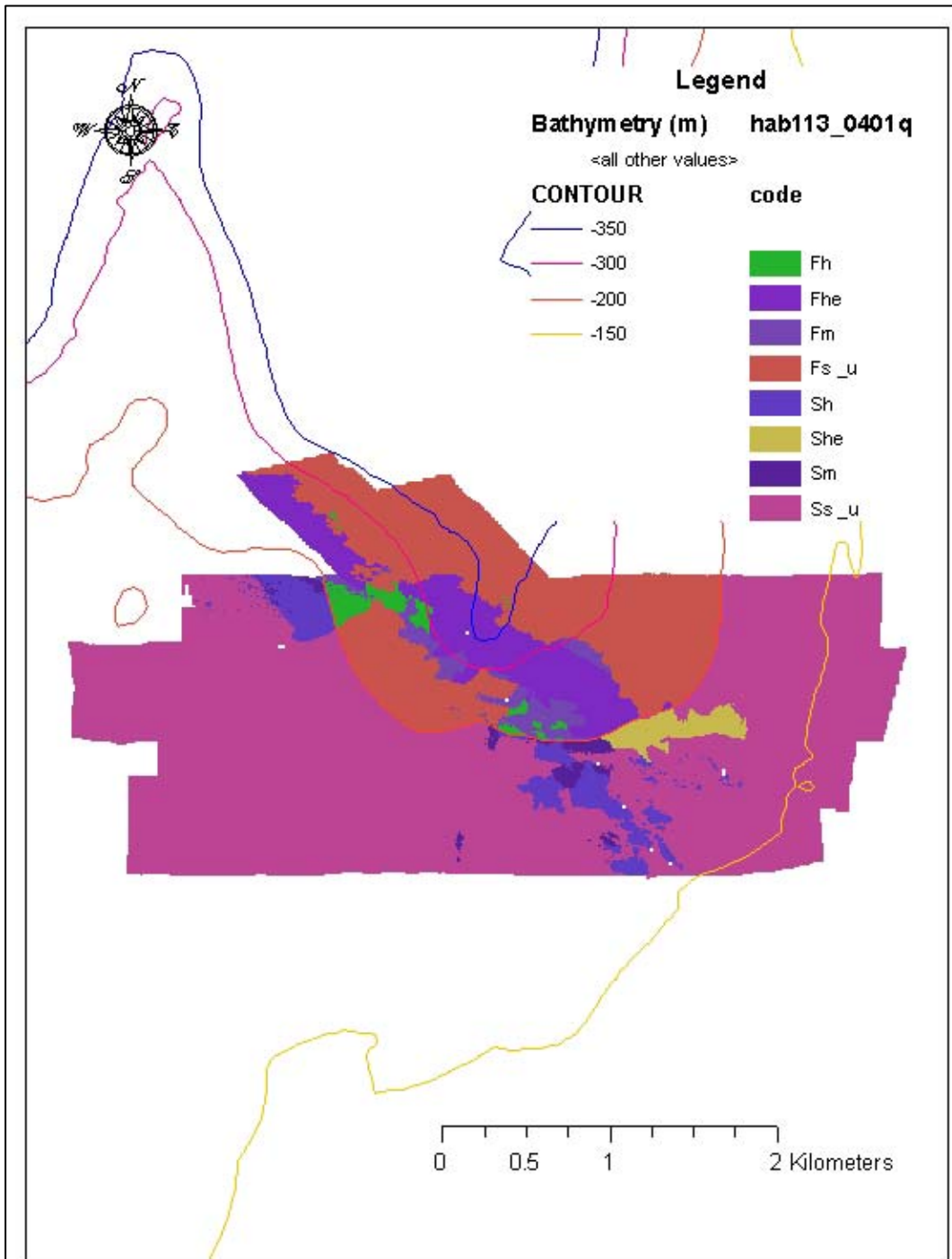


### Appendix 3. Attributed Habitat Classification Polygons

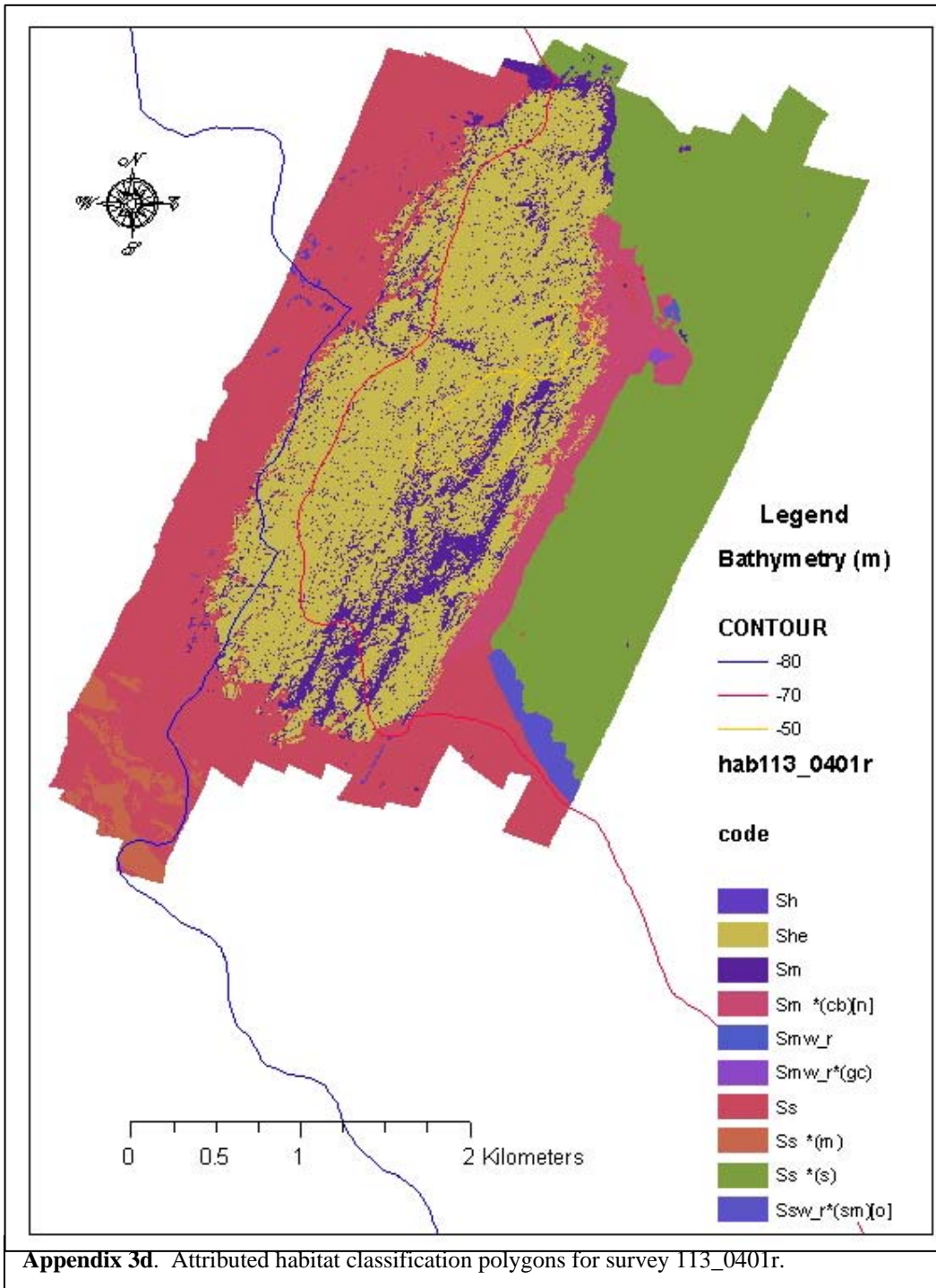
See Figure 1 for perspective of survey locations in relation to OCNMS boundary.



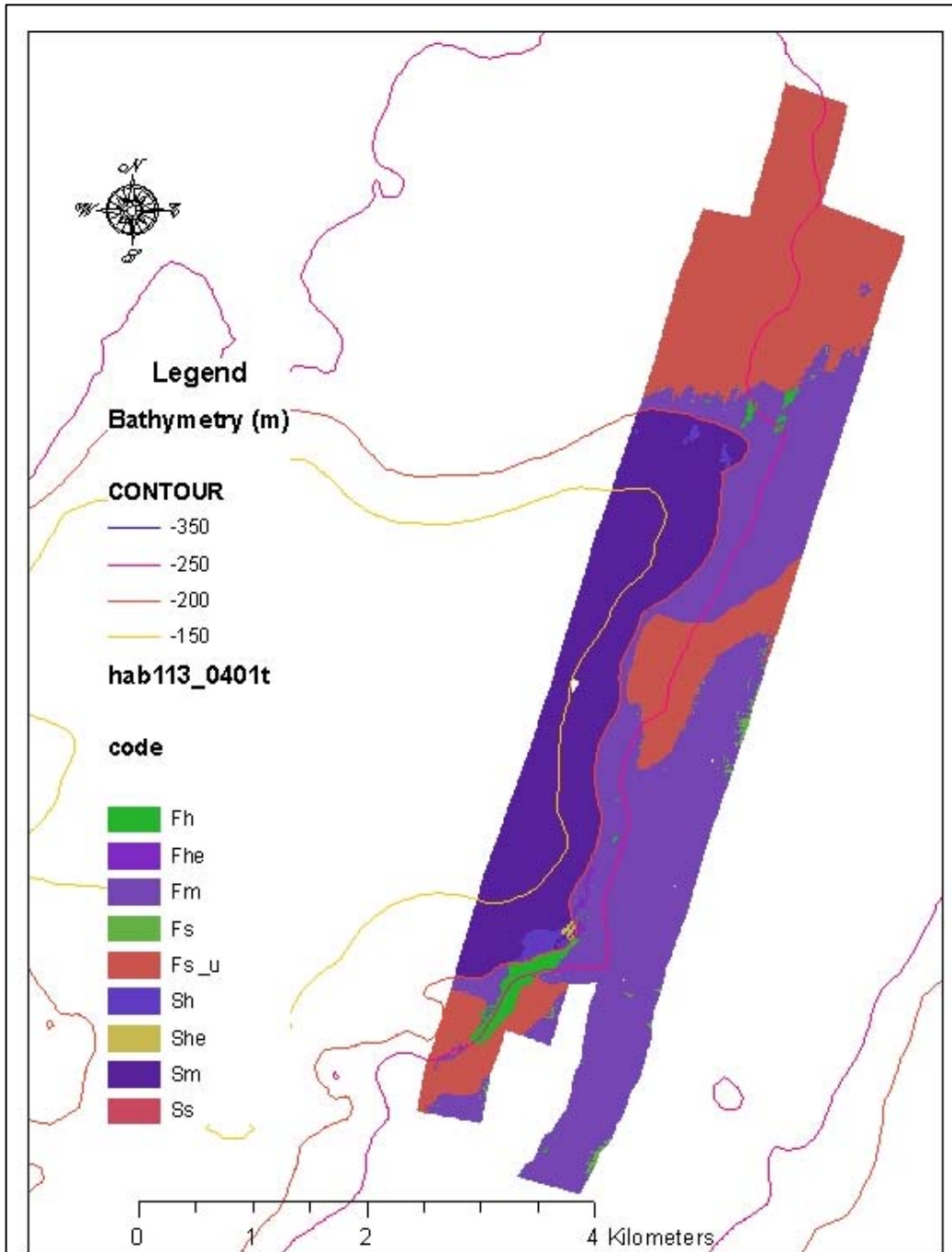




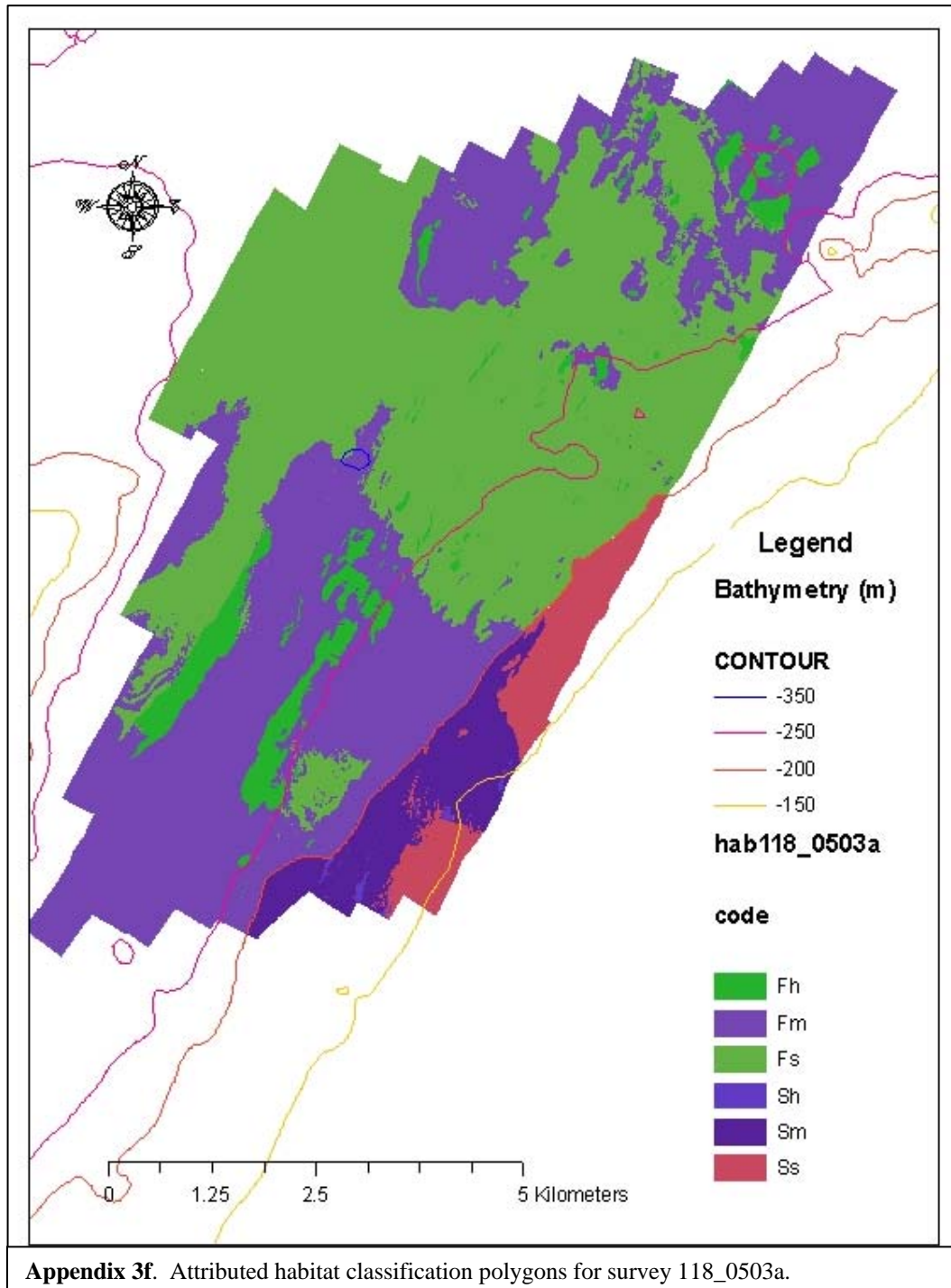
**Appendix 3c.** Attributed habitat classification polygons for survey 113\_0401q.

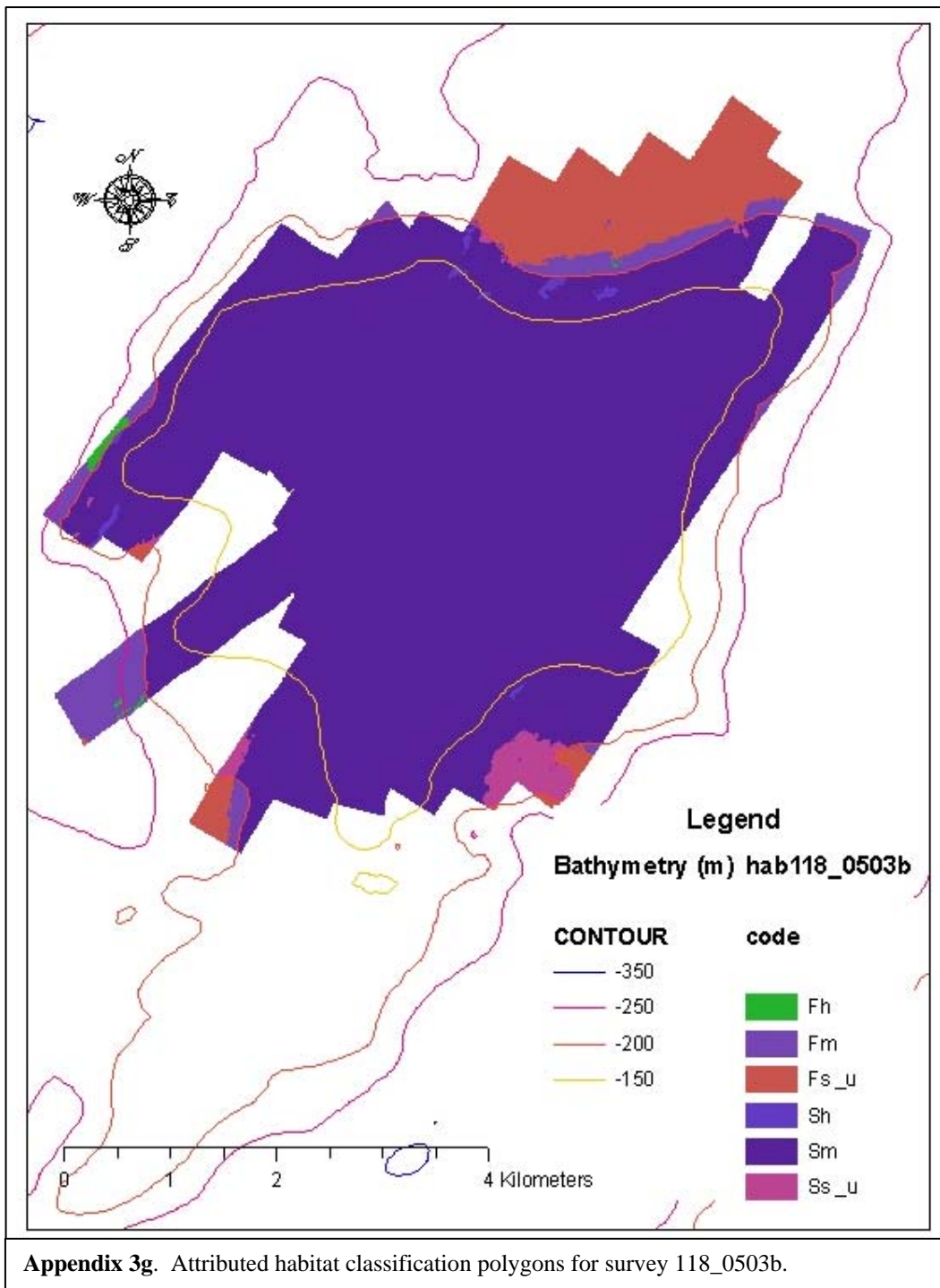


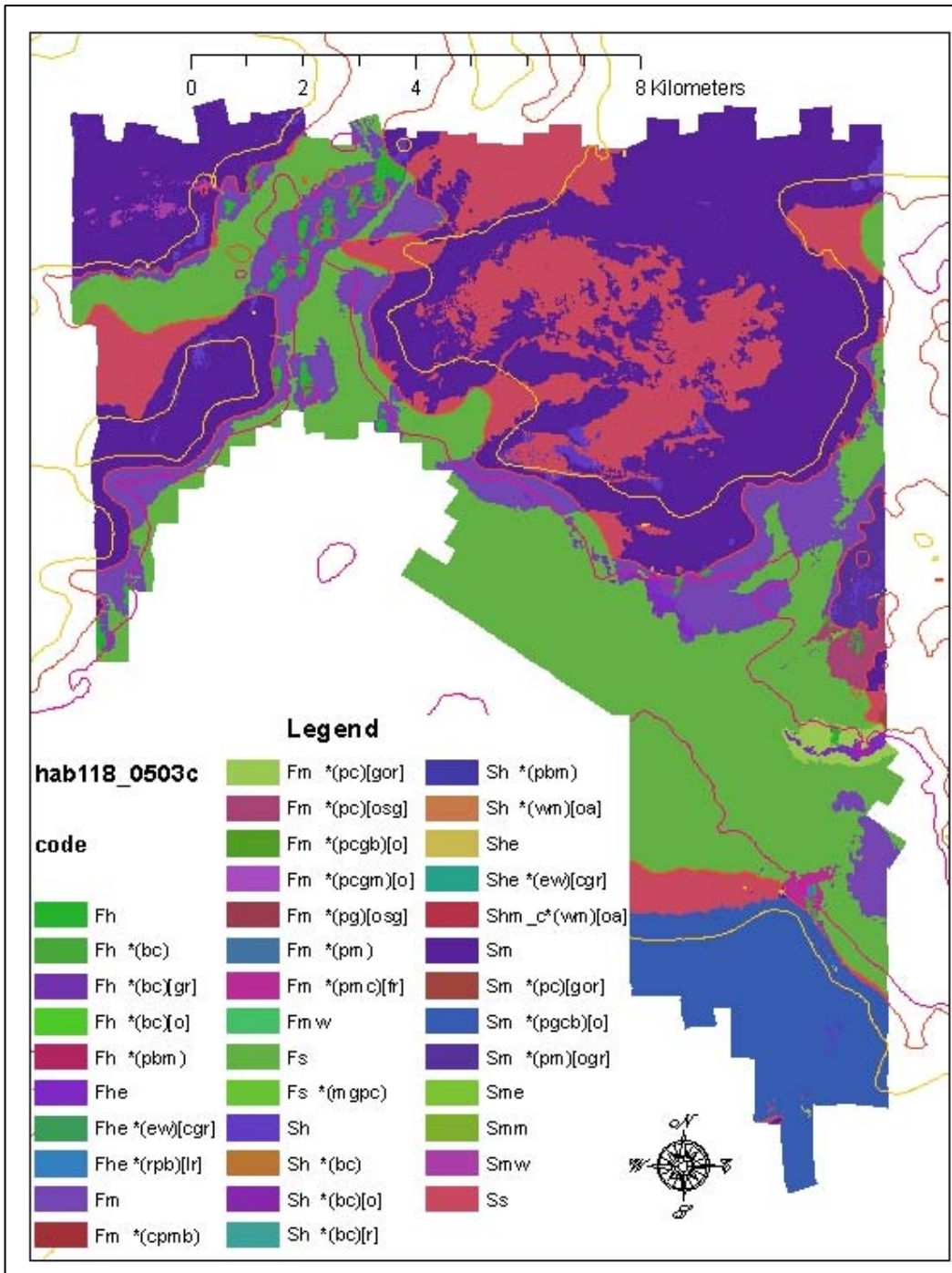
**Appendix 3d.** Attributed habitat classification polygons for survey 113\_0401r.



**Appendix 3e.** Attributed habitat classification polygons for survey 113\_0401t.

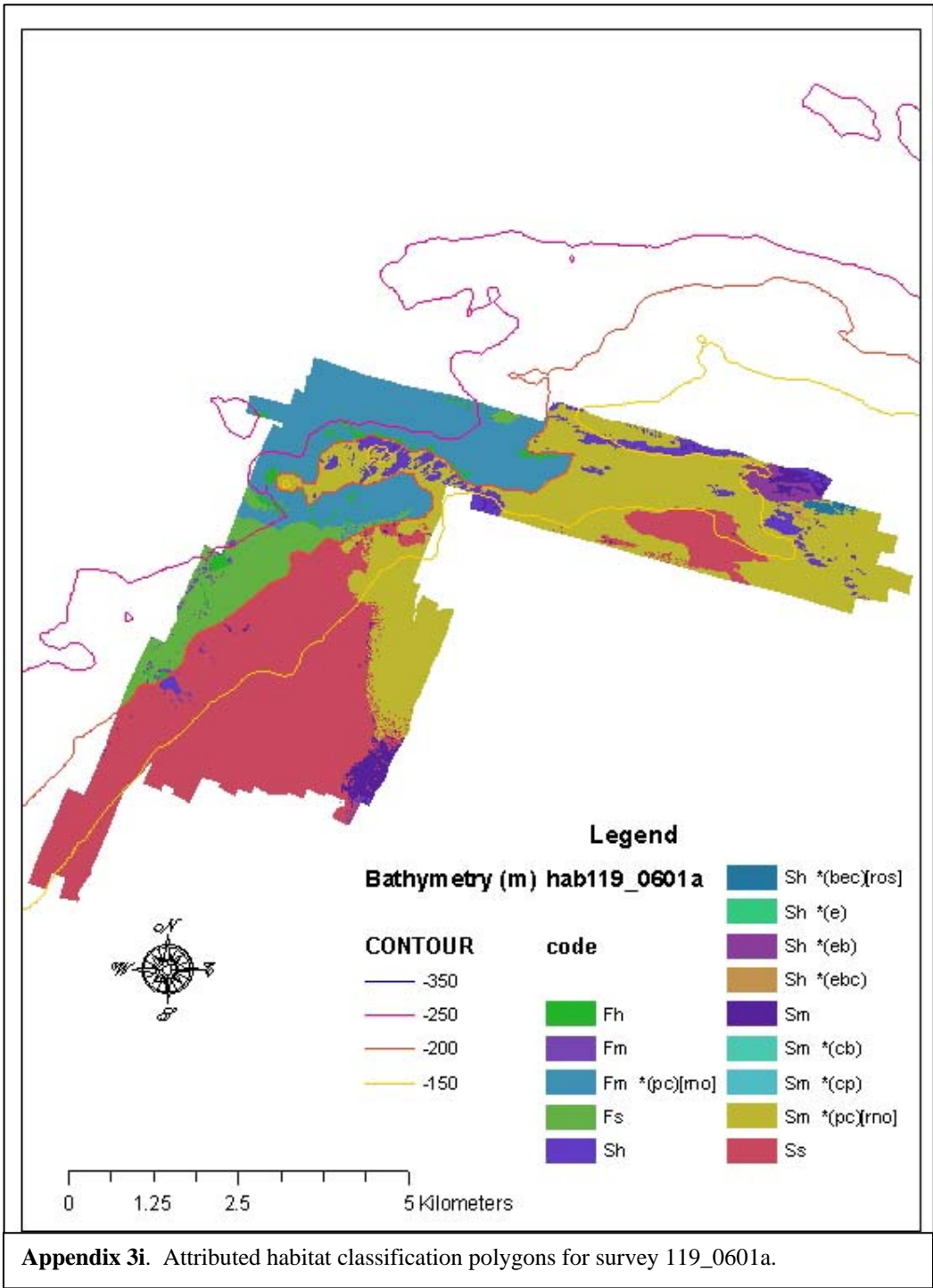


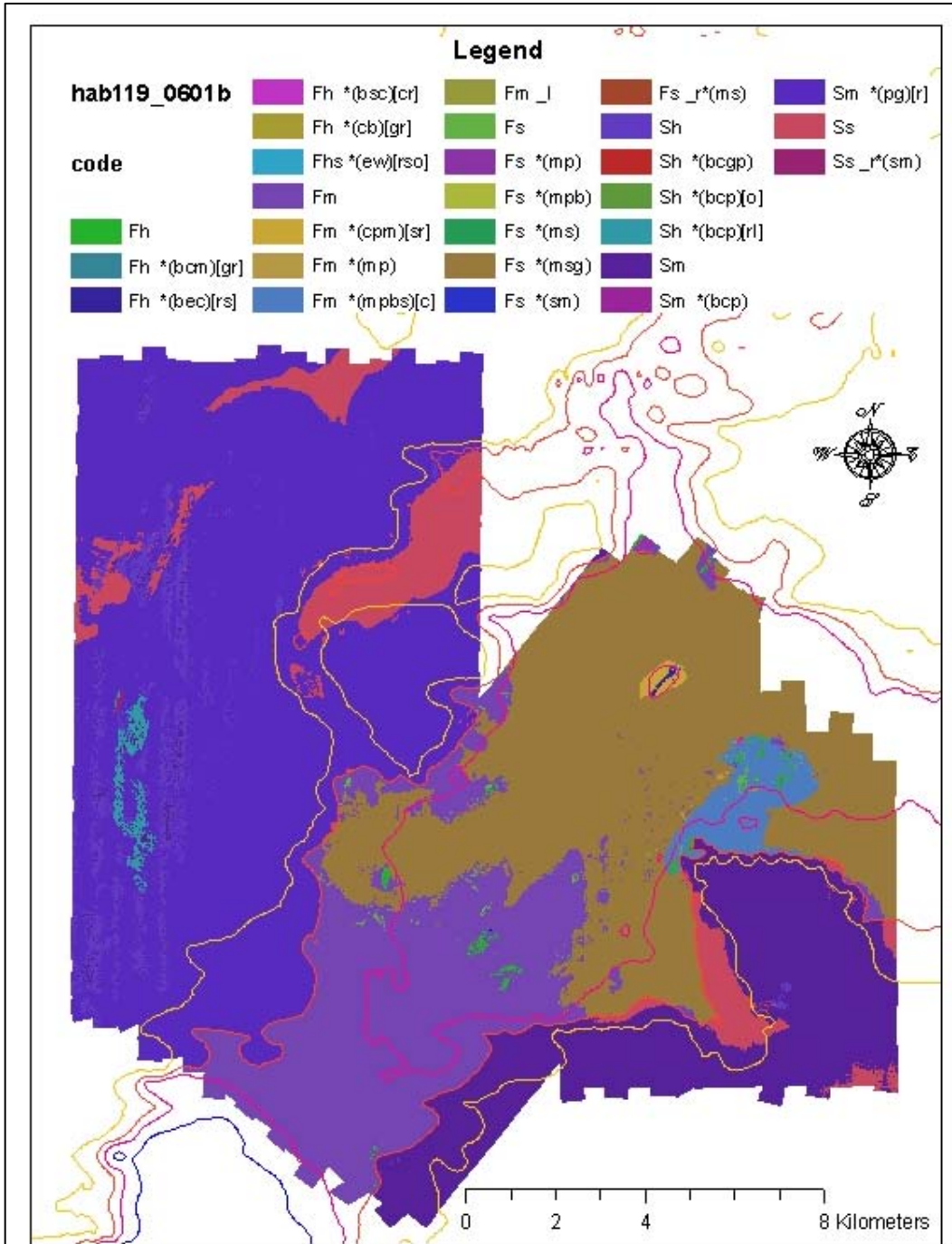




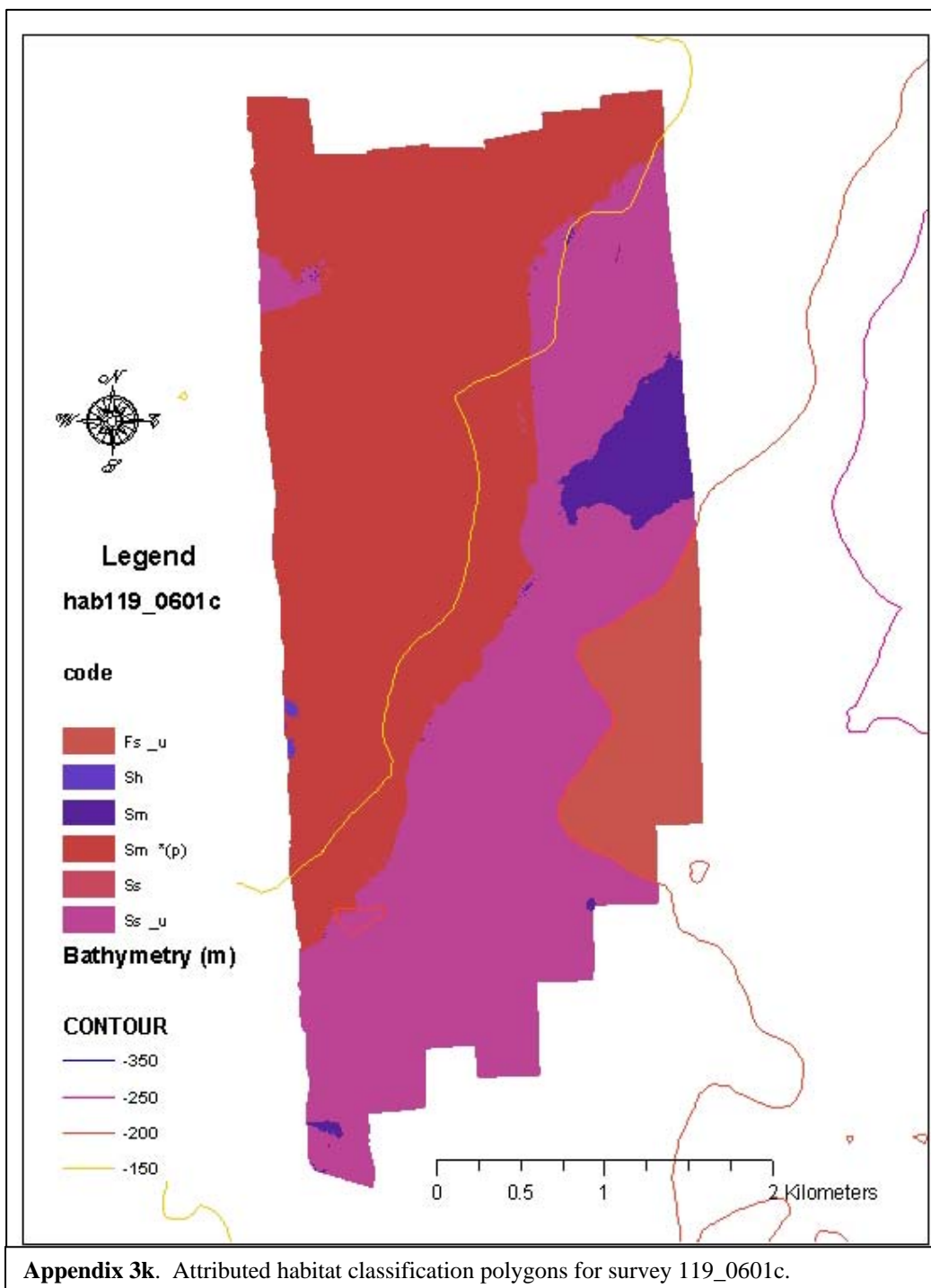
**Appendix 3h.** Attributed habitat classification polygons for survey 118\_0503c.

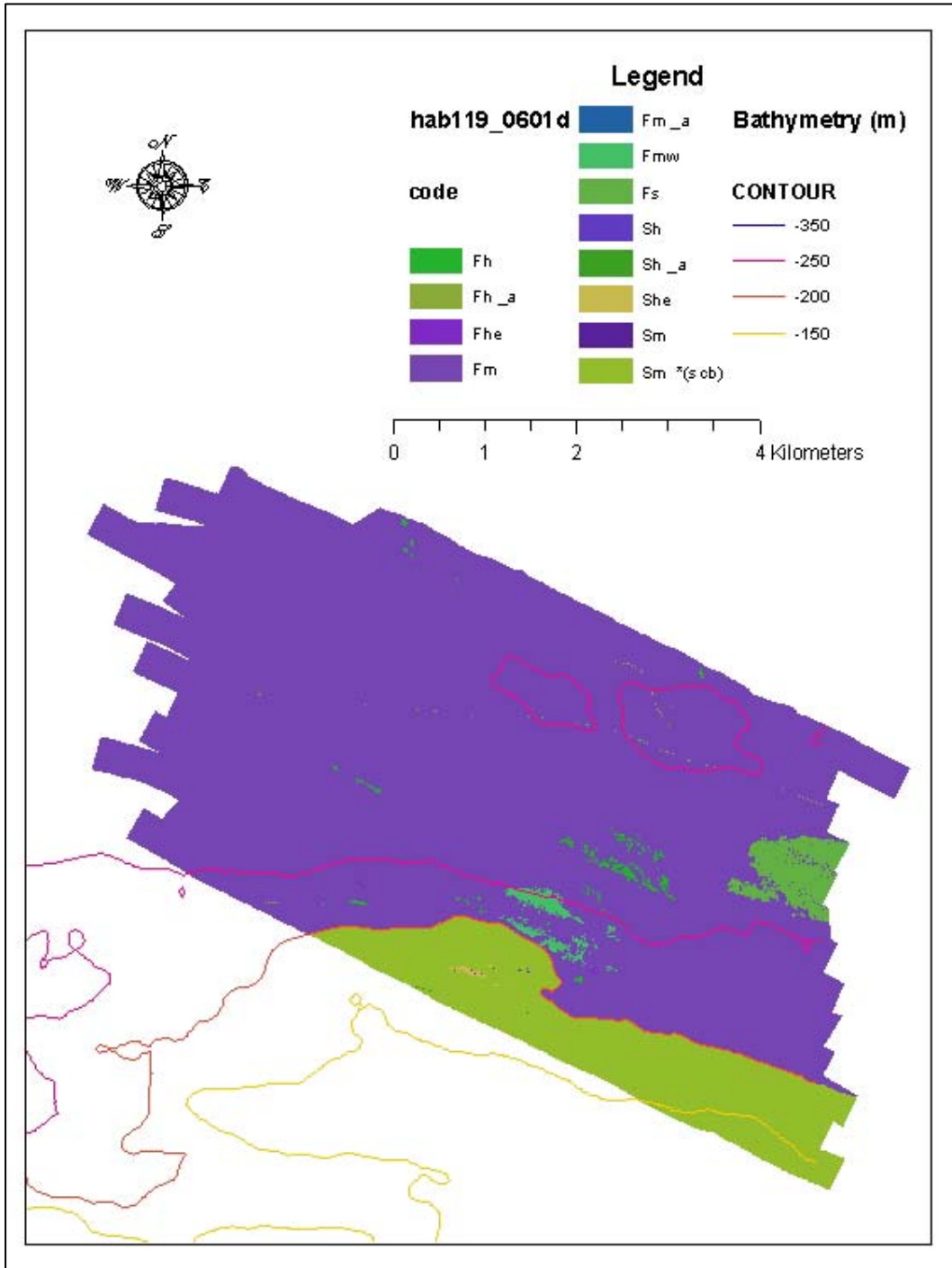






**Appendix 3j.** Attributed habitat classification polygons for survey 119\_0601b.





**Appendix 3I.** Attributed habitat classification polygons for survey 119\_0601d.

#### Appendix 4. Habitat Attribute Classification Tables

Habitat codes in the following tables only present information for the megahabitat, bottom induration, mesohabitat, and geologic modifier fields. Data for slope, complexity, and microhabitat observations have been truncated due to the large number of categorical possibilities.

**Appendix 4a.** Distribution of habitat classified from survey block 113\_0401d side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

Habitat Code	Descriptor	Square m	Percentage
Fs_u	Flank soft unconsolidated	56,539,634.6	81.21
Ss_u	Shelf soft unconsolidated	6,313,940.9	9.07
Fm	Flank mixed	5,744,059.2	8.25
Fs	Flank soft	386,986.3	0.56
Fhe	Flank hard bedrock	358,492.0	0.51
Sm	Shelf mixed	140,296.7	0.20
Fh	Flank hard	113,040.0	0.16
Sh	Shelf hard	11,413.0	0.02
Ss	Shelf soft	9,915.0	0.01

**Appendix 4b.** Distribution of habitat classified from survey block 113\_0401p side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

Habitat Code	Descriptor	Square m	Percentage
Fs	Flank soft	12,636,874.6	41.13
Fm	Flank mixed	9,132,081.4	29.72
Sm	Shelf mixed	6,798,665.6	22.13
Ss	Shelf soft	2,024,145.4	6.58
Fh	Flank hard	59,440.4	0.19
Sh	Soft hard	33,073.6	0.10
Fsg	Flank soft gully	32,486.7	0.10
Fmg	Flank mixed gully	2,098.3	0.00

**Appendix 4c.** Distribution of habitat classified from survey block 113\_0401q side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

<b>Habitat Code</b>	<b>Descriptor</b>	<b>Square m</b>	<b>Percentage</b>
Ss_u	Shelf soft unconsolidated	5,443,063.8	62.39
Fs_u	Flank soft unconsolidated	1,798,130.1	20.61
Fhe	Flank hard bedrock	644,696.3	7.39
Sh	Shelf hard	327,934.4	3.75
Fm	Flank mixed	191,289.7	2.19
She	Shelf hard bedrock	131,235.5	1.50
Fh	Flank hard	103,565.5	1.18
Sm	Shelf mixed	83,632.2	0.95

**Appendix 4d.** Distribution of habitat classified from survey block 113\_0401r side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

<b>Habitat Code</b>	<b>Descriptor</b>	<b>Square m</b>	<b>Percentage</b>
Ss	Shelf soft	11,236,319.1	65.74
She	Shelf hard bedrock	3,961,318.0	23.17
Sm	Shelf mixed	1,723,408.0	10.08
Ssw_r	Shelf soft waves ripples	125,594.6	0.73
Sh	Shelf hard	27,754.9	0.16
Smw_r	Shelf mixed waves ripples	15,916.0	0.09

**Appendix 4e.** Distribution of habitat classified from survey block 113\_0401t side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

<b>Habitat Code</b>	<b>Descriptor</b>	<b>Square m</b>	<b>Percentage</b>
Fm	Flank mixed	6,017,690.2	39.84
Fs_u	Flank soft unconsolidated	4,834,260.0	32.01
Sm	Shelf mixed	3,817,780.7	25.27
Fh	Flank hard	228,727.0	1.51
Sh	Shelf hard	97,979.9	0.64
Fs	Flank soft	66,105.0	0.43
Fhe	Flank hard bedrock	29,030.9	0.19
She	Shelf hard bedrock	10,344.0	0.68
Ss	Shelf soft	364.0	0.00

**Appendix 4f.** Distribution of habitat classified from survey block 118\_0503a side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

<b>Habitat Code</b>	<b>Descriptor</b>	<b>Square m</b>	<b>Percentage</b>
Fs	Flank soft	26,286,693.2	45.49
Fm	Flank mixed	22,800,954.4	39.46
Sm	Shelf mixed	3,247,783.1	5.62
Fh	Flank hard	2,798,650.0	4.84
Ss	Shelf soft	2,550,014.2	4.41
Sh	Shelf hard	91,207.0	0.15

**Appendix 4g.** Distribution of habitat classified from survey block 118\_0503b side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

<b>Habitat Code</b>	<b>Descriptor</b>	<b>Square m</b>	<b>Percentage</b>
Sm	Shelf mixed	24,351,126.9	83.96
Fs_u	Flank soft unconsolidated	2,719,120.2	9.37
Fm	Flank mixed	1,282,623.9	4.42
Ss_u	Shelf soft unconsolidated	481,601.7	1.66
Sh	Shelf hard	110,698.3	0.38
Fh	Flank hard	55,298.6	0.19

**Appendix 4h.** Distribution of habitat classified from survey block 118\_0503c side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

<b>Habitat Code</b>	<b>Descriptor</b>	<b>Square m</b>	<b>Percentage</b>
Sm	Shelf mixed	62,038,714.8	41.37
Fs	Flank soft	42,594,349.8	28.40
Ss	Shelf soft	23,401,838.7	15.60
Fm	Flank mixed	17,930,683.9	11.95
Sh	Shelf hard	1,559,744.8	1.04
Fh	Flank hard	1,379,090.5	0.91
Fhe	Flank hard bedrock	696,654.5	0.46
Smw	Shelf mixed waves	287,731.2	0.19
She	Shelf hard bedrock	43,225.3	0.02
Shm_c	Shelf hard mixed consolidated	5,086.1	0.00
Fmw	Flank mixed waves	4,691.7	0.00
Smm	Shelf mixed mound	1,169.9	0.00
Sme	Shelf mixed bedrock	68.2	0.00



**Appendix 4i.** Distribution of habitat classified from survey block 119\_0601a side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

<b>Habitat Code</b>	<b>Descriptor</b>	<b>Square m</b>	<b>Percentage</b>
Ss	Shelf soft	12,632,926.0	36.76
Sm	Shelf mixed	11,260,928.0	32.77
Fm	Flank mixed	5,927,294.1	17.24
Fs	Flank soft	2,334,826.8	6.79
Sh	Shelf hard	1,808,231.8	5.26
Fh	Flank hard	397,115.1	1.15

**Appendix 4j.** Distribution of habitat classified from survey block 119\_0601b side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

<b>Habitat Code</b>	<b>Descriptor</b>	<b>Square m</b>	<b>Percentage</b>
Sm	Shelf mixed	128,789,713.1	50.85
Fs	Flank soft	57,412,124.5	22.66
Fm	Flank mixed	43,736,995.1	17.26
Ss	Shelf soft	14,677,347.2	5.79
Sh	Shelf hard	7,873,582.2	3.10
Fh	Flank hard	739,851.0	0.29
Ss_r	Shelf soft ripples	36,548.4	0.01
Fs_r	Flank soft ripples	5,036.4	0.00
Fm_l	Flank mixed carbonate	770.0	0.00
Fhs	Flank hard scarp	648.7	0.00

**Appendix 4k.** Distribution of habitat classified from survey block 119\_0601c side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

<b>Habitat Code</b>	<b>Descriptor</b>	<b>Square m</b>	<b>Percentage</b>
Sm	Shelf mixed	6,872,935.9	51.45
Ss_u	Shelf soft unconsolidated	5,382,746.0	40.47
Fs_u	Flank soft unconsolidated	1,051,683.9	7.90
Sh	Shelf hard	13,059.0	0.09
Ss	Shelf soft	7,665.0	0.05

**Appendix 4l.** Distribution of habitat classified from survey block 119\_0601d side scan sonar survey data. Habitat codes are provided per Greene et al. (1999) and are presented by area in square meters and percentage of total mapped area.

<b>Habitat Code</b>	<b>Descriptor</b>	<b>Square m</b>	<b>Percentage</b>
Fm	Flank mixed	31,858,451.8	84.39
Sm	Shelf mixed	4,796,725.1	12.70
Fs	Flank soft	664,909.0	1.76
Fmw	Flank mixed waves	209,201.6	0.55
Fh	Flank hard	162,668.7	0.43
She	Shelf hard bedrock	25,487.0	0.06
Fh_a	Flank hard anthropogenic	17,654.2	0.04
Fhe	Flank hard bedrock	10,483.3	0.02
Sh	Shelf hard	2,175.9	0.00
Sh_a	Shelf hard anthropogenic	1,655.9	0.00
Fm_a	Flank mixed anthropogenic	45.0	0.00

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To date, the following reports have been published in the Marine Sanctuaries Conservation Series. All publications are available on the National Marine Sanctuary Program website (<http://www.sanctuaries.noaa.gov/>).

2002 – 03 Florida Keys National Marine Sanctuary Science Report: An Ecosystem Report Card After Five Years of Marine Zoning (NMSP-06-12)

Habitat Mapping Effort at the Olympic Coast National Marine Sanctuary – Current Status and Future Needs (NMSP- 06-11)

*M/V Connected* Coral Reef Restoration Monitoring Report Monitoring Events 2004 – 2005 Florida Keys National Marine Sanctuary, Monroe County, Florida (NMSP-06-10)

*M/V Jacquelyn L* Coral Reef Restoration Monitoring Report Monitoring Events 2004 – 2005, Florida Keys National Marine Sanctuary, Monroe County, Florida (NMSP-06-09)

*M/V Wave Walker* Coral Reef Restoration Baseline Monitoring Report - 2004 Florida Keys National Marine Sanctuary Monroe County, Florida (NMSP-06-08)

Olympic Coast National Marine Sanctuary Habitat Mapping: Survey report and classification of side scan sonar data from surveys HMPR-114-2004-02 and HMPR-116-2005-01 (NMSP-06-07)

A Pilot Study of Hogfish (*Lachnolaimus maximus* Walbaum 1792) Movement in the Conch Reef Research Only Area (Northern Florida Keys) (NMSP-06-06)

Comments on Hydrographic and Topographic LIDAR Acquisition and Merging with Multibeam Sounding Data Acquired in the Olympic Coast National Marine Sanctuary (ONMS-06-05)

Conservation Science in NOAA's National Marine Sanctuaries: Description and Recent Accomplishments (ONMS- 06-04)

Normalization and characterization of multibeam backscatter: Koitlah Point to Point of the Arches, Olympic Coast National Marine Sanctuary - Survey HMPR-115-2004-03 (ONMS-06-03)

Developing Alternatives for Optimal Representation of Seafloor Habitats and Associated Communities in Stellwagen Bank National Marine Sanctuary (ONMS-06-02)

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Olympic Coast National Marine Sanctuary: Proceedings of the 1998 Research Workshop, Seattle, Washington (MSD-01-04)

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