BOTTOM SUBSTRATE AND ASSOCIATED EPIBENTHIC BIOTA OF THE FORCE TIDAL ENERGY TEST SITE IN MINAS PASSAGE, BAY OF FUNDY

Final Report

Prepared for

Fundy Ocean Research Centre for Energy

by

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EXECUTIVE SUMMARY

Environmental data collected in the Fundy Ocean Research Centre for Energy (FORCE) lease area in Minas Passage, Bay of Fundy, during 2008-2009, included underwater video surveys and >2000 still photographs of the seafloor. The present study uses these materials and associated technical reports by Envirosphere Ltd to further examine the epibenthic fauna-substrate relationships for the purposes of quantifying baseline conditions prior to installation of in-stream tidal energy conversion infrastructure (cables, moorings and turbines) in the FORCE test area.

Computer image analysis and qualitative and quantitative classification techniques were used to characterize the benthic environment and to map the epibenthic macrofauna (for organisms >10 mm) of three FORCE berth sites and associated cable routes. Still frames taken from videographic surveys were processed using ImageJ software. Data recorded include presence/absence and percent cover of macrofaunal species, percent cover of substrate type (based on bedrock type and clast size) and depth below MLW. Commonly observed macrofauna from video stills include *Halichondria panicea* (yellow breadcrumb sponge), *Asterias vulgaris* (a variety of seastar), *Henricia sanguinolenta* (bloodstar), and *Urticina felina* (northern red anemone). *H. panicea* is the most abundant species observed in the FORCE lease area, with extensive sponge cover appearing in Berth A, an area of exposed basalt bedrock and the shallowest of the three berth areas.

The distribution patterns of the dominant epibenthic fauna in the FORCE test area were mapped as an aid to FORCE project developers and environmental regulators. A Classification and Regression Tree (CART) statistical analysis was used to determine the environmental factors most influential in determining species distribution. CART analyses showed that the most important factor controlling *H. panicea* distribution was substrate type (volcanic or sedimentary bedrock), followed by water depth.

Given the observed low biodiversity of macrofauna and the prevalence of encrusting yellow breadcrumb sponge, the risk of negative impact on epibenthic productivity and biodiversity, following any installation of subsea infrastructure at FORCE, is low.

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1.0 INTRODUCTION

This study examines the bottom substrate features and associated biological communities in an extreme high flow, high energy tidal energy test site (FORCE) in the Minas Passage of the upper Bay of Fundy (Figure 1). The following sections describe the physical environment in the region, factors known to affect settlement and establishment of biota, and the use of the region for tidal energy demonstration projects. This study is an extension of the work conducted under the FORCE Environmental Assessment and will be useful in the assessment of impacts on the benthic environment following installation of infrastructure to harness tidal energy.

1.1 Environments of Channels & Passages

The funneling of tidal water passing through any channel or passage amplifies the flow velocity and increases the potential for bottom scour. Flow rate intensity and exposure are factors that strongly affect epibenthic assemblages (Cerame-Vivas and Gray, 1966). Biological communities in channels are typically dominated by encrusting organisms and/or organisms that are sessile or temporarily attached to the substrate (Rees et al., 1999). In very high flow areas, benthic biota tend to be dominated by sessile epifauna, as there is generally little or no surficial material in which organisms can burrow (Todd and Kostylev, 2010). Those most commonly observed in high flow channels include varieties of encrusting or mounding sponge, seastars, anemones, gastropods, and scallops (Peattie and Hoare, 1981).

1.2 Minas Passage Geology

The bedrock in the Minas Passage is primarily Triassic-Jurassic sedimentary rock, overlain by a linear volcanic unit called McKay Head basalt, striking in an east-west direction (King and Maclean, 1976).

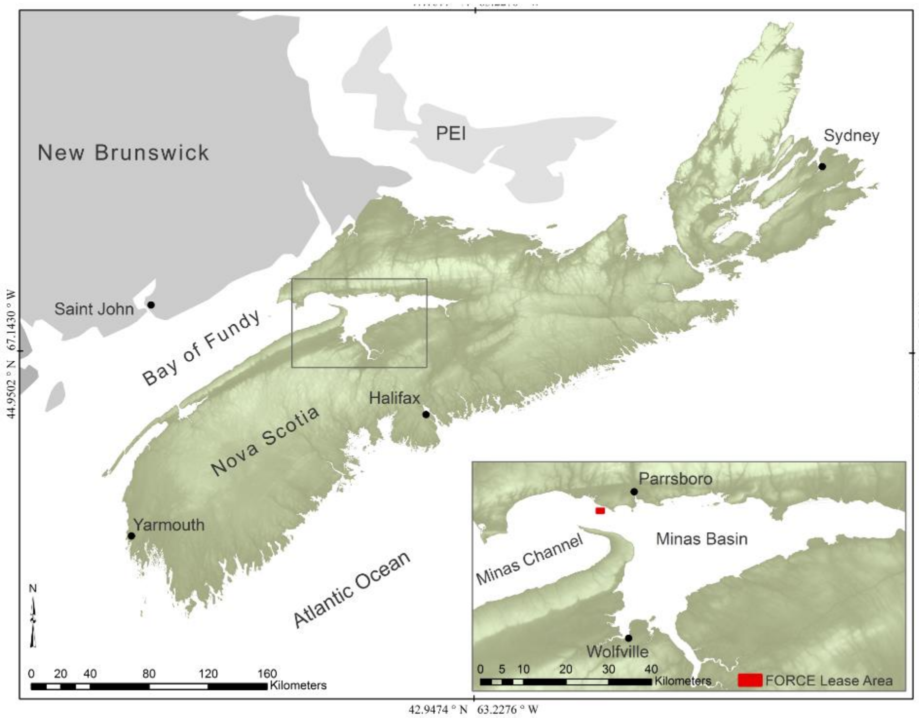

Figure 1. Map of the southern arm of the upper Bay of Fundy inset within a map of the Maritimes. The Minas Passage is the 5-6 km wide passage between Minas Basin and Minas Channel and includes the FORCE Crown Lease Area. Prepared by Shalon Oldford-McLellan.

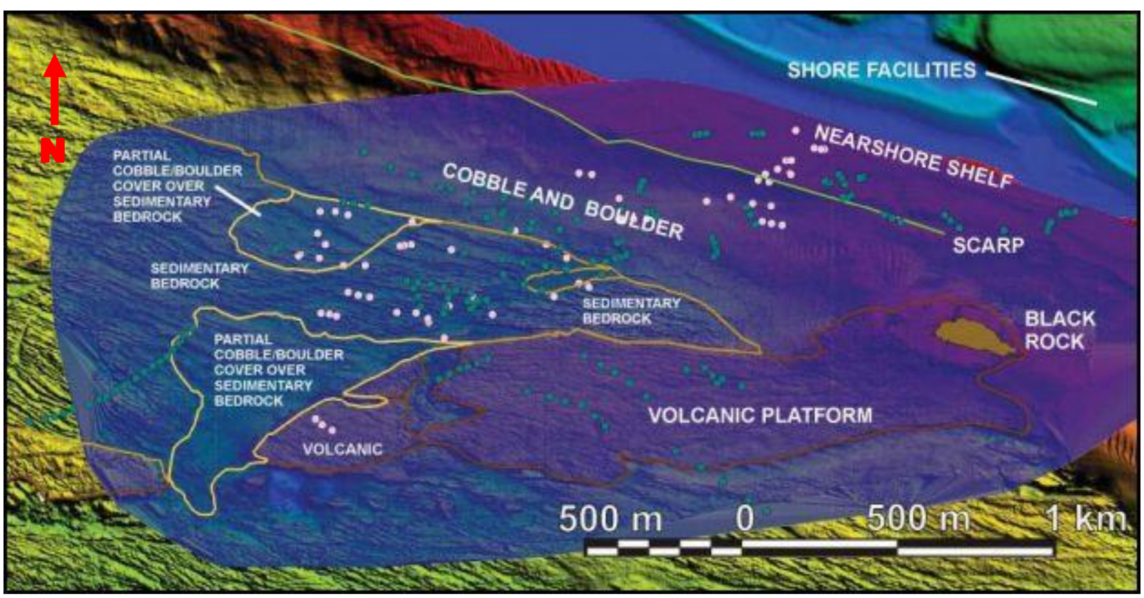

Figure 2. Surficial geology and multibeam bathymetry of the Minas Passage, Bay of Fundy (Envirosphere Consultants Ltd., 2009).

Fader (2009) characterized the Minas Passage using multibeam bathymetry data (Figure 3) combined with the most recent geological map of Nova Scotia. The northern region of the Minas Passage houses broad, exposed bedrock platform ridges with some gravel cover and glaciomarine till units, possibly relict moraines (Fader, 2009). Surficial sediment typically consists of boulders and cobbles, with very little fine-grained silt and clay. These unconsolidated materials are located within troughs that exist between ridges of exposed sedimentary and volcanic bedrock (Fader, 2009). The area closer to Cape Sharp has smoother seafloor topography and is shallower (Fader, 2009). A transition from scoured bedrock to well-sorted, rounded gravel and boulders occurs at approximately 40 m below mean low water (MLW). This denotes the paleo-beach location, prior to the Wisconsinan glaciation (Fader, 2009). It is noteworthy that the bedforms present in the Minas Passage are not static; multi-beam sonar surveys conducted between 2008 and 2012 indicate significant near-shore slumping of sand and gravel beds, areas of erosion and other shifts in sediment (pers. comm., Gordon Fader, AMGC).

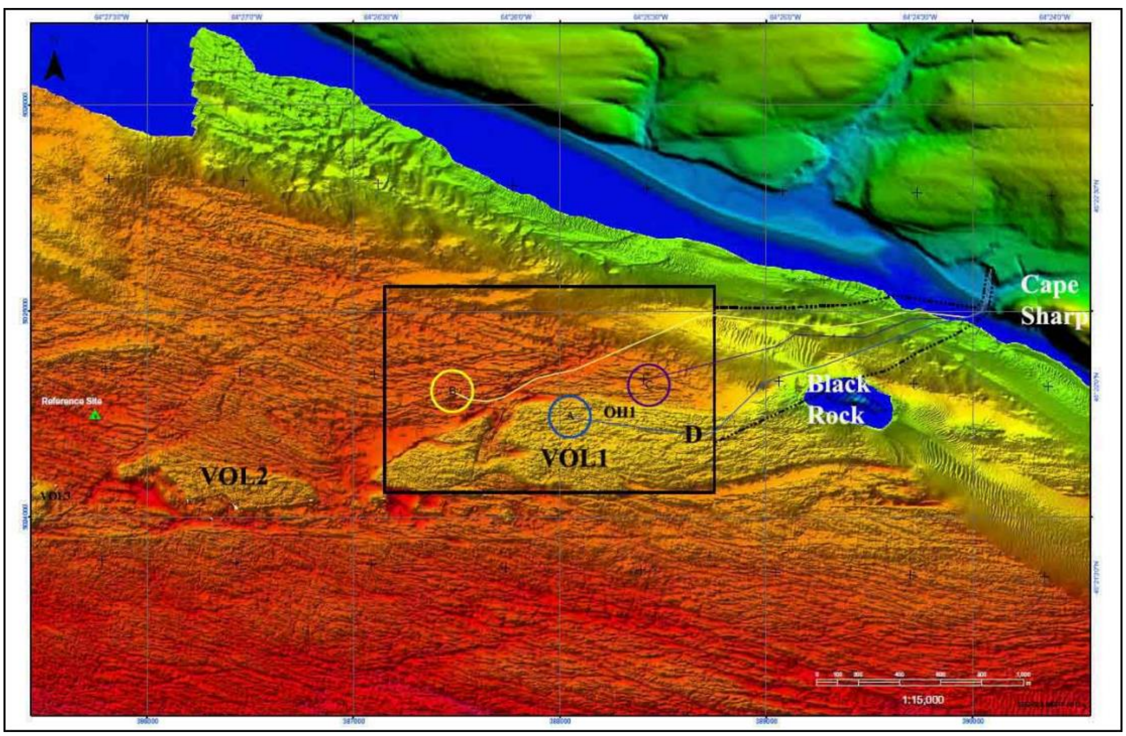

Figure 3. Multibeam bathymetric map of the FORCE test area, Minas Passage, Bay of Fundy (Source: GSC, in Fader 2011), showing gravel waves, troughs, and various bedforms. Black Rock, a small island composed of volcanic bedrock, is located east of the FORCE site.

The great depth achieved in the center of the Minas Passage (120 m) is postulated to be a result of the contact between the Triassic Blomidon Formation in the southern portion and the Carboniferous rocks in the northern section (Fader, 2009). These contacts are autochthonous with the Minas Fault Zone. One of these fault lines is visible in recently obtained multibeam data, striking from near Cape Sharp to northwest of Cape Split, on the opposite shore of the Minas Passage (Fader, 2009).

1.3 Minas Passage Flow Regime

The Minas Passage is an unusually high energy, turbulent, megatidal environment (Oceans Ltd., 2009). The tidal amplitude in the Bay of Fundy is the largest in the world in part because of the tidal resonance which is perpetuated by the geometry and bathymetry of the Bay of Fundy itself (Figure 1). The shape of the Bay of Fundy results in an oscillation period of 13 hours which is close to the maximum tidal resonance achieved (12.4 hours), thus the Bay of Fundy comes very close to perfect resonance (Oceans Ltd., 2009). The difference in water level between high and low tide in the Bay of Fundy has been recorded to be as great as 17 m (Parrott, 2009), and about 13 m in the Minas Passage, and is in striking contrast to the range that is typical of open ocean tidal variation (1-2 m). Mean current speed in the Minas Passage during spring tides is 4.5-5.2 m/s in surface waters and decreases with depth, with an average water column decrease of 1.3 m/s from surface to near bottom (1 to 2 m above the seafloor) (Oceans Ltd., 2009). During spring tides, current speeds of up to 150 cm/s have been detected 0.5 m above the seafloor (Oceans Ltd., 2009a). A model of the power density for the Bay of Fundy (Figure 4) shows the Minas Passage to be the Bay of Fundy site with the greatest power density and thus greatest tidal energy extraction potential.

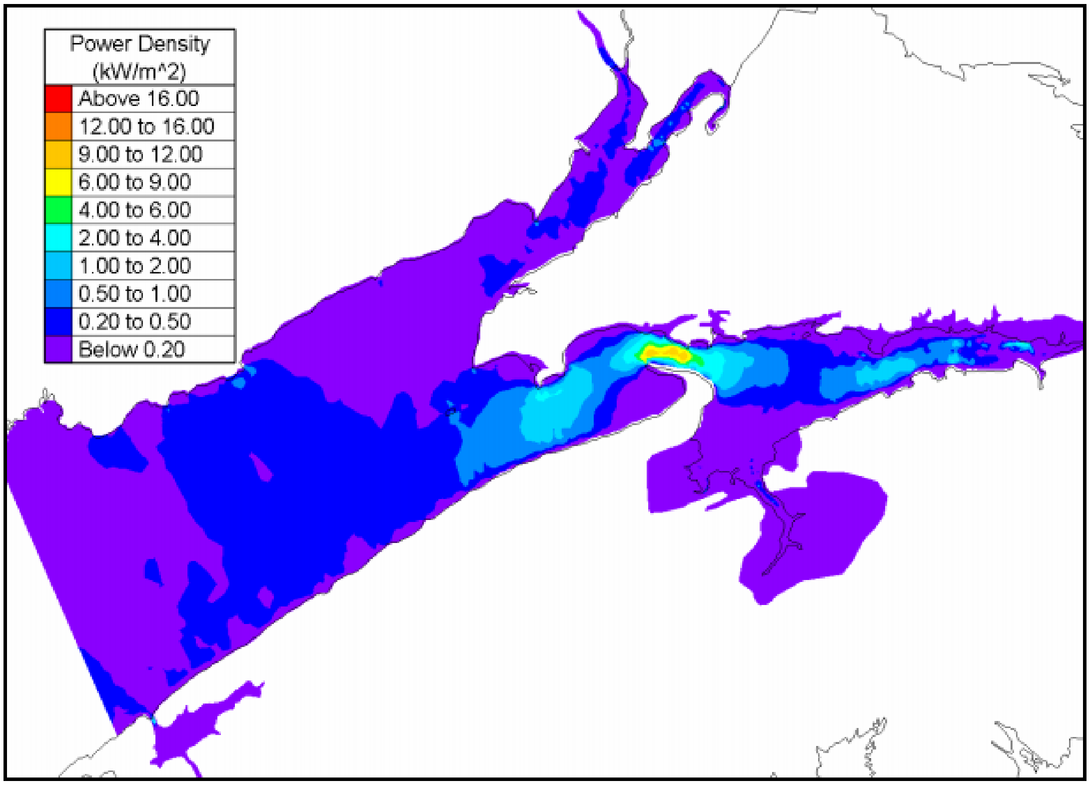

Figure 4. Minas Passage power density in kW/m^2 (Cornett, 2006).

Tidal currents in the Minas Passage create a high stress environment, with mobile sediments and areas that are highly scoured. Sediment is transported (by suspension and bedload) from nearshore regions eastward during flood tide and westward during ebb tide. The sediment model of Wu et al. (2011) depicts anticlockwise motion of suspended sediments, with net sediment movement of $2.4 \times 10^6\ m^3 yr^{-1}$ eastward into Minas Basin, a region of sediment deposition.

The flow regime in the Minas Passage influences the substrate type, patterns in sediment movement and the biota that live in association with the bottom. Immobile clasts, as found in the Minas Passage, are more likely to be colonized by strongly attached sessile organisms, whereas clasts subject to diurnal tidal motion provide less suitable habitat.

Multibeam or sidescan sonar, and other geophysical techniques, provide high resolution substrate information. The relationship between substrate features and epibiota can be assessed using geo-referenced photographs and, where possible, bottom grab samples for ground-truthing

(Diaz et al., 2004). With the exception of very high flow areas, ground-truthing for taxonomic identification can be assisted by remotely operated vehicles fitted with cameras.

1.4 Minas Passage Water Quality

Some of the major factors known to influence the distribution of biota include water temperature, degree of light penetration, nutrient regime, flow velocity, oxygen levels, salinity, and the physical substrate (Valentine et al., 2005). These environmental factors influence taxonomic composition and both abundance and morphology of organisms present in a particular sublittoral benthic community.

Envirosphere Consultants Ltd. (2009a, 2010, 2011) report water quality data from the Minas Basin and the Minas Passage, including water temperature, suspended sediment concentrations, turbidity, and Secchi depth (Table 1). Given strong vertical mixing, measures of suspended sediments (suspended particulate matter) taken at the surface are assumed to be similar with depth (Envirosphere Consultants Ltd., 2011). Maximum turbidity has been observed during the months of February and March (Envirosphere Consultants Ltd., 2009a), following ice melt, with relative low SPM and NTU values during July-September (Table 1, Figure 5).

Table 1. Minas Passage water quality data from surveys in 2008-2011 (Envirosphere Consultants Ltd., 2008, 2009a, 2011).

Date	Depth (m)	Surface Temp (°C)	Secchi Depth (m)	SPM (mg/L)	Turbidity (NTU)
15 Jan 2011	Surface	3.86	1.5	10.8	N/A
2 Feb 2009	5m from bottom	-0.19	N/A	19.2	3.1
10 March 2009	5m from bottom	0.20	N/A	21.0	0.5
18 June 2009	24.7	10.35	5.8	13.75	0.39
2 July 2009 19 July 2010	30.3	nd 15.56	nd 2.75	7.31	1.35 (water column ave)
4 Aug, 2009 18 Aug 2010	38.48	Nd 16.76	nd 3.27	6.74	1.54 (water column ave)
23-24 Sept 2008	5m from bottom	15.0	N/A	8.8	N/A
26 Oct 2010	surface	12.93	2.0	6.2	N/A

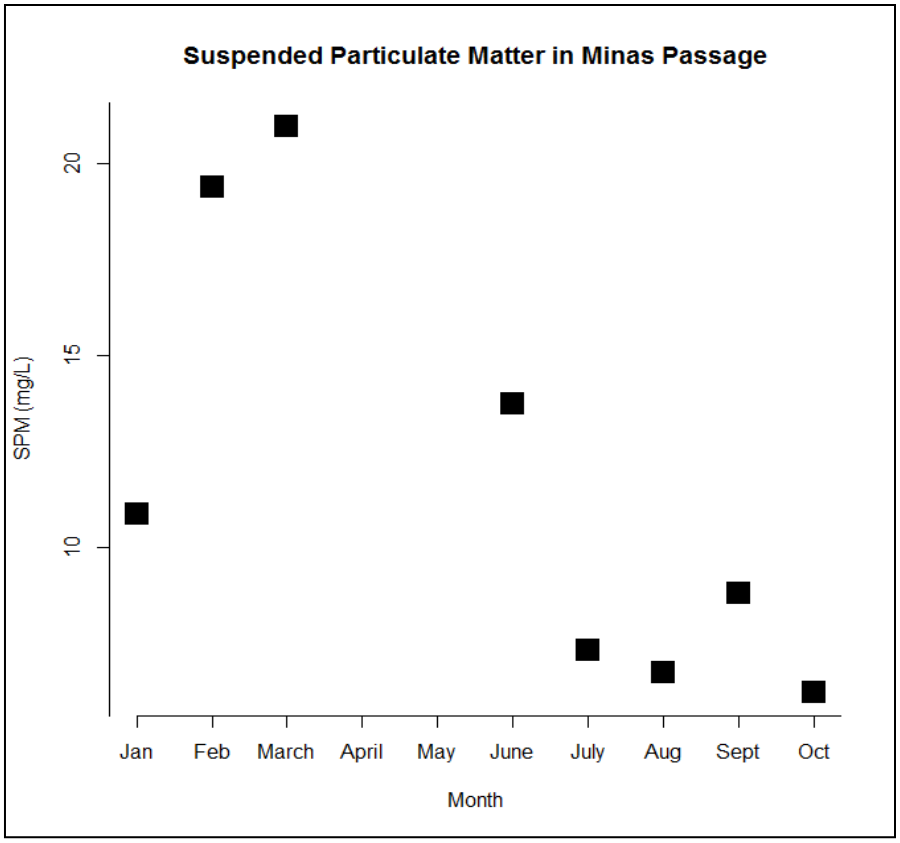

Figure 5. Surface measurements of suspended particulate matter (mg/L) in the Minas Passage, Bay of Fundy. Data sourced from Envirosphere Consultants Ltd. (2009a, 2010, 2011).

1.5 Minas Passage Benthic Surveys

There have been very few surveys of the benthic community in the Minas Passage area. The bottom features were profiled by the Geological Survey of Canada in 2006 using multibeam sonar (Fader, 2009). In 2007, a preliminary benthic video survey of the Minas Passage west of Parrsboro, Nova Scotia, included video footage along predetermined nearshore transects for two to three minute time periods using a weighted video camera, attached to an umbilical/tow cord (Brylinsky, 2008). It was found that bedrock and boulders provided the best substratum for epifaunal community development but macrofauna, including bryozoans, seastars, sea urchins, and sponges were also observed atop unconsolidated sediment (Brylinsky, 2008). Video footage of the seafloor in the FORCE area has revealed low diversity of epibiota, with the main biota observed being sponge taxa (Envirosphere Consultants Ltd., 2009).

1.6 FORCE Tidal Turbine Test Site

The northern side of the Minas Passage is the location of the Fundy Ocean Research Centre for Energy (FORCE) test facility, an in-stream tidal energy turbine demonstration centre (Figure 6). The Minas Passage is characterized by a maximum tidal range of 13 m and currents that exceed 2 m/s for >50% of the time, peaking at >6 m/s (Richard Karsten, pers comm). The physical constriction of water as it flows between the Minas Channel and the Minas Basin creates current speeds that are ideal for harnessing tidal energy. Although energy extraction potential is high, near- and far-field impacts of tidal energy development remain largely unknown.

For the most part, the seafloor in the FORCE crown lease area (1 km x 1.6 km; Figure 6) is scoured, with either exposed bedrock or moderate amounts of cobble cover (AECOM, 2009). Depth ranges from 30-50 m at mean low water (MLW) (Fader, 2009). When the environmental assessment for FORCE was conducted in 2008-2009, FORCE had established three 200 m diameter berth sites for the installation of commercial size (1 MW or greater) in-stream tidal energy conversion devices, with an associated cable route to shore for each berth (Figure 6). The benthic biota in the three berths and associated cable routes are the focus of this study.

Double armoured subsea cables (18 cm in diameter) will be laid atop the substrate, with the cable route utilizing the existing areas of low relief that offer protection for the cable (*e.g.* between boulders, Figure 2). The subsea cables and turbine infrastructure (*e.g.* gravity bases) have the potential to create a 'footprint'. The current study will help address assessments of the impact of infrastructure on both the substrate and epibenthic fauna in the FORCE test site.

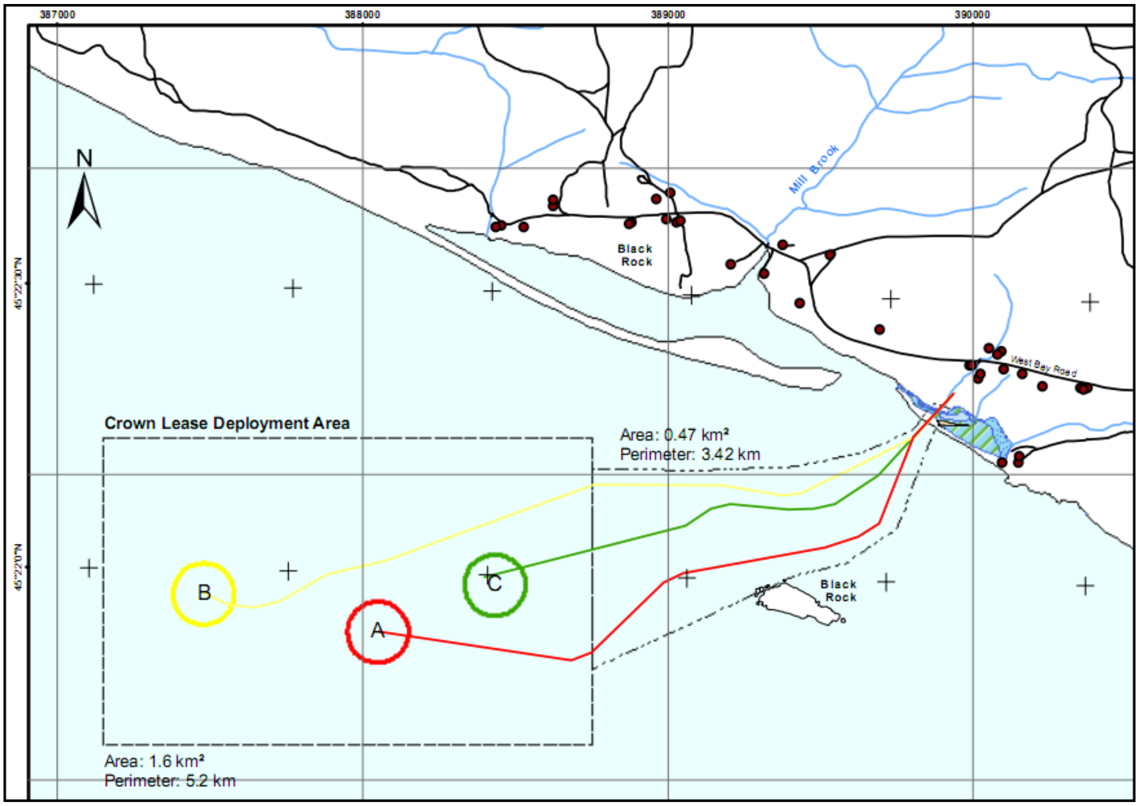

Figure 6. Map of the northern side of the Minas Passage, showing the FORCE crown lease deployment area (rectangle) and the locations of turbine berth areas A, B, and C and associated cable routes (Source: AECOM, 2009).

1.7 Minas Passage Environmental Assessment for FORCE

The project to set up FORCE and the tidal energy turbine test facility began in January 2008. Soon after, baseline information was collected to provide basic information for site selection and to support an environmental assessment (EA) for the project. Studies included assessment of substrate features and general composition of the benthic community in the proposed crown lease area (shore to berth areas; up to 50 m deep).

From the shore to the center of the Minas Passage, the substrate transitions from a nearshore platform, to an area of unconsolidated sediment, to a region of volcanic bedrock, to sedimentary bedrock in the center of the channel (Envirosphere Consultants Ltd., 2009a). The nearshore platform is a shallow zone, composed of unconsolidated sediment of increasing grain size downslope along the sloping shelf leading to the center of the Minas Passage. This zone is an extension of the intertidal/beach zone, sharing similar characteristics but always fully submerged (Fader, 2009). This region is 20-25 m below MLW (Envirosphere Consultants Ltd., 2009a, Stewart, 2009).

Videographic surveys of the three berth sites and cable routes were conducted for the EA in 2008 (Envirosphere Consultants Ltd., 2008). The EA report noted variable bedrock (sedimentary and volcanic) and surficial sediment, and the presence of brown and red macroalgae (*Fucus*, dulse*),* coralline algae, bryozoans, hydroids, an unidentified "biolayer" (an encrusting, semi-adhesive amalgamative layer of biological material), anemones, seastars, yellow breadcrumb sponge, white sponge, and rare observations of fish (Envirosphere Consultants Ltd., 2008; Stewart, 2009).

The subtidal zones that are differentiated by exposed sedimentary bedrock are typically 50 m below MLW, with sand, silt, and mudstone ridges with intervening troughs (Envirosphere Consultants Ltd., 2008). The troughs contain some cobbles and boulders, as well as some fine grained sediment. This region has a well-developed "biolayer", as well as hydroids, bivalves, hermit crabs, red anemones, barnacles, seastars, amphipods, polychaetes, and rarely longhorn sculpins (Envirosphere Consultants Ltd., 2008). Markings were noted on red mudstone outcrops (Figure 7) that are believed to be either borings or root fossils (Envirosphere Consultants Ltd., 2008; Fader, AMGC pers. comm.,).

Figure 7. Photograph of mudstone with possible root fossils from within Berth B, FORCE test site (Envirosphere Consultants Ltd. 2008).

The FORCE crown lease area includes volcanic bedrock approximately 30 m below MLW (Envirosphere Consultants Ltd., 2009a). It is basaltic, with cracks and some boulders strewn over it. Darker hued biolayers exist here, as well as encrusting organisms (barnacles, yellow ridged sponges).

The large set of photographs available in the Envirosphere Consultants Ltd. reports (Envirosphere Consultants Ltd., 2009b, 2009c, 2009d) provides the basis of the present study – a description of benthic habitat conditions of the FORCE crown lease area, mapping of the dominant biota, and examination of the relationships between biota and other habitat variables (substrate type, depth, etc.).

1.8 Objectives

The main aim of the study was to examine both qualitative and quantitative aspects of the relationships between biological and physical features of the benthic environment in the FORCE crown lease area (berth areas and cable routes) and is based on videographic material collected for the 2008 EA. The study examines in greater detail the benthic communities in the FORCE test area and provides baseline data that can be used to examine the effects, if any, of subsea infrastructure (cables, gravity bases for turbines).

The main objectives were to:

1. characterize the benthic substrate (bedrock type, percent exposed bedrock, type, nature, and size of cobbles if present) and their prospective mobility;
2. determine the percent cover of biota on the seafloor (identifying taxa when possible);
3. examine patterns in habitat use with depth and substrate type; and
4. create distribution maps of the dominant fauna in the berth areas and along cable routes, for use by berth developers and assessment of potential environmental effects.

2.0 METHODOLOGY

2.1 Field methods

Background oceanographic, geological and geophysical information at the FORCE test site was derived from a multidisciplinary survey program conducted during 2008-2010 by the initial test site developer (Minas Basin Pulp and Power Ltd., Hantsport, NS). The survey included detailed multibeam bathymetric profiles with sub-metre resolution; sub-bottom profiling; video/still photographic imaging surveys of the seabed, current profiles using ADCPs, and oceanographic measurements of temperature, salinity and turbidity. Water samples were collected for the determination of suspended particulate matter (SPM).

Video and oceanographic surveys completed in 2008 and 2009 for the environmental assessment and site characterization of the FORCE tidal energy demonstration area, provided the raw data utilized in the present study. It included geological information pertinent to the FORCE site, as well as presence or absence of biota and counts of non-colonial species (Envirosphere Consultants Ltd., 2009 a-d, 2010, 2011). The video surveys include Berths A, B, and C and Cable Routes A, B, and C (Figure 3)

With the exception of one survey in February 2009, a 15-metre (50 foot) lobster boat (*Tide Force*), captained by Mark Taylor, Halls Harbour, was used for surveys. The other survey used the *Eric Junior,* captained by Robert Vaughan, also from Halls Harbour. Target sites within the designated turbine berth areas (Figure 8) were pre-selected for data collection from representative seafloor types in the region (Envirosphere Consultants Ltd., 2008).

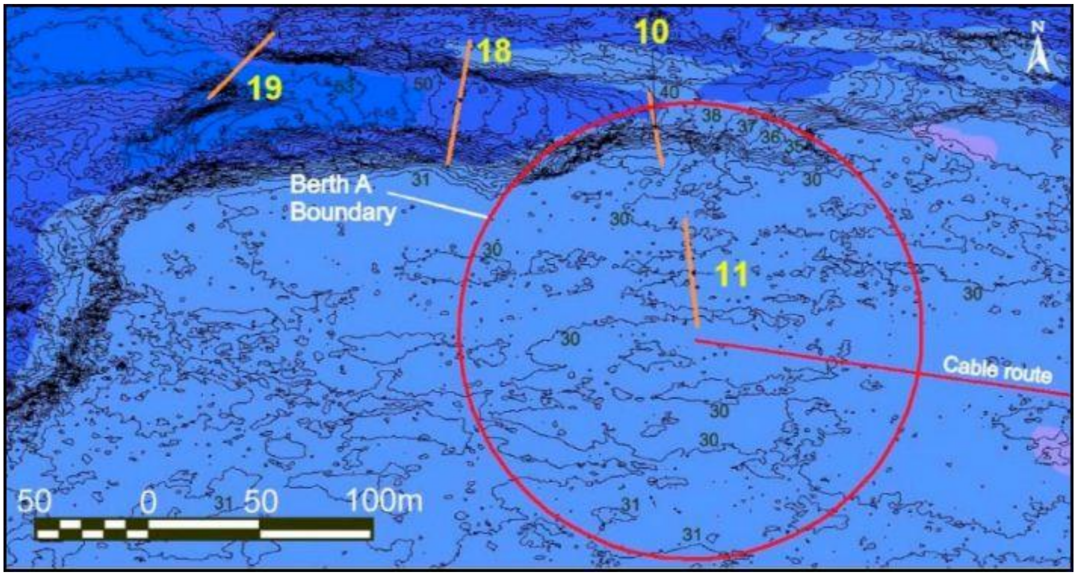

Figure 8. Bathymetric map of Berth A and surrounding area. The four numbered lines represent depth transects (Envirosphere Consultants Ltd., 2009b).

The video recording apparatus (Sony Hi-8 handicam, encased in an Amphibico underwater housing and mounted in an aluminum frame with a 10W Amphibico underwater light), was lowered to the seafloor, while continuously recording, to obtain video coverage. The camera had a field of view of 40 cm top-to-bottom wide and 52.5 cm side-to-side; a scale-bar on the frame was included in the images (Envirosphere Consultants Ltd., 2008). The camera was lowered to the bottom at the pre-selected stations and between stations. At each location, the camera was ‘hopped’ or bounced up and down off of the seafloor for approximately one minute. Several samples of rock were collected in the initial surveys (2008) using a large grab sampler (0.2 m Van Veen) and a scallop drag (Envirosphere Consultants Ltd., 2008).

Video surveys were conducted in August and September 2008 (initial surveys) and on 2 February, 10 March, 18 June, 2-3 July, and 4-5 August, 2009 (site characterization and cable route surveys) (Envirosphere Consultants Ltd., 2009a). These surveys focused on regions not covered in the initial video footage but that were within the FORCE leased area, as well as along the three cables routes, which included the nearshore benthic communities near Black Rock. Depth profiles at berth sites were derived from multibeam bathymetric data obtained by Seaforth Geosurveys (Dartmouth, Nova Scotia) in July and October 2008 (Figure 9).

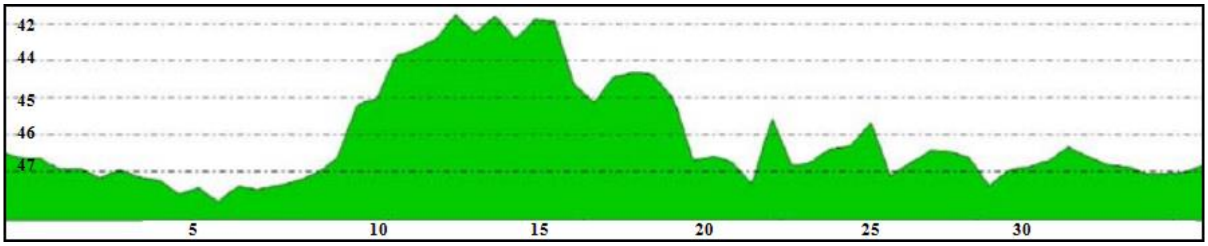

Figure 9. Depth transect 6 within and adjacent to Berth B derived from multibeam bathymetry data (Envirosphere Consultants Ltd., 2009c). The x axis shows the transverse distance (m) and the y axis shows depth (m) below mean low water.

2.2 Photo Processing

Hi-8 video from the surveys was initially digitized through an off-the-shelf video capture system, and edited to contain only useful views of the bottom. The edited video and representative image captures were presented in DVDs and CDs distributed with the original project reports.

About 2000 digitized still frames captured from the cable route and berth surveys (Berths A, B, and C) were examined for the purposes of this study. An initial assessment of the quality of the photos was conducted. Poor quality images were removed from the sample and the remainder analyzed for geological and biological features. Assessment of geological features of all useable photos included classification of the bedrock, based on observation, and the surficial, unconsolidated material, according to the Wentworth classification scheme (Table 2).

Table 2. Wentworth Classification scheme (Wentworth, 1922).

Millimetres (mm)	Phi (φ)	Size Class	Rock Type
256	-8.0	Boulder	Conglomerate/ Breccia
64	-6.0	Cobble	
4	-2.0	Pebble/Gravel	
2	-1.0	Granule	

For those photos exhibiting exposed bedrock and cobble or clasts, the percent cover of cobbles was determined using ImageJ, an image analysis software program. Unconsolidated lithic material present was selected using the freehand tool and the percent cover per frame of surficial material was calculated (Figure 10). Clast size was estimated using the straight line drawing tool in ImageJ.

Biota observed in the 1191 photos examined in detail was assessed using counts and/or percent cover of biological material (echinoderms, Cirripedia, Porifera, etc). Identification of taxa, based on a selection of good quality still photos was undertaken at the Hunstman Marine Lab (St. Andrews, New Brunswick) with the aid of taxonomists Dr. David Wildish, Lou van Guelpen, and Dr. Gerhard Pohle.

2.3 Data Analysis

Distribution maps of the dominant biota were created in ARCView for comparison with mapped physical features of the area. Mapped taxa include yellow breadcrumb sponge (*Halichondria panicea*), white sponge (*Leucosolenia botryoides*), blood stars (*Henricia sanguinolenta*), white seastars (*Asterias vulgaris*), and the northern red anemone (*Urticina felina*).

Relationships between physical and biological variables were examined using CART (Classification and Regression Tree), a multivariate data analysis tool. Using the statistics program R, CART trees were created for Berths and Cable Routes A, B, and C (Figures 15 and 16). CART analysis determined which habitat features (depth below MLW, the percentage cover of exposed bedrock (volcanic or sedimentary - sandstone and/or mudstone), and the percent cover of boulder, cobble, and gravel) that most influenced the percent cover of yellow breadcrumb sponge. CART analyses are used to split data sets in such a way that one feature (the categorical or dependent variable) varies in response to various independent or predictor variables (Lewis, 2000). Trees are produced with nodes or ‘leaves’ containing the dependent variable; branches from the leaves indicate subsequent splits.

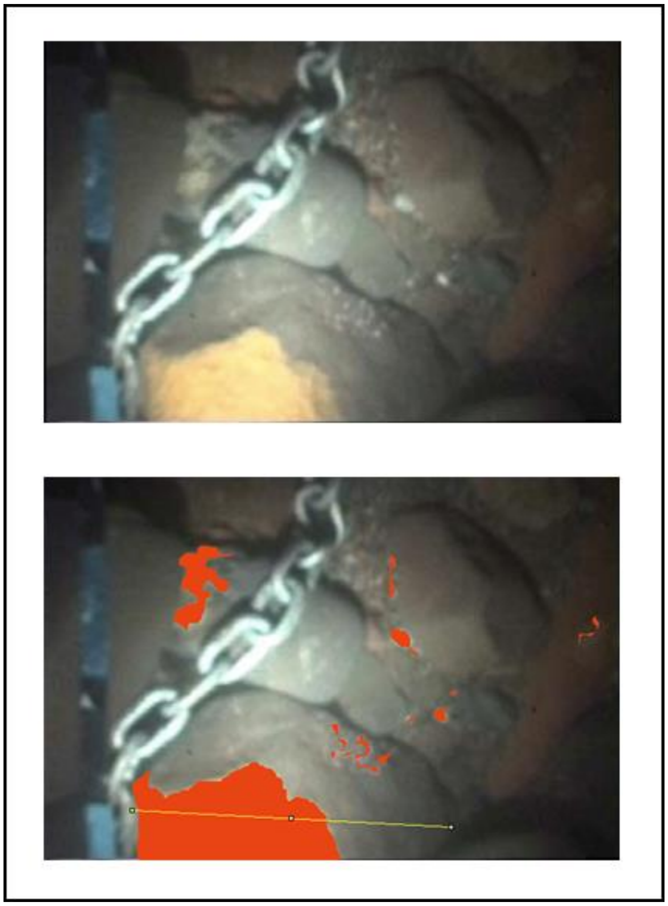

Figure 10. Image from Berth C pre- and post-ImageJ analysis showing percent cover of biota (shaded in orange) and determination of maximum clast size (yellow horizontal line).

3.0 RESULTS

3.1 Biota present

Within the FORCE test site, the species most commonly observed in video stills are two sponge taxa, *Halichondria panicea* and *Leucosolenia botryoides,* two seastar taxa, *Henricia sanguinolenta* and *Asterias vulgaris*, and the northern red anemone, *Urticina felina*.

Halichondria panicea is an encrusting, siliceous, yellow breadcrumb sponge. Mats are typically 1 cm thick and the osculae are short, between 1 and 4 mm (Bromley and Bleakney, 1984). *Leucosolenia botryoides* is a white, calcareous sponge, between 10 and 20 mm tall, commonly branching (Bromley and Bleakney, 1984). This species was present in small, isolated clusters or in thicker mats but not as extensive as *H. panicea* mats.

Henricia sanguinolenta is a blood star and red/orange in colour (can also be purple), exhibiting characteristic upturned arm tips (Bromley and Bleakney, 1984). Individuals present were approximately 5 cm in diameter. *Asterias vulgaris* is a white variety of seastar (can also be orange) with arms that lie flat on the substrate below it (Bromley and Bleakney, 1984). *A. vulgaris* were approximately 2-3 cm in length and generally smaller than *H. sanguinolenta*.

Urticina felina, referred to by the older name *Tealia felina* in Bromley and Bleakney (1984), is the northern red anemone and tend to be green in shallow waters and red in deep waters (Bromley and Bleakney, 1984). Anemones observed in this study were red and up to 3 cm in diameter.

3.2 Berth A

Of the still photos captured from the video footage taken within Berth A, 32% were excluded from subsequent calculations due to various clarity issues and/or obstruction of the field of view by portions of the camera deployment apparatus (Table 3). A total of 91 frames remained for analysis.

The clast composition in Berth A appeared to be sandstone and greywacke, but without grab samples this could not be determined with certainty. Clasts ranged in size from 10 cm to 1 m (10 frames containing boulder, 13 frames containing cobble), with an average length of 26 cm. The mean percent clast cover in Berth A was 23 (Table 4). Clasts were generally smooth and subangular to subrounded. It should be noted that some of the photos exhibited clasts larger than the field of view. These photos captured regions of exposed volcanic bedrock. Based upon the well-established layer of organisms (mostly sponge) atop the clasts, it is reasonable to assume that there is limited mobility of these clasts.

Berth A features extensive mats of yellow breadcrumb sponge, *Halichondria panicea* (49% cover; Figure 11), on bedrock and atop large boulders (Figure 19). *Leucosolenia botryoides,* a white sponge, covered less of the substrate (<1%) but appeared in 68% of frames from Berth A (Table 4). This species was present in varying degrees of thickness, appearing in small clustered mats or isolated colonies. Also present were two species of seastar, *Henricia sanguinolenta* (11% frames) and *Asterias vulgaris* (32% frames). *Urticina felina* (northern red anemone) was abundant at Berth A, appearing in 41% of frames and with an overall average density of about 5 individuals per m^2. Other biota observed in Berth A images include hydroids, sculpins (rarely), and an unidentified encrusting biolayer which appeared to be semi-adhesive and formed in clusters atop bedrock. It was commonly found in association with hydroids and adjacent to yellow sponge mats. Unfortunately, no physical samples were available to allow taxonomic identification of this material.

Table 3. Summary of videographic survey periods and general quality of photos for use in identification of taxa.

Berth/ Cable Route		Date Collected mo/yr	Total frames	Image Quality		
				Poor and not used (% total frames)	Adequate quality (% total frames)	Good quality (% total frames)
Berth	**A**	July-Aug/2009	136	32.1	18.7	49.3
	B	June-July/2009	168	14.9	27.4	57.7
	C	Feb-July/2009	302	0	39.1	60.9
Cable Route	**A**	Aug/2009	114	0	13.0	87.0
	B	July-Aug/ 2009	144	0	9.0	91.0
	C	June-July/2009	397	0	64.0	36.0

Table 4. Summary of substrate features and cover by dominant epibenthic fauna as shown by still frames taken from the site characterization videographic surveys (Envirosphere Consultants Ltd., 2009b, 2009c, 2009d) of Berths A, B, and C and their associated cable routes. Note: includes only biota >1 cm long. *exposed bedrock

Features		Berth			Cable Route		
		A	B	C	A	B	C
Location (center of berth)		45.358982, -64.4243816	45.359597, -64.4354337	45.35984, -64.421469	N/A	N/A	N/A
Depth Range (m at MLW)		29-31	44-51	36-54	7-39	2-53	5-39
Collection Time (mo/yr)		July-Aug/ 2009	June-July/ 2009	Feb-July/ 2009	Aug/ 2009	July-Aug/ 2009	June-July/ 2009
# Frames		91	143	302	114	144	397
Primary Bedrock Type		Vol	Sed/Muds	Sed/Muds	Vol/ Sed	Sed/ Muds	Sed
% Frames	**Bedrock***	74.7	54.9	23.7	43.9	19.4	18.6
	Boulder	11.0	8.74	11.3	11.4	18.8	5.8
	Cobble	14.3	33.9	65.0	40.4	53.4	68.8
	Gravel	0	2.45	0	4.3	8.4	6.8
% Frames with *H. panicea* (ave % cover)		100 (49.0)	39.9 (8.7)	24.5 (3.0)	52.2 (18)	15.3 (3.0)	12.6 (1.0)
% Frames with *L. botryoides* (ave % cover)		68.1 (0.45)	67.8 (2.0)	36.1 (0.81)	73.9 (0.98)	49.3 (0.52)	36.5 (0.64)
% Frames with *A. vulgaris* (ave density/m^2)		31.9 (3.0)	18.2 (1.3)	3.6 (0.21)	12.1 (0.59)	2.8 (0.13)	4.5 (0.20)
% Frames with *H. sanguinolenta* (ave density/m^2)		11.0 (0.58)	7.0 (0.40)	8.6 (0.47)	14.3 (0.63)	1.4 (0.07)	2.5 (0.12)
% Frames with *U. felina* (ave density/m^2)		40.7 (5.44)	8.4 (0.50)	2.7 (0.03)	14.8 (1.96)	2.1 (0.40)	0
% Frames with Tunicates		0	6.3	0	0	0	0.5
% Frames with visible Gastropods		0	0	5.6	3.5	2.7	3.8
% Frames with Macroalgae		0	0	1.7	1.7	7.6	0.5
% Frames with Bryozoans		0	0	2.7	0	0	0
% Frames with Fish		2.2	0	0	0.9	0	0

3.3 Cable Route A

Of the 114 photos that represent Cable Route A, 100 frames (87%) were of good quality (Table 3). For the majority of the cable route the bedrock was not visible because the image was not sufficiently clear, or there was biological or clast cover. In photos where the bedrock was visible, volcanic and mudstone types were present.

Clasts in Cable Route A tended to be subangular to subrounded, ranging in size from 2 cm to 41 cm. Frames from this route showed a mean percent clast cover of 56% (Table 4) and the presence of some fine, reddish, muddy material throughout the cable route.

Halichondria panicea was present in a total of 60 of the 114 frames available, and within these, the mean percent cover was 18% (± sd = 26.8). *Leucosolenia botryoides* appeared in 74% of frames but overall cover was <1%. Each of the two species of seastar and the northern red anemone were present in densities of $<2/m^2$ (Table 4). Other biota observed in images along Cable Route A included hydroids, *Leucosolenia botryoides*, red seaweed, gastropods, and a sculpin. Macroalgae was found largely in shallow waters close to shore.

3.4 Berth B

Bedrock in Berth B was generally sedimentary with some mudstone. Mean percent clast cover was 44% (Table 4). Clast size ranged from fine-grained gravel to boulders and average clast size was 19 cm. Clasts were smooth and rounded, and subangular to rounded.

Halichondria panicea was less common in Berth B (9% cover) than Berth A. And *Leucosolenia botryoides* (2% cover) appeared in sparse, isolated colonies or, more rarely, in thick patches on sandstone bedrock. Densities of *Asterias vulgaris*, *Henricia sanguinolenta,* and *Urticina felina* were low (≤ 1 ind / m^2).

Other biota included hydroids, tunicates (*Boltenia ovifera*), serpulid worms, an unidentified encrusting biolayer, and an unidentified vegetative biolayer. The vegetative biolayer differed from the encrusting biolayer in that it appeared to be less firm and more filamentous in nature. As well, the vegetative biolayer consisted of a filmy layer of growth on bedrock or cobble, and formed more expansive mats than the encrusting biolayer.

3.5 Cable Route B

Clasts were subangular to subrounded, sedimentary in nature, and ranged in size between 1 cm and 43 cm. Mean percent cobble cover in Cable Route B was 76% (Table 4). Sedimentary bedrock and mudstone bedrock were observed, as was a muddy layer in shallower waters.

Leucosolenia botryoides was identified in 49% of the frames but cover was <1% overall (Table 4). Percent cover of *Halichondria panicea* was higher at 3% but appeared in only 15% of frames. Both species of seastar, *Henricia sanguinolenta* and *Asterias vulgaris,* and the anemone, *Urticina felina,* appeared in <3% of the frames. Other biota present in Cable Route B included gastropods, hydroids, red seaweed, and an unidentified encrusting biolayer. Also present were structures that appeared to be root fossils (white, elongated features on mudstone).

3.6 Berth C

A total of 302 still frames of Berth C were examined. Clasts were sedimentary, subrounded to subangular, and ranged in size from 6.6 cm to greater than 1 m. More than half of the images showed cobble and about 10% of the images showed boulders. The mean percent clast cover in Berth C was 76 (Table 4). A muddy surface layer was present in 3% of the frames.

Of the 3 berth areas, the sponges *Leucosolenia botryoides* and *Halichondria panicea* were least common in Berth C, with mean percent cover of 0.8 and 3.0%, respectively (Table 4; Figures 12 and 14). Also present, but in small numbers (<0.5 ind/m^2), were the seastars, *Henricia sanguinolenta* and *Asterias vulgaris,* and the anemone*, Urticina felina.* Other taxa observed included gastropods, hydroids, red macroalgae, bryozoans, serpulid worms and an unidentified encrusting and vegetative biolayer.

3.7 Cable Route C

Clasts were subrounded to subangular, sedimentary, and ranged in size from 3 cm to 39 cm. The mean percent clast cover in Cable Route C was 81% (Table 4). Cobble was present in 69% of frames. Gravel and boulder were found in <7% of the frames. Bedrock was sedimentary and a muddy layer was present in some photos.

Sponge cover by both species was low (<2%). Densities of the seastars *Henricia sanguinolenta* (0.12/m^2) and *Asterias vulgaris* (0.20/m^2) were low compared to Cable Route A.

Gastropods, hydroids, *Leucosolenia botryoides* (<1% cover), red macroalgae, *Flustra*, tunicates, serpulid worms and an unidentified vegetative biolayer were also present.

3.8 Relationship of Biota to Substrate Features and Water Depth

Classification and Regression Tree (CART) statistical analyses were performed on the datasets from Berths A, B and C (Figure 15) and Cable Routes A, B, and C (Figure 16) to determine the habitat features with the most influence on the mean percent cover of the dominant species, *Halichondria panicea* (yellow breadcrumb sponge). Habitat features included in this analysis were depth below MLW (see Figures 20-22 in Appendix), percent cover of exposed bedrock (volcanic or sedimentary - sandstone and/or mudstone), and percent cover of boulder, cobble, and gravel.

The berth area analyses indicated that the feature most influencing the percent cover of *H. panicea* varied among berth sites; it was percent of exposed volcanic bedrock in Berth A, the percent of exposed sedimentary bedrock in Berth B, and the depth below MLW in Berth C (Figure 15). It should be noted that Berth C exhibited significant clast cover (mostly cobble) and little visible bedrock (Table 4). Abundant loose clast cover in this berth would have prevented much colonization by sponges.

The cable route analyses showed similar diversity in results. The feature that appears to most influence the percent cover of *H. panicea* was the percent of exposed volcanic bedrock in Cable Route A, the percent cover of boulders in Cable Route B, and depth below MLW in Cable Route C (Figure 16).

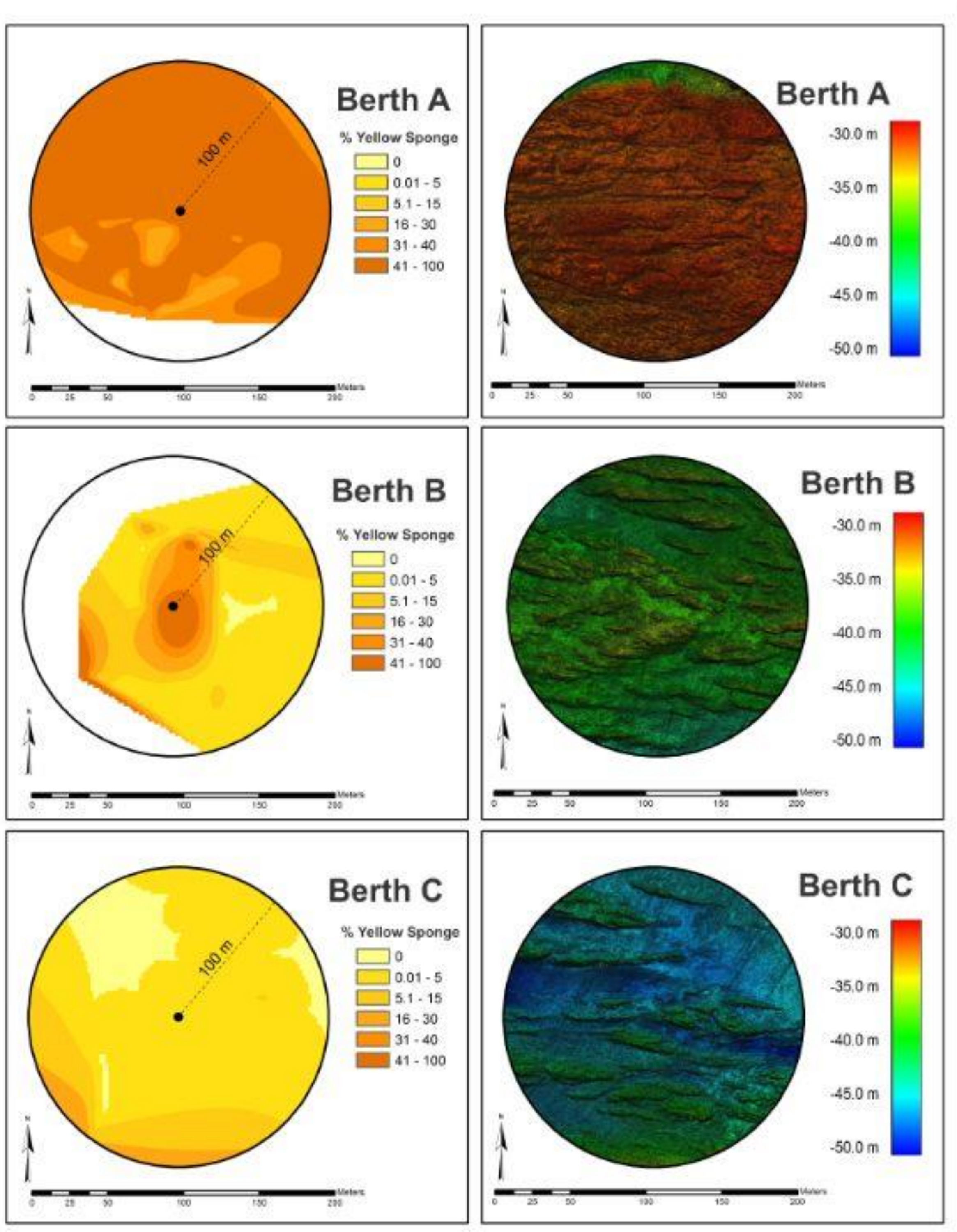

Figure 11. Maps of percent cover of yellow breadcrumb sponge (*Halichondria panicea*) (left panel), and bathymetry (depth below MLW), as determined by multibeam sonar (right panel), for Berths A, B, and C. Multibeam data provided by FORCE.

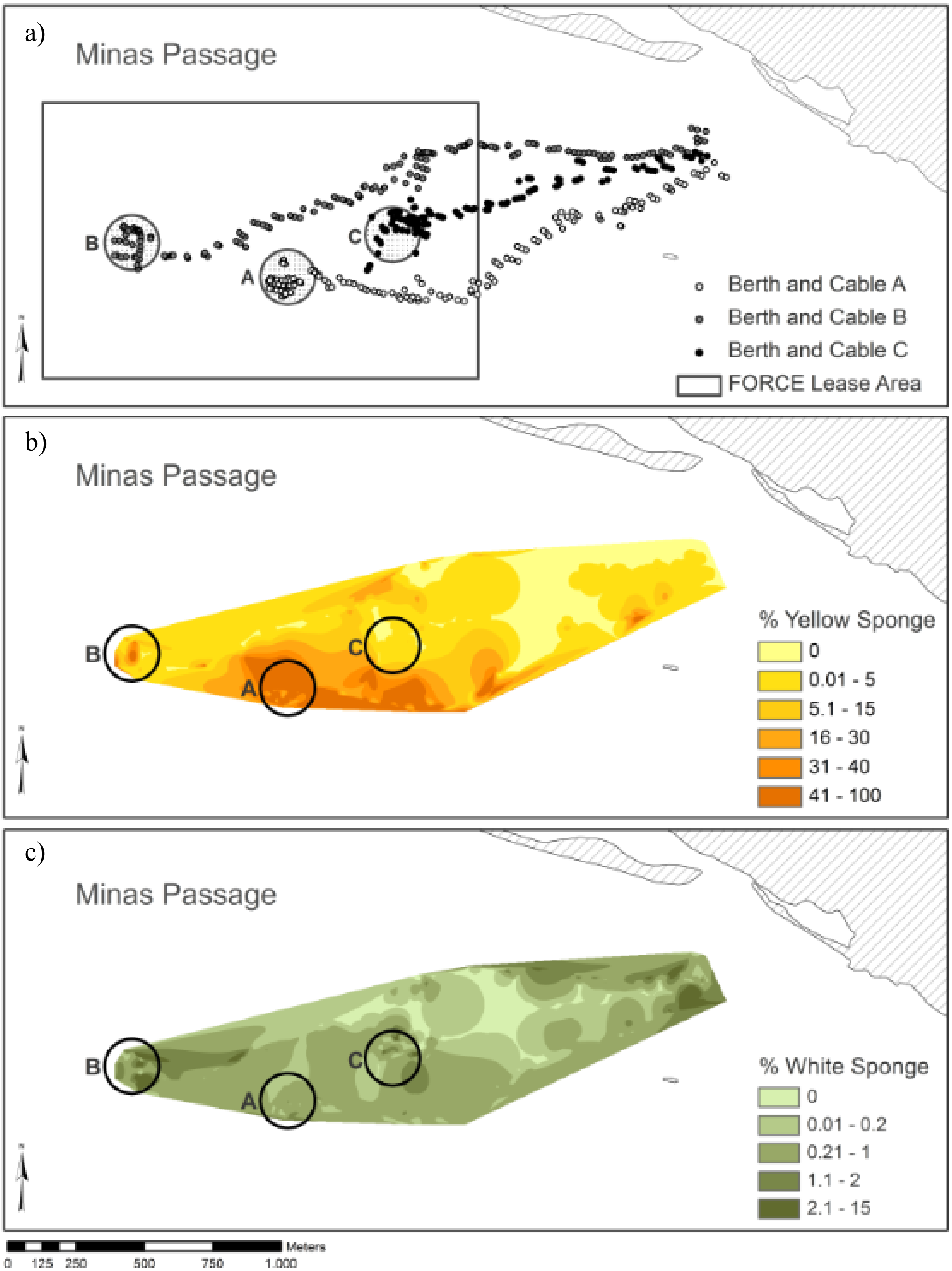

Figure 12. Maps of a) FORCE test area depicting all sample stations for which photos were analyzed in Berths A, B, and C and Cable Routes A, B, and C, b) extrapolated percent cover of yellow breadcrumb sponge (*Halichondria panicea*), c) extrapolated percent cover of white sponge (*Leucosolenia botryoides*).

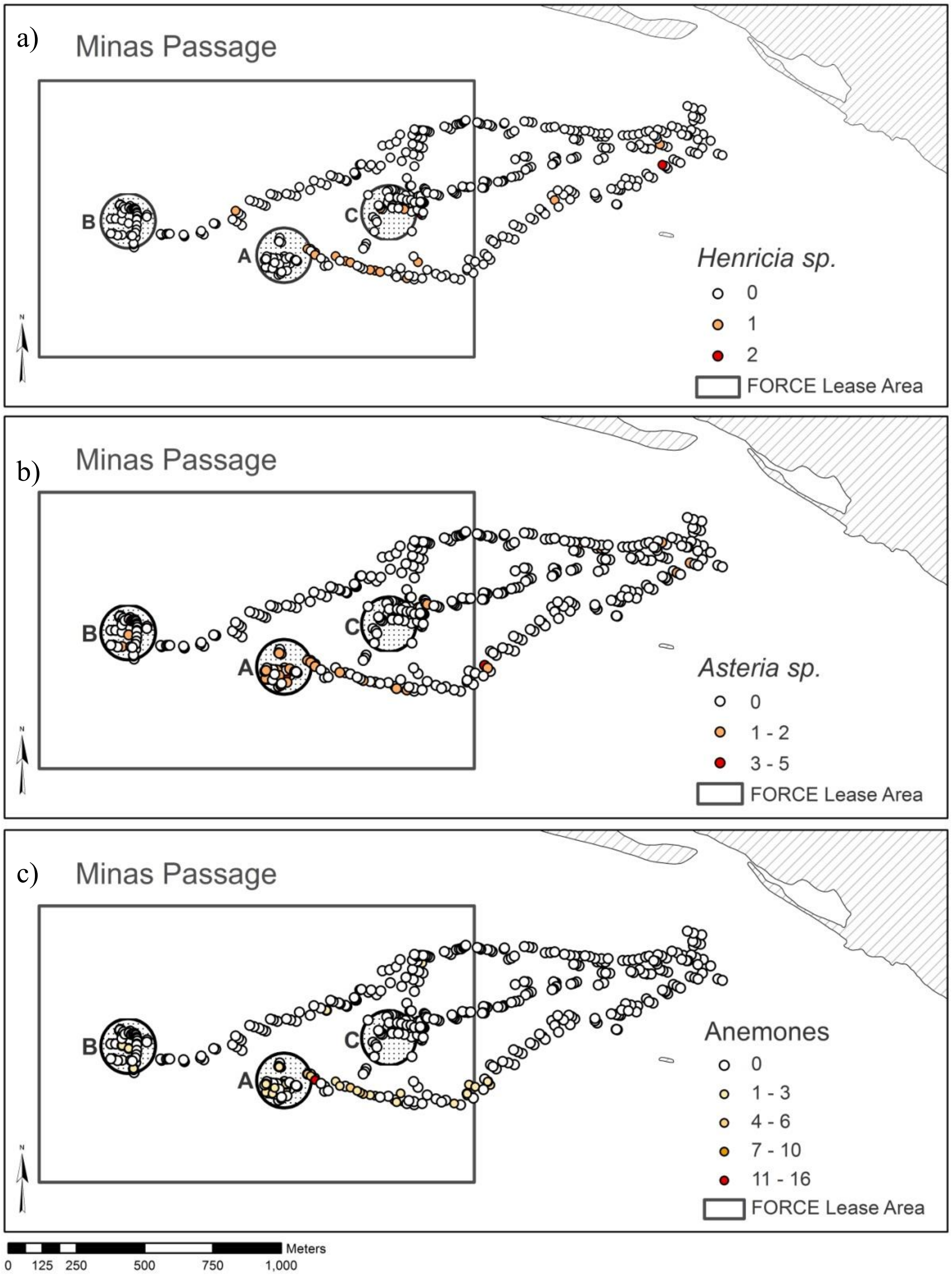

Figure 13. Maps illustrating the presence and densities per frame (40 cm x 52 cm) of a) blood stars (*Henricia sanguinolenta*), b) white seastars (*Asterias vulgaris*), and c) northern red anemones (*Urticina felina*).

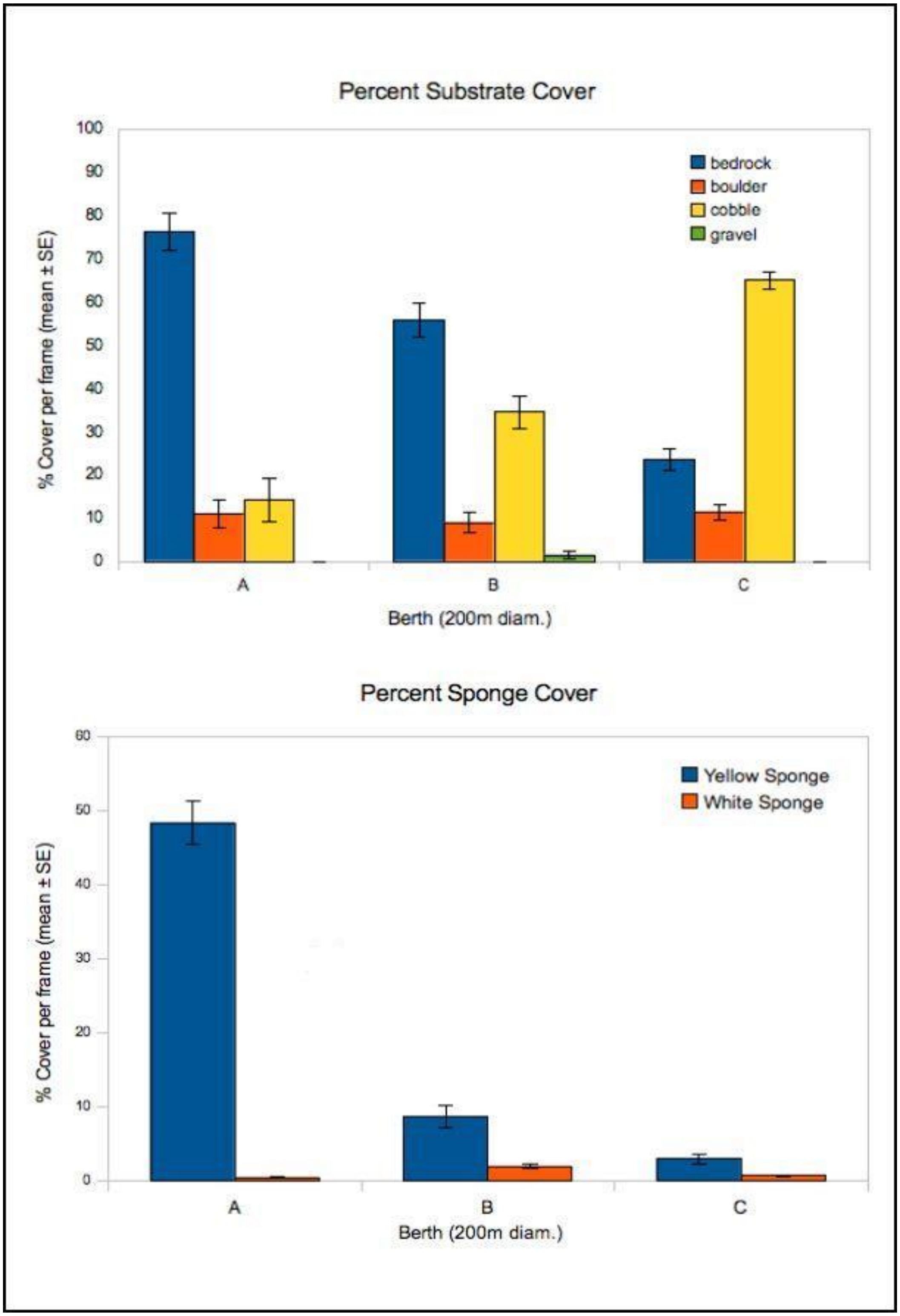

Figure 14. Plots showing percent substrate cover (top) and percent sponge cover (bottom) for yellow breadcrumb sponge (*Halichondria panicea*), and white sponge (*Leucosolenia botryoides*) in Berths A, B, and C.

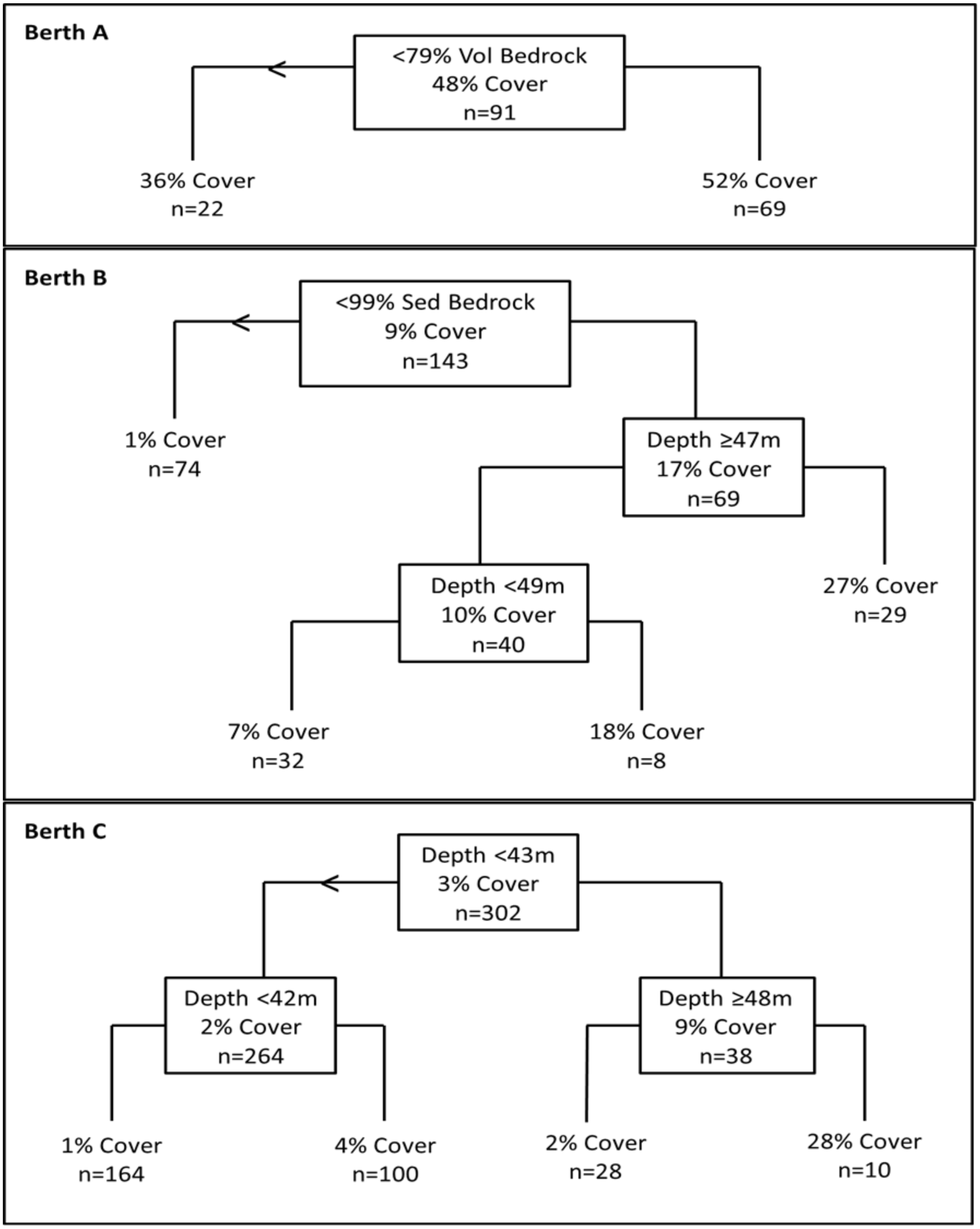

Figure 15. Classification and Regression Tree (CART) statistical analysis based on habitat features (depth, % boulder, % cobble, % gravel, % volcanic bedrock, and % sedimentary bedrock per frame) most influential in determining the percent cover of *Halichondria panicea* in FORCE Berths A,B and C.

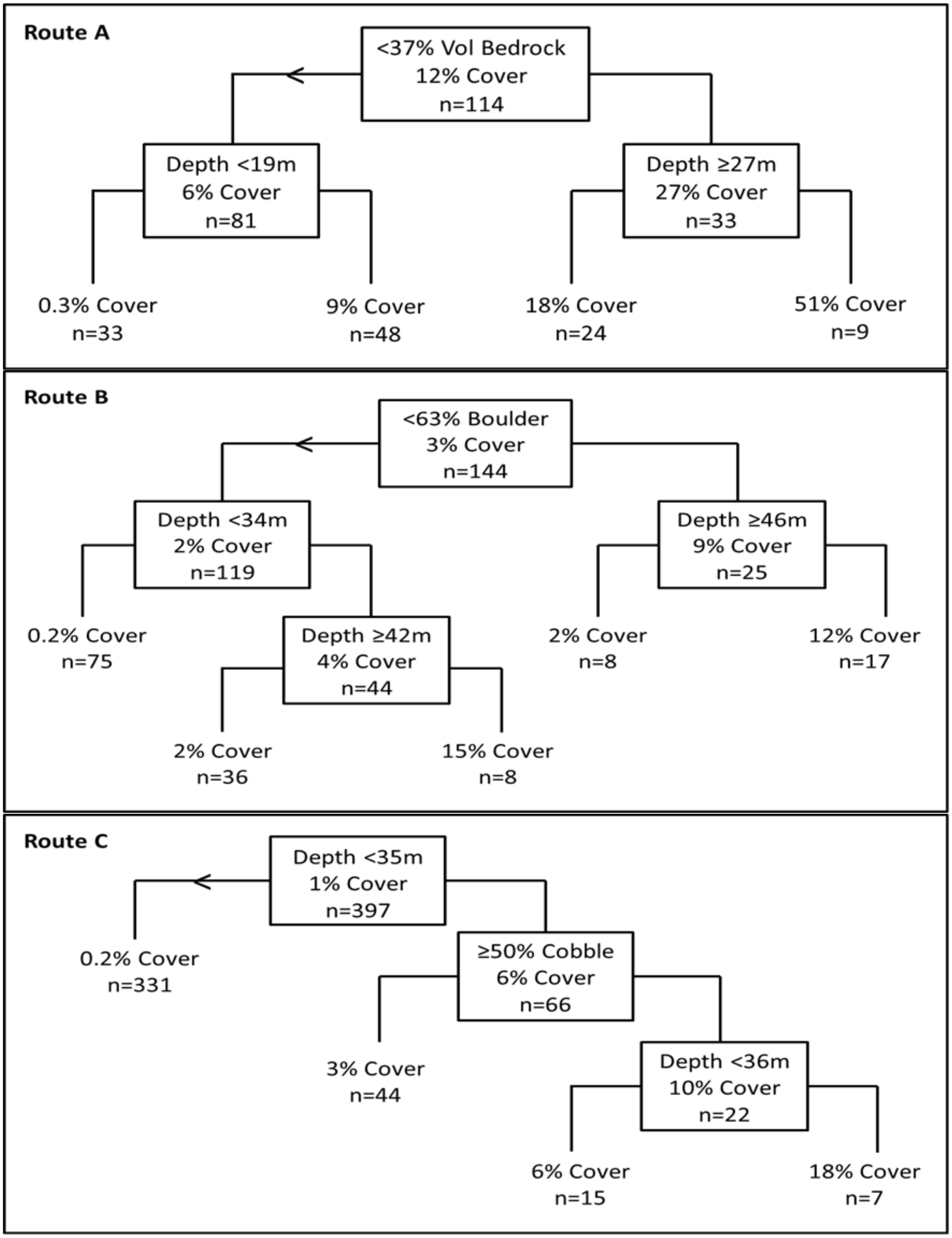

Figure 16. Classification and Regression Tree (CART) analysis based on habitat features (depth, % boulder, % cobble, % gravel, % volcanic bedrock, and % sedimentary bedrock per frame) most influential in the percent cover of *Halichondria panicea* Cable Routes A, B, and C. Depth below MLW was 7-39 m for Route A, 2-53 m for Route B, and 5-39 m for Route C.

4.0 DISCUSSION

4.1 Habitat Classification

In order to sufficiently classify benthic habitats, Valentine et al. (2005) recommend examining eight variables that span physical and biological features: topographic setting, seabed dynamics or currents, seafloor texture, grain size, roughness, flora and fauna, habitat use, and habitat recovery. If a site is typified by its ability to handle stochastic events and restabilize, it is considered a robust habitat (Valentine, 2005).

Several habitat types were observed in the FORCE test area (Figures 17 and 18): exposed volcanic bedrock, exposed sedimentary bedrock, regions characterized by partial cover by loose sediment (gravel, cobble, and/or boulder), and regions fully covered by loose sediment. The cable routes and shallow regions of the FORCE test area (<15 m) support seaweeds, macroalgae, and greater amounts of fine grained, sandy sediment. In deeper areas (>25 m), subject to greater current speeds, few species of macrofauna are present and those organisms that are present are sessile epifauna with no or limited mobility.

4.2 Nature of Substrate

The substrate observed throughout all three berths and cable routes is subangular to subrounded in nature. Under normal circumstances, at non-coastal locations, such roundness is not observed. However, the cobble and boulder roundness in the FORCE test site can be linked to the relict or paleo-beach environment that existed prior to the last major glaciation, at approximately 65-70 m below modern sea level (Fader, 2005). This is evident because the character of the substrate at this depth, in the nearshore environment, resembles modern sediments found in beaches. This sediment does not share similar traits with the sediment found at greater depths, which resemble typical marine sediments (Fader, 2005). The degree of clast movement influences the type of organisms that the region can support. For example, gravel or cobble based substrates are more susceptible to movement, which is reflected in the degree of colonization by sessile organisms (Ginn et al., 2000). FORCE berths with largely unconsolidated material support fewer sessile organisms (Figure 14) and thus represent lower biological impact areas for the installation of subsea infrastructure. However, unconsolidated substrates are subject to reduced stability due to sediment mobility, a factor that needs consideration when planning for the deployment of infrastructure such as large gravity base structures that support turbines.

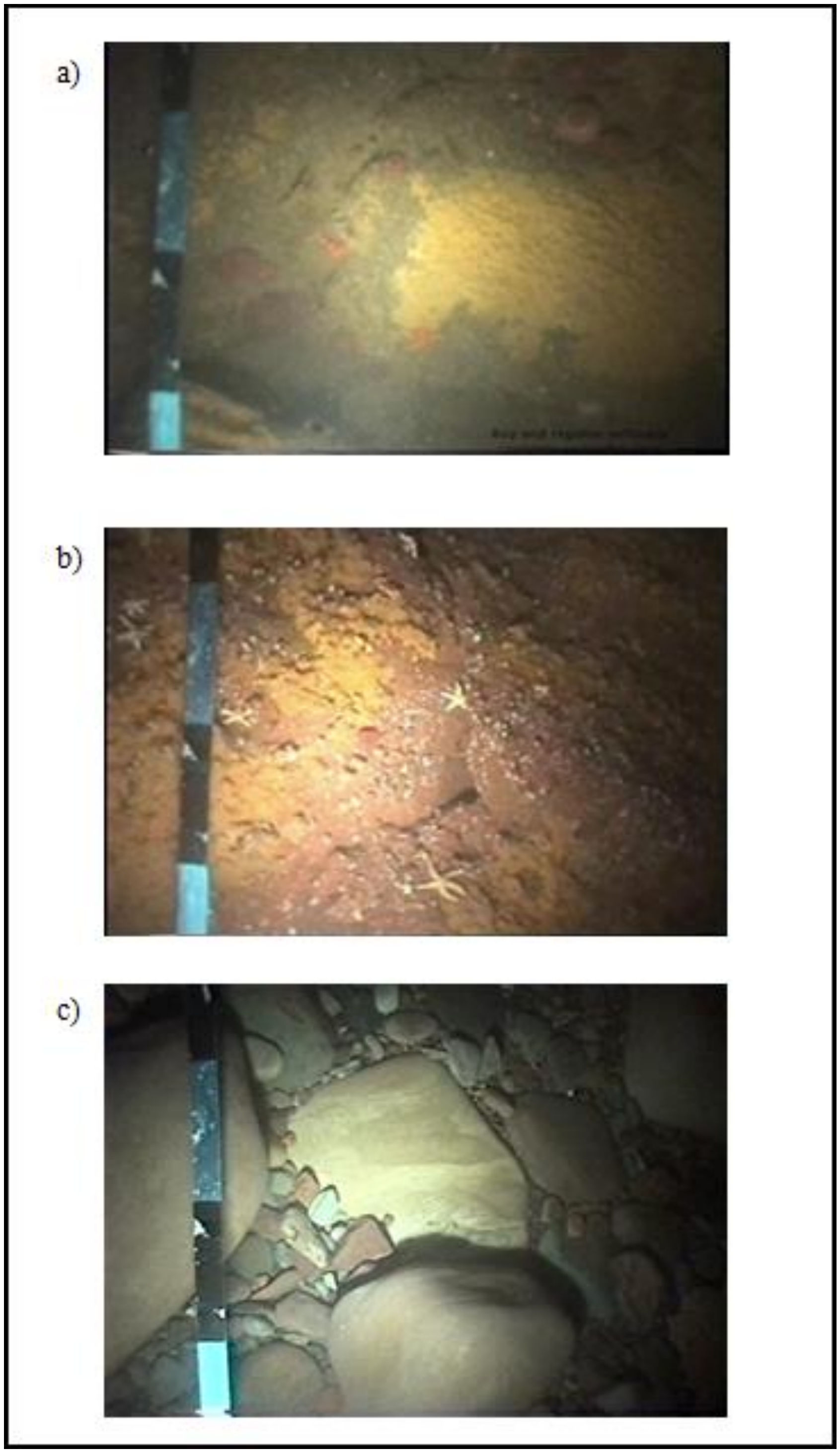

Figure 17. Representative seafloor photos from a) Berth A, b) Berth B, and c) Berth C. (Envirosphere Consultants Ltd., 2009).

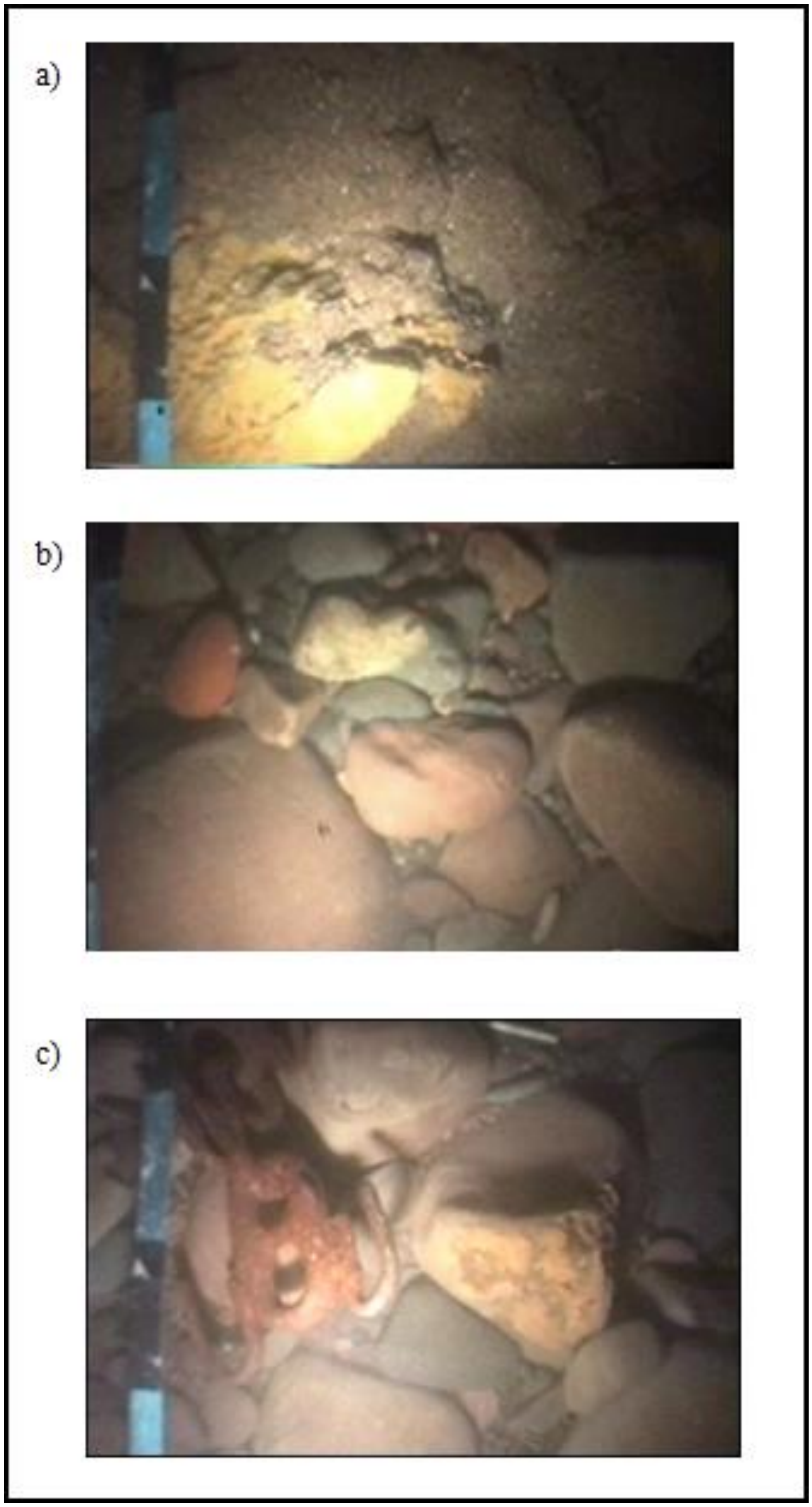

Figure 18. Representative seafloor photos from a) Cable Route A, b) Cable Route B, and c) Cable Route C. (Envirosphere Consultants Ltd., 2009).

4.3 Biota-Substrate Associations

The percent cover of encrusting sponge (yellow breadcrumb and white sponge) is greatly reduced in berths with high percent cover of loose sediment (cobble and gravel) (Figure 14). In the North Sea, Rees et al. (1999) show a positive correlation between the size of loose substrate and the density of epifaunal and infaunal organisms; the dominant factor in determining the density of organisms present in a particular area was tidal strength. They demonstrated a negative, linear relationship between the number of taxa per square metre and spring tidal velocity. The regional hydrodynamics in that study influenced particle size, degree of sorting, physical disturbance (likelihood of mobility), habitat and fauna found there (Rees et al., 1999), much like the FORCE test area.

In the FORCE berth areas and cable routes with loose clasts, it was observed that colonial biota form largely on top of large clasts; the bottom of large clasts are generally scoured and without biota. Fader (2009) reports that the bedload in the Minas Passage is largely within the bottom 20 cm, a zone of limited colonization of sessile organisms (Figure 19).

Figure 19. Clasts, with sponge growth only appearing on large clasts above the zone of smaller, mobile clasts (cobble) (Envirosphere Consultants Ltd., 2009).

The Minas Passage and the FORCE test area feature bedforms that likely cause variable flow patterns and regimes within the boundary layer. In general, boundary layer conditions do not provide an environment with a low enough Reynolds number for most epifaunal organisms to thrive and survive (Palumbi, 1986), which explains, at least in part, the limited biodiversity observed in the FORCE lease area.

Koehl (1977) investigated how anemones cope with current velocities off the coast of Washington. It was found that *Metridium senile* and *Anthopleura xanthogrammica* exhibit more compact, low profile body plans which minimize drag (the force that has the ability to detach the organism from rocky substrate). This lowers the Reynolds number and the number of eddies surrounding the anemone, keeping the organism within the calmer boundary layer conditions, and decreasing the forces acting against the organism's adherence to the seafloor (Koehl, 1977). Anemones observed within the FORCE test site are small in size (approx. 4 cm diameter) and located within a relatively low flow zone immediately above the substrate.

4.4 Distribution of Biota

One of the major factors that appears to determine how macrobenthic epifauna are distributed in the Minas Passage is current speed. Flow velocity can be affected by variable seafloor topography (rock walls, boulders, trenches, ridges, etc.) and can greatly influence the distribution and abundance of sessile marine organisms. Leichter and Witman (1996) found that low relief organisms were in the greatest concentrations in the highest flows, whereas mounding organisms (sponges exhibiting greater topographic relief) were located in lower flow regimes. Berth A, the shallowest berth in the FORCE test site (about 30 m below MLW) is highly scoured and had no loose sediment, indicating high flow conditions at the substrate-water interface. Berth A is also the berth in which sponges were most abundant (average cover was 49%). The noteworthy *H. panicea* cover can also be attributed to the less turbulent boundary layer conditions likely created by the volcanic bedrock surface. This differs from the boundary layer environments created by blocky, irregular sandstone and/or boulder cover.

Filter-feeding organisms are commonly located in areas of high flow (Leichter and Witman, 1996). In the FORCE test site, high flow velocity is achieved near the top of rock walls and adjacent to other elevated or exposed benthic surfaces. Thus, the greatest abundance of filter feeding organisms is concentrated on these topographically flat regions, providing even growth surfaces or habitat on which epibiota can thrive. Such conditions are found in Berth A, which is located on a volcanic platform, with less than two metres of variation in depth below MLW. This berth is typified by a more uniform substrate, contains more prolific yellow sponge communities than Berths B and C, which are deeper and feature ridges and trenches (less optimal yellow sponge habitat). An expansive platform, uninterrupted by topographical variation, has a relatively uniform flow regime, allowing sponges to grow extensively (Gili and Coma, 1998). Peattie and Hoare (1981) found that the distribution of *Halichondria panicea* was most affected by depth in the water column, with greater abundance found in areas of high current speed. In contrast, anemones use facultative feeding mechanisms and tend to inhabit regions at the base of rock walls or within boundary layer-type flow conditions (Leichter and Witman, 1996).

4.5 Biodiversity

In the FORCE test site, photos showing a high percent cover of yellow sponge did not show significant numbers of other organisms. *Halichondria panicea* is known to live in symbiotic associations with toxin producing *Roseobacter* bacteria (Antje et al., 2006), another factor that decreases community diversity when extensive colonies of this sponge are present. A more diverse suite of organisms, including *A. vulgaris*, *H. sanguinolenta*, *U. felina*, tunicates, and gastropods appear in photos exhibiting little sponge. Some species are, however, able to use sponge mats as settling surfaces. Where benthic habitat is limited, organisms such as hydroids, tunicates, coralline algae, and serpulid worms may utilize sponge mats as if they were an abiotic, benthic substrate (Bell, 2008). In the FORCE site, hydroids, serpulid worms, and the unidentified 'biolayer' were in some cases observed on yellow sponge mats.

4.6 *Halichondria panicea*, Yellow Breadcrumb Sponge

Suitable flow speeds and substrate conditions needed for extensive yellow breadcrumb sponge growth are present within Berth A (and Cable Route A) at an approximate depth of 30 m. Similar findings were noted in the synthesis report produced by Patrick Stewart (2009) which summarized some observations from video surveys (Envirosphere Consultants Ltd., 2008, 2009, 2009a, 2009b, 2009c). At this depth, the cover of yellow sponge is very high, commonly greater than 90% (Figures 11 and 12). Ginn et al. (2000) found that the percent cover of low relief encrusting varieties of sponge (including *Halichondria panicea*) in the outer Bay of Fundy was less affected by current velocity, substrate type, and water column depth than other types of sponge (massive or upright). However, Vogel (1974) found that high flow rates increased the internal flow rate in *Halichondria* sponges. Sponges situated in high flow environments are thus likely to filter more water, acquire more nutrients, and therefore proliferate and thrive.

Palumbi (1986) noted that the number of oscula in the *Halichondria* genus increased as hydrodynamic energy increased. Mats of the sponge were found to be stiff and thick in high-energy regions, making them less susceptible to damage (Palumbi, 1986). The FORCE test site, characterized by strong tidal currents, exhibited thick yellow sponge mats (Figure 12), most likely with high numbers of oscula.

4.7 Limitations of the Study

The quality of the video taken in late winter and spring was generally poor due to elevated turbidity from the late winter/spring ice melt. Poor image quality limited the number of images that could be used for the analysis of substrate and epifauna. In some cases, distortion of the image (*ie.* shadows and/or discolouration) due to the lighting used in the camera system, and anchor weights, which obscured the field of view, decreased the ease with which biota and substrate could be assessed. Virtually no ground-truthing of species present was possible due to difficulties operating conventional bottom samplers on the rocky bottom at FORCE. A few bottom grab samples were obtained during the surveys. Rocks were archived with Natural Resources Canada at the Bedford Institute of Oceanography. Any biota collected was examined and identified by Patrick Stewart, Envirosphere Consultants Limited, but not retained for later use.

Although the dominant organisms in video surveys could be identified with reasonable confidence, some of the growth forms differed from descriptions in the literature, which could be accounted for by the unique conditions at the FORCE site. For example, some sponge species exhibit morphological plasticity to best suit the environment in which they are situated (Bell et al., 2002). Thus, it is possible for error in visual identification of organisms in a high flow velocity environment. Accuracy of identification can be achieved when photographic identification can be paired with a grab sample, enabling the assessment of other characteristics, including species identification, not readily visible from a photo or video footage.

A fundamental issue with the analysis methodology is the fact that photographs were treated as two dimensional images, when the site itself is three dimensional. Observing and analyzing the benthos from a plan view may lead to underestimates of biota present. The sides of ledges, boulders, and cobbles may house organisms that were not accounted for in the analysis performed in this study. The number of organisms counted and the percent cover noted is representative of the surfaces visible in each frame.

Another limitation related to this study is the narrowness of the scope of each frame. The field of view of each photograph has an area of approximately 0.21 m^2. The benefit of a field of view this small is that meso-scale data can be obtained. The drawback of a field of view this small is that the viewer is unable to distinguish between substrate that is exposed bedrock or a portion of a boulder. This could result in the misidentification of substrate characteristics for a given area.

4.8 Recommendations

1. In future surveys, reference samples including biota, should be obtained and stored for later taxonomic identification by marine invertebrate specialists.
2. New videographic surveys should be conducted in mid- to late summer when suspended particle loads are seasonally low and biological growth has reached, or is near, its peak.
3. Future surveys within the Minas Passage should be conducted over a broader area and not just in berth areas and cable routes. This will limit the need for extrapolation when mapping habitat features.
4. Utilizing remotely operated vehicles, especially in the nearshore areas, would enable broader coverage of the seafloor in the Minas Passage.
5. Video-grab surveys around boulders and rock faces would provide a more thorough account of the faunal assemblages associated with these physical features.
6. Since the initial video surveys were conducted, FORCE has designated an additional berth (Berth D). Similar surveys of the epibiota in this berth area and its cable route to shore should be undertaken prior to deployment of any infrastructure at this berth location.
7. Repeat sampling following the testing of turbines in the FORCE lease area (before and after surveys) would be required for an assessment of impact.

5.0 CONCLUSIONS

The epibenthic community present within the FORCE test site exhibits low biodiversity in relation to other sites used to test TISECs (Thuringer and Reidy, 2006). No "at risk" species were observed in the videographic records. The factor appearing to have the most influence over faunal abundance and distribution was substrate type and this factor varied among berth areas. Type of bedrock present (volcanic or sedimentary), as well as depth below MLW, most influenced the distribution and percent cover of the dominant sponge species, *Halichondria panicea,* a high-flow adapted species.

Given the observed low biodiversity of macrofauna and the prevalence of encrusting yellow breadcrumb sponge, it is unlikely that the installation of TISEC infrastructure will negatively impact the benthic community in the FORCE lease area. It can be expected that the increase in habitat heterogeneity created by the installation of infrastructure will increase both the diversity and overall biomass of macrofauna associated with the seafloor in the turbine test area.

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8.0 APPENDIX

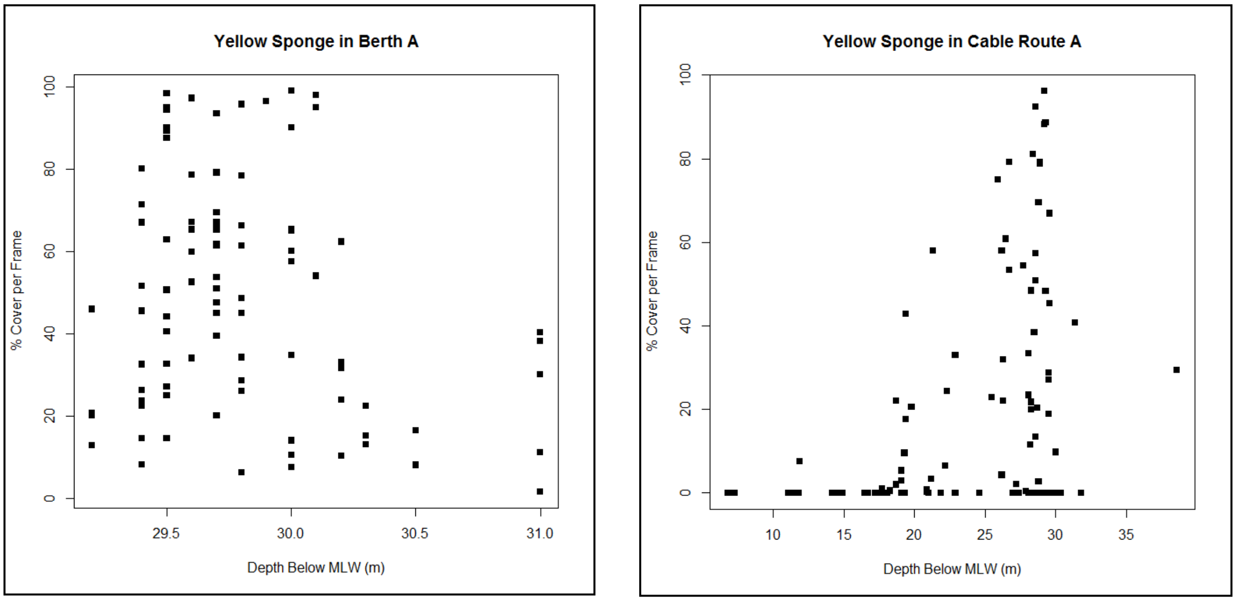

Figure 20. Yellow sponge, *Halichondria panicea*, percent cover with depth below MLW in Berth A (left) and Cable Route A (right). Depth range is 29-31m for Berth A.

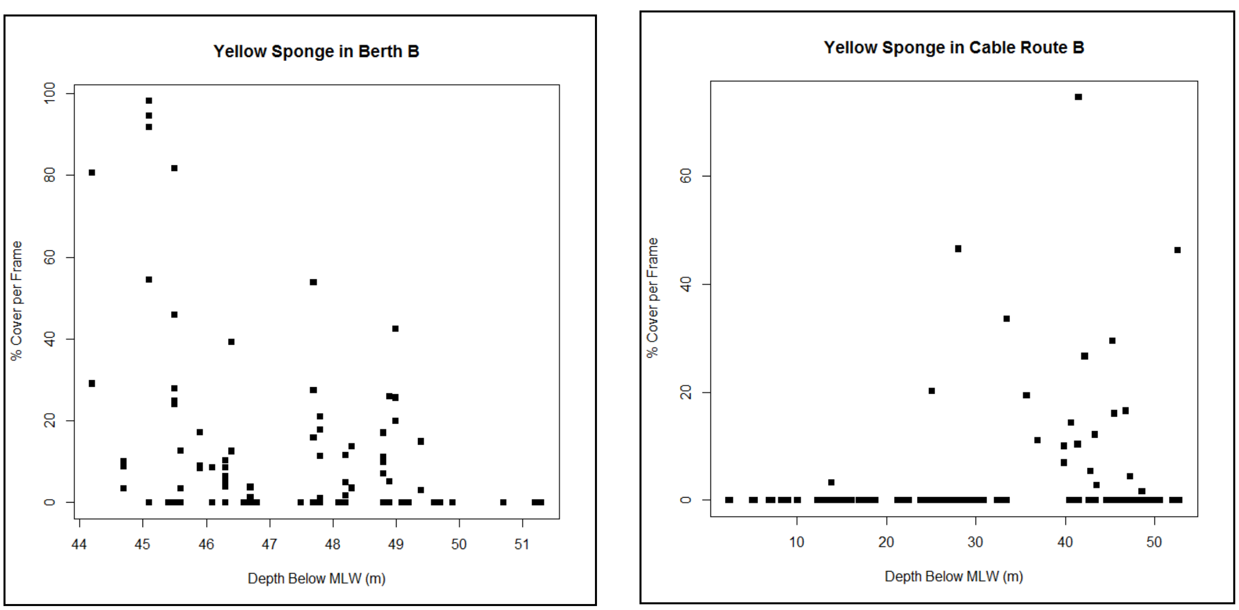

Figure 21. Yellow sponge, *Halichondria panicea*, percent cover with depth below MLW in Berth B (left) and Cable Route B (right). Depth range is 44-52 m for Berth B.

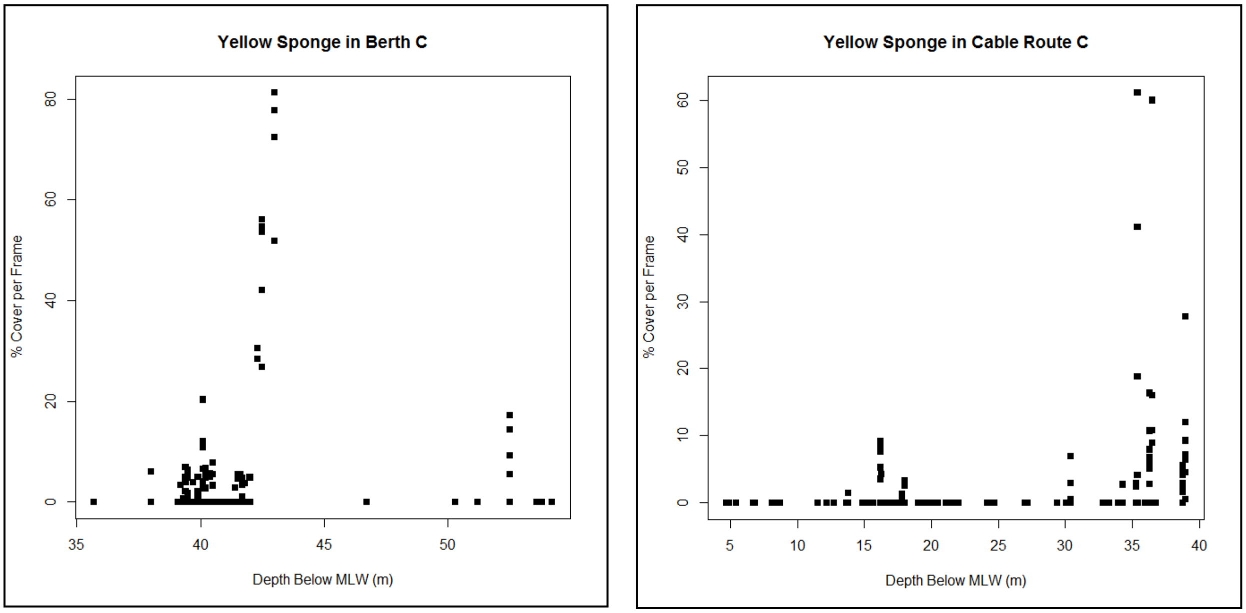

Figure 22. Yellow sponge, *Halichondria panicea*, percent cover with depth below MLW in Berth C (left) and Cable Route C (right). Depth range is 35-55 m for Berth C.