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The Boundary Reefs: Glass Sponge (Porifera: Hexactinellidae) Reefs on the International Border Between Canada and the United States

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ABSTRACT

Hexactinellid sponge reefs have been discovered in shallow-water areas in Portland Canal on the international boundary between Southeast Alaska and British Columbia. The reefs were first observed on multibeam imagery data collected in 2008 and were examined in detail with a survey undertaken with a remotely operated vehicle in April 2010. The Boundary Reefs consist of three distinct reef areas at depths between 53 and 107 m. Framework constructing, dictyonine sponges (*Aphrocallistes vastus*, *Heterochone calyx*, and *Farrea occa*) form bioherms up to 200 m in diameter and 21 m in height on glacial sediments, and extensive beds on moraines and glacial promontories. Variations in the morphology and structure of some of the Portland Canal reefs are attributed to variations in sedimentation compared to other shelf and fjord reef sites in British Columbia. Development of extensive oxide crusts, pervasive colonization by zooanthid corals on reef surfaces, and the largely skeletal nature of the reefs suggest very low sedimentation rates as a result of low overall riverine inflow to the surface waters of the fjord and possibly reduced glacial meltwater input in recent years. A second complex of small reefs was discovered near Benjamin Island north of Juneau, Alaska. These reefs are the northernmost documented in the world and are very shallow, occurring at depths between 22 and 56 m. The two newly discovered reef sites are separated by almost 500 km indicating that the Inside Passage of Southeast Alaska may harbour additional undiscovered sponge reefs.

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INTRODUCTION

Glass or hexactinellid sponge reefs were first discovered in Queen Charlotte Sound and Hecate Strait on the British Columbia continental shelf in 1986 (Conway et al. 1991) and since that time have been well documented there (Conway et al. 2001, Krautter et al. 2001) and also farther south in the coastal waterways of the Strait of Georgia (Leys et al. 2004, Conway et al. 2005a). Reefs have also been documented in shallow waters of Howe Sound (Chu and Leys 2010)—the southernmost fjord in mainland British Columbia. The British Columbia sponge reefs have gained international attention and considerable scientific interest as “living fossils” (Conway et al. 2001) and “living dinosaurs” (Krautter et al. 2001) since they are the only known siliceous sponge reefs remaining in the world from a global network of reefs prominent during the Jurassic (Conway et al. 2001, Krautter et al. 2001). The reefs are formed by frame-building processes (Krautter et al. 2006) that include framework construction by the overgrowth of the holdfasts of growing sponges overtop the skeletons of dead sponges. The baffling of fine organic-rich sediments from tidally driven bottom currents allows the trapping of sediments that support the construction of extensive reef complexes (Whitney et al. 2005). The reefs are readily mapped using swath bathymetric multibeam data because of the distinctive biohermal seabed morphology and anomalous acoustic backscatter due to the very low reflectivity of the surface of the reefs (Conway et al. 2005a).

Sponge reefs are typically found on glacial seabeds including broad glaciated shelf troughs where they form very large reef complexes on iceberg furrowed surfaces relict since the last glaciation (Conway et al. 1991). Ice stream-lined ridges or drumlins are typical reef locations in the Strait of Georgia (Conway et al. 2004, 2005a) as are terminal moraines in fjords such as

those found in Howe Sound (Conway et al. 2007a). Reefs have not been observed growing on bedrock or in areas of recent sand or mud accumulation where framework sponges are unable to find suitable attachment (Conway et al. 1991). Reefs are also considered to be associated with specific oceanographic conditions including relatively high dissolved silicate concentrations and low or absent oscillatory wave energy conditions (Whitney et al. 2005, Conway et al. 2005b). Tidal currents are thought to provide accessory feeding opportunities to sponges when located on the top of promontories or in other settings where ambient currents augment sponge feeding by inducing currents through the sponge body wall (Leys et al. 2011).

Sponge reefs provide complex habitat for a variety of species and for this reason are thought to provide essential fish habitat and given their fragility and spatial overlap with human activities also constitute vulnerable marine ecosystems (Cook 2005). Trawling for groundfish has damaged or destroyed reefs in many areas of British Columbia (Conway et al. 2001) and other bottom contact fishing gears, including pots/traps and longlines, are thought to cause damage to the fragile reefs (Jamieson et al. 2007).

The purpose of this study was to document the geological, biological, and ecological significance of the newly discovered reefs in Lynn Canal in Southeast Alaska and Portland Canal on the northern British Columbia/Alaska boundary and compare them to the published data from well-known counterparts previously documented off British Columbia. The Portland Canal reefs were discovered in 2008 in much the same way the first sponge reefs were discovered in Queen Charlotte Sound in 1986—acoustic anomalies were noted during routine seafloor mapping by the Geological Survey of Canada. The Benjamin Island reefs were first discovered in August 2001

during routine investigations of nearshore rockfish (*Sebastes* spp.) habitat with a remotely operated vehicle (ROV). Additional observations were made with scuba in December 2001 followed by unsuccessful attempts to measure growth of specimens tagged in September 2002.

GEOLOGICAL AND OCEANOGRAPHIC SETTING

Portland Canal is a glacial fjord that extends 114 km from Portland Inlet in Dixon Entrance near Pearse Island, British Columbia to its terminus at Stewart, British Columbia, and Hyder, Alaska. The boundary between Canada and the United States approximately bisects the fjord along its entire length. Major rivers that flow into the fjord include the Salmon, Bear, and Soule rivers -- all glacial rivers. The Soule River watershed is currently the focus of a potential hydro-electric project and there are concerns that damming the glacial system may alter sediment input into the Canal. The Portland Canal Region also has diverse and rich ore deposits (Westgate 1920).

Benjamin Island is a small island located on the east side of Lynn Canal--the northernmost fjord penetrating the Coastal Range of Southeast Alaska. At about 110 km long and more than 600 m deep in some locations, Lynn Canal is one of the longest and deepest fjords in the world (Martin and Williams 1924). The reef complex at Benjamin Island is located along the south side of the island and about 5.5 km from the mouth of the large Eagle and Herbert Rivers that drain their respective glaciers of the Juneau Icefield. Lynn Canal lies on a lateral strike slip fault (Weingartner et al. 2009) but the seafloor in many areas is glacially scoured with sediments deposited from local glacial rivers (Martin and Williams 1924).

METHODS

A cruise was conducted aboard the NOAA ship *John N. Cobb* on 28–29 April 2008 to investigate shallow-water sponge reefs previously discovered near Benjamin Island in Lynn Canal about 39 km north of Juneau, Alaska (Fig. 1). Only ROV operations and associated specimen sampling was conducted at this site. A second cruise was conducted aboard the FV *Savage* between 29 March and 6 April 2010 to investigate sponge reefs discovered in 2008 in Portland Canal (Fig. 1).

Field Operations -- Collection of Multibeam and Backscatter Data

Multibeam data were collected in Portland Canal aboard the Canadian Coast Guard ship *Vector* by the Canadian Hydrographic Service in summer 2008. Data were collected with a Kongsberg-Simrad EM1002¹ system, which operates at a frequency of 95 kHz utilizing 127 beams. The tracks were positioned to insonify 100% of the seafloor with 100% overlap. Positioning was by broadcast differential global positioning system (DGPS) and the data were corrected for sound speed variations in the stratified water column using frequent sound speed casts. The data were corrected for tides and then edited for spurious bathymetric and navigational points using CARIS software. The gridded data were exported as ASCII files and then imported into ARCInfo software for processing and image production. Backscatter data were gathered and processed using CARIS software and exported into ARCInfo for imaging. The draping of backscatter data onto the multibeam bathymetric data emphasizes anomalies of soft sediment

¹ Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

packages perched on high elevations. These soft, non-reflective, high-elevation sediment bodies are typically associated with sponge reefs.

Field Operations -- Sub-bottom Profiling (Chirp Data)

A 3.5 kHz sub-bottom profiler was mounted on the starboard side of the FV *Savage* during surveys conducted in April 2010. The system employed a two-element (TR-109) transducer array mounted on a pole assembly coupled to a Knudsen 3200 transceiver operated with a workstation located on the ship's bridge. The system could be towed at up to 4 knots and acquired good resolution sub-bottom records at depths to 300 m.

Field Operations -- ROV Investigations

The Deep Ocean Engineering ROV (Phantom XTL) was equipped with two 150-W lights, three thrusters, a low-light, high-resolution video camera (12:1 zoom), and a stainless steel crash frame. The ROV was operated from a small skiff via a 168-m neutrally buoyant umbilical attached to a control console. Nonlinear joystick controls on the console allowed maneuvering the ROV both vertically and horizontally (maximum cruise speed 1.3 m s^{-1}). Depth and heading were displayed on a real-time viewing monitor and aided in navigation. The ROV was also equipped with a probe fitted with a 2-cm cork corer that was used to collect small samples of sponges. The camera was mounted with the imaging plane directed at about a 45° angle to the seafloor and recorded a pair of parallel laser marks (10 cm apart) projected onto the seafloor to provide a reference for area of view and size of fauna.

The ROV was used to collect video along five transects of the seafloor at the Portland Canal sites: one at the North Reef and two each at the Middle and South Reefs. The ROV was deployed to the seafloor at each site from a small skiff and traversed the reef several times generally in a south-north direction.

Field Operations -- Biota and Sediment Sampling

We used a Van Veen grab (sampling area = 0.1 m², volume = 24 L) to collect samples of the seafloor at each of the Boundary Reefs. Several samples were collected in the middle of each reef. Sponge skeletons and associated biota were frozen or preserved in 90% ethyl alcohol for laboratory examination. Sediments contained within intact *Aphrocallistes vastus* tubes collected at the South Reef were examined for grain size composition by wet sieving and graded using the Wentworth classification scale (Holme and McIntyre 1971).

Field Operations -- Physical Oceanography

A Seabird Electronics SBE19 was used to collect oceanographic profiles of the entire water column at both sides of each reef on 4 April 2010. The instrument was lowered to the seafloor at an average rate of 1.5 m sec⁻¹ and measured depth, temperature, salinity, dissolved oxygen, pH, fluorescence, and PAR irradiance (irradiance of photosynthetically active radiation) every 0.5 seconds during descent.

RESULTS

Detailed mapping using acoustic backscatter data, rendered as a semi-transparent overlay on the swath multi-beam bathymetric data, clearly revealed the distribution of siliceous sponge reefs at three sites in Portland Canal (Figs. 2, 3). The method of draping the transparent backscatter data onto the bathymetric data (Conway et al. 2005a) allowed resolution of reefs greater than 20 m in diameter. The method is successful due to the anomalous appearance of sponge reefs which appear as non-reflective high points in the data set. Normally such high elevation features are associated with till or rock outcrops or sandwaves – which are reflective and of a high backscatter property. Using this method sponge reef distribution is readily established (Fig. 3). The chirp data indicated that the reefs (i.e., exposed live and skeletal reefs and reef sediments) were up to 21 m thick with isolated biohermal forms (Figs. 4–6) and more extensive biostromal deposits covering some ridges especially at the South Reef site (Fig. 6).

The North Boundary Reef site (Figs. 3a) shows an anomalously smooth and reflective surface that has very little high frequency content on backscatter imagery and little roughness which are typically associated with sponge reefs on multibeam bathymetry. The reef area, which is largely a contiguous body formed of only about five separate reef areas, has a maximum thickness of 15 m with most of the area between 8 and 12 m thick covering the top of a well-developed glacial terminal moraine (Fig. 4). The total reef area is about 58 hectares. Much of the area surveyed by ROV transect was associated with extensive oxide crust development and sparse areas of live sponges.

The Middle Boundary Reef site (Fig. 3b) is composed of at least 33 reefs with a discontinuous pattern of development. The reefs as presented in Figure 3 are in some cases amalgamated into one polygon for mapping purposes. A high degree of uncertainty is associated with the condition and thickness of each reef due to their small size and discontinuous nature. The reefs are up to 12 m thick with more typical thicknesses of 3 to 5 m (Fig. 5). The total area of reef here is a maximum area of 35 hectares, with some of this area only sparsely covered with reef.

The South Boundary Reef site is composed of about 31 individual reefs (Fig. 3c) composed of isolated and coalescing bioherms. The largest bioherm encountered in the entire study area is in this area and is approximately 21 m in thickness (Fig. 6). In addition, an elongate area of thin reef or biostromal layer mantles part of the central ridge (Figs. 3c, 6) and the total reef area covers roughly 15 hectares.

A single ROV dive was conducted at the North Reef site at depths between 73 and 107 m. Both live and skeletal reef were observed at depths between 89 and 107 m. Video footage indicated that the reef was composed entirely of *Aphrocallistes vastus* Schulze, 1886 and *Heterchone calyx* (Schulze, 1886) (both species in white morph only). *Aphrocallistes vastus* appeared to be the dominant reef builder at depths shallower than about 104 m, whereas *H. calyx* appeared more dominant deeper. Exposures of living reef up to 2 m in height were observed in some areas. Approximately 90 to 95% of the exposed reef was skeletal and at least two species of Rossellidae, including *Rhabdocalyptus dawsoni* (Fig. 7a), were observed growing directly on hexactinellid skeletons. The North Reef was unique in that much of the exposed skeletal material

was covered with oxide crusts and heavily colonized by zoanthids (Fig. 7b) (Family Parazoanthidae, zoanthid sp. 1)² and the encrusting homoscleromorph sponge *Plakina atka*. Small (< 30 cm) gorgonians (*Primnoa* sp.) and small (< 5 cm) hydrocorals (*Stylaster* sp.) were observed growing on cobbles at depths between 91 and 102 m near the reef. Fish observed immediately near the reef included adult sharpchin rockfish (*Sebastes zacentrus*), walleye pollock (*Gadus chalcogrammus*), and Pacific cod (*Gadus macrocephalus*). Squat lobsters (*Munida quadrispina*) were particularly abundant on and near the reef. Other fauna on the reef included sea stars (*Mediaster aequalis*, *Ceramaster* sp., *Henricia* sp.), sea urchins (*Strongylocentrotus* spp.), spiny lithode crab (*Acantholithodes hispidus*), and spot shrimp (*Pandalus platyceros*).

Two ROV dives were conducted at the Middle Reef site at depths between 53 and 115 m. Both live and skeletal reef were observed at depths between 53 and 85 m. Video footage indicated that the reef was composed entirely of *A. vastus* and *H. calyx* (both species in white morph only) with the former species dominant. Scattered hexactinellid sponge debris was observed on soft sediment with scattered cobbles in deeper water. In some areas there were large patches of live sponge (> 50%) with exposures of almost 3 m in height and at least two species of Rossellidae, some relatively large individuals (> 50 cm in height) were observed growing directly on hexactinellid skeletons. A larger percentage of the reef was composed of live sponge at depths shallower than about 60 m. Encrusting zoanthids were not observed on this reef but small numbers of the encrusting homoscleromorph sponge *P. atka* were present. Fish immediately near the reef included adult redstripe rockfish (*S. proriger*) and juvenile rockfish

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(*Sebastes* sp.). Eelpouts (family Zoarcidae), poachers (family Agonidae), and juvenile flatfish (family Pleuronectidae) were common on soft-sediment areas flanking the reef. Squat lobsters (*Munida quadrispina*) were particularly abundant on and near the reef. Other fauna on the reef included the sea star *Orthasterias koehleri*, sea urchins (*Strongylocentrotus* spp.), and spot shrimp (*Pandalus platyceros*).

Two ROV dives were conducted at the South Reef site at depths between 73 and 116 m. Both live and skeletal reef were observed at depths between 72 and 113 m with scattered sponge debris in deeper water on soft sediment. Video footage indicated that the reef was composed of approximately equal amounts of *A. vastus* and *H. calyx* (both species in white morph only) with the latter species dominant at depth. This reef was unique in that it contained large patches of *Farrea occa* Bowerbank, 1862 (Fig. 7c) at depths between 74 (a new shallow depth record for the species; Stone et al. 2011) and 113 m. Some individual live and skeletal *F. occa* were more than 1 m in diameter. In some areas there were large patches of live sponge (> 50%) with exposures of almost 3 m in height and at least two species of Rossellidae (Fig. 7d), some relatively large (> 50 cm in height), were observed growing directly on hexactinellid skeletons. Neither encrusting zoanthids nor the homoscleromorph sponge *P. atka* were observed on this reef. Fish observed immediately near the reef included adult rougheye rockfish (*Sebastes aleutianus*), walleye pollock (*Gadus chalcogrammus*), and Pacific cod (*Gadus macrocephalus*). A scattered aggregation of brown box crab (*Lopholithodes foraminatus*) was also observed on and near the reef at depths near 84 m. Squat lobsters (*Munida quadrispina*) were particularly abundant on and near the reef and spot shrimp (*Pandalus platyceros*) were also present.

Three ROV dives were conducted at the Benjamin Island reef complex. The complex consists of about three small (approximately 200–300 m²) reefs (Fig. 8) scattered in an area of about 16.5 hectares. The reefs range in depth from 22 to 56 m and are bordered above by fine sand/silt substrate and by homogeneous silt habitat deeper with scattered sponge debris. Some areas of the reef have been partially disturbed, probably by boats that anchor seasonally at this location to gain a lee during periods of north wind. The reefs are composed entirely and about equally of *A. vastus* (Fig. 7e) and *H. calyx* (Fig. 7f) (both species in white and yellow/orange morphs) and at least two species of rosselids including *Acanthascus* cf. *alani* Ijima, 1898. The majority of the reefs are skeletal and much of the skeletal (Fig. 7g) material was covered with a dense growth of bryozoans (Fig. 7h) (probably *Dendrobeatia* sp.); live sponge coverage ranged from 10 to 50% and sedimentation rates appear to be low. Reef exposures were up to 2 m and individual sponges (both *A. vastus* and *H. calyx*) had diameters exceeding 1 m. Rosselids were attached to hexactinellid skeletons and ranged in height to more than 50 cm and ranged in depth from 44 to 52 m. Fishes observed immediately near the reef included adult quillback rockfish (*Sebastes maliger*) and at least three species of juvenile rockfish (Fig. 7g). Other fauna on the reef included squat lobsters (*Munida quadrispina*), the sea stars *Ceramaster* sp. and *Henricia* sp., green sea urchins (*Strongylocentrotus droebachiensis*), giant sea cucumbers (*Parastichopus californicus*), pandalid shrimps, and Pacific giant octopus (*Enteroctopus dofleini*).

Grain-size analysis performed on sediments extracted from skeletal *A. vastus* tubes collected by grab at the Portland Canal South Reef site indicated that the sediment was poorly sorted and consisted of 5.6% medium sand (500–250 µm) including silica spicules, 22.3% fine

sand (250–125 μm), 38.8% very fine sand (125–63 μm), 14.1% silt (63–38 μm), and 19.2% clay (< 38 μm).

Measurements made at the three Portland Canal reef sites indicated that oceanographic parameters were similar in the water column and at the seafloor at the South and Middle Reef sites (Table 1). At the North Reef site, water temperature was lower and salinity was generally higher but more variable along the south and north margins of the reef than the other two reefs (Tables 1 and 2). All sites were well oxygenated at all depths and pH decreased steadily but only slightly from the surface to the seafloor (Table 1). Fluorescence and PAR decreased rapidly from the surface to deeper water at all sites (Table 1). Based on the depth range of the reefs (live and skeletal) observed from ROV footage the temperature ranged from 6.33 to 6.42 °C, 6.37 to 6.43 °C, and 6.03 to 6.08 °C at the South, Middle, and North Reefs, respectively (Table 2), while salinity ranged from 31.16 to 31.53 psu, 30.92 to 31.22 psu, and 31.17 to 31.92 psu at the three reefs, respectively (Table 2).

DISCUSSION

The geological setting of the Portland Canal sponge reefs is similar to other sites, most notably moraines in Howe Sound and at glacially streamlined banks such as Halibut and McCall Banks in the Strait of Georgia (SoG) (Conway et al. 2005a). Sedimentation rates are higher in the SoG than in Portland Canal due to the proximity of the Fraser River and consequently coverage of sponges is less dense at most sites there. However, very dense sponge populations are found at the Fraser Ridge that is exposed to the full impact of the Fraser River plume. Reefs at several

sites in the SoG adopt a wave form aspect (Conway et al. 2005a) that appears to be related to high suspended sediment loading and sedimentation rates. These sites are typically less densely occupied by sponges than the typical biohermal reef forms seen at the South Reef site in Portland Canal. The location of the North and South Reefs on bathymetrically elevated features is typical for sponge reefs in inshore areas (Conway et al. 2007a) and an elevated position in the water column where tidal currents are of sufficient strength would enhance feeding efficiency by inducing flow through the sponge body (Leys et al. 2011). This advantage may explain the success of biohermal growth forms of glass sponge populations (Leys et al. 2011) since individual sponges would benefit from exposure to increased ambient current flow as the reef grows vertically.

The 21-m thick bioherm at the South Reef in Portland Canal compares favourably with the thickest reefs known in the very large complexes on the British Columbia shelf (Conway et al. 2005a) and is possibly more than 5,000 years old. The main reef site at Malcolm Island (Jamieson et al. 2007), which is the fastest growing reef site yet documented, has grown 12 m in about 3,000 years based on radiocarbon dating of reef-contained shells in cores (Conway, unpubl. data, 2009)³. These sites are quite similar in setting and bathymetry with the top of the glacial landform at about 80 m in Queen Charlotte Strait and about 70 m in Portland Canal. If we apply this relatively rapid growth rate to the 21-m thick reef at the South Reef in Portland Canal then it would be about 5,200 years old. The texture of sediments incorporated into the south reef was coarse relative to measured grain sizes from shelf reef systems in British Columbia (Conway et al., 2001) which are normally clay rich. The measured sample contained sponge spicules and

³ Kim Conway, Pacific Geoscience Centre, Geological Survey of Canada, unpublished data.

fragments and these may have contributed to the relatively large sand fraction. In addition it is possible that some fine sand is entrained periodically during seasonal floods which may transport fine to very fine sand attached to anomalous floating debris such as logs and rooted stumps. Very low sedimentation rates are inferred for all the reef sites as glacial sediments are exposed at the seabed at all locations where the reefs are found.

We found no indication of mechanical disturbance at the three reefs in Portland Canal. The Benjamin Island reefs also appear from video imagery to be very healthy but have sustained some physical damage presumably from anchoring fishing vessels. Large areas of broken and dislodged sponges have been observed on the seafloor at British Columbia shelf sites (Conway et al. 2001). Complete removal of all reef-forming sponges, including living and upright dead skeletons, has been noted at some sites (Conway et al. 2007b). The wave-form reefs at McCall and Halibut Banks in the SoG have been subjected to significant groundfish trawling activity in the past which has removed large areas of the reefs and left distinctive trawl marks that are observed in sidescan sonar data (Cook et al. 2008). Some reefs have also been damaged farther south in the Georgia Basin such as those near Galiano Island (Conway et al. 2007a) and in Howe Sound (Chu et al. 2010).

Portions of the North Reef have likely been skeletal for several centuries based on the development of thick oxide crusts on many sponge skeletons and the pervasive growth of zooanthids over much of the reef. We suspect that a localized environmental change has caused the transition from sponge reef accumulation to crust and zooanthid growth. This change is possibly related to a hiatus or decrease in sedimentation or change in some other oceanographic

factor. Oxides composed of iron, magnesium, phosphate, manganese and trace elements have coated sponge skeletons at sponge reef sites in the southern SoG. In some British Columbia fjords thick manganese crusts on sponges as well as pebbles have formed (Grill et al. 1968). Manganese nodules in the deep sea are generally associated with very low sedimentation rates and crusts are inferred to similarly indicate low sedimentation rates. Additional changes in sedimentation rates within upper Portland Canal, such as those possible from the proposed damming of the Soule River, should be considered cautiously since they appear to play an important role in sponge reef maintenance.

We observed four species of adult rockfish (*S. maliger*, *S. zacentrus*, *S. proriger*, *S. aleutianus*), at least three unidentified species of juvenile rockfish (*Sebastes* spp.), walleye pollock (*Gadus chalcogrammus*), and Pacific cod (*G. macrocephalus*) on or in very close proximity to the studied sponge reefs. None of these fish taxa were observed in high abundance but all are “FMP species” (i.e., managed under a fishery management plan) in Alaska. Studies in the Strait of Georgia and Howe Sound, British Columbia, however, indicated that hexactinellid sponge gardens (non-biohermal) but not bioherms within the same depth range provided important nursery habitat for newly recruited juvenile rockfish (Marliave et al. 2009). Marliave et al. (2009) also found that the sponge gardens were more species-rich than the bioherms and postulated that only the gardens provided the necessary food subsidy to young-of-year rockfish. However, our observations of juvenile rockfish (likely age-1 and -2) on most studied reefs using sponges as refuge habitat clearly indicate that it is essential fish habitat for later juvenile stages of those taxa. On continental shelf reef areas juvenile (sub-adult) rockfish were 10 times more common on than off the reef indicating a strong preference for this habitat type in

these areas (Cook 2005). There is evidence that intact, undisturbed reefs have more habitat value than disturbed reefs; quillback (*S. maliger*) and sub-adult yelloweye rockfish (*S. ruberrimus*) were observed at undisturbed reefs but were absent at adjacent disturbed reef sites along Galiano Island in the southern SoG (Conway et al. 2007a). While there are differences in rockfish species assemblages observed in inshore reefs versus offshore shelf reefs these differences are consistent with known distributions of rockfish species (Jamieson and Chew 2002, Cook 2005).

We found clear evidence that the Boundary Reefs are remnant to some extent. While the reef formations themselves were massive in profile (the South Reef was more than 21 m thick), typical living reef exposures seldom exceeded 2 m and the majority of sponges on all reefs were skeletal. The living reef surfaces at the Portland Canal sites were similar to most healthy (i.e., non-disturbed) reef sites in British Columbia with the exception of some steep reefs forming walls of living sponges in Hecate Strait which show greater exposure of living reef in section. The distribution of living sponges on healthy reefs is variable, and it is inferred that cyclicality of growth of sponges varies across the reef with time as optimal conditions wax and wane (Conway et al. 2001). While the reef mass is largely composed of sediments and sponge skeletons, the density of living sponges over the reef surface will vary in space and time. Much like a coral reef, the greatest part of the total mass of the reef does not host living corals—they occur only at the reef surface. Some sponge skeletons (*A. vastus* and *H. calyx*) collected at each of the Boundary Reefs were also covered with iron oxide crusts. These crusts may also play a role in preserving the reefs as the siliceous skeletons will dissolve more slowly after being coated with oxide (Chu et al. 2011). Normally sponge skeletons and other biogenic silica (opaline silica) are

subject to dissolution over time (Chu et al. 2011), though sponge skeletons dissolve more slowly than for example diatom frustules.

Many of the hexactinellid skeletons observed at the North Reef in Portland Canal were heavily encrusted with an undescribed zoanthid belonging to the parazoanthid “clade 2” *sensu* Sinniger et al. (2010). Zoanthids in the family Parazoanthidae are typically epizoic but most generally on demosponges (Sinniger et al. 2010) and octocorals (Sinniger et al. 2013). Zoanthids grouped in the parazoanthid “clade 2” have regularly been found associated with hexactinellid sponge stalks (Beaulieu 2002), but this is the first report of their epizoic nature on hexactinellid sponge skeletons (other than stalks) anywhere including Alaska or British Columbia. Complex symbioses have also been reported between zoanthids and sponges elsewhere (Crocker and Reiswig 1981, Pawlik et al. 1995, Swain and Wulff 2007). Many of the hexactinellid skeletons observed (and collected via grab) at the North and Middle Reef in Portland Canal were encrusted with the homoscleromorph sponge *Plakina atka* and represents a new southern range extension for the species (Stone et al. 2011).

CONCLUSIONS

In northern Southeast Alaska and in Portland Canal, along the border between Alaska and British Columbia, we have documented the presence of aerially small but long-lived sponge reefs, similar in species composition and form to, but much smaller in size than, the massive reef complexes reported farther south on the British Columbia shelf. The reefs represent the northernmost reefs discovered to date.

Our findings indicate that sponge reefs are likely to occur in other areas of Southeast Alaska where favorable areas for reef development exist (i.e., areas of seafloor with glacial sediment deposits and areas with optimal sedimentation rates). Unlike many of the reefs in Canadian waters the reefs in Portland Canal and Lynn Canal have not been impacted by bottom contacting fishing activity. Sponge reefs have now been documented along the mainland Pacific margin from the southernmost major west coast fjord, Howe Sound, to the northernmost Alaskan fjord at Lynn Canal, a distance of 1,300 km. Additional research is needed to determine if large reef complexes, such as those found off British Columbia, exist on the Alaska continental shelf.

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Table 1. -- Oceanographic parameters measured at the south and north margins of each of the sponge reefs in Portland Canal. Measurements were made on 4 April 2010 with a Seabird Electronics SBE19 of the entire water column. Data are provided at 25-m depth intervals and the maximum depth (i.e., at the water column/reef interface) of each cast.

Reef - margin	Depth (m)	Temp. (°C)	Salinity (psu)	DO (ml/L)	Fluorescence (mg/m ³)	PAR (x 1000)	pH
South - south	25	6.34	30.13	7.09	0.26	4140	8.21
	50	6.37	31.03	7.04	0.07	0.0911	8.18
	75	6.40	31.23	7.03	0.06	0.1060	8.16
	100	6.35	31.38	7.03	0.04	0.1060	8.14
	112	6.33	31.53	7.02	0.03	0.1940	8.11
South - north	25	6.38	30.32	7.07	0.22	4460	8.20
	50	6.37	30.91	7.05	0.09	0.0763	8.17
	75	6.42	31.16	7.03	0.06	0.1060	8.17
Middle - south	100	6.37	31.30	7.03	0.06	0.0322	8.14
	25	6.35	30.26	7.08	0.26	5270	8.11
	50	6.37	30.89	7.05	0.12	18.8	8.09
	75	6.44	31.12	7.03	0.08	0.1060	8.08
	100	6.37	31.43	7.03	0.06	0.0910	8.06
Middle - north	125	6.31	31.65	7.02	0.04	0.0616	8.01
	127	6.31	31.70	7.02	0.03	0.0175	8.00
	25	6.36	30.40	7.07	0.23	5290	8.20
	50	6.41	30.94	7.04	0.10	17.1	8.19
	75	6.43	31.18	7.03	0.10	0.1650	8.16
North - south	100	6.38	31.32	7.03	0.07	0.0617	8.14
	121	6.32	31.49	7.03	0.05	0.0763	8.12
	25	6.10	29.99	7.13	0.50	393	8.25
	50	6.09	31.12	7.08	0.14	0.5630	8.14
	75	6.09	31.14	7.08	0.09	0.2530	8.13
North - north	100	6.08	31.20	7.08	0.07	0.1940	8.10
	125	6.06	31.65	7.07	0.11	0.1060	8.09
	150	6.06	31.66	7.06	0.07	0.4740	8.04
	174	6.10	31.92	7.05	0.05	0.3560	7.99
	25	6.12	30.49	7.12	— [*]	—	—
	50	6.08	31.13	7.09	—	—	—
	75	6.05	31.50	7.07	—	—	—
100	6.04	31.88	7.06	—	—	—	
125	6.04	31.97	7.05	—	—	—	
136	6.04	31.98	7.05	—	—	—	

*Not measured due to equipment failure.

Table 2. -- Comparison of the range of oceanographic parameters measured at the three reef sites in Portland Canal. The depth range of the three reefs was determined from ROV observations.

Parameter	South Reef	Middle Reef	North Reef
Depth (m)	72–113	53–85	89–107
Temperature (°C)	6.33–6.42	6.37–6.43	6.03–6.08
Salinity (psu)	31.16–31.53	30.92–31.22	31.17–31.92
DO (ml/L)	7.02–7.03	7.03–7.05	7.06–7.08
Fluorescence (mg/m ³)	0.01–0.06	0.07–0.10	0.09–0.12
PAR (x 1000)	0.01–0.19	0.08–0.11	0.17–0.27
pH	8.11–8.17	8.08–8.19	8.09–8.11

Figure 1. -- Location of the two study sites in Southeast Alaska and northern British Columbia.

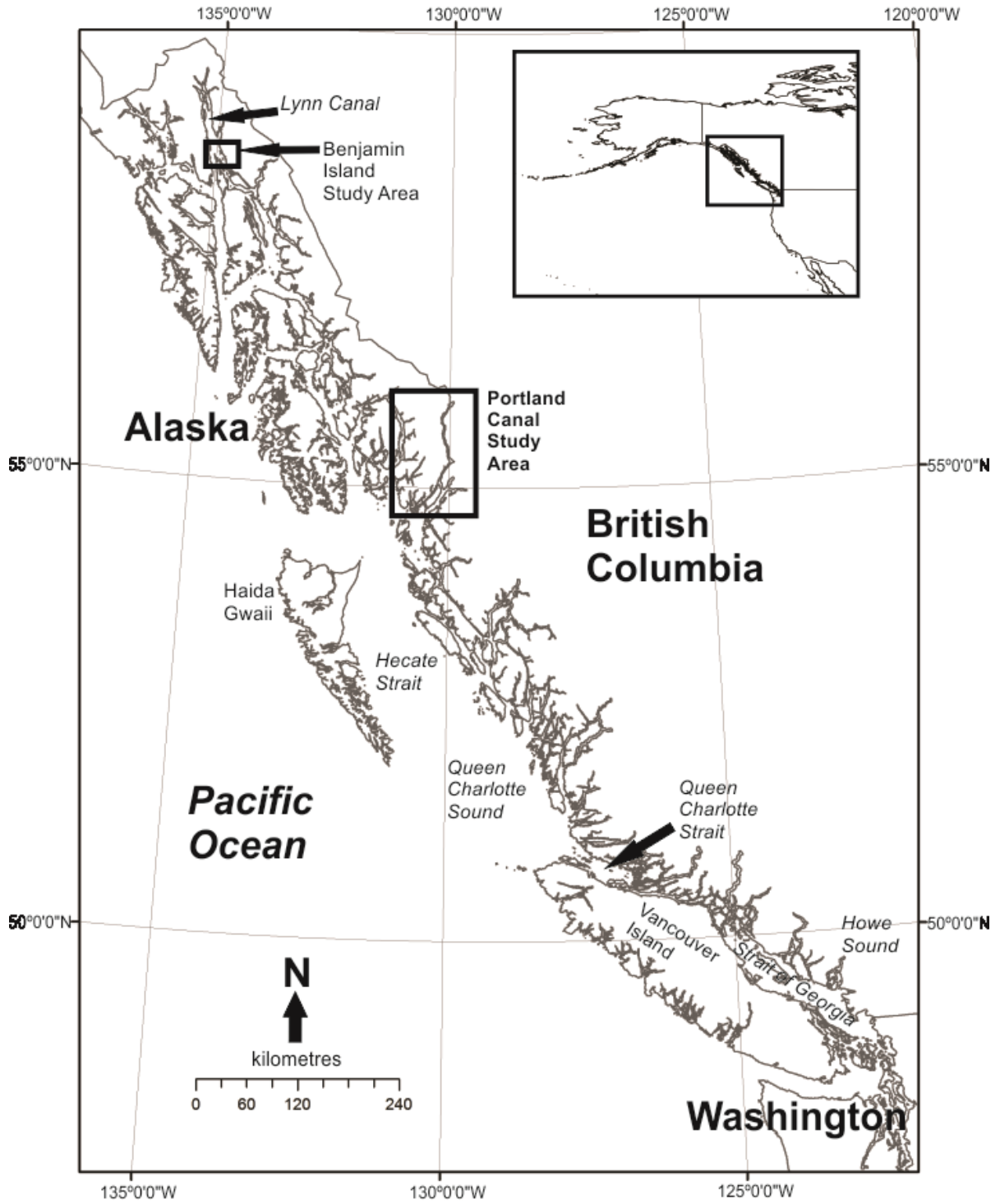


Figure 2. -- Location of the three reefs in Portland Canal on the border between Southeast Alaska and British Columbia. The multi-beam swath bathymetry data are draped over the study areas and depths are rendered as a color map from red (shallow) to blue (deep).

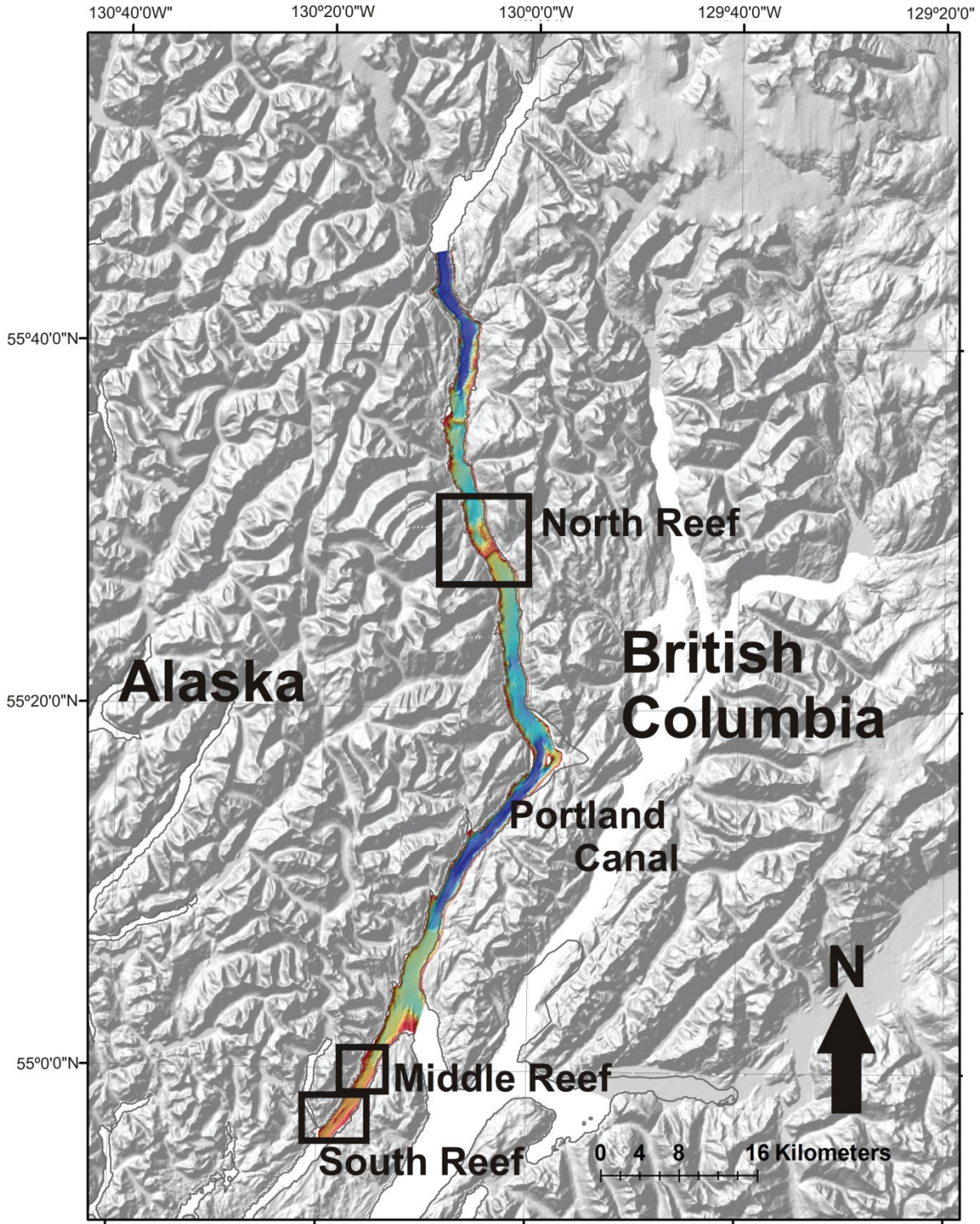


Figure 3. -- Multi-beam backscatter data draped on bathymetry (left) and interpreted sponge reef distribution (right) for (a) North Reef, (b) Middle Reef, and (c) South Reef in Portland Canal. Bathymetric depths are rendered as a color ramp from red (shallow) to blue (deep). See Figure 2 for reef locations. The depth range is 50 to 250 m and the terrestrial imagery is SPOT satellite imagery with 15 m resolution. (a) The North Reef area. Note the smooth aspect of the reef surface where pervasive oxide crusts and zooanthid growth was observed and the large alluvial fan deltas to the north and south of the reef area. (b) The Middle Reef area. Numerous small reefs observed in the backscatter data are enclosed as larger polygons showing general reef areas. (c) The South Reef area. The arrow indicates the location of the large 21-m high bioherm.

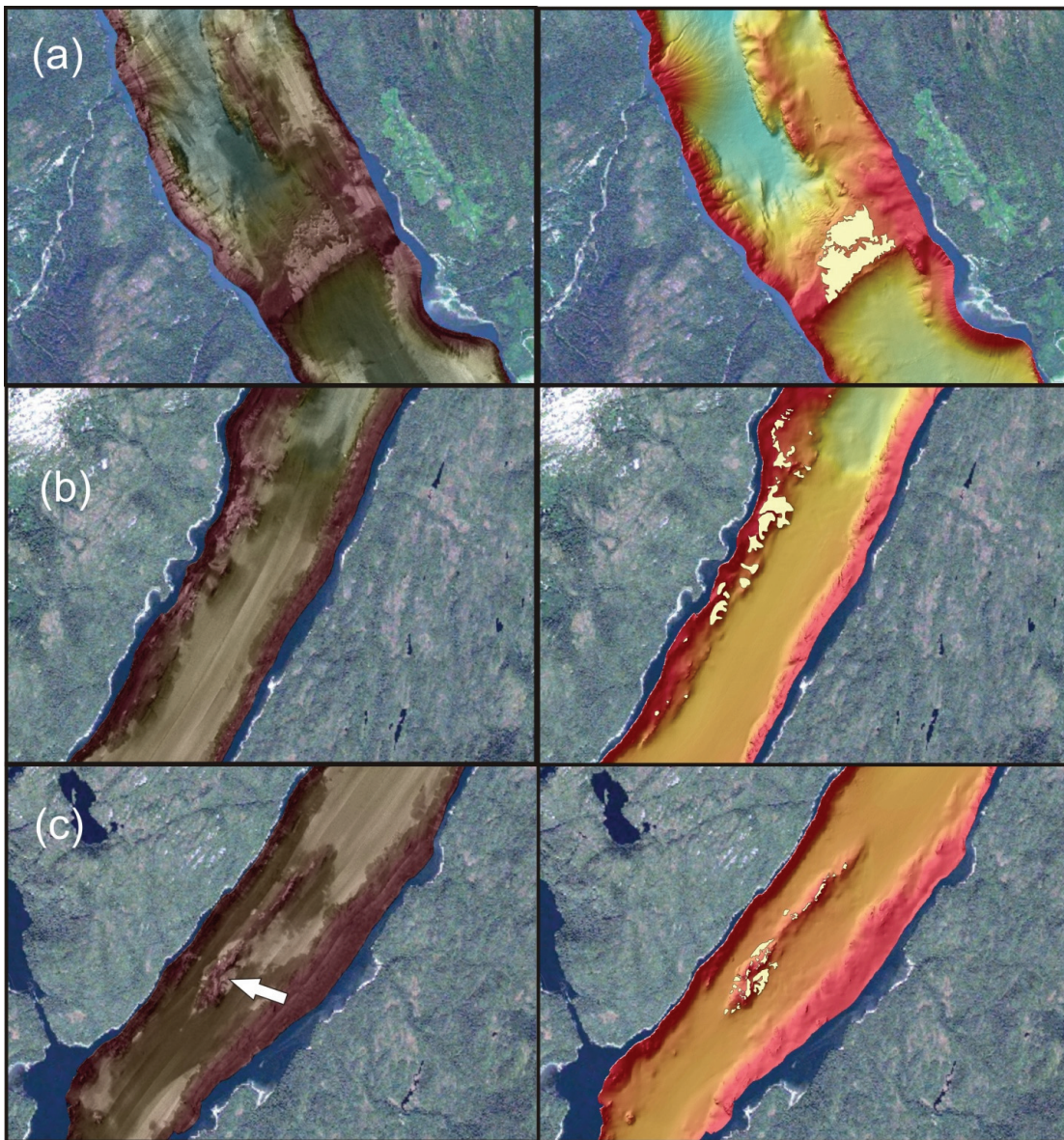


Figure 4. -- Sub-bottom profiles (lower panels) and track locations on multi-beam data (upper panel) showing thickness and form of the reefs in the North Reef area in Portland Canal.

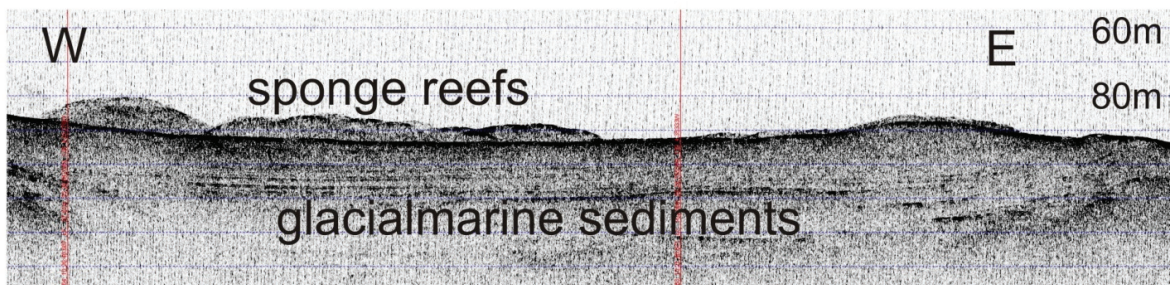
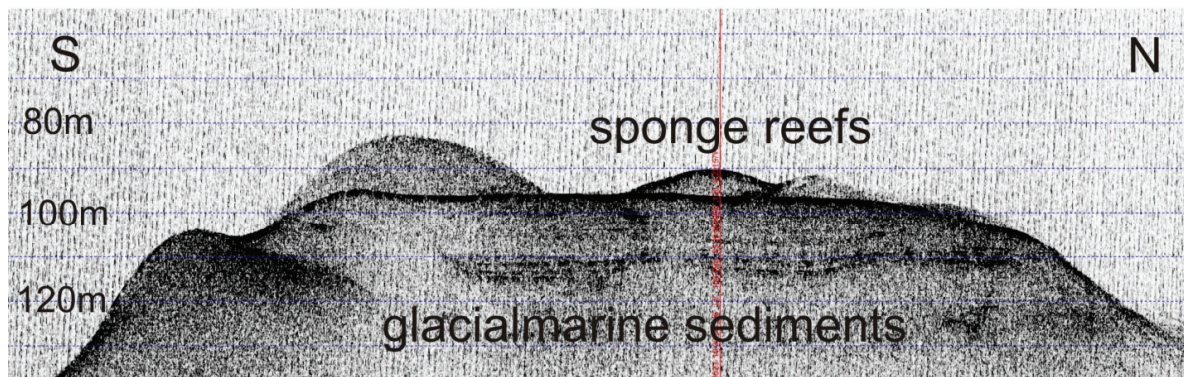
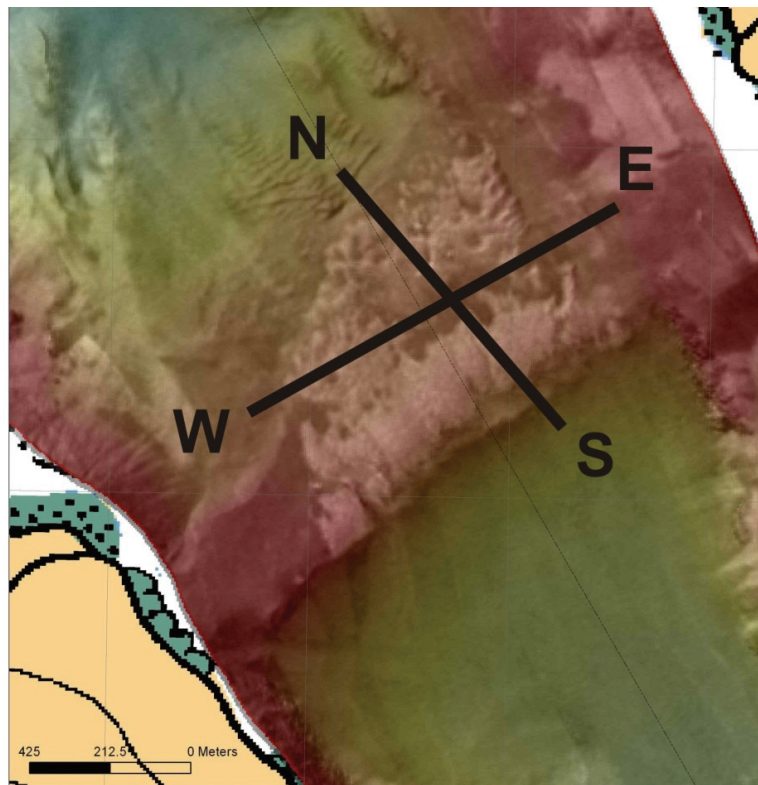


Figure 5. -- Sub-bottom profiles (lower panels) and track locations (upper panel) showing thickness and form of the reefs in the Middle Reef area in Portland Canal.

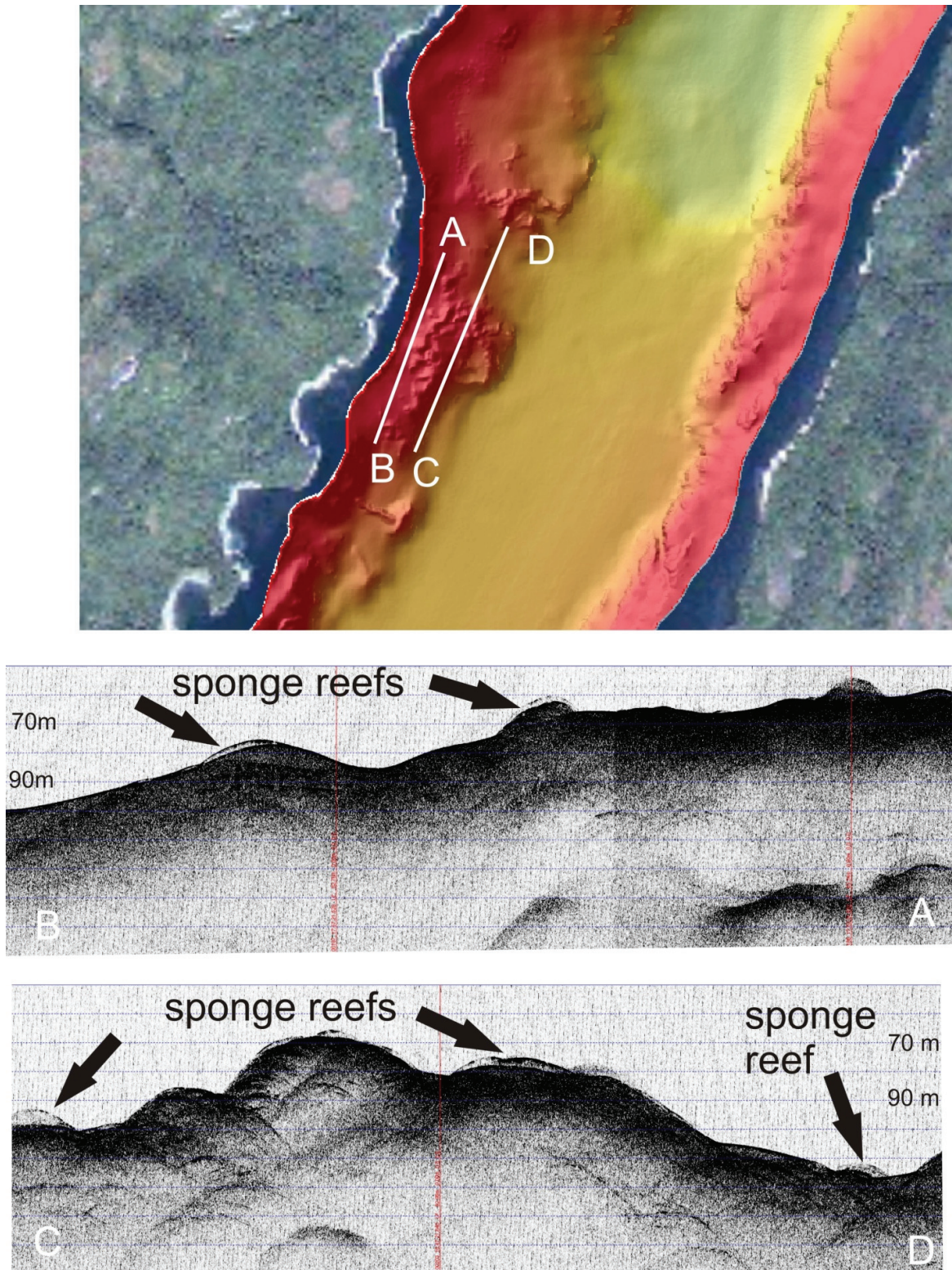


Figure 6. -- Sub-bottom profiles (lower panels) and track locations on multi-beam data (upper panel) showing thickness and form of the reefs in the South Reef area in Portland Canal.

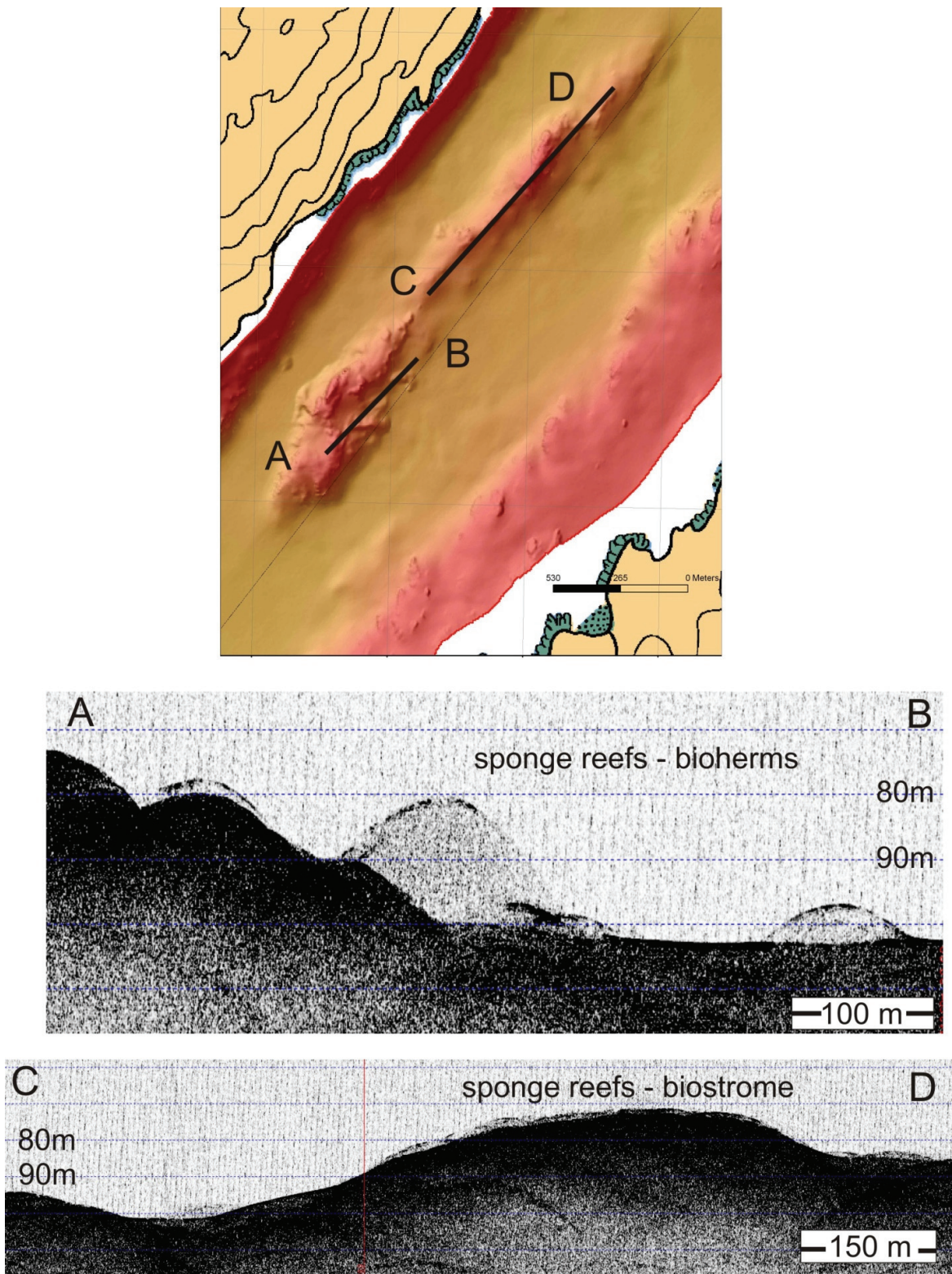


Figure 7. -- a) A rossellid sponge (*Rhabdocalyptus dawsoni*) growing on the sponge reef surface at a depth of 88 m at the North Reef in Portland Canal; b) zoanths (Family Parazoanthidae) covering the reef surface at a depth of 90 m at the North Reef in Portland Canal; c) a large *Farrea occa* at a depth of 92 m at the South Reef in Portland Canal; d) a large rossellid sponge (upper right) growing on glass sponge skeletons at a depth of 81 m at the South Reef in Portland Canal; e) a large *Aphrocallistes vastus* at a depth of 40 m at the Benjamin Island reef complex; f) *Heterchone calyx* (right) and *A. vastus* (left) growing on a base of skeletons at a depth of 42 m at the Benjamin Island reef complex; g) intact sponge skeleton structure at a depth of 35 m at the Benjamin Island reef complex. A juvenile rockfish uses the skeletons as refuge (center) and the ROV sampling probe is attached at the center of the left margin; H) a reef buttress overgrown by bryozoans at a depth of 27 m at the Benjamin Island reef complex. The red laser dots in all figures are separated by 10 cm.

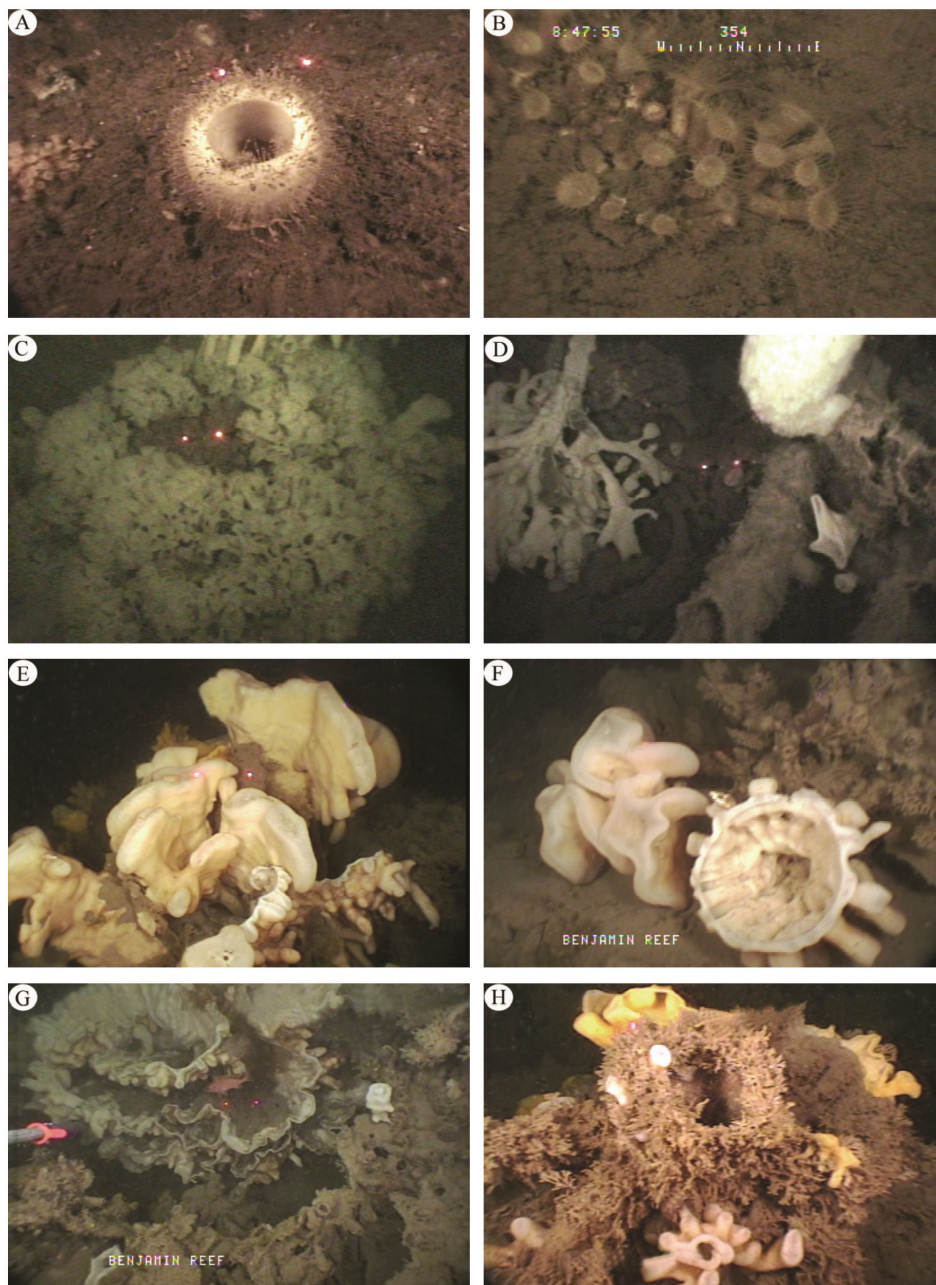
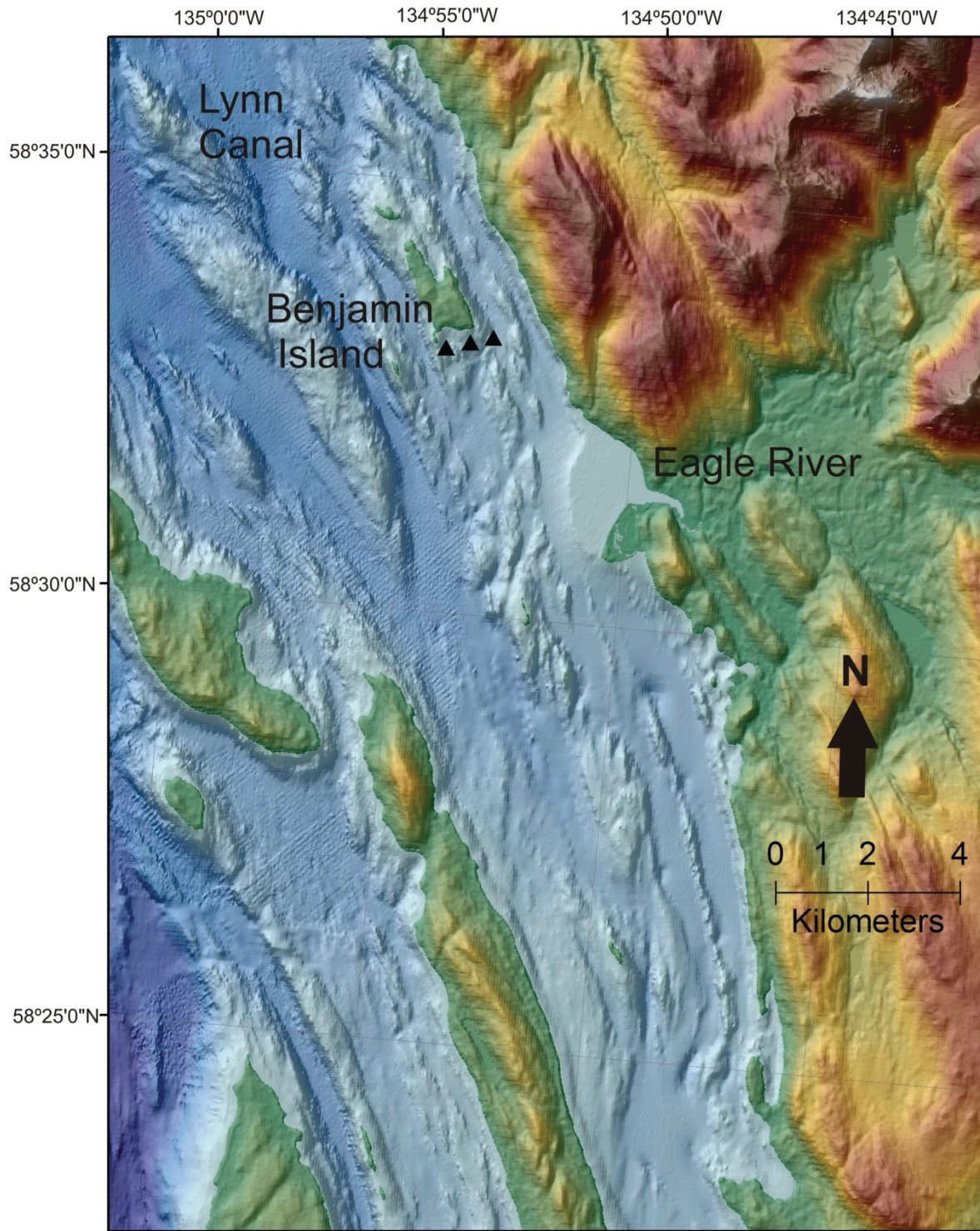


Figure 8. -- Location of sponge reefs near Benjamin Island in Lynn Canal, Southeast Alaska.



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