Fisheries and Oceans Canada / Pêches et Océans Canada
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Canadian Science Advisory Secretariat
Science Response 2020/026

GROUND-TRUTHING THE LATEST SET OF SUSPECTED GLASS SPONGE REEFS IN HOWE SOUND: REEF DELINEATION AND STATUS ASSESSMENT

Context

Fisheries and Oceans Canada (DFO) has been working to identify and mitigate the impacts of bottom-contact fishing on glass sponge reefs in the Strait of Georgia and Howe Sound through the Strait of Georgia and Howe Sound Glass Sponge Reef Conservation Initiative (DFO 2019). Glass sponge reefs are unique biogenic habitats found along the Pacific coast of Canada and the United States with historic, ecological, and economic value. The reefs play important roles in carbon and nitrogen processing, act as silica sinks, and support diverse communities of invertebrates and fish (Cook et al. 2008, Chu and Leys 2010, Tréguer and De La Rocha 2013, Kahn et al. 2015, DFO 2018, Dunham et al. 2015, 2018b).

Over the past 16 years, a number of glass sponge reefs have been discovered and mapped in the Strait of Georgia and Howe Sound using remote sensing (Conway et al. 2004, 2005, 2007) and standardized visual surveys (Dunham et al. 2018b). Two recent DFO Science initiatives carried out in collaboration with Natural Resources Canada and conservation organizations delineated 19 glass sponge reef complexes, assessed their condition, and recommended assessment and monitoring methods. The resulting science advice (subsequently published as DFO 2018; Dunham et al. 2018a) formed the scientific basis for nine bottom-contact fishing area closures implemented in June 2015, followed by eight closures implemented in April 2019. These closures are considered Other Effective Area-Based Conservation Measures (DFO 2016), contributing to Canada's Marine Conservation Target commitment to protect 10% of Canada's coast by 2020.

When the latest set of closures was implemented in April 2019, nine additional areas in Howe Sound were identified as possible sponge reefs based on SCUBA divers' observations, drop camera footage, or geological records. Data available at the time were deemed insufficient for reef status confirmation; these areas required ground-truthing before their status could be determined (DFO 2018, see Appendix 7).

DFO Sustainable Fisheries Framework Unit has requested advice from the Science Branch assessing the status of these nine suspected reefs, to serve as the final component of science support and advice for the above-mentioned Conservation Initiative (DFO 2019).

The primary goals of the present assessment are to (1) gather all available ecological and geological data for the nine areas in Howe Sound suspected to be glass sponge reefs; (2) ground-truth seven visual-data-deficient areas by surveying them with a Remotely Operated Vehicle (ROV); and (3) determine reef status and quantitatively describe the condition of each reef.

Specific objectives of this assessment include:

1. For each of the nine areas:
   - Map geological signature indicative of glass sponge reefs, if present, using available multibeam and backscatter data layers;
   - Map the presence of live reef-building glass sponges and reef structure based on ROV video and still images;
   - Determine whether the area is a living glass sponge reef based on criteria outlined in DFO (2018).
2. For each area determined to be a glass sponge reef:
   - Characterize reef condition (sponge cover, habitat categories) using quantitative metrics developed in Dunham et al. (2018a) and applied in DFO (2018);
   - Create 1-page summaries of reef extent and status similar to DFO (2018);
   - Provide advice on potential benefits of protection;
   - Identify any uncertainties in the data.

For consistency, this assessment follows the terminology, methods, content order, and layout of DFO (2018), with minor adjustments described in the text.

The assessment and advice arising from this Canadian Science Advisory Secretariat (CSAS) Science Response will be used to inform management and monitoring of the sponge reefs in Howe Sound and to respond to stakeholder requests for scientific information. It is expected to support DFO Sustainable Fisheries Framework Unit and Oceans in advancing Canada's commitments around Other Effective Area-Based Conservation Measures. This report is not intended to explicitly recommend areas for spatial protection, but rather to gather and summarize all available geological and ecological information for each of the nine areas to facilitate management decisions.

This Science Response results from the Science Response Process of February 19, 2020 on Ground-truthing the final set of suspected sponge reef complexes in Howe Sound: Reef delineation and status assessment.

Background

Glass sponge reefs are built by hexactinellid sponges that have silicon dioxide spicules fused into a rigid, but delicate three-dimensional structure (Leys et al. 2007). As larval sponges attach to the exposed dead skeletons of previous generations, the reef grows and reef structure solidifies by trapping fine, organic-rich sediments delivered by bottom currents (Leys et al. 2004, Krautter et al. 2006). The bulk of the reefs thus consists of sub-surface dead sponge structure (Fig. 1, dark grey), with the most recent generation of sponges growing one to two meters above the surface (Fig. 1, orange and light grey).

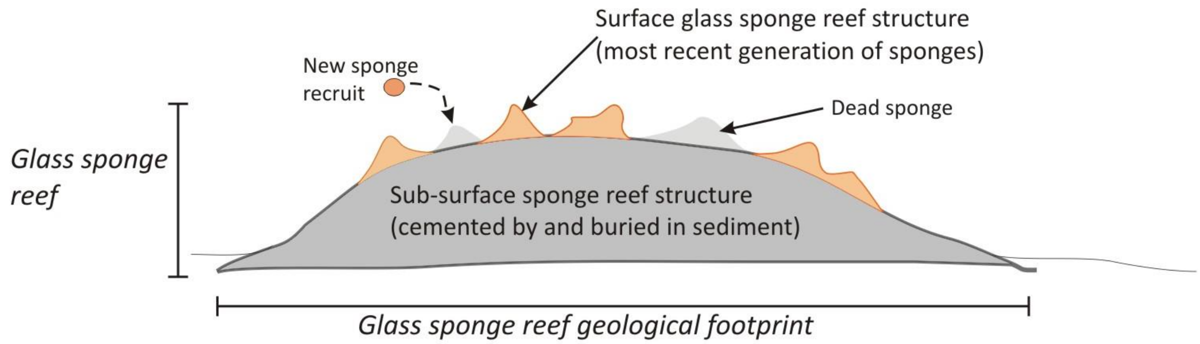

Figure 1 (reproduced from DFO 2018). Diagram of glass sponge reef structure.

Large contiguous areas of sponge reef structure are readily identified as "acoustic anomalies" using remote sensing techniques, because the reefs are less acoustically reflective than the surrounding and underlying substrates: the sponge-rich clay sediments and the siliceous skeletons of the sponges absorb acoustic energy. Typically, areas of the seafloor exhibiting positive relief are reflective with higher backscatter strength, but sponge reefs appear as non-reflective high relief points in backscatter imagery (Conway et al. 2005). However, this or any other remote sensing technique available to date cannot differentiate between live, dead, and dead and buried patches of glass sponges within a reef. To determine current extent and status of the reefs (e.g. live reef-building sponge cover), visual field surveys are required.

Terminology

The following operational definitions are used throughout this paper (consistent with Dunham et al. 2018a,b and DFO 2018):

- Reef-building glass sponge: Individual specimen of *Aphrocallistes vastus, Heterochone calyx, or Farrea occa;* in the context of this assessment, limited to species known to construct reefs in the Strait of Georgia and Howe Sound: *A. vastus* and *H. calyx*.
- Glass sponge reef: Bioconstruction formed by reef-building glass sponges with sub-surface and above surface structure sufficient to produce a contiguous geological signature and/or exhibiting clear visual evidence of reef formation (reef-building sponges growing atop of previous generation of sponges). May consist of live and dead areas (reflecting natural patchiness) or be completely dead.
- Glass sponge garden: Aggregation of sponges at a notably higher biomass than in surrounding areas, but without evidence of reef formation.
- Glass sponge reef geological footprint: Area covered by an individual glass sponge reef that produces a contiguous multibeam and backscatter signature.
- Index: A quantitative measure of a property related to individual sponge condition or whole reef status.

Datasets Used

To provide a comprehensive review of all available evidence, we combined the following three datasets:

1. Glass sponge aggregation map (ecological dataset #1) provided by project collaborators, the Marine Life Sanctuaries Society (MLSS) and Glen Dennison and Lora Tryon (McAuley). All reef-building sponge records from drop camera transects and SCUBA-based observations were mapped in Google Earth; the polygons were then drawn to encompass all records (sparse to dense). Visual survey methods, as well as the approaches and software used for outlining polygons are described in McAuley (2017) and Clayton and Dennison (2017). ***Note: This dataset matches ecological dataset #1 used in DFO (2018); in this assessment we include expanded qualitative descriptions of the video.***
2. DFO Science Remotely Operated Vehicle (ROV) survey results (ecological dataset #2). A survey of 7 suspected reef areas was conducted by DFO Science in May 2019 using DFO Phantom ROV HD2+2 aboard the CCGS Vector, cruise Pac2019-015. (The other 2 suspected glass sponge reefs are too close to shore for the CCGS Vector to safely access and were not surveyed.) Video and still imagery were collected along predetermined line transects (Appendix 2); transect placement was informed by ecological dataset #1 and the geological dataset described below. Data processing and analyses were consistent with the methods developed by Dunham et al. (2018a). ***Note: This dataset consists of new data collected in 2019 that has not been previously published.***
3. NRCan geological footprint maps (geological dataset). All remote sensing (multibeam swath bathymetry and backscatter) imagery collected in Howe Sound by the Geological Survey of Canada and the Canadian Hydrographic Service were reviewed for geological reef footprint evidence as described in Conway et al. (2005). The multibeam swath bathymetry provided a 5 m resolution map of the seabed. Backscatter layer for areas suspected to be sponge reefs was reprocessed, using original survey data, to 0.5-1 meter resolution in FM Geocoder (Fledermaus suite of data visualization products). Geological reef polygons were created by draping the backscatter layer over multibeam bathymetry layer and identified as areas simultaneously exhibiting positive relief, low backscatter strength, and acoustic transparency (Conway et al. 2005). In addition, raised seafloor areas displaying a “snowcapped morphology” while being non-reflective have been identified as indicative of sponge reefs. These methods can reliably identify a contiguous glass sponge reef patch ≥20 m in diameter. ***Note: This geological dataset matches the one used in DFO (2018) exactly.***

Analysis and Response

1. Quantitative analyses: methods

1.1 Determining the status of each of the nine areas

The three datasets described above were combined, and the resulting maps and descriptions were used to determine whether each of the nine areas met the following criteria (DFO 2018):

1. Standing live reef-building glass sponges observed in ecological dataset #1 and/or ecological dataset #2.
2. Visual evidence of reef formation: reef-building glass sponges growing atop previous generations identified in ecological dataset #1 and/or ecological dataset #2.
3. Evidence of geological reef signature (geological dataset).

These were used as decision criteria for assigning sponge reef status and condition (Table 1). Not all criteria combinations were encountered in this project, but we listed all plausible combinations in Table 1 to facilitate future applications. Appendix 3 illustrates how to apply these criteria via a decision tree.

Table 1 (reproduced and updated from DFO 2018). Decision criteria for assigning sponge reef status and condition showing all combinations of criteria possible.

Criterion 1* **Standing live reef-building glass sponges**	***Criterion 2**** **Visible reef formation**	***Criterion 3*** **Geological evidence of reef structure**	**Status (reef/garden/unknown) and condition (live/dead/unknown) assigned**	**Notes**
Present	Present	Present	Reef, live	Evidence of live reef status
Present	Absent	Present	Reef, live	Evidence of live reef status
Present	Not surveyed	Present	Reef, live	Evidence of live reef status
Present	Present	Data not available	Reef, live	Evidence of live reef status
Present	Present	Absent	Reef, live	Evidence of live reef too small or patchy to produce geological signature (no contiguous reef areas ≥20 m in diameter)
Absent	Absent	Present	Reef, condition unknown	Geological reef; further visual ground-truthing required to determine live or dead
Not surveyed	Not surveyed	Present	Reef, condition unknown	Geological reef; visual ground-truthing required to determine live or dead
Absent	Not surveyed	Present	Reef, condition unknown	Geological reef; further visual ground-truthing required to determine live or dead
Present	Not surveyed	Absent	Sponge garden or small reef**, live	Visual ground-truthing required to determine whether the aggregation is a sponge garden or a small reef (no contiguous reef areas ≥20 m in diameter)
Present	Not surveyed	Data not available	Status unknown, live	Status unknown, ground-truthing needed
Present	Absent	Data not available	Status unknown, live	Status unknown, ground-truthing needed
Present	Absent	Absent	Sponge garden or small reef**, live	Could be a garden or a reef too small or patchy to produce clear geological signature (no contiguous reef areas ≥20 m in diameter). Visual ground-truthing needed
Not surveyed	Not surveyed	Data not available	Status and condition unknown	No evidence of sponge aggregation at present; could be a reef, a garden, or a small reef
Absent	Not surveyed	Data not available	Status and condition unknown	No evidence of sponge aggregation at present; could be a reef, a garden, or a small reef
Not surveyed	Not surveyed	Absent	Status and condition unknown	No evidence of sponge aggregation at present; could be a garden or a small reef
Absent	Not surveyed	Absent	Status and condition unknown	No evidence of sponge aggregation at present; could be a garden or a small reef
Absent	Absent	Absent	Status and condition unknown	No evidence of sponge aggregation at present; could be a garden or a small reef

* Note that "Absent" under criteria #1 and #2 indicates absence of evidence, but not evidence of absence (e.g. feature of interest may be absent in the surveyed area, but present in other areas).
** Updated from "Status unknown" (DFO 2018).

1.2 Determining reef condition

All quantitative indices were calculated using DFO ROV survey data; detailed methods can be found in Dunham et al. (2018a,b). Briefly, reef-building glass sponge cover was assessed using both video and still image datasets because our earlier work demonstrated the advantages of combining video- and image-based approaches in sponge reef status assessment (Dunham et al. 2018a).

Video: ROV video was annotated using VideoMiner V3.0 by recording observations for each 10-second interval, hereinafter referred to as a video bin. Each video bin can be viewed as a rectangle, with width equal to the video camera's field of view (3.1±1.09, mean±SD, *n*=30) and length equal to the distance along the sea floor the ROV travelled over the 10-second interval. Geological and biological features recorded for each video bin were: dominant and subdominant substrate type, relative abundance of live reef-building sponges, and counts of reef-building sponges; these were combined into a single metric – habitat category – using an assignment matrix (Table 2).

Table 2 (reproduced from Dunham et al 2018b). Habitat category assignment matrix.

Habitat category	**Live reef-building sponge: counts per bin**	**Live reef-building sponge: relative abundance**	**Substrate type**
Live reef*	>16	Abundant, common, or frequent	Live sponge – dominant or subdominant
Mixed reef	2-15	Occasional or rare	Dead sponge – dominant or subdominant
Dead reef**	0-1	Not applicable	Dead sponge – dominant or subdominant
No visible reef**	0	Not applicable	No live or dead sponges – dominant or subdominant

*This category combines “dense live reef” and “live reef” categories used in DFO (2018), because in our subsequent work we found these two categories hard to distinguish from one another: complex morphology of sponges makes exact counts of individuals problematic in dense sponge areas.

**”Dead reef” habitat has visible dead sponge skeletons, whereas “no visible reef” has no visible live or dead sponges (although sponge structure may be buried under the sediment); the distinction was introduced because these areas differ in recovery potential.

The resulting habitat categories (‘live reef’, ‘mixed reef’, ‘dead reef’, and ‘no visible reef’) were mapped (Figures 3-8, A) and used to calculate *% Visible Reef Index* and *% Live Reef Habitat Index* as follows:

$$\%\, Visible\ Reef\ index = \frac{\boldsymbol{N} video\ bins\ with\ any\ visible\ reef\ designation\ (i.e. all\ except\ \text{‘}no\ visible\ reef\text{’})}{\boldsymbol{N} video\ bins\ per\ transect}$$

$$\%\, Live\ Reef\ Habitat\ index = \frac{\boldsymbol{N} video\ bins\ with\ 'live\ reef'\ designation}{\boldsymbol{N} video\ bins\ per\ transect}$$

% Visible reef index and % Live Reef Habitat index were averaged for multiple transects within each reef, where applicable. The resulting values are summarized in Table 4.

Still images: All still images that captured an unobstructed, clear view of the benthos were processed (1624 images total; for numbers of still images per reef complex see Appendix 1, Table A1-1). A 10 × 10 cm cell grid was overlaid onto each image (see Appendix 1, Fig. A1-2) and dominant (occupying ≥50% of the cell) benthic cover was recorded for each cell. Benthic cover categories included non-biogenic substrate (e.g. mud, sand, and gravel), live reef-building sponge, dead reef-building sponge, other sponge, reef-building sponge rubble, non-sponge biota, and anthropogenic objects. *Live % cover index* was calculated as follows:

$$Live\ \%\ Cover\ Index = \frac{\boldsymbol{N} grid\ cells\ in\ image\ with\ live\ reef-building\ sponge\ as\ dominant\ benthic\ cover}{\boldsymbol{N}\ total\ grid\ cells\ in\ image}$$

Live % cover index was calculated for each image and then averaged across all images within each reef. This index thus represents the expected percent of the benthos that would be covered by live reef-building sponges for any randomly selected square meter of a glass sponge reef.

Mapping: Reef extent polygons were created by enclosing all evidence of reef presence (geological and/or ecological) with straight lines drawn between available outermost data points. 3D maps were created by draping the transects and reef extent polygons over bathymetry mosaicked from multiple Canadian Hydrographic Service and National Oceanic and Atmospheric Administration datasets, with a 1.5x vertical exaggeration to visually highlight reef areas.

2. Status assigned to each of the nine areas: summary

The results of the status assessment for each area are presented in Table 3 and Figure 2.

Five areas (Langdale, Carmelo Point, Collingwood Channel, Mariners Rest, and Alberta Bay) were assigned live reef status. One area – Passage Island – is likely a dead glass sponge reef; no live reef areas were found during the visual survey, although they may exist outside of the surveyed area. Note that this reef is located among the Passage Island reef polygons currently protected by the Queen Charlotte Channel fishing closure; hereinafter this reef will be referred to as “Passage Island (additional polygons)”. The six reefs are the primary focus of this paper and are described in Section 3.

Christie Islet was determined to be a live glass sponge garden. The remaining two areas – Ellesmere Creek and September Morn Beach – are likely to be sponge gardens or sponge reefs too small or patchy (i.e. no contiguous reef areas exceeding 20 m in diameter) to produce a geological signature. Observations on these areas are consolidated in Section 4.

Table 3. Nine areas suspected to be sponge reefs: recommended names, summary of available scientific knowledge, status assigned, and current spatial management measure in the area (if any). Ecological datasets #1 and #2 are visual survey results (qualitative drop camera/SCUBA-based observations and quantitative ROV survey, respectively). Grey shading denotes glass sponge reefs.

Recommended name	***Criterion 1:* Standing live reef-building glass sponges**		***Criterion 2:* Visible reef formation**	***Criterion 3:* Geological signature**	**Status assigned**	**Current spatial management measure**
	Ecological dataset #1	**Ecological dataset #2**				
Langdale	Not surveyed	Present	Present	Present	**Reef, live**	None
Carmelo Point	Not surveyed	Present	Present	Present	**Reef, live**	None
Collingwood Channel	Not surveyed	Present	Present	Present	**Reef, live**	None
Mariners Rest	Not surveyed	Present	Present	Present	**Reef, live**	Within Mariners Rest RCA
Alberta Bay	Not surveyed	Present	Present	Present	**Reef, live**	Within Lions Bay RCA
Passage Island (additional polygons)	Absent (no live sponges seen)	Absent	Present	Present	**Reef, condition unknown (no live areas found during visual survey)**	Partially protected by existing glass sponge reef fishing closure
Christie Islet	Present (polygon provided)	Present	Absent	Absent	Sponge garden, live	Within Pam Rock Rockfish Conservation Area (RCA)
Ellesmere Creek	Absent (no live sponges seen)	Not surveyed	Not surveyed	Absent	Sponge garden or <20 m reef, dead	None
September Morn Beach	Present (markers provided)	Not surveyed	Some evidence	Absent	Sponge garden or <20 m reef, live	None

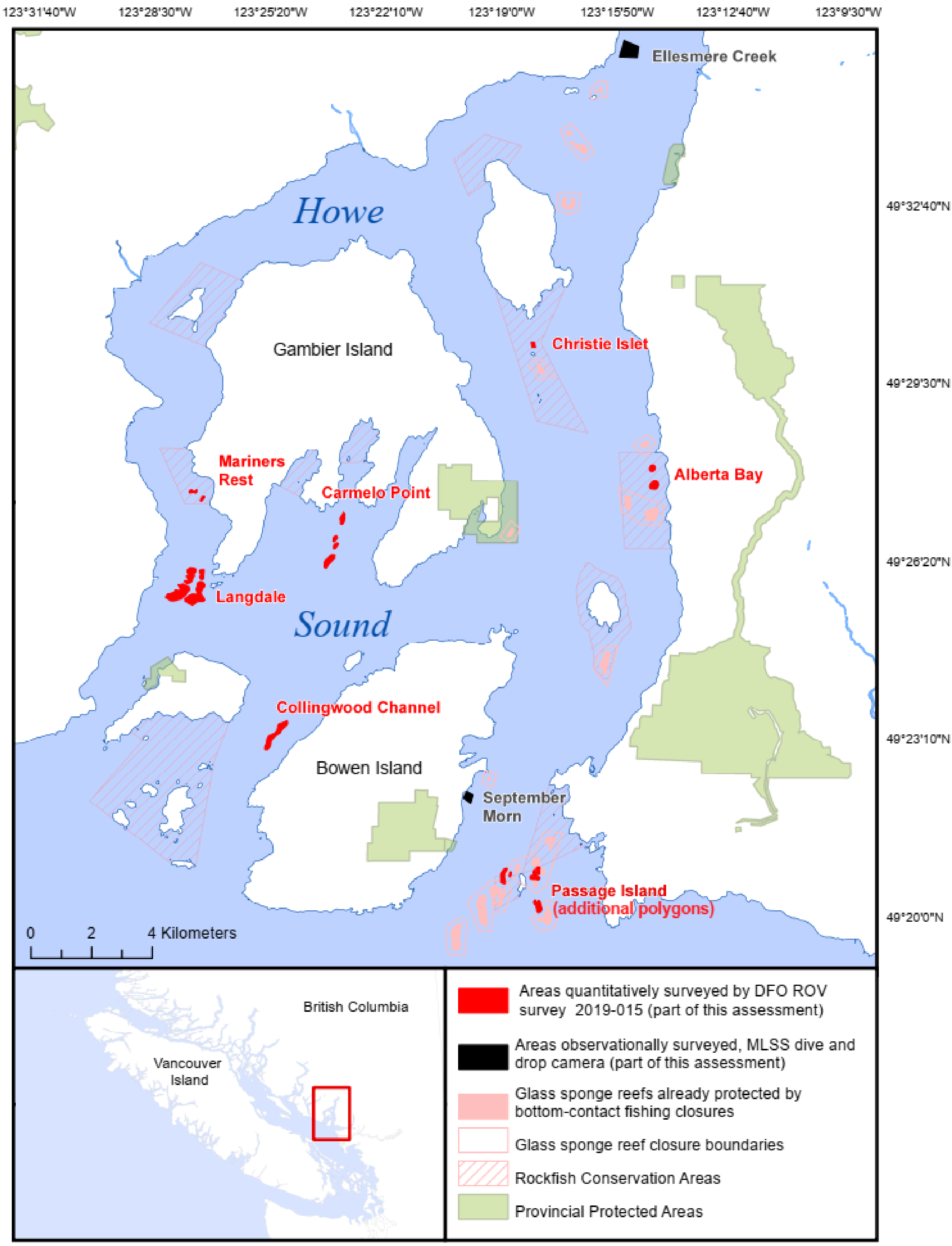

Figure 2. Overview of 9 areas in Howe Sound included in this report (shown in red and black) in relation to existing glass sponge reef bottom-contact fishing closures (pink polygons) and other spatial closures.

3. Areas determined to be glass sponge reefs

3.1 Condition

Maps, environmental parameters, and habitat characteristics for the six reefs are shown in Table 4 and Figures 3 through 8.

Table 4. Summary indices and surveyed depth ranges of the six glass sponge reefs in Howe Sound (see Figures 3-9 for maps and additional details).

Index	**Glass sponge reef**					
	Langdale	Carmelo Point	Collingwood Channel	Mariners Rest	Alberta Bay	Passage Island (additional polygons)
% Visible Reef index (video-based)	83.7	57.0	36.6	76.5	47.1	17.8
% Live Reef Habitat index (video-based)	73.1	14.1	25.4	25.5	6.0	0.0
Live % Cover index (still image-based)	6.0	1.0	2.2	0.5	0.2	0.0
Depth range surveyed, m	30-92	70-134	43-111	66-112	78-138	28-84

No live reef-building sponges were observed within the Passage Island (additional polygons); dead reef covered 17.8% of the surveyed area. In all other reefs, ‘live reef’ habitat category has been observed, ranging from 6% at Alberta Bay to 73% at Langdale (shown in orange in Figures 3-8, panels A and C).

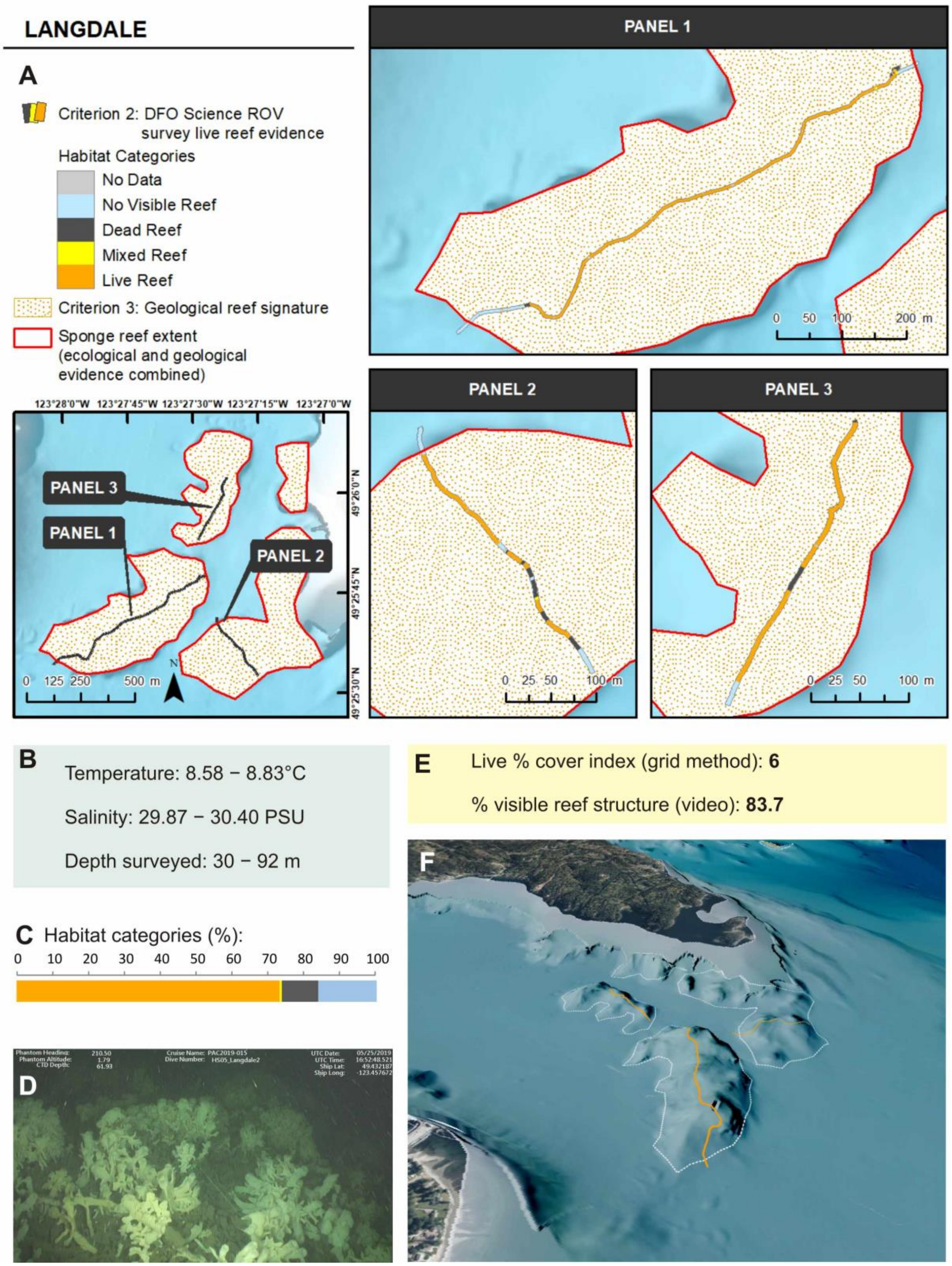

Figure 3. Langdale: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in May 2019; (C) Frequency of occurrence of habitat categories; (D) Image of live reef habitat; (E) Sponge-based indices of reef status; and (F) 3D bathymetry showing transect locations. For methods see Dunham et al. (2018a).

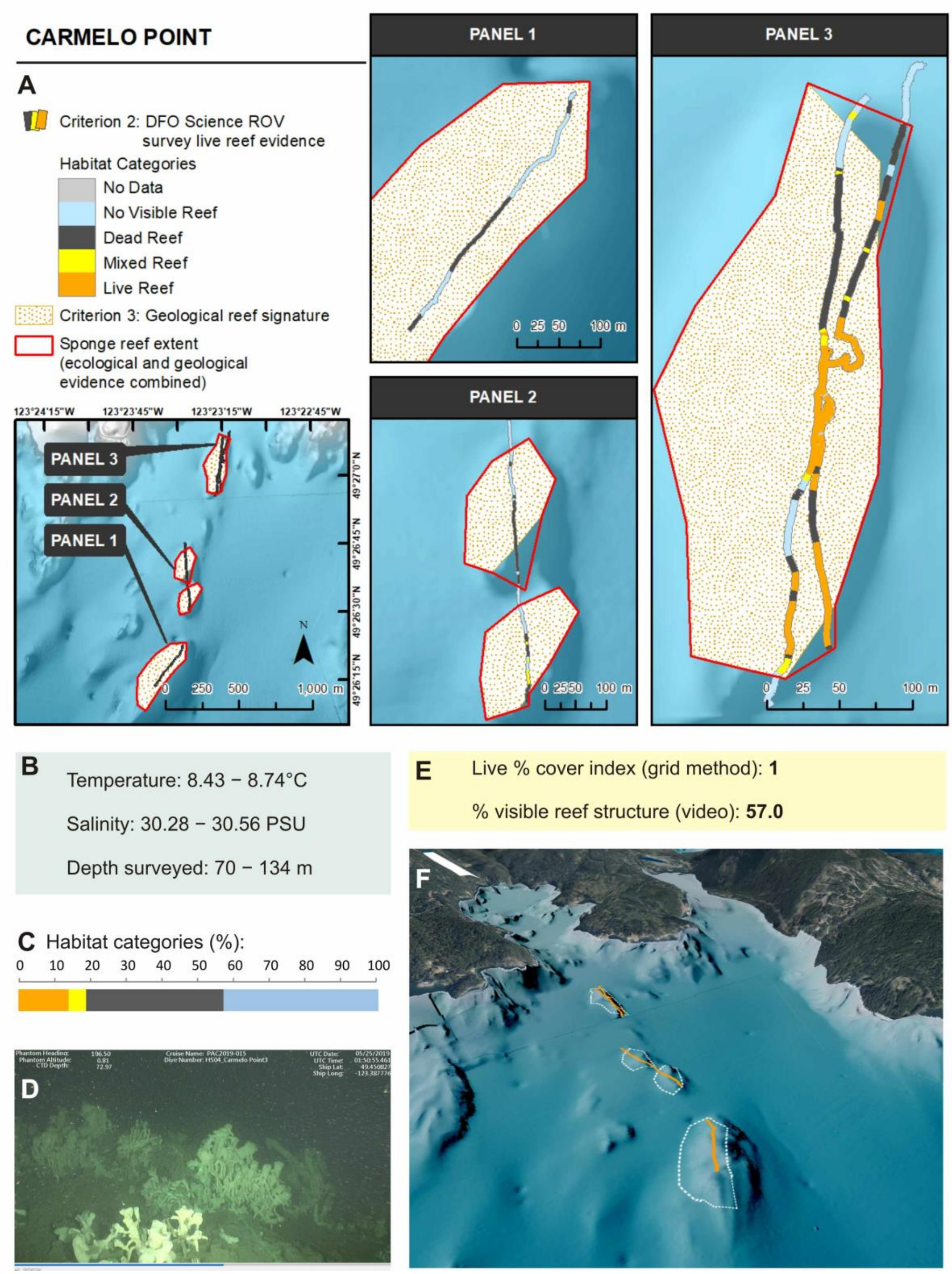

Figure 4. Carmelo Point: (A) map showing available geological and ecological evidence and reef extent (red line) – note that one of the transects shown in panel 3 was surveyed for illustration purposes and excluded from quantitative analysis; (B) Environmental ranges recorded in May 2019; (C) Frequency of occurrence of habitat categories; (D) Image of live reef habitat; (E) Sponge-based indices of reef status; and (F) 3D bathymetry showing transect locations. For methods see Dunham et al. (2018a).

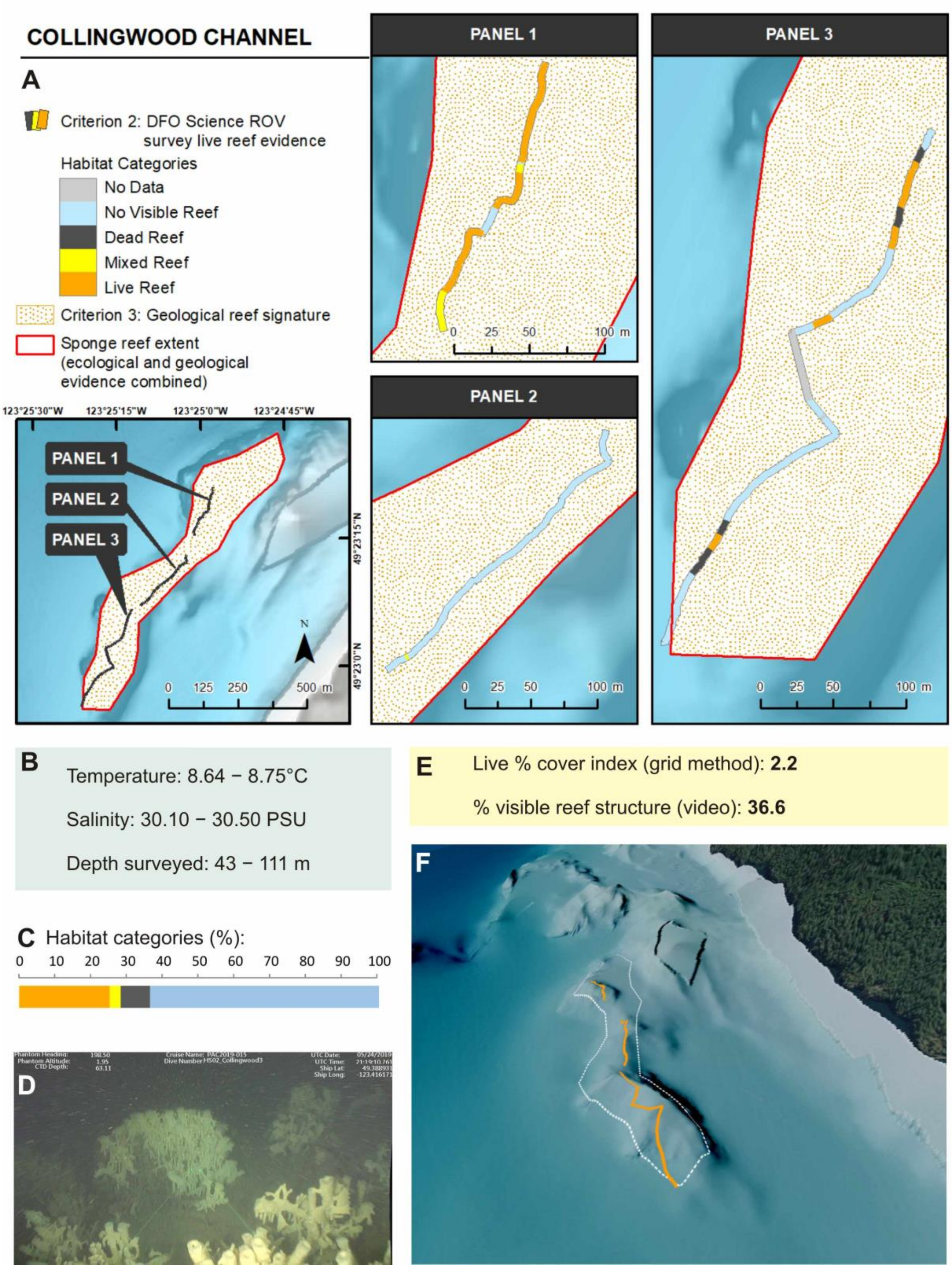

Figure 5. Collingwood Channel: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in May 2019; (C) Frequency of occurrence of habitat categories; (D) Image of live reef habitat; (E) Sponge-based indices of reef status; and (F) 3D bathymetry showing transect locations. For methods see Dunham et al. (2018a).

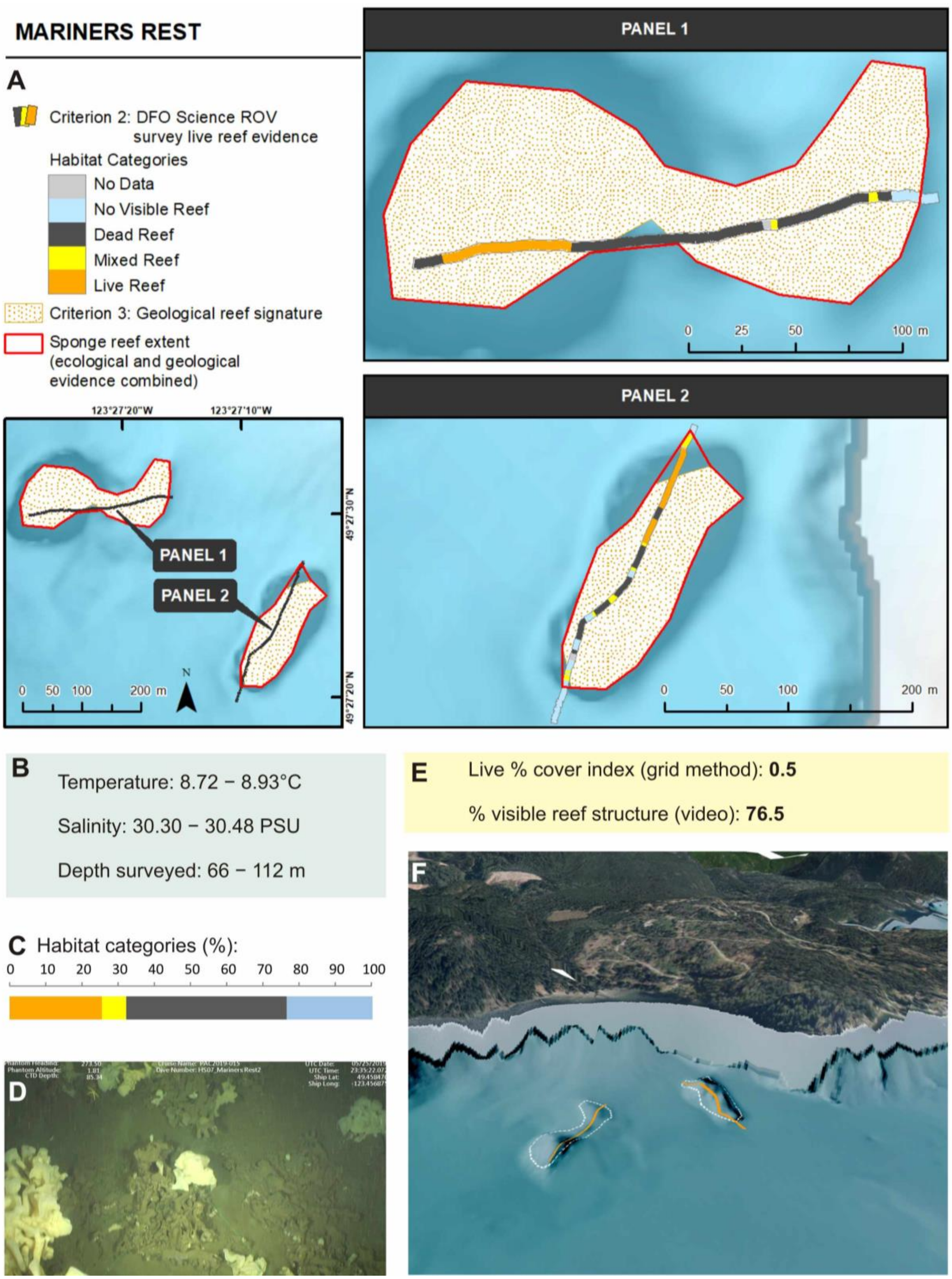

Figure 6. Mariners Rest: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in May 2019; (C) Frequency of occurrence of habitat categories; (D) Image of live reef habitat; (E) Sponge-based indices of reef status; and (F) 3D bathymetry showing transect locations. For methods see Dunham et al. (2018a).

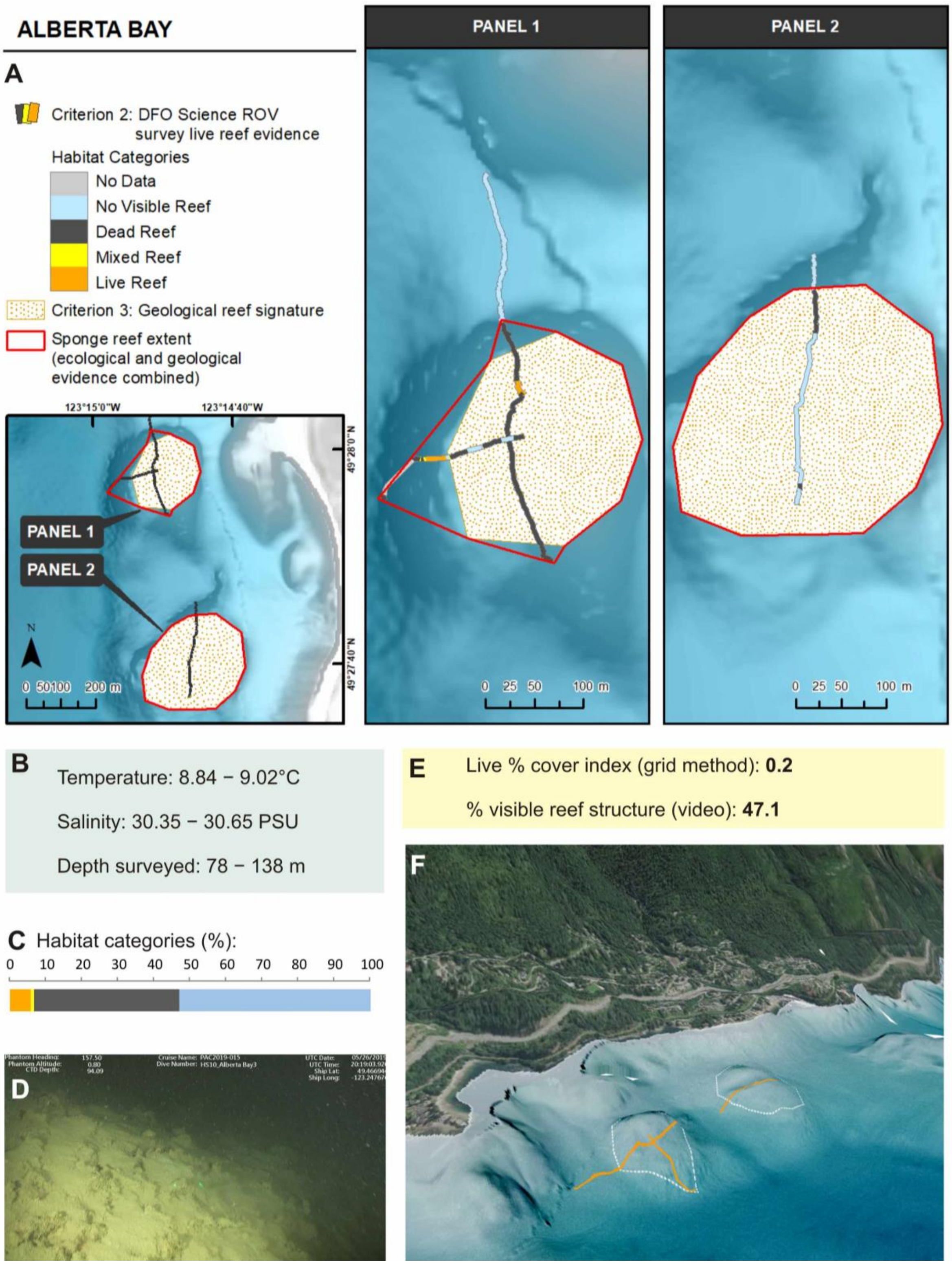

Figure 7. Alberta Bay: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in May 2019; (C) Frequency of occurrence of habitat categories; (D) Image of dead reef habitat; (E) Sponge-based indices of reef status; and (F) 3D bathymetry showing transect locations. For methods see Dunham et al. (2018a).

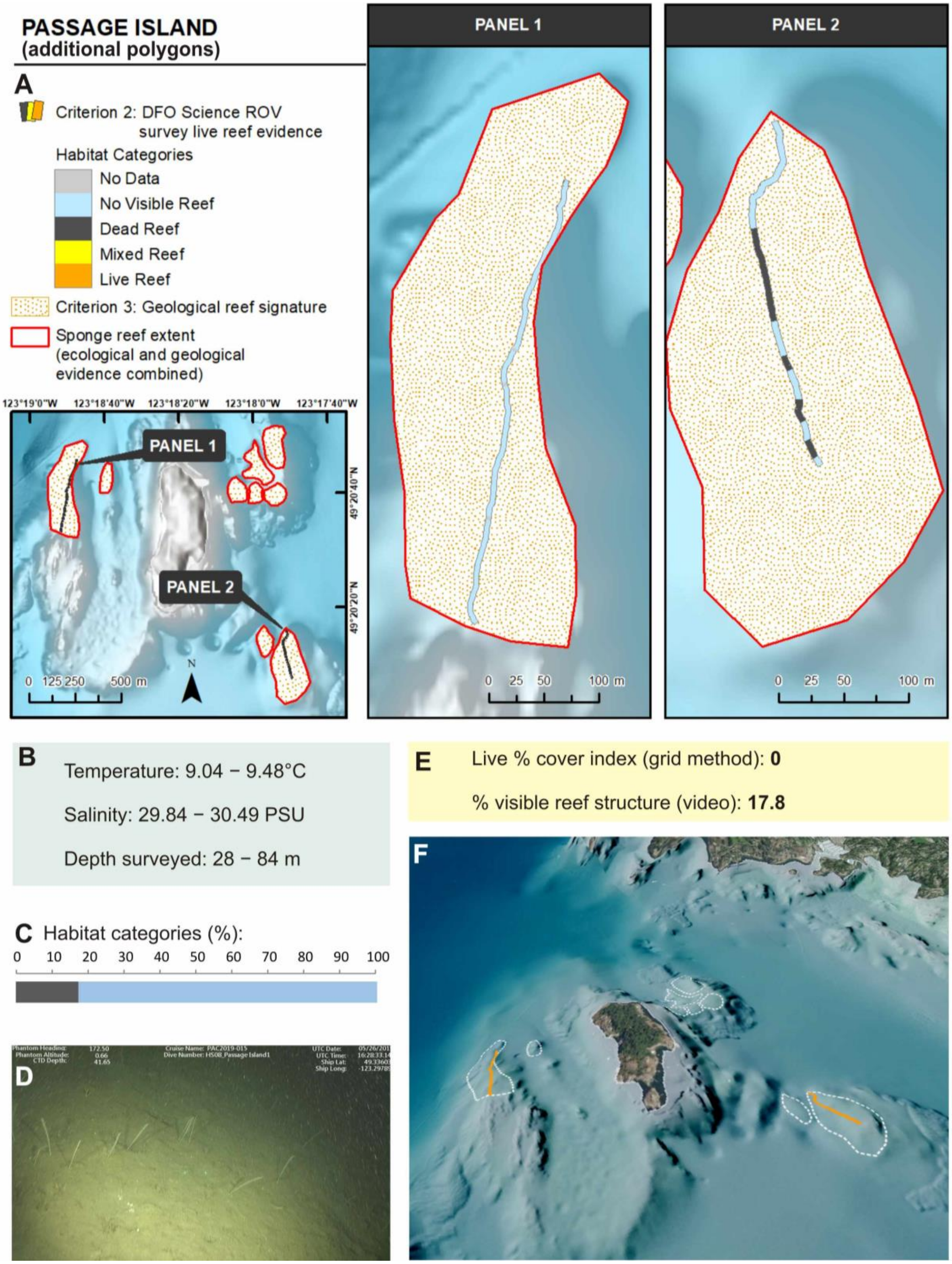

Figure 8. Passage Island (additional polygons): (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in May 2019; (C) Frequency of occurrence of habitat categories; (D) Image of no visible reef habitat; (E) Sponge-based indices of reef status; and (F) 3D bathymetry showing transect locations. For methods see Dunham et al. (2018a).

3.2 Ecological function

Glass sponge reefs filter large amounts of water (Chu and Leys 2010, Kahn et al. 2015, Dunham et al. 2018b). Together, nine reefs in Howe Sound that are already protected by fishing closures cover 5.9 km^2 and clear over 17 billion L of water daily (DFO 2018). We did not quantitatively assess filtration capacity of the five live reefs described in this paper, but given the area they collectively cover (~11 km^2) and the frequencies of occurrence of live reef habitat within them (Appendix 2, Fig. A2-1), we can expect filtration capacity of a similar magnitude, thus considerably increasing previous total estimates for Howe Sound. Through filtration, the reefs remove organic carbon at rates similar to those of kelp forests and terrestrial old growth forests (Dunham et al. 2018b), making them important “blue carbon” sinks.

In addition to their role in filtration and carbon processing, the Howe Sound glass sponge reefs form important biogenic habitats. We did not quantify species richness or individual taxa densities for the new reefs, because our qualitative observations indicated community composition and densities similar to the other reefs in Howe Sound which have already been described in detail in DFO (2018) and Dunham et al. (2018b). The reefs are inhabited by diverse communities of invertebrates and fish, including those of economic importance. Representative examples are shown in Figure 9.

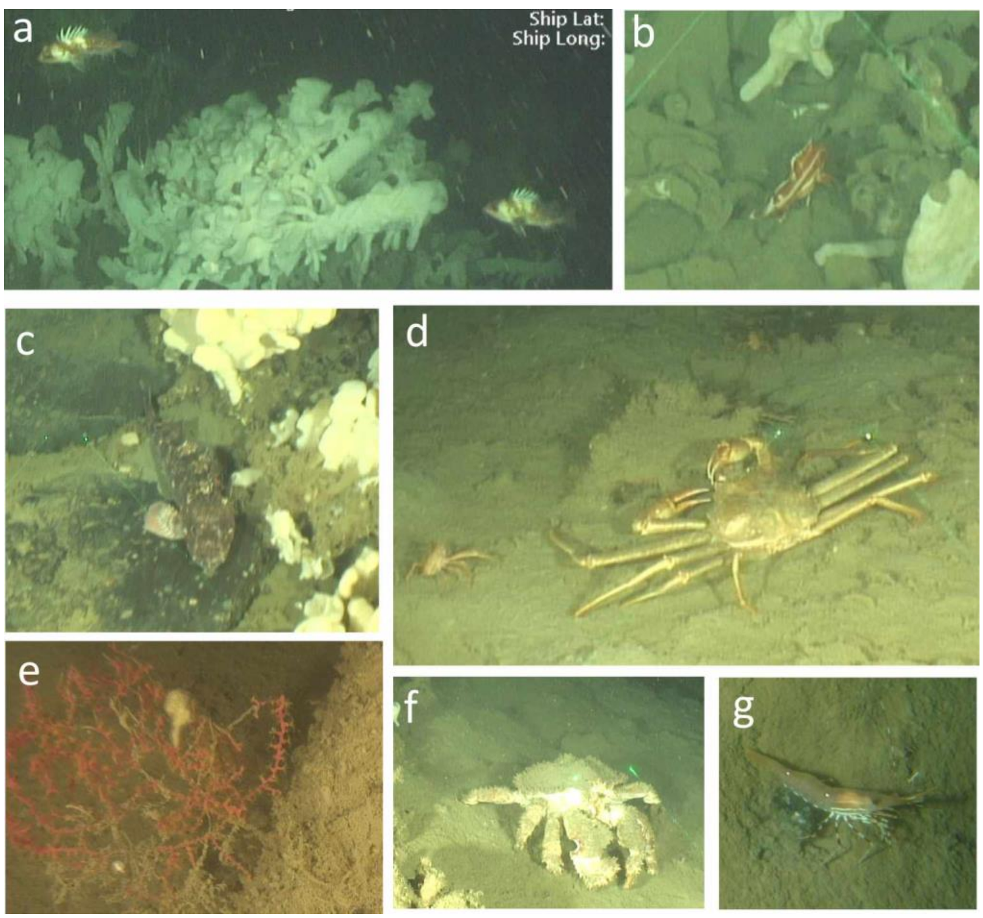

Figure 9. Examples of fish and invertebrates living on the reefs: (a) Quillback rockfish Sebastes maliger, (b) juvenile Yelloweye rockfish Sebastes ruberrimus, (c) lingcod Ophiodon elongatus, (d) Tanner crab Chionoecetes sp. and squat lobster Munida quadrispina, (e) soft coral, (f) box crab Lopholithodes sp., (g) spot prawn Pandalus platyceros.

3.3 Potential benefits of protection

Reef-building glass sponges are long-lived, but slow growing and exceptionally fragile. While the longevity of individual reef-building sponges is unknown, data on related rosselid (non-reef-building glass sponge) species suggest life spans greater than 220 years (Leys and Lauzon 1998). Reef-building glass sponge growth rates are estimated at 1-9 cm per year (Dunham et al. 2015, Kahn et al. 2016), and, as a result, the reefs have low recovery rates from disturbances. Mechanical injuries, such as crushing, damage the framework of the reef and its ability to grow; the effects are observed years after initial impact (Dunham et al. 2015; Kahn et al. 2016). Intact old skeletons provide the framework for the vertical growth of the reef. Preserving reef structure, both live and dead, is crucial for reef recovery and growth, which in turn preserves the reefs' ecological function.

As the ROV approached the transect start points, we observed actively fishing and lost fishing gear near all reefs described in this report. We also observed what appeared to be bottom-contact fishing impacts (e.g. areas of flattened sponges, drag lines) in most reefs. Lost fishing gear, crab traps and rope, were observed within the Passage Island (additional polygons) and Carmelo Point reef footprints.

We did not observe any live reef-building sponges within Passage Island (additional polygons; Fig. 8), the southern polygon in the Carmelo Point reef (Fig. 4), or the southern polygon in the Alberta Bay reef (Fig. 7). However, live sponges may exist in parts of the reefs we did not have an opportunity to survey. In addition, all three areas had some dead reef habitat and may be able to recover if viable glass sponge larvae arrive from other reefs in the area. Genetic mixing has been suggested to occur among sponge reefs in the Strait of Georgia through larval dispersal (Brown et al. 2017). It is reasonable to expect genetic mixing to occur across all reefs in Howe Sound. Extending protection to reef areas where no live sponges were observed in 2019 – Passage Island (additional polygons), southern polygon of Carmelo Point, and southern polygon of Alberta Bay – will increase the probability of recovery for these areas.

Two reefs – Carmelo Point and Alberta Bay – are located within Rockfish Conservation Areas (RCAs). However, RCAs provide little to no protection to the sponge reefs, as many types of commercial and recreational bottom-contact fishing activities are currently permitted within them, including prawn and crab by trap. Protecting glass sponge reefs through spatial management measures, such as prohibiting bottom-contact fishing and other human activities, may indirectly benefit RCAs by protecting rockfish and their habitats (including rockfish nursery habitats, Fig. 10a; also see Cook et al. 2008).

The Langdale reef is located under the ferry routes connecting Langdale to West Vancouver (Horseshoe Bay) and Gambier Island. Both polygons in this reef have large areas of live reef habitat, with many tall, tube-like *Aphrocallistes vastus* (Fig. 10b). It may be beneficial to develop an information package to show on the ferry – for example, a video or a poster – describing glass sponge reefs and featuring the Langdale reef. This would raise public awareness of BC's unique glass sponge reefs which in turn may improve stakeholder acceptance and compliance with spatial management measures.

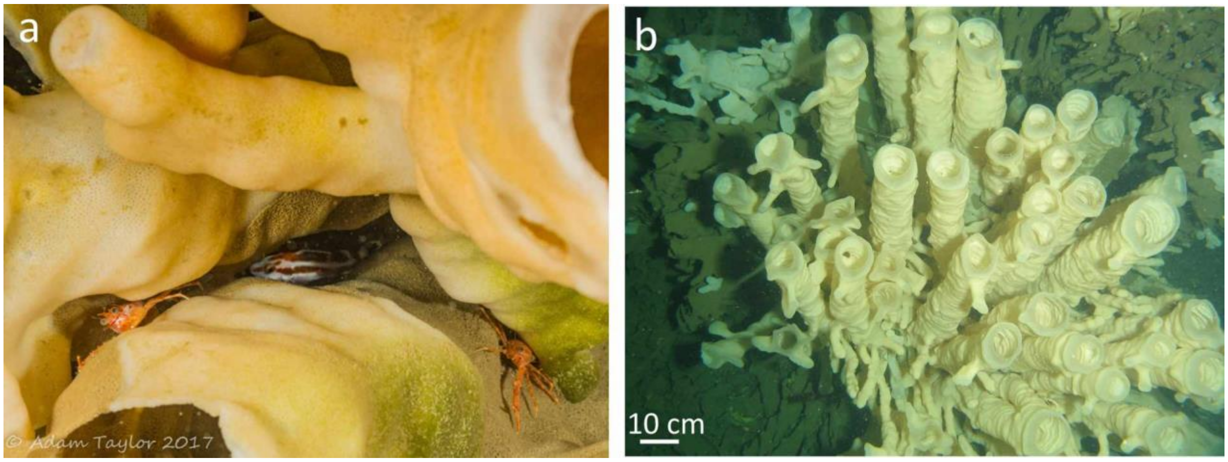

Figure 10. Examples of glass sponge reef habitat: (a) Young-of-the-year Yelloweye rockfish and squat lobsters on Aphrocallistes vastus (image courtesy of Adam Taylor), and (b) an example of a tall, structurally complex Aphrocallistes vastus in the Langdale reef.

4. Areas with no evidence of glass sponge reef presence

Christie Islet

The geological dataset does not show reef presence in this area. DFO ROV footage revealed dense aggregations of live glass sponges on bedrock (Fig. 11). Occurrence of live sponge habitat (measured from the DFO ROV video in the same way as % Live Reef Habitat index) was estimated at 63.8%. Percent cover of live glass sponges (measured from the DFO ROV still images in the same way as Live % Cover index for the reefs) was estimated at 7.9%. This area was determined to be a live glass sponge garden.

Figure 11. Christie Islet sponge garden on bedrock.

Ellesmere Creek

Drop camera footage collected by Glen Dennison showed dead and broken glass sponges. It was not possible to identify these fragments to species or even to determine conclusively whether these were fragments of reef-building sponges or non-reef building glass sponges like *Rhabdocalyptus* sp. Similar results were reported by Leys et al (2004) from this site (called 'Woodfibre') based on an ROV survey conducted in 1982; the authors also noted high concentrations of dioxins and furans, byproducts of the pulp industry, in the sediments at this site. No live reef-building glass sponges were observed at this site in 1982 (Leys et al 2004) or

2012-17 (McAuley 2017). The geological dataset does not show reef presence. This sponge aggregation is located on a pinnacle and is likely a sponge garden. It is also possible that it is a dead reef too small or patchy to produce a geological signature.

September Morn Beach

An ROV assessment in June 2017 by Terra Remote and Lake Trail Environmental Consulting (Lora Tryon) for BC Hydro identified a glass sponge aggregation with reef-like appearance (Fig. 12). The geological dataset does not show reef presence. This aggregation may be a reef (too small and/or patchy to produce a clear geological signature) or a sponge garden.

Figure 12. September Morn Beach sponge aggregation. Image courtesy of Rob Sicotte (BC Hydro).

5. Uncertainties and limitations

Despite incorporating over nine hours of high-quality video and accompanying still images, the visual datasets underlying our analyses covered only a small percentage of each reef (0.8-5.1%; see Appendix 1, Table A1-1). Reef polygons where we did not observe any live reef-building sponges (Passage Island (additional polygons), southern polygon in Carmelo Point, and southern polygon in Alberta Bay) may have live reef-building sponges in areas we did not survey.

Live % Cover Index is based on two-dimensional (top view) measurements. The values presented here can be used as a baseline for future comparisons as long as data are collected using analogous methods. Sponge reef habitat is highly complex, and thus the true glass sponge area available for new sponge recruits to settle and for associated biota to utilize is likely greater than our cover estimates.

This paper provides a comprehensive review of scientific information on Howe Sound glass sponge reefs available to date. Because the geological dataset covered the entire study area, it is unlikely that the datasets we reviewed missed any glass sponge reefs of comparable size in Howe Sound. However, smaller reefs or glass sponge gardens may be discovered in Howe Sound in the future.

Conclusions

Combined, available evidence for five areas in Howe Sound – Langdale, Carmelo Point, Collingwood Channel, Mariners Rest, and Alberta Bay – indicates presence of live glass sponge reefs with important ecological functions. Only dead reef habitat was observed within the Passage Island (additional polygons) reef, but live sponges may exist outside of the surveyed area; in addition, the presence of dead reef structure suggests the possibility of future recovery. Extremely sensitive to physical disturbances, these reefs receive little to no protection from existing spatial management measures in Howe Sound. Protection of these glass sponge reefs can be achieved through the use of management tools including prohibition of bottom-contact fishing and other human activities resulting in bottom contact.

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April 2, 2020

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Appendix 1. DFO Science Pac2019-015 ROV survey summary

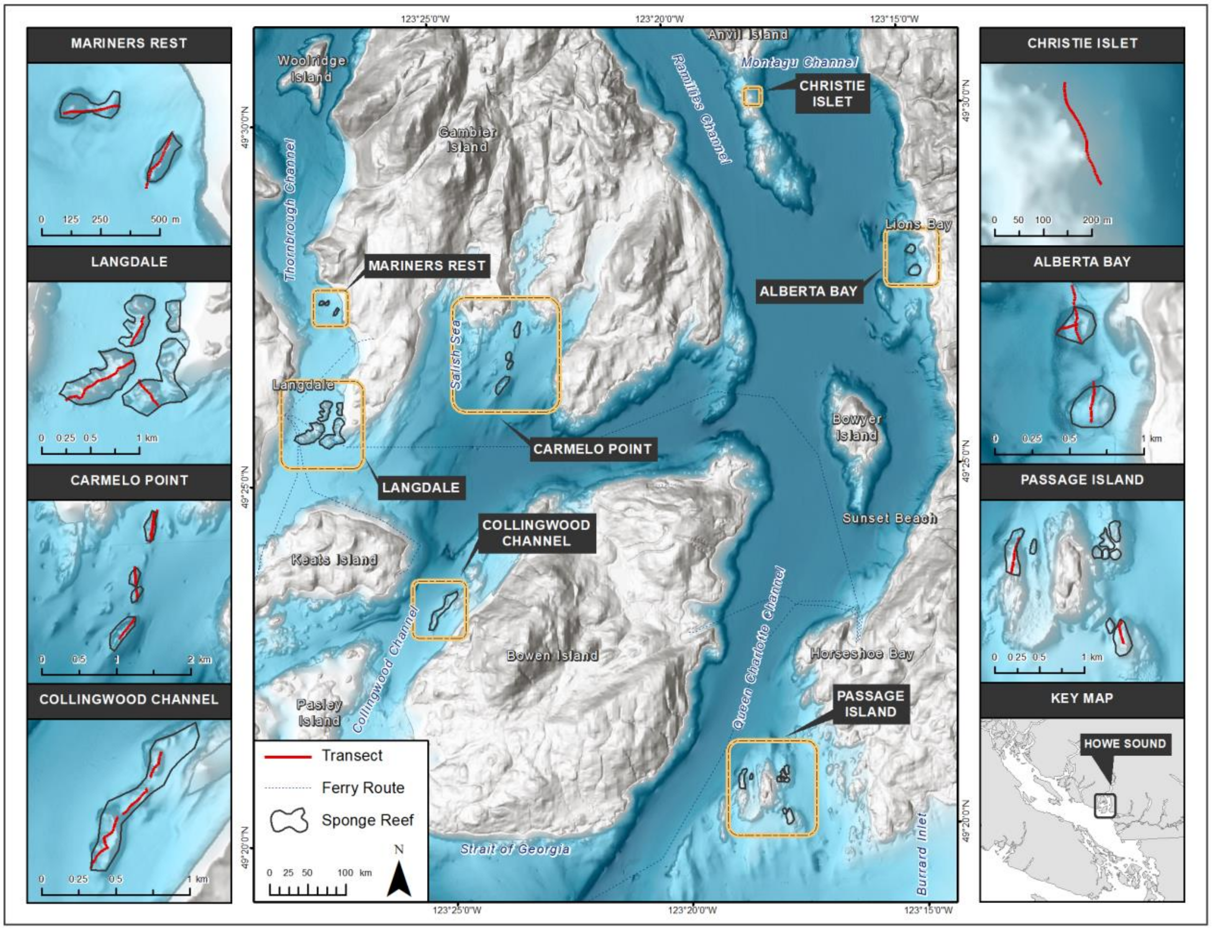

Figure A1-1. Eighteen ROV transects completed by DFO Science in 2019 (cruise PAC2019-015).

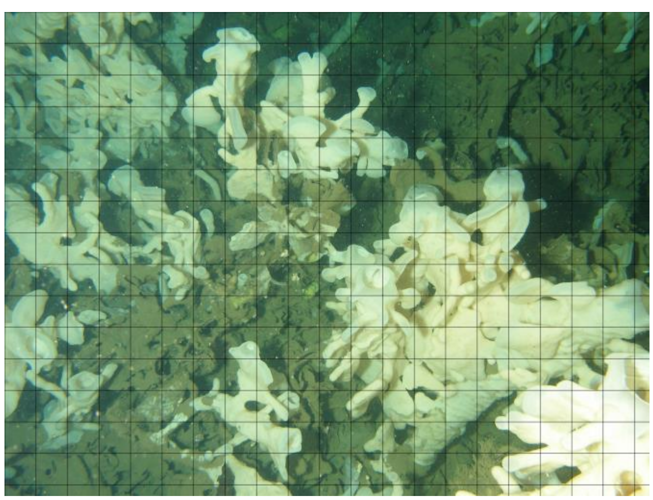

Figure A1-2. An example of a 10 x 10 cm grid placement over a still image used to calculate Live % Cover Index.

Table A1-1. Glass sponge reef sizes, with corresponding spatial coverage by the ROV survey.

Reef complex	Total reef area*, m²	PAC2019-015 ROV transect names	Transect length, m	Reef area surveyed (with video coverage), m²	Reef area surveyed, %	Number of still images analyzed
Langdale	616,236	HS05_Langdale2 HS05_Langdale4 HS06_Langdale1	341 348 953	5,051	0.8	404
Carmelo Point**	164,197	HS03_CarmeloPoint1 HS03_CarmeloPoint2 HS04_CarmeloPoint3	382 475 442	3,994	2.4	338
Collingwood Channel	174,295	HS01_Collingwood1 HS02_Collingwood2 HS02_Collingwood3	462 264 209	2,874	1.6	275
Mariners Rest	31,474	HS07_Mariners1 HS07_Mariners2	274 250	1,610	5.1	147
Alberta Bay	104,651	HS10_AlbertaBay3 HS11_AlbertaBay1 HS12_AlbertaBay4	493 303 180	3,000	2.9	248
Passage Island - additional polygons	211,048	HS08_PassageIsland1 HS09_PassageIsland4	287 424	2,186	1.0	212

**Calculated as a sum of all reef polygons within each reef complex.*
***Transect HS14_Carmelo was mapped in Fig. 4 and Fig. A1-1, but excluded from spatial statistics and reef health indices calculations, because it was filmed for the purpose of collecting representative imagery and partially overlapped with Transect HS04_CarmeloPoint3.*

Appendix 2. Comparison to the reefs in the Strait of Georgia and Howe Sound currently protected by bottom-contact fishing closures

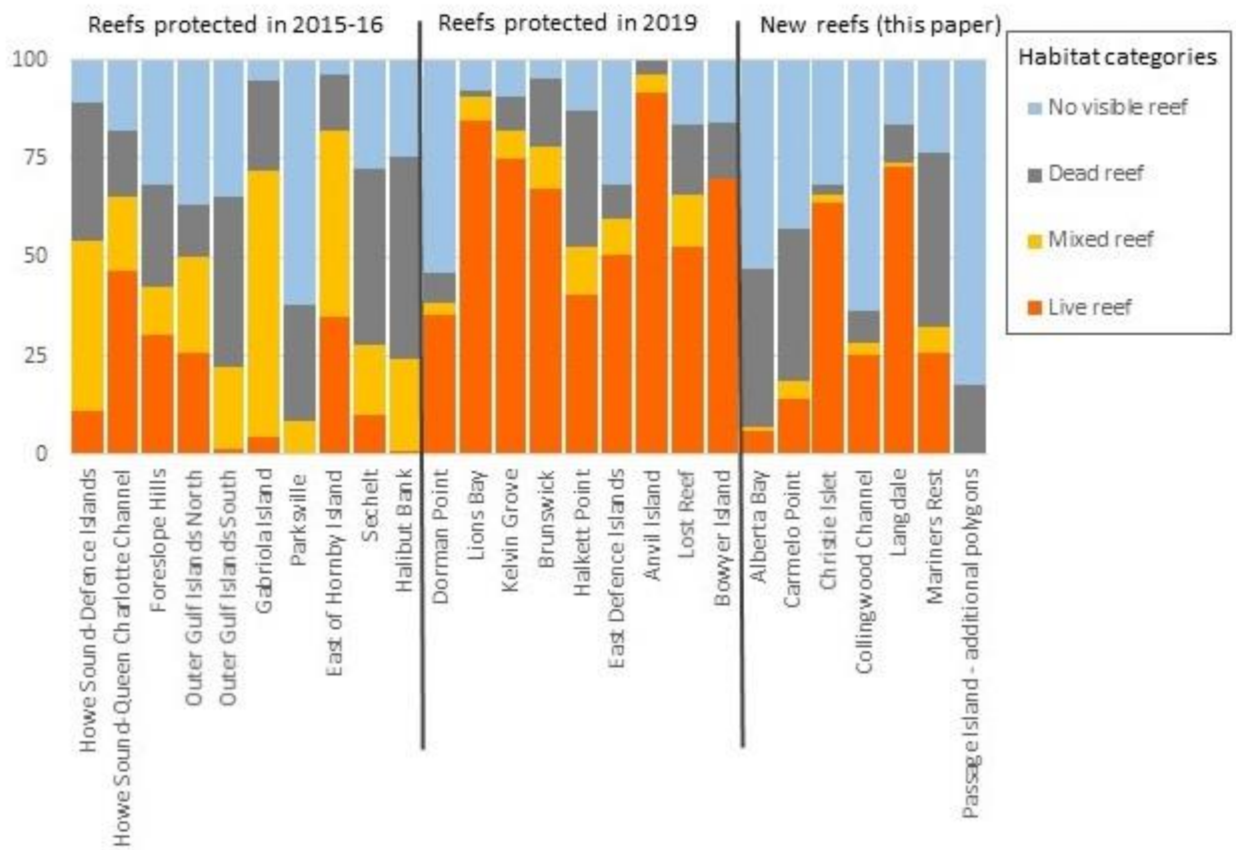

Figure A2-1. Frequency of occurrence of habitat categories: relative comparison with reef complexes in the Georgia Basin and Howe Sound already protected by the bottom-contact fishing closures. Quantitative assessment of the already protected reefs can be found in Dunham et al (2018) and DFO (2018); the Conservation Initiative, including existing closure boundaries, is described on the Initiative's webpage (DFO 2019). Note that "live reef" category (shown in orange in this figure) combines "dense live reef" and "live reef" categories used in DFO (2018) because in our subsequent work we found these two categories hard to distinguish from one another: complex morphology of sponges makes exact counts of individuals problematic in dense sponge areas.

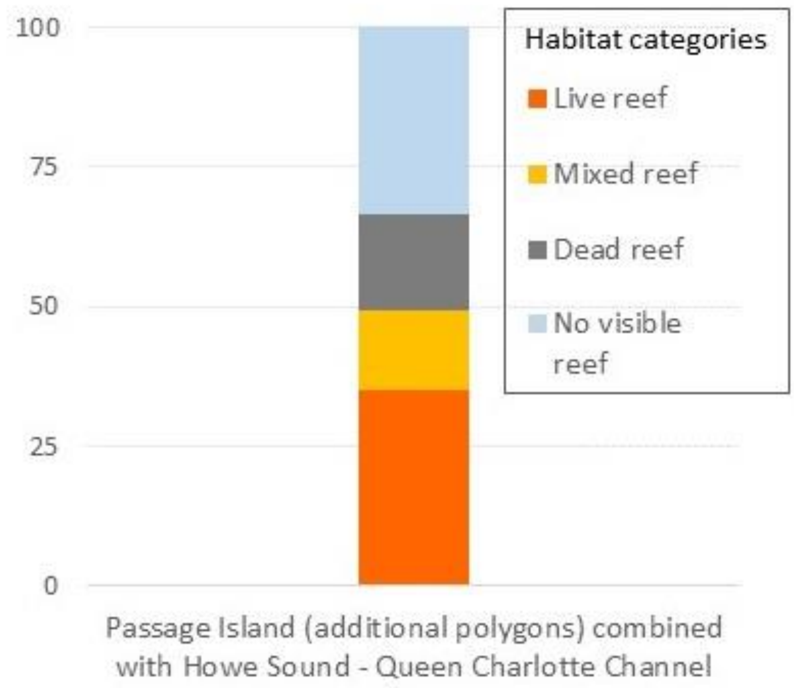

Figure A2-2. Frequency of occurrence of habitat categories within a combined reef complex that incorporates Passage Island – additional polygons and Howe Sound – Queen Charlotte Channel reefs. These reefs occur in close proximity to each other and can be considered the same reef complex.

Appendix 3. Application of criteria to determine status and condition of sponge aggregations

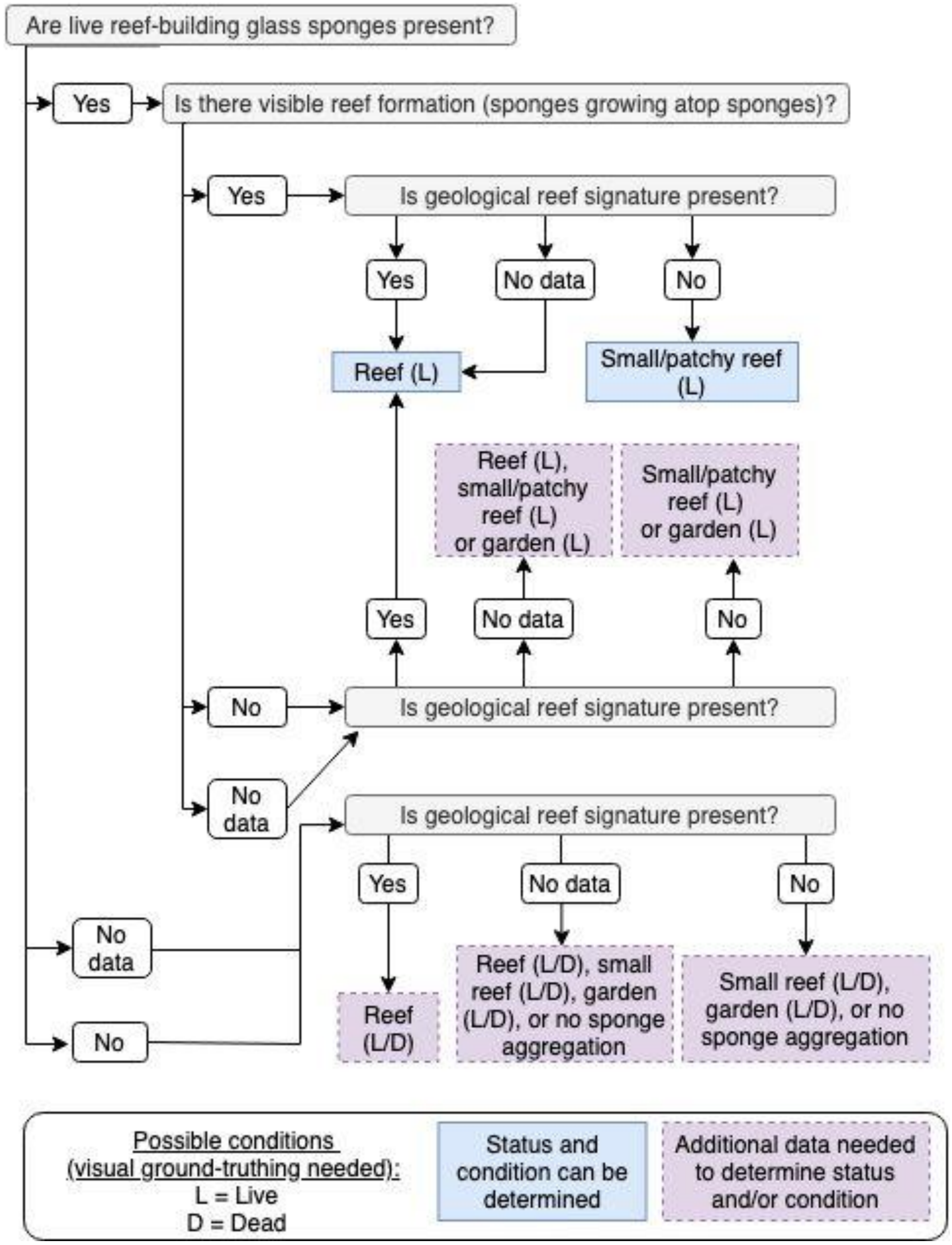

Figure A3-1. A decision tree illustrating the application of criteria for determining sponge aggregation status and condition. Glass sponge reefs are a combination of subsurface and above-surface structure, and sponges on the surface can be alive or dead. Remote acoustics methods allow detecting reef structure ≥20 m in contiguous patch diameter (geological reef signature); these methods allow assigning reef status, but do not distinguish between live and dead areas within the reef. Reef condition (whether sponges are present on reef surface and whether they are alive or dead) must be determined using visual surveys. A geological signature may not be present if the reef is too small or patchy (i.e. lacks patches >20 m in diameter). Reef status can be assigned solely on positive visual observations of reef formation: reef-building glass sponges growing atop of one another. Unlike reefs, sponge gardens are sponge aggregations without evidence of reef formation.

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