GLASS SPONGE AGGREGATIONS IN HOWE SOUND: LOCATIONS, REEF STATUS, AND ECOLOGICAL SIGNIFICANCE ASSESSMENT

Context

The protection of benthic communities and features falls within the mandate of the Department of Fisheries and Oceans (DFO) at the national level under the Oceans Act, Fisheries Act, and under ratified international agreements. The plan to meet conservation targets includes advancing Other Effective Area-Based Conservation Measures (OEABCM), such as fishing closures, to protect sensitive sponge and coral aggregations.

Glass sponge reefs are unique habitats found along the Pacific coast of Canada and the United States with historic, ecological, and economic value. They link benthic and pelagic environments by playing important roles in filtration and carbon and nitrogen processing, and acting as silica sinks (Chu et al. 2011, Tréguer and De La Rocha 2013, Kahn et al. 2015). They also form habitat for diverse communities of invertebrates and fish, including those of economic importance (Cook et al. 2008, Chu and Leys 2010, Dunham et al. 2015, 2018).

Over the past 15 years, nine glass sponge reef complexes were discovered and mapped in the Strait of Georgia and Howe Sound using remote sensing (Conway et al. 2004, 2005, and 2007) and subsequently ground-truthed by DFO Science using standardized visual survey methods in 2012-2013. In 2014, DFO requested that fishers using bottom-contact gear voluntarily avoid these areas while DFO consulted on formal protection measures. After reviewing important input from the consultation process with First Nations, commercial and recreational fishers, and conservation organizations, formal bottom-contact fishing closures were established, effective June 12, 2015. Since April 1, 2016, the closures also apply to First Nations Food, Social, and Ceremonial fisheries. In 2017, DFO Science provided peer reviewed and approved quantitative assessment methods, outputs, and monitoring advice for these sponge reef complexes (DFO 2017, Dunham et al. 2018).

Recently, 13 additional areas thought to be glass sponge reefs were discovered by the Marine Life Sanctuaries Society (MLSS) and volunteer divers in Howe Sound, using drop camera and dive surveys (Clayton and Dennison 2017). In 2016, the MLSS shared their findings with DFO Science and Fisheries Management (Glen Dennison Triumf, Vancouver, BC, pers. comm., McAuley 2017), and a collaborative project between the MLSS, DFO Science, and Natural Resources Canada (NRCan) was initiated to map and characterize these glass sponge areas.

In September 2017, DFO Fisheries Management issued a letter to stakeholders asking for voluntarily avoidance of fishing in the 13 areas thought to be sponge reefs (DFO Fishery Notice FN1150, Appendix 1) and requested DFO Science Branch provide advice on the characteristics and the biological significance of the sponge reefs listed in the notice. This advice will be used during stakeholder consultation meetings planned for 2018.

The advice provided in this Science Response utilizes peer-reviewed and accepted methods of assessing current sponge reef status as previously described (DFO 2017, Dunham et al. 2018).

The specific objectives of this Science Response are to:

1. Map the geological extent of the known reefs in Howe Sound using available multibeam bathymetry and backscatter data.
2. Map and characterize the modern ecological extent (reef-building glass sponge cover) using available visual survey data.
3. Characterize associated megafaunal communities.
4. Characterize ecological function of the glass sponge reefs using best available knowledge on the reefs in Howe Sound and elsewhere along the coast of British Columbia.
5. Provide advice on the potential benefits of protection.

The advice arising from this Science Response will be used to inform decisions regarding management and future monitoring of the sponge reefs in Howe Sound, as well as to respond to stakeholder requests for scientific information. It is expected to aid DFO Fisheries Management in implementing conservation-based fisheries closures as part of advancing OEABCM, as well as aid Canada's Marine Conservation Target commitment to protect 10% of Canada's coast by 2020.

This Science Response Report results from the Science Response Process of December 2017 on newly discovered Howe Sound glass sponge complexes: locations, status, and ecological significance assessment.

Background

Glass sponge reefs are built by hexactinellid sponges that have spicules made of silicon dioxide fused into a rigid, but delicate three-dimensional structure (Leys et al. 2007). The reefs grow as larval sponges attach to exposed skeletons of dead sponges and the structure solidifies by trapping fine, organic-rich sediments brought by bottom currents (Leys et al. 2004, Krautter et al. 2006). The bulk of the reefs thus consists of dead sponges buried by sediments, with only the most recent generation of sponges growing 1 to 2 m above the surface (Conway et al. 2001) (Fig. 1).

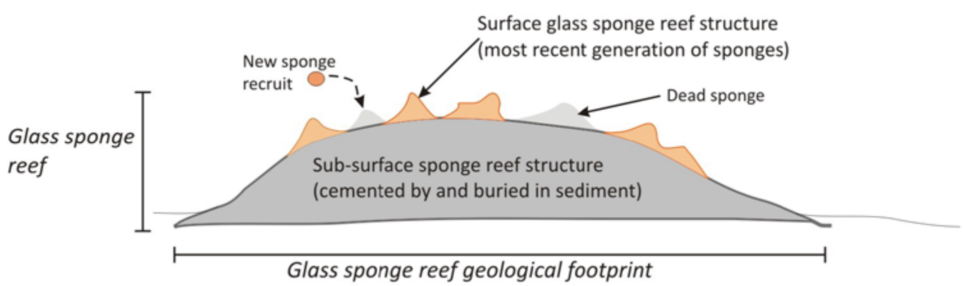

Figure 1. Diagram of glass sponge reef structure (modified from Dunham et al. 2018).

Large contiguous areas of sponge reef structure (shown in darker grey in Fig. 1) are readily identified as “acoustic anomalies” using remote sensing techniques as they 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 (Conway et al. 2005). Typically, areas exhibiting positive relief are reflective with higher backscatter strength (darker shading on image), but sponge reefs appear as non-reflective high points (low backscatter strength; lightest shading on image) (Conway et al. 2005). However, this or other remote sensing techniques available to date cannot differentiate between live, dead, and dead and buried patches of glass sponges within a reef. Visual surveys are needed to provide information on current extent and characteristics of the reefs, such as live sponge cover and associated biodiversity.

Terminology

The following operational definitions are used throughout this paper (consistent with Dunham et al. 2018):

- Bioherm: Ancient organic reef of mound-like form built by a variety of marine invertebrates and calcareous algae (Bioherm, 1998).
- Reef-building glass sponge: Individual specimen of *Aphrocallistes vastus* or *Heterochone calyx* (here limited to species known to construct reefs in the Georgia Basin).
- Glass sponge aggregation: Assemblage of glass sponges at a notably higher biomass than in surrounding areas; may represent a glass sponge reef or a glass sponge garden.
- Glass sponge reef: Bioherm formed by hexactinellid 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. Synonymous with glass sponge bioherm.
- Glass sponge garden: Assemblage 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.
- Habitat category: A type of benthic environment based on reef-building sponge (live and dead) abundance. One of five habitat categories (‘dense live reef’, ‘live reef’, ‘mixed reef’, ‘dead reef’, or ‘no visible reef’) was assigned to every 10 second video bin by integrating three types of reef-building sponge records from DFO ROV imagery.
- % Visible reef index: The percent of reef area surveyed classified as visible glass sponge reef. Calculated as the number of 10 second video bins with any visible reef designation (*i.e*. all habitat categories except ‘no visible reef’) divided by the total number of video bins per transect.
- Live % cover index: 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. Calculated using still images as the number of grid cells assigned to ‘live reef-building sponge’ divided by the total number of cells; results in an estimate of percent cover per image which is then averaged across all images from a reef.

Data used

To provide a comprehensive review of all available evidence on glass sponge aggregations throughout Howe Sound that are thought to be sponge reefs, we combined the following three datasets:

1. MLSS glass sponge aggregation map (ecological dataset #1). All reef-building sponge locations from the drop camera transects and SCUBA-based observations were mapped in Google Earth; the polygons were then drawn to encompass all sponge points (sparse to dense) or, in cases of single or clustered observations, markers were placed near the centre points by the MLSS. Visual survey methods, as well as the approaches and software used for placing markers and outlining polygons are described in McAuley (2017) and Clayton and Dennison (2017).
2. DFO Science Remotely Operated Vehicle (ROV) survey results (ecological dataset #2). To further ground-truth sponge aggregation locations provided by the MLSS, a survey of nine reef aggregations was conducted by DFO Science in September 2016 (cruise Pac2016-063) using the Phantom ROV HD2+2 (Deep Ocean Engineering) aboard the CCGV Neocaligus. Video and still imagery were collected along predetermined line transects (Appendix 2); transect placement was informed by the MLSS dataset. Data processing and analyses followed methods described in Dunham et al. (2018).
3. NRCan geological footprint maps (geological dataset). All remote sensing (multibeam swath bathymetry and backscatter) imagery previously collected within the entire Howe Sound area 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 of interest 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 were 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. This method was not yet available during an earlier review of multibeam and backscatter imagery in the Georgia Basin, and thus not all sponge reefs were identified in Howe Sound at the time. The methods used in this paper can reliably identify a contiguous glass sponge reef patch of ≥20 m in diameter.

Analysis and Response

1. Sponge aggregation summary

The three datasets were combined spatially in ArcMap (10.4.1) by overlaying ecological polygons from the MLSS and DFO ROV survey transects with the geological polygons from NRCan. We reviewed information available for each of the 13 areas identified in DFO Fishery Notice FN1150 and for additional areas in Howe Sound where any of the three datasets indicated a sponge aggregation. We determined whether each area met the following three criteria:

1. Standing live reef-building glass sponges observed by MLSS (using SCUBA and/or drop camera, with a marker or polygon outline placed at the sponge aggregation, ecological dataset #1) and/or by DFO Science ROV survey (ecological dataset #2).

2. Visual evidence of reef formation observed: reef-building glass sponges growing atop previous generation of sponges identified in DFO Science ROV imagery (video and/or still images, ecological dataset #2).
3. Evidence of geological reef signature observed (geological dataset).

These were used as decision criteria (Table 1) for assigning sponge reef status and condition. Not all criteria combinations were encountered in our dataset, but we listed all plausible combinations in Table 1 to facilitate future applications.

Table 1. Decision criteria used for assigning sponge reef status and condition. 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 parts of sponge aggregation).

Criterion 1 **Standing live reef-building glass sponges** (ecological datasets #1 & #2)	***Criterion 2*** **Visible reef formation** (ecological dataset #2)	***Criterion 3*** **Geological evidence** (geological dataset)	**Status (reef/garden) 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 status; likely too small or patchy to produce geological signature
Absent	Absent	Present	Reef, condition unknown	Geological reef; visual ground-truthing needed to determine live or dead
Not surveyed	Not surveyed	Present	Reef, condition unknown	Geological reef; visual ground-truthing needed to determine live or dead
Absent	Not surveyed	Present	Reef, condition unknown	Geological reef; visual ground-truthing needed to determine live or dead
Present	Not surveyed	Absent	Status unknown, live	Status unknown; ground-truthing needed
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	Status unknown, live	Could be a garden or a reef too small or patchy to produce clear geological signature. Visual ground-truthing needed
Not surveyed	Not surveyed	Absent	Reef structure not detected	No evidence of sponge aggregation
Absent	Not surveyed	Absent	Reef structure not detected	No evidence of sponge aggregation
Absent	Absent	Absent	Reef structure not detected	No evidence of sponge aggregation

The results, along with a summary of current management measures, are presented in Table 2 and Figure 2. The 13 areas described in DFO Fishery Notice FN1150 are listed first. These 13 areas (Table 2, column 2) were combined into 11 aggregations (Table 2, column 3) and named to maintain consistency with existing primary literature (Clayton and Dennison 2017). Of these 11 aggregations, nine (Dorman Point, Lions Bay, Kelvin Grove, Brunswick Point, Halkett Point, East Defence Islands, Anvil Island, Lost Reef, and Bowyer Island) were assigned live reef status. These nine reefs are the primary focus of this paper and are described in Section 2.

Two potential aggregations described in DFO Fishery Notice FN1150 – Ellesmere Creek and North Christie – as well as one additional aggregation identified by MLSS only and six additional areas identified by remote sensing methods only (light grey shaded cells in Table 2) are data-deficient and require further visual ground-truthing to confirm their status and/or condition. These potential aggregations are described in more detail in Section 3.

Finally, two glass sponge reef complexes in Howe Sound that are already protected by bottom-contact fishing closures – Defence Islands and Queen Charlotte Channel (dark grey shaded cells in Table 2) – were listed for completeness. They are described in Dunham et al. (2018).

Table 2. Twenty-two sponge aggregations in Howe Sound: recommended names, summary of available scientific knowledge, and status assigned. Clear cells (reefs 1-9) denote aggregations that were assigned live reef status and are the primary focus of this paper. Light grey cells (aggregations 1GT-9GT) denote nine aggregations that are data-deficient and require further visual ground-truthing to confirm their status and/or condition. Dark grey cells denote reefs already protected by the bottom-contact fishing closures under the 2014 Strait of Georgia and Howe Sound Conservation Initiative.

Letter code and name in *DFO Fishery Notice FN1150*	**Recommended #**	**Recommended name**	***Criterion 1*: Standing live reef-building glass sponges**		***Criterion 2*: Visible reef formation (ecological dataset #2)**	***Criterion 3*: Geological signature (multibeam and backscatter)**	**Status assigned**	**Current spatial management measure**
			Ecological dataset #1 (MLSS)	**Ecological dataset #2 (DFO)**				
DP: Dorman Point Bioherm	1	Dorman Point	Present (polygon provided)	Present	Present	Present	Reef, live	None
LB-b: Lions Bay Seamount	2	Lions Bay	Present (polygon provided)	Present	Present	Present	Reef, live	Within Lions Bay RCA
LB-c: Kelvin Grove Seamount	3	Kelvin Grove	Present (polygon provided)	Present	Present	Present	Reef, live	Within Lions Bay RCA
LB-a: Brunswick Bioherm	4	Brunswick Point	Present (marker provided)	Present	Present	Present (incomplete backscatter)	Reef, live	None
HP: Halkett West Pinnacle	5	Halkett Point[1]	Present (polygon provided)	Present	Present	Present (patchy backscatter)	Reef, live	Within Halkett Bay Marine Provincial Park
D1-b: East Defence Island; D1-c: East Defence Island Pinnacle	6	East Defence Islands[2]	Present (polygon provided)	Present	Present	Present (patchy backscatter)	Reef, live	None
AI-a: Clayton Bioherm	7	Anvil Island	Present (polygon provided)	Present	Present	Present	Reef, live	None
AI-c: Lost Reef	8	Lost Reef	Present (markers provided)	Present	Present	Backscatter data not available	Reef, live	Within Pam Rock RCA
SB-a: South Bowyer; SB-b: Southern-South Bowyer	9	Bowyer Island	Present (markers provided)	Present	Present	Present	Reef, live	Within Bowyer Island RCA
D1-a: Ellesmere Creek Bioherm	1GT	Ellesmere Creek	Absent (no live sponges seen within survey area)	Not surveyed	Not surveyed	Absent	Reef structure not detected	None

Letter code and name in *DFO Fishery Notice FN1150*	Recommended #	Recommended name	*Criterion 1*: Standing live reef-building glass sponges		*Criterion 2*: Visible reef formation (ecological dataset #2)	*Criterion 3*: Geological signature (multibeam and backscatter)	Status assigned	Current spatial management measure
			Ecological dataset #1 (MLSS)	Ecological dataset #2 (DFO)				
AI-b: North Christie	2GT	Christie Islet	Present (polygon provided)	Not surveyed	Not surveyed	Absent	Status unknown, liv	Within Pam Rock RCA
N/A	3GT	September Morn Beach	Present (markers provided)	Not surveyed	Not surveyed	Absent	Status unknown, live	None
N/A	4GT	Langdale	Not surveyed	Not surveyed	Not surveyed	Present	Reef, condition unknown	None
N/A	5GT	Carmelo Point	Not surveyed	Not surveyed	Not surveyed	Present	Reef, condition unknown	None
N/A	6GT	Collingwood Channel	Not surveyed	Not surveyed	Not surveyed	Present	Reef, condition unknown	None
N/A	7GT	Mariners Rest	Not surveyed	Not surveyed	Not surveyed	Present	Reef, condition unknown	Within Mariners Rest RCA
N/A	8GT	Alberta Bay	Not surveyed	Not surveyed	Not surveyed	Present	Reef, condition unknown	Within Lions Bay RCA
N/A	9GT	Queen Charlotte Channel – NW, NE, and SE polygons	Absent (no live sponges seen within survey area) in NE and SE polygons	Not surveyed	Not surveyed	Present	Reef, condition unknown	Partially protected by bottom-contact fishing closure (#21 below)
N/A	NA	Defence Islands	Not surveyed	Present	Present	Present	Reef, live	Protected by bottom-contact fishing closure
N/A	NA	Queen Charlotte Channel	Not surveyed	Present	Present	Present	Reef, live	Protected by bottom-contact fishing closure

[1]Ongoing sponge larval settlement study by MLSS and DFO Science.
[2]Area monitored by the Vancouver Aquarium for sponge growth and water quality.

2. Aggregations with strong evidence of live reef status and ecological significance

Dorman Point, Lions Bay, Kelvin Grove, Brunswick Point, Halkett Point, East Defence Islands, Anvil Island, Lost Reef, and Bowyer Island (clear cells in Table 2, mapped in red in Figure 2) were determined to be live glass sponge reefs.

Detailed maps and summaries of environmental parameters, habitat characteristics, and indicator species densities for these nine reefs are presented in Figures 3 through 11 and summarized in Table 3. Methods for indices calculations can be found in Dunham et al. (2018). All indices in Table 3 and Figures 3-11(B-F) were calculated using DFO ROV survey data.

Reef extent polygons (red outlines in Figures 3-11) were created by enclosing all geological and ecological evidence of reef presence (live or dead) with straight lines between available data points. “No data” habitat category along ROV transects was treated as reef presence for the purpose of outlining reef extent as a precautionary approach. Latitude and longitude coordinates for simplified, four-sided polygons encompassing full reef extents are provided in Appendix 3.

All nine reefs have areas of dense live sponge cover (range: 8 to 37% of all habitat categories recorded; shown in red in Figs. 3-11, section C). The reefs are home to diverse megafaunal communities that include rockfish – an indicator taxon associated with dense live reef (Dunham et al. 2018). A complete taxonomic list can be found in Appendix 4.

Table 3. Summary of indices calculated for characterizing nine glass sponge reef complexes in Howe Sound (for maps and more details see Figures 3-11).

Index type	Index	Glass sponge reef								
		Dorman Point	Lions Bay	Kelvin Grove	Brunswick Point	Halkett Point	E Defence Islands	Anvil Island	Lost Reef	Bowyer Island
Reef-building glass sponge based indices	Live % cover, grid method	18	14	14	11	4	7	17	12	16
	% visible reef	45.4	83.9	87.1	98.5	87.2	51.9	100.0	80.8	67.5
	Oscula density, count/m^2, mean±SD	17.3 ± 0.17	7.6 ± 0.03	7.8 ± 0.02	6.5 ± 0.03	6.6 ± 0.04	7.9 ± 0.06	14.1 ± 0.04	12.5 ± 0.05	10.3 ± 0.03
Community structure	Shannon-Wiener diversity index	2.49	2.48	2.52	2.79	2.55	1.96	2.18	1.74	2.13
Indicator taxa of dense live and live reef (ind/m^2)[1]	*Chorilia longipes*	0	0.007	0.008	0.007	0.001	0	0.007	0.009	0.018
	Sebastes maliger	0.014	0.011	0.003	0.005	0.022	0.024	0.001	0.005	0.002
	Family Sebastidae	0.031	0.028	0.022	0.053	0.027	0.024	0.038	0.006	0.064
Indicator taxa of visible reef (ind/m^2)[1]	*Rhabdocalyptus dawsoni*	0.005	0	0	0.004	0.001	0	0	0.001	0.004
	Pandalus platyceros	0	0.004	0.007	0.037	0	0	0.021	0	0.009
Indicator taxa of no visible reef (ind/m^2)[1]	Pennatulacea	0.007	0	0	0	0	0.172	0	0	0
	Ophiuroidea	0.002	0	0	0	0.067	0	0.001	0.004	0

[1]Indicator taxa from Dunham et al (2018) were used because all taxa-habitat associations in Dunham et al (2018) were statistically significant for the Georgia Basin reefs as a group, as well as at an individual reef level for at least one of the two reefs assessed therein in Howe Sound. However, *Munida quadrispina* was not included because, although this species was present, densities were not determined as part of the imagery annotation protocol.

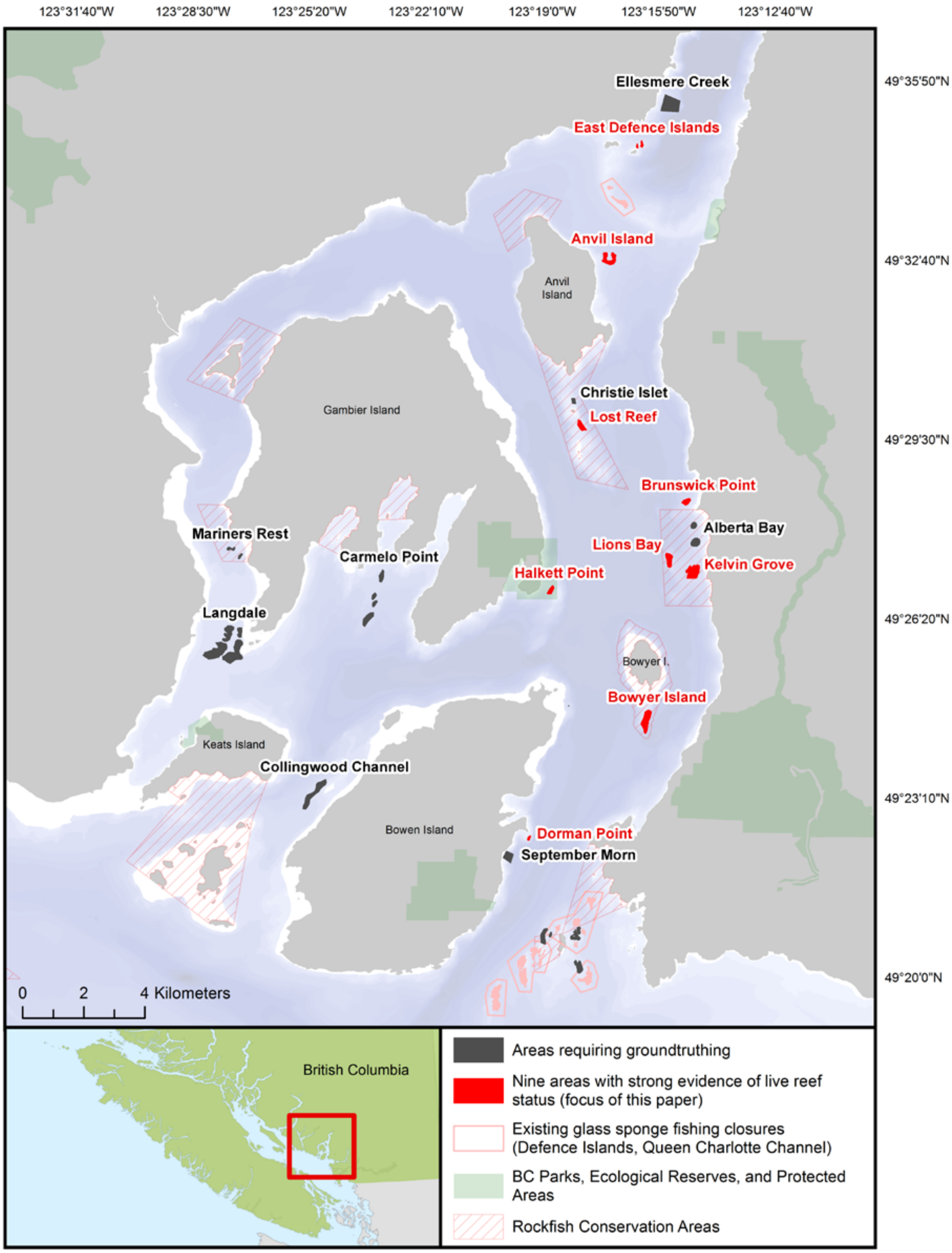

Figure 2. Overview of all known glass sponge aggregations in Howe Sound: areas assigned live reef status (red polygons and labels), areas requiring further ground-truthing and research (grey), and existing bottom-contact fishing closures (pink polygons and closure boundaries).

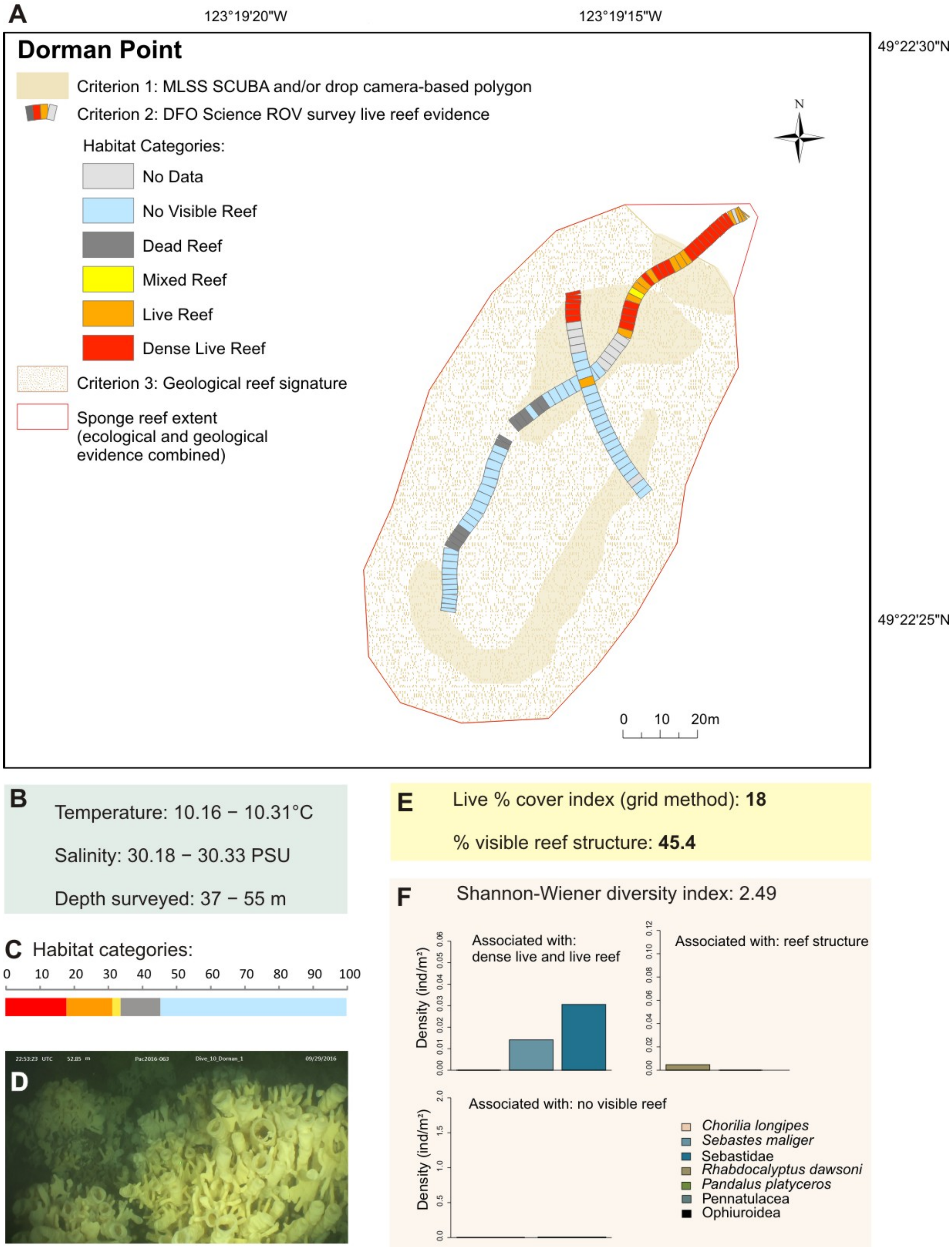

Figure 3. Dorman Point: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in September 2016; (C) Frequency of occurrence of habitat categories; (D) Representative image of dense live reef habitat; (E) Sponge-based indices of reef status; and (F) Diversity index and densities of indicator taxa. For methods see Dunham et al. (2018).

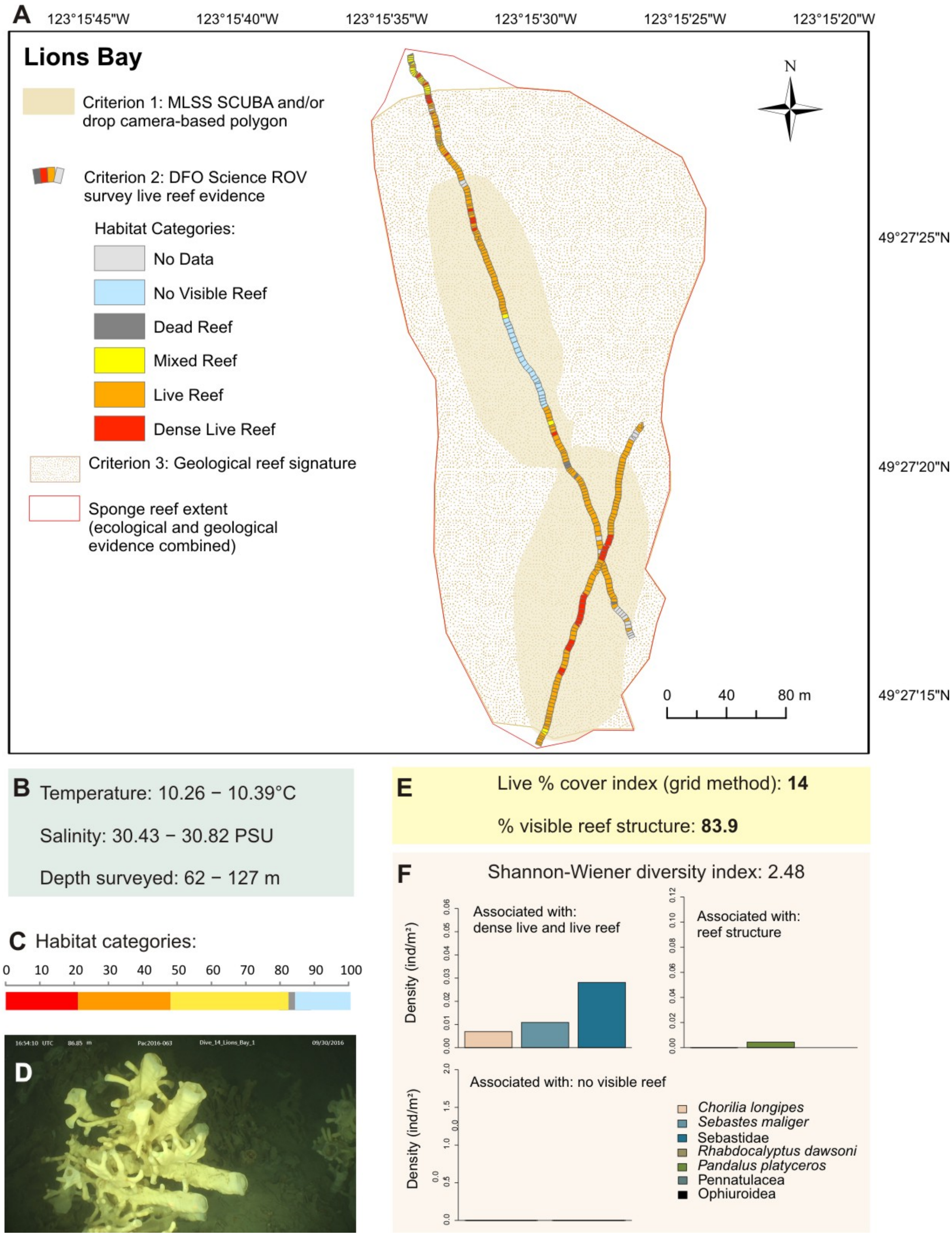

Figure 4. Lions Bay: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in September 2016; (C) Frequency of occurrence of habitat categories; (D) Representative image of dense live reef habitat; (E) Sponge-based indices of reef status; and (F) Diversity index and densities of indicator taxa. For methods see Dunham et al. (2018).

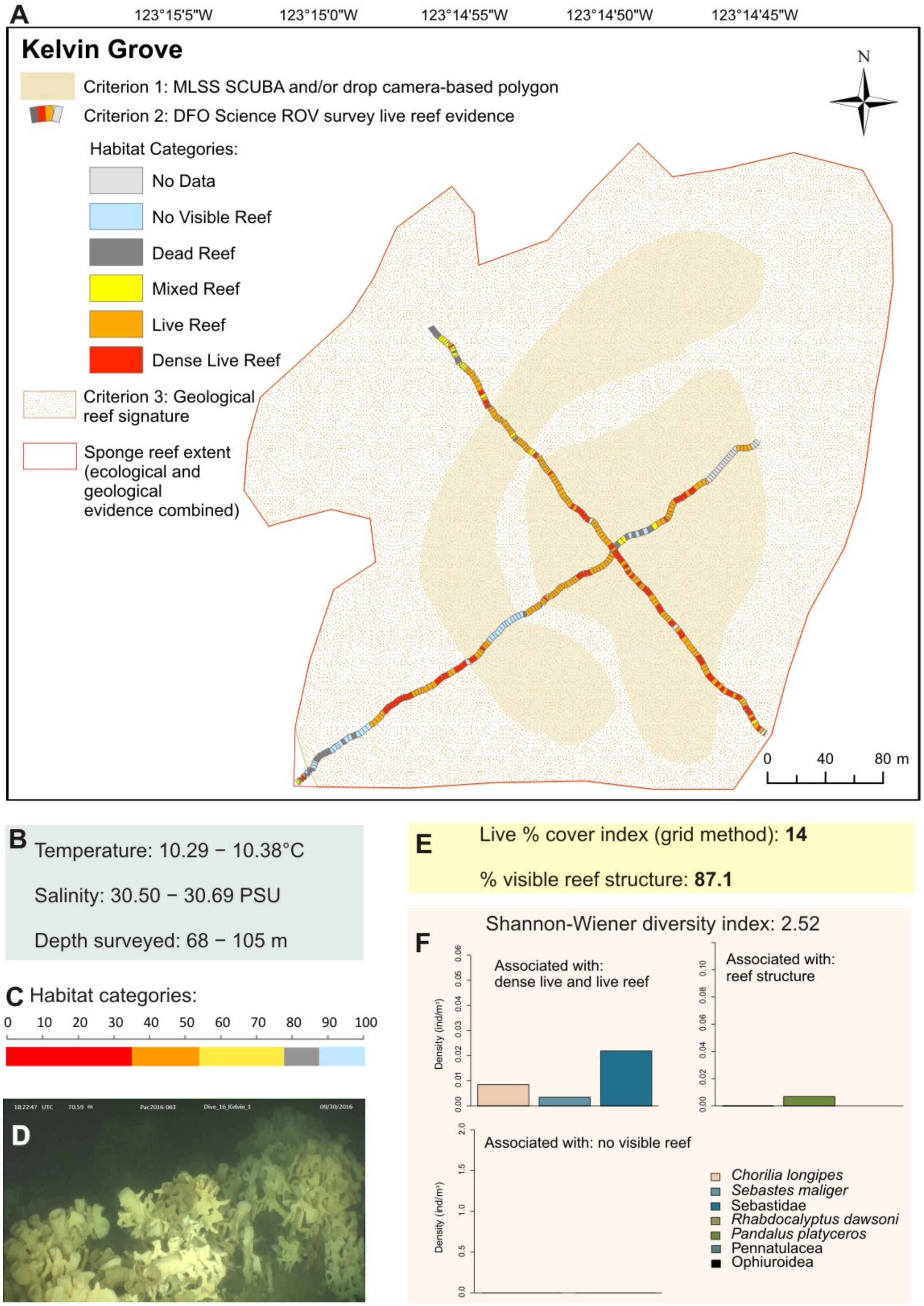

Figure 5. Kelvin Grove: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in September 2016; (C) Frequency of occurrence of habitat categories; (D) Representative image of dense live reef habitat; (E) Sponge-based indices of reef status; and (F) Diversity index and densities of indicator taxa. For methods see Dunham et al. (2018).

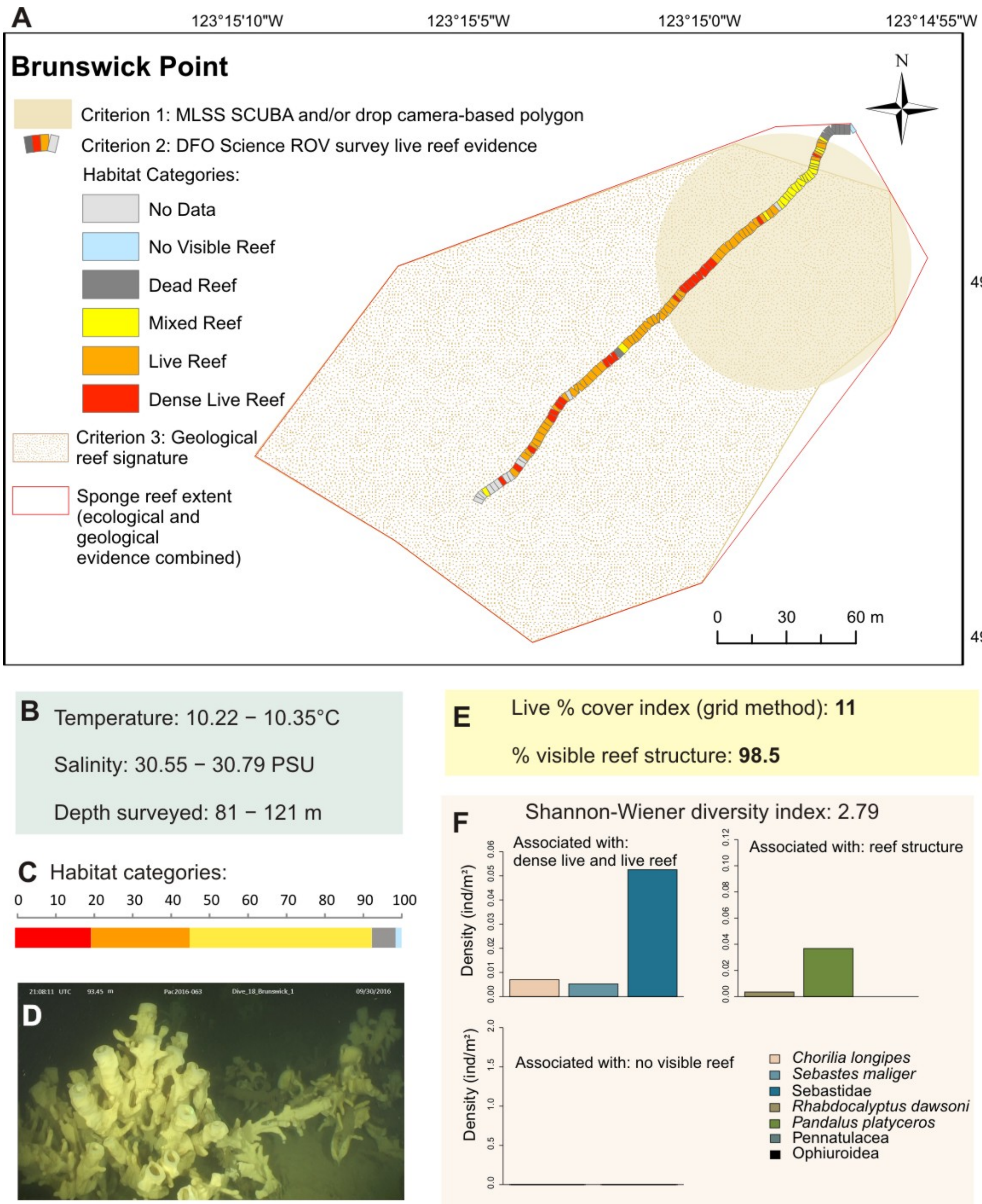

Figure 6. Brunswick Point: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in September 2016; (C) Frequency of occurrence of habitat categories; (D) Representative image of dense live reef habitat; (E) Sponge-based indices of reef status; and (F) Diversity index and densities of indicator taxa. For methods see Dunham et al. (2018).

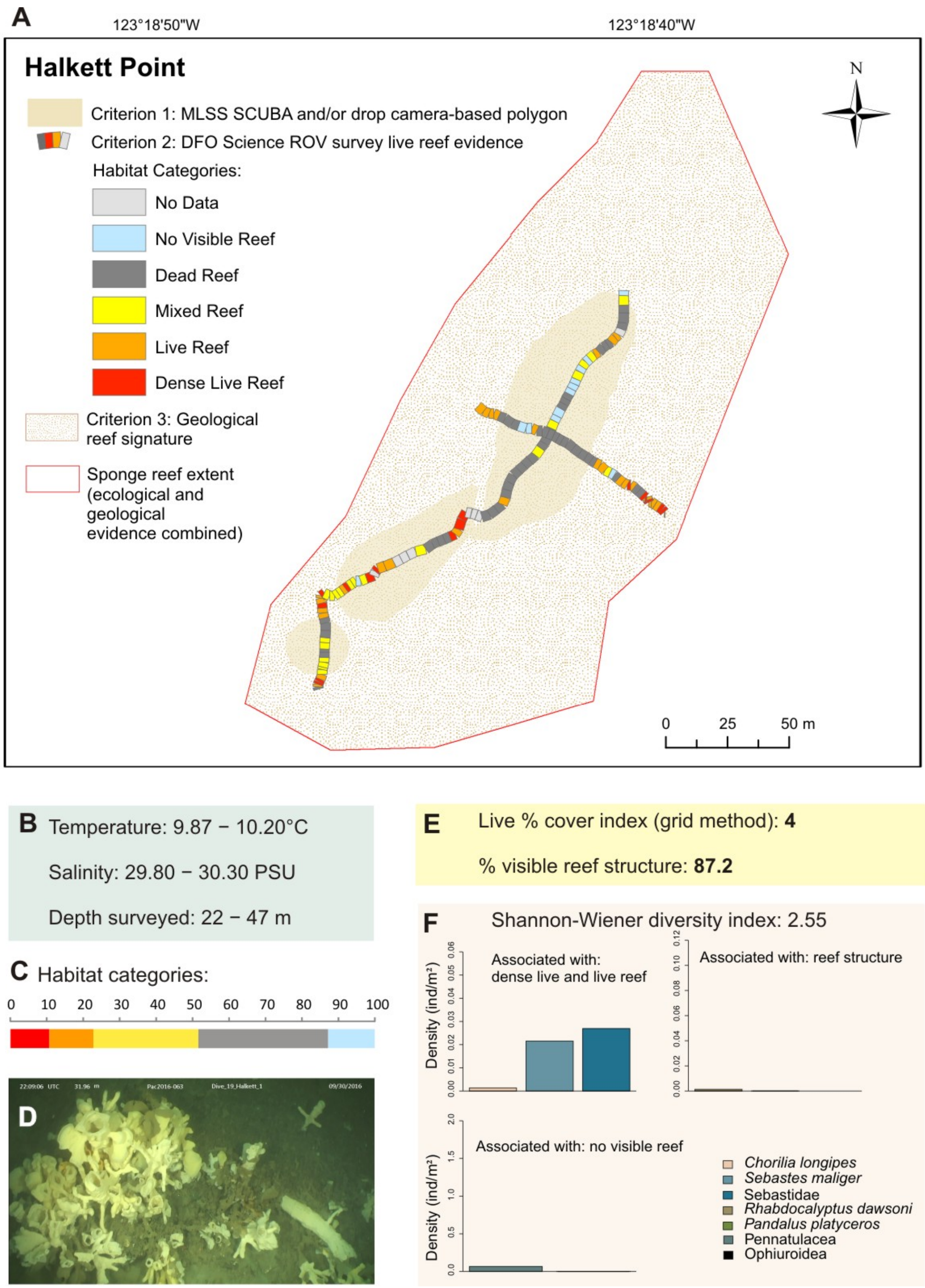

Figure 7. Halkett Point: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in September 2016; (C) Frequency of occurrence of habitat categories; (D) Representative image of dense live reef habitat; (E) Sponge-based indices of reef status; and (F) Diversity index and densities of indicator taxa. For methods see Dunham et al. (2018).

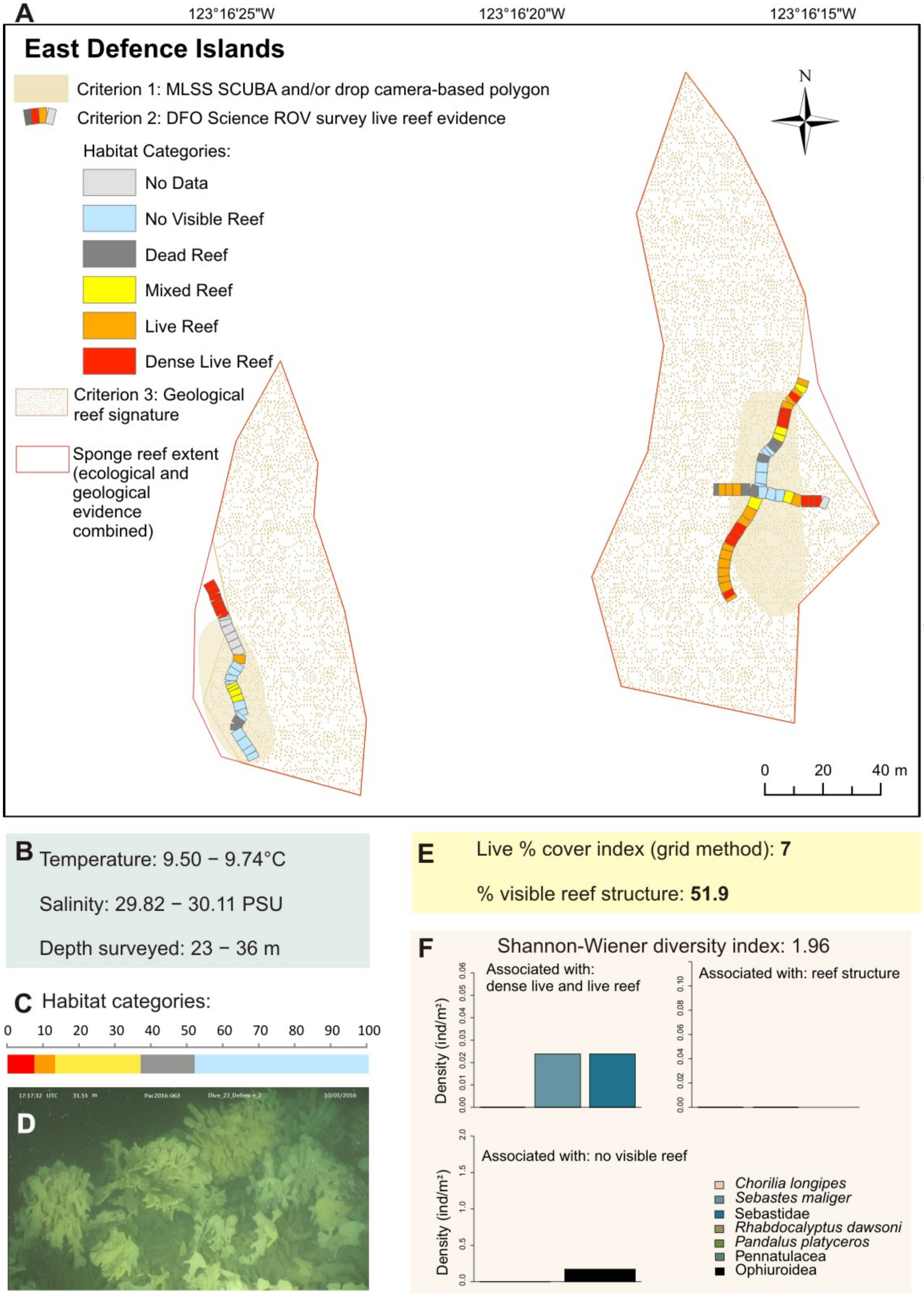

Figure 8. East Defence Islands: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in September 2016; (C) Frequency of occurrence of habitat categories; (D) Representative image of dense live reef habitat; (E) Sponge-based indices of reef status; and (F) Diversity index and densities of indicator taxa. For methods see Dunham et al. (2018).

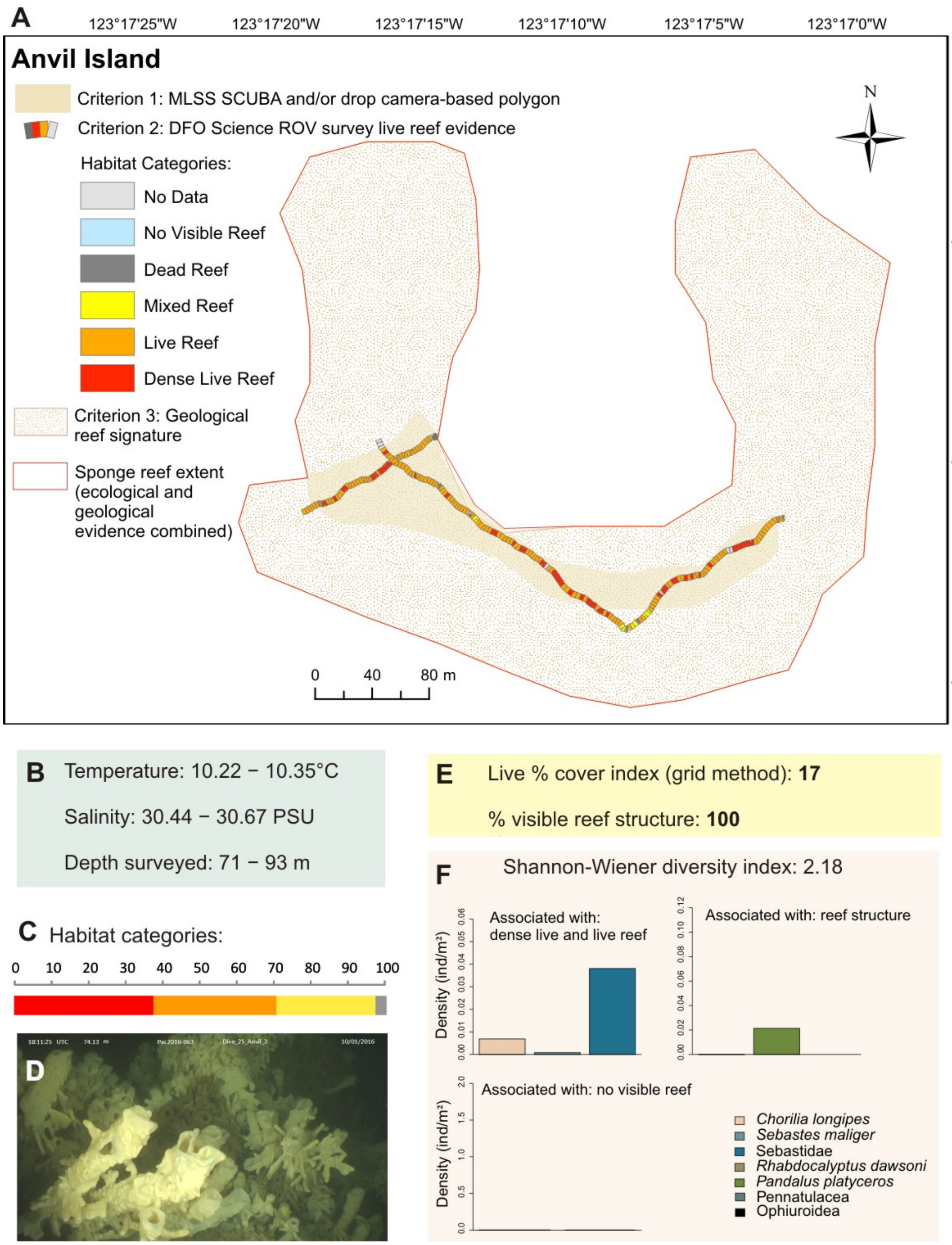

Figure 9. Anvil Island: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in September 2016; (C) Frequency of occurrence of habitat categories; (D) Representative image of dense live reef habitat; (E) Sponge-based indices of reef status; and (F) Diversity index and densities of indicator taxa. For methods see Dunham et al. (2018).

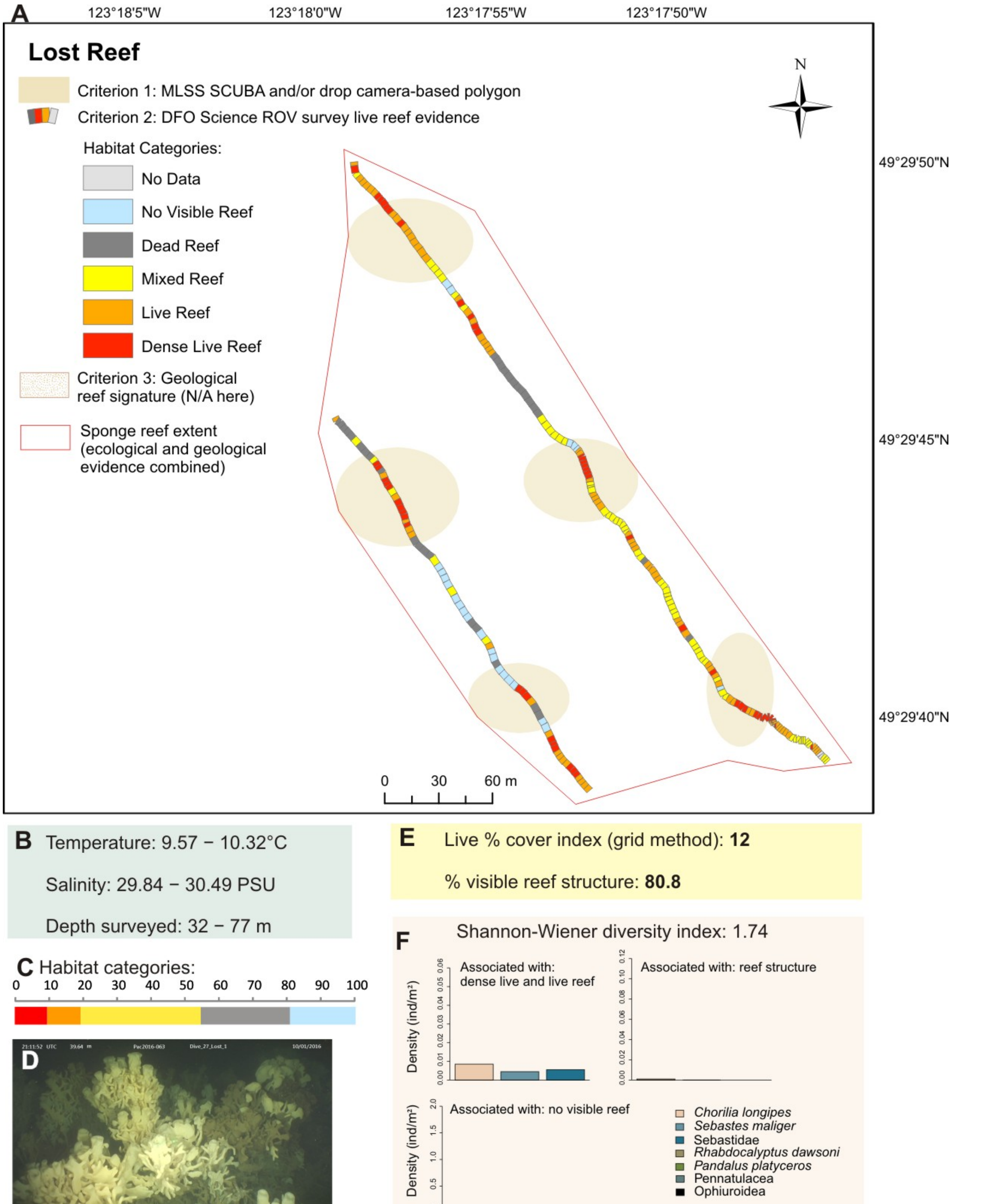

Figure 10. Lost Reef: (A) map showing available ecological evidence (geological evidence not available) and reef extent (red line); (B) Environmental ranges recorded in September 2016; (C) Frequency of occurrence of habitat categories; (D) Representative image of dense live reef habitat; (E) Sponge-based indices of reef status; and (F) Diversity index and densities of indicator taxa. For methods see Dunham et al. (2018).

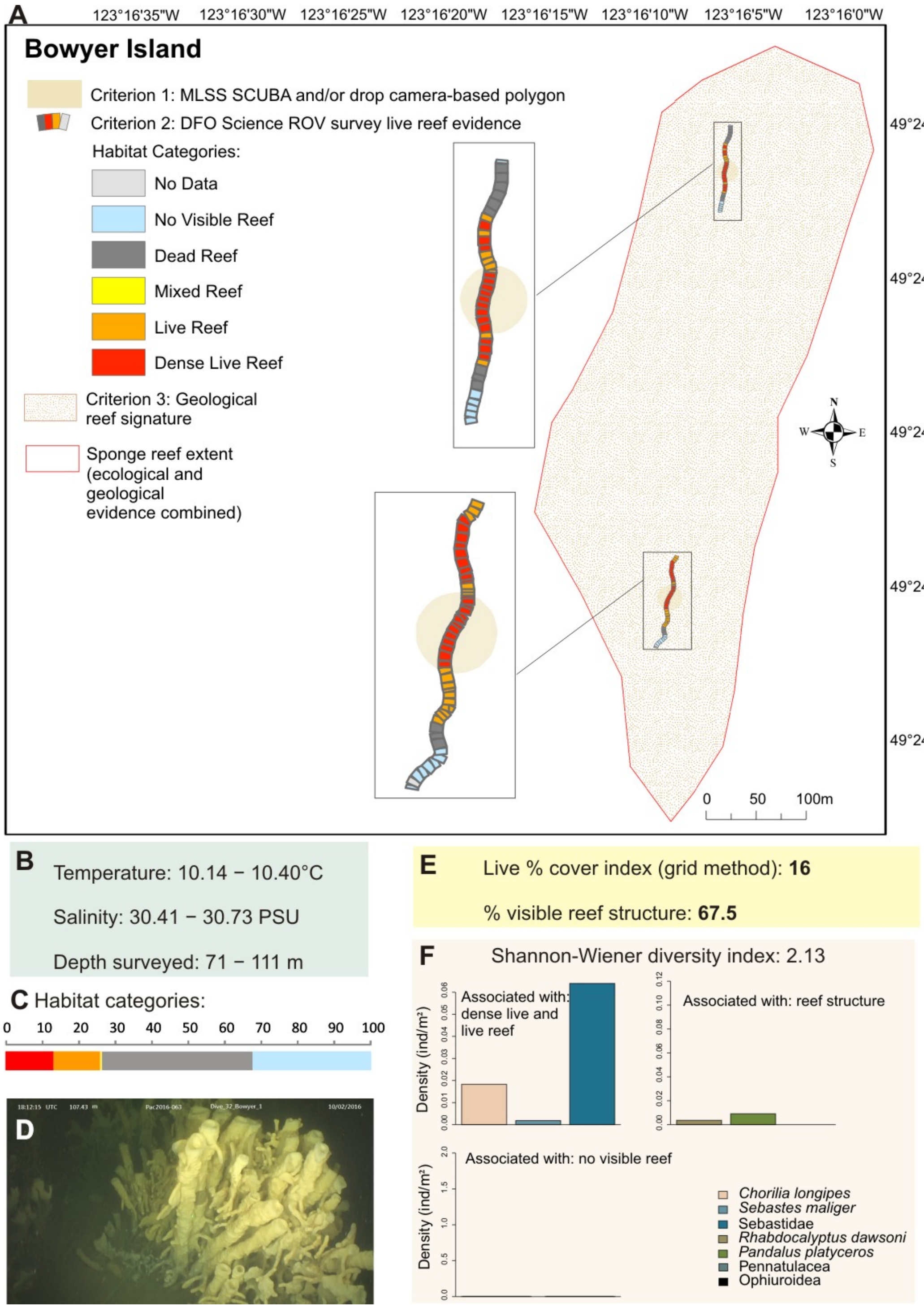

Figure 11. Bowyer Island: (A) map showing available geological and ecological evidence and reef extent (red line); (B) Environmental ranges recorded in September 2016; (C) Frequency of occurrence of habitat categories; (D) Representative image of dense live reef habitat; (E) Sponge-based indices of reef status; and (F) Diversity index and densities of indicator taxa. For methods see Dunham et al. (2018).

2.1 Ecological function

Glass sponge reefs are known to play an important role in filtration, processing large amounts of carbon and nitrogen (Chu and Leys 2010, Kahn et al. 2015). Filtration capacity of the nine Howe Sound reefs was estimated using Monte Carlo methods (a full description of the method can be found in Appendix 5). Briefly, reef-building sponge oscula were counted and the total area of each still image was calculated for all images collected during the DFO Science ROV Pac2016-063 survey (images were taken every 15 sec along each transect). Oscula density was determined for each image (number of oscula divided by image area). An exponential function was then fitted to the empirical distribution of oscula densities for each reef (Appendix 5, Fig. A5-1; goodness-of-fit determined using Kolmogorov-Smirnov tests). Next, 150 oscula per reef were randomly selected and measured to determine mean osculum opening area (Table 4, column 3). A Weibull distribution was fitted to the empirical distribution of oscula areas for each reef (Appendix 5, Fig. A5-2; goodness-of-fit determined using Kolmogorov-Smirnov tests). Then, using the variables and equations presented Appendix 5, total oscula abundance, total water filtration capacity, and carbon and nitrogen removal rates were calculated for each reef (Table 4). Values were calculated 1,000 times, each time drawing new values from the distributions described in Appendix 5 to get an estimate of error.

Assuming continuous pumping conditions (Tompkins-MacDonald and Leys 2008), one m^2 of reef area filters 25,400 to 45,150 L of water per day. Together, the nine reefs clear over 17 billion L of water in Howe Sound daily. This is equivalent to over 6,500 Olympic-size swimming pools.

Together, the nine Howe Sound reefs remove approximately 436 kg of total organic carbon and 112 kg of nitrogen daily. The nine Howe Sound sponge reefs remove nearly five times more carbon per m^2 (~0.658 ± 0.2952 g/m^2, mean ± SD, *n*=9) than can be exported by vertical flux alone in a typical Pacific fjord (~0.135 g/m^2 not accounting for potential seasonality aspects; Timothy et al. 2003). For comparison, 1 hectare of old-growth forest sequesters, on average, 2.4 tonnes of carbon per year (Luyssaert et al. 2008), which also corresponds to 0.658 g/m^2 per day.

Table 4. Estimated filtration capacity and carbon and nitrogen processing rates of the nine reef complexes.

Reef complex	Total reef area, m²	Osculum area, cm^2, median (range), *n*=150	Estimated oscula count per reef	Estimated filtration capacity, L/day	Total organic carbon removal rate, g/day	Nitrogen removal rate, g/day
Dorman Point	9,578	10.6 (0.1 − 233.4)	165,898	432,421,140	10,899	2,833
Lions Bay	72,394	12.8 (0.2 − 261.7)	552,099	1,600,218,375	39,839	10,331
Kelvin Grove	150,287	18.9 (0.1 − 369.6)	1,174,241	4,827,407,012	123,154	30,624
Brunswick Point	38,224	6.4 (0.3 − 80.2)	249,251	398,365,176	10,159	2,480
Halkett Point	31,682	8.3 (0.3 − 280.2)	207,459	457,407,756	11,620	2,878
East Defence Islands	17,772*	10.9 (0.6 − 140.5)	140,532	273,560,036	6,776	1,758
Anvil Island	98,138	9.4 (0.3 − 141.2)	1,385,966	3,729,412,054	95,749	24,538
Lost Reef	50,552	14.4 (0.3 − 175.8)	632,030	1,283,746,081	33,045	8,476
Bowyer Island	135,225	24.3 (0.3 − 295.6)	1,393,082	4,113,595,551	104,436	28,382

**Calculated as a sum of both reef polygons within this complex.*

In addition to their role in filtration and carbon and nitrogen processing, the Howe Sound glass sponge reefs form important biogenic habitats. These nine glass sponge reefs are smaller when compared to most other known glass sponge reefs (9,578-150,287 m^2, Table 4): for example, the Strait of Georgia reefs range from 99,794 to 2,004,966 m^2 [Dunham et al. 2018], while the Hecate Strait reefs discontinuously cover over 700,000,000 m^2. However, the Howe Sound reefs exhibit high live sponge cover (Appendix 6). The frequencies of occurrence of all live sponge habitat categories (combined) within these reefs are among the highest known to date (range: 26-97%; see Appendix 6 for comparison with other glass sponge reefs in the Georgia Basin). These reefs are also the shallowest confirmed glass sponge reefs thus far (<25 m depth recorded within Halkett Point and East Defence Island reefs).

The reefs support diverse and abundant communities of invertebrates and fish, with 84 taxonomic groups observed (Appendix 4), including those of economic importance (Fig. 12). Species richness and diversity (measured using the Shannon-Wiener diversity index) within Howe Sound reefs were as high as 29.2 ± 7.53 and 2.3 ± 0.33 (mean ± SD), respectively. In comparison, benthic areas in Howe Sound outside of reef boundaries were characterized by species richness and diversity of 12.7 ± 3.69 and 1.6 ± 0.36 (mean ± SD), respectively (Dunham et al. 2018).

Figure 12. Rockfish at the Lions Bay reef.

2.2 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) 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 are known to 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.

Genetic mixing was 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 reefs in Howe Sound; sponge larvae may also be able to reach the Strait of Georgia. Thus, recovery of a particular reef may be influenced by the status of other reefs and vice versa. Protecting reefs in Howe Sound may promote recovery of impacted reefs not only in Howe Sound, but also elsewhere in the Strait of Georgia.

Coldwater corals and sponges are currently the focus of international efforts to reduce the impacts of fishing on benthic environments (e.g. FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas, NAFO Vulnerable Marine Ecosystem impact assessments). These benthic communities and features are consistently used as examples of ecosystem components that require special attention in national and international initiatives (e.g. FAO 2009). Protecting Howe Sound glass sponge reefs helps advance Canada's commitments related to marine habitat conservation.

Four out of nine reefs are located within Rockfish Conservation Areas (RCAs) and one reef is located within a Marine Provincial Park. However, it is important to note that these existing spatial management measures provide little to no protection for the reefs. Many types of commercial and recreational bottom-contact fishing activities are currently permitted within RCAs, including prawn and crab by trap. As described above, glass sponge reefs are extremely sensitive to physical disturbances (Dunham et al. 2015; Kahn et al. 2016).

Four reefs – Dorman Point, Halkett Point, East Defence Islands, and Lost Reef – are located at air gas dive-able depths and are thus accessible recreationally. Divers may wish to collect glass sponges or may physically damage the reefs through poor buoyancy control or by dropping anchors within reef areas.

Protection of glass sponge reefs in Howe Sound can be improved through the use of management tools including prohibition of bottom-contact fishing and other human activities that would result in bottom contact. This may also indirectly benefit RCAs and their management objectives by protecting sponge reefs that are used by rockfish as nursery habitats (Cook et al. 2008, Dunham et al. 2018, Alejandro Frid, Environmental Studies, University of Victoria, Victoria, BC, pers. obs.). In addition, along with potentially closing these areas to bottom contact fishing, an activity application process for persons planning an activity on the reefs, similar to one required to work within Marine Protected Areas, may be used to manage or mitigate sample collection and/or accidental damage by divers.

3. Areas requiring further ground-truthing and research

Reviewing the three available datasets revealed two aggregations included in DFO Fishery Notice FN1150 (Ellesmere Creek and Christie Islet) and seven additional areas where either status (reef or garden) or condition (live or dead), or both status and condition, could not be determined based on the data that exists at this time. These areas require ground-truthing and additional field research efforts using visual survey tools. Information on the nine areas requiring further investigation, along with suggestions for future work, is summarized in Appendix 7.

It is unlikely that other glass sponge reefs of comparable size will be discovered in Howe Sound in the future. Most of the extent of Howe Sound has now been surveyed using remote sensing methods, with the exception of shallow areas (Conway et al. 2013); the resulting datasets have been thoroughly reviewed for geological evidence of sponge reef presence as part of this paper. However, the geological evidence method used in this paper can reliably identify a contiguous glass sponge reef patch of 20 or more meters in diameter. Smaller and/or patchy reefs, as well as sponge gardens may be discovered in Howe Sound in the future.

Conclusions

Combined, available evidence for nine glass sponge aggregations in Howe Sound − Dorman Point, Lions Bay, Kelvin Grove, Brunswick Point, Halkett Point, East Defence Islands, Anvil Island, Lost Reef, and Bowyer Island – indicates that each site represents live glass sponge reefs with important ecological functions. These reefs have a high frequency of occurrence of live sponge habitat, support diverse and abundant communities of invertebrates and fish, and play important roles in water processing and nutrient dynamics in Howe Sound. Extremely sensitive to physical disturbances, these reefs receive little to no protection from existing spatial management measures. Protection of these glass sponge reefs can be improved through the use of management tools including prohibition of bottom-contact fishing and other human activities resulting in bottom contact.

An additional nine areas − Ellesmere Creek and Christie Inlet identified in DFO Fishery Notice FN1150, one additional area identified by MLSS visual surveys only, and six additional areas identified using NRCan geological dataset only − require further research before their status and ecological function can be determined. Field surveys assessing live sponge cover using visual survey methods, as well as research focusing on the ecological importance of non-reef sponge aggregations (sponge gardens) will help determine their status and ecological function. Continued advancement and application of visual survey tools (e.g. drop cameras and ROVs), as well as development and improvement of associated assessment and monitoring methods, is crucial for advancing our understanding of the ecosystem function and services provided by glass sponge reefs, and other biogenic habitats.

This paper provides a comprehensive review of scientific information on Howe Sound glass sponge aggregations available to date. It is unlikely that the datasets reviewed missed other glass sponge reefs of comparable size in Howe Sound. However, smaller reefs or glass sponge aggregations may be discovered in Howe Sound in the future.

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March 2, 2018

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Appendix 1. DFO Fishery Notice FN1150

Fishery Notice Category(s):

ABORIGINAL - General Information
COMMERCIAL - General Information
COMMERCIAL - Groundfish Trawl
COMMERCIAL - Groundfish: Halibut
COMMERCIAL - Groundfish: Other Hook and Line
COMMERCIAL - Groundfish: Rockfish Hook and Line
COMMERCIAL - Groundfish: Sablefish
COMMERCIAL - Groundfish: Sablefish Seamount
COMMERCIAL - Invertebrates: Crab
COMMERCIAL - Invertebrates: Crab - Tanner
COMMERCIAL - Invertebrates: Prawn and Shrimp by Trap
COMMERCIAL - Invertebrates: Scallop by Trawl
COMMERCIAL - Invertebrates: Shrimp Trawl

General Information
RECREATIONAL - Fin Fish (Other than Salmon)
RECREATIONAL - General Information
RECREATIONAL - Shellfish

Subject:
FN1150-Glass Sponge Reefs - Area 28 - Howe Sound - Request for Voluntary Avoidance of All Bottom Contact Fishing Gear for Prawn, Shrimp, Crab and Groundfish

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This notice requests voluntary avoidance of the use of all bottom contact fishing gear for Commercial, Recreational and Food, Social and Ceremonial (FSC) fisheries for Prawn, Shrimp, Crab and Groundfish, in Subareas 28-2, 28-4, and 28-5 of Howe Sound, to protect newly discovered glass sponge reefs.

In 2014, the Department of Fisheries and Oceans (DFO) embarked on a consultation process to protect nine glass sponge reefs in the Strait of Georgia and Howe Sound through a process called the Strait of Georgia and Howe Sound Glass Sponge Reef Conservation Initiative. In 2015, fishery closures were put in place to protect these nine glass sponge reefs from all bottom contact fishing gear.

During the 2014 consultation process, additional sponge reefs were brought to the Department's attention by the Marine Life Sanctuaries Society (MLSS). At the time, it was decided that consultations would proceed on the original nine reefs while the new reefs would be set aside for further research and consideration. Since that time, DFO has initiated work in partnership with MLSS and other groups to gain a better understanding of the new reefs locations and biological composition.

Although a final report from DFO Science is pending, DFO has concluded that these additional reefs are biologically significant enough to warrant a precautionary management approach and are asking the public to voluntarily avoid fishing in these areas with bottom contact fishing gear of any kind until further research and consultation with First Nations and stakeholders can occur. Bottom contact fishing gear includes: crab by trap; shrimp by trap; prawn by trap; shrimp by trawl; scallop by trawl; and, groundfish by trawl, hook and line, and trap used for Commercial, Recreational and Food, Social and Ceremonial (FSC) fisheries.

Further research will be completed over the coming months with consultations anticipated in the winter of 2017.

Maps of Fishery Management Areas and Subareas

The geographic descriptions of the reefs follow:
Defence Islands/Ellesmere Creek:

DI-a: Ellesmere Creek bioherm
49°35.572'N 123°15.635'W
49°35.293'N 123°15.763'W
49°35.281'N 123°15.283'W
49°35.472'N 123°15.243'W

DI-b: East Defence Island
49°34.639'N 123°16.281'W
49°34.653'N 123°16.213'W
49°34.728'N 123°16.243'W
49°34.713'N 123°16.313'W

DI-c: East Defence Island pinnacle
49°34.630'N 123°16.449'W
49°34.663'N 123°16.366'W
49°34.687'N 123°16.422'W
49°34.641'N 123°16.481'W

Anvil Island:
AI-a Clayton bioherm
49°32.756'N 123°17.356'W
49°32.607'N 123°17.353'W
49°32.581'N 123°17.009'W
49°32.749'N 123°16.992'W

AI-b North Christie
49°30.208'N 123°18.156'W
49°30.118'N 123°18.133'W
49°30.116'N 123°18.040'W
49°30.208'N 123°18.070'W

AI-c: Lost Reef
49°29.812'N 123°18.043'W
49°29.559'N 123°17.970'W
49°29.660'N 123°17.701'W
49°29.958'N 123°17.961'W

Lions Bay:
LB-a: Brunswick bioherm
49°28.324'N 123°15.062'W
49°28.397'N 123°14.886'W
49°28.475'N 123°14.959'W
49°28.420'N 123°15.154'W

LB-b: Lions Bay Seamount
49°27.126'N 123°15.512'W
49°27.145'N 123°15.243'W
49°27.543'N 123°15.379'W
49°27.481'N 123°15.688'W

LB-c: Kelvin Grove Seamount
49°26.973'N 123°15.028'W
49°26.981'N 123°14.676'W
49°27.270'N 123°14.660'W
49°27.260'N 123°15.016'W

Halkett Point, Gambier Island:
HP: Halkett West pinnacle
49°26.747'N 123°18.825'W
49°26.740'N 123°18.658'W
49°26.887'N 123°18.598'W
49°26.884'N 123°18.790'W

South Bowyer Island:
SB-a: South Bowyer
49°24.715'N 123°16.158'W
49°24.586'N 123°16.162'W
49°24.567'N 123°16.021'W
49°24.703'N 123°16.0074'W

SB-b: Southern-South Bowyer
49°24.352'N 123°16.156'W
49°24.357'N 123°16.112'W
49°24.448'N 123°16.095'W
49°24.449'N 123°16.185'W

Dorman Point, Bowen Island:
DP: Dorman Point bioherm
49°22.481'N 123°19.241'W
49°22.416'N 123°19.311'W
49°22.384'N 123°19.292'W
49°22.452'N 123°19.209'W

FOR MORE INFORMATION:

If you have any questions or would like more information, please visit
http://www.dfo-mpo.gc.ca/oceans/ceccsr-cerceef/closures-fermetures-eng.html
Or contact Aleria Ladwig at Aleria.ladwig@dfo-mpo.gc.ca.
Fisheries & Oceans Operations Center - FN1150
Sent October 27, 2017 at 1455

Appendix 2. DFO Science Pac2016-063 ROV survey results (spatial coverage, sponge observation, and anthropogenic objects recorded)

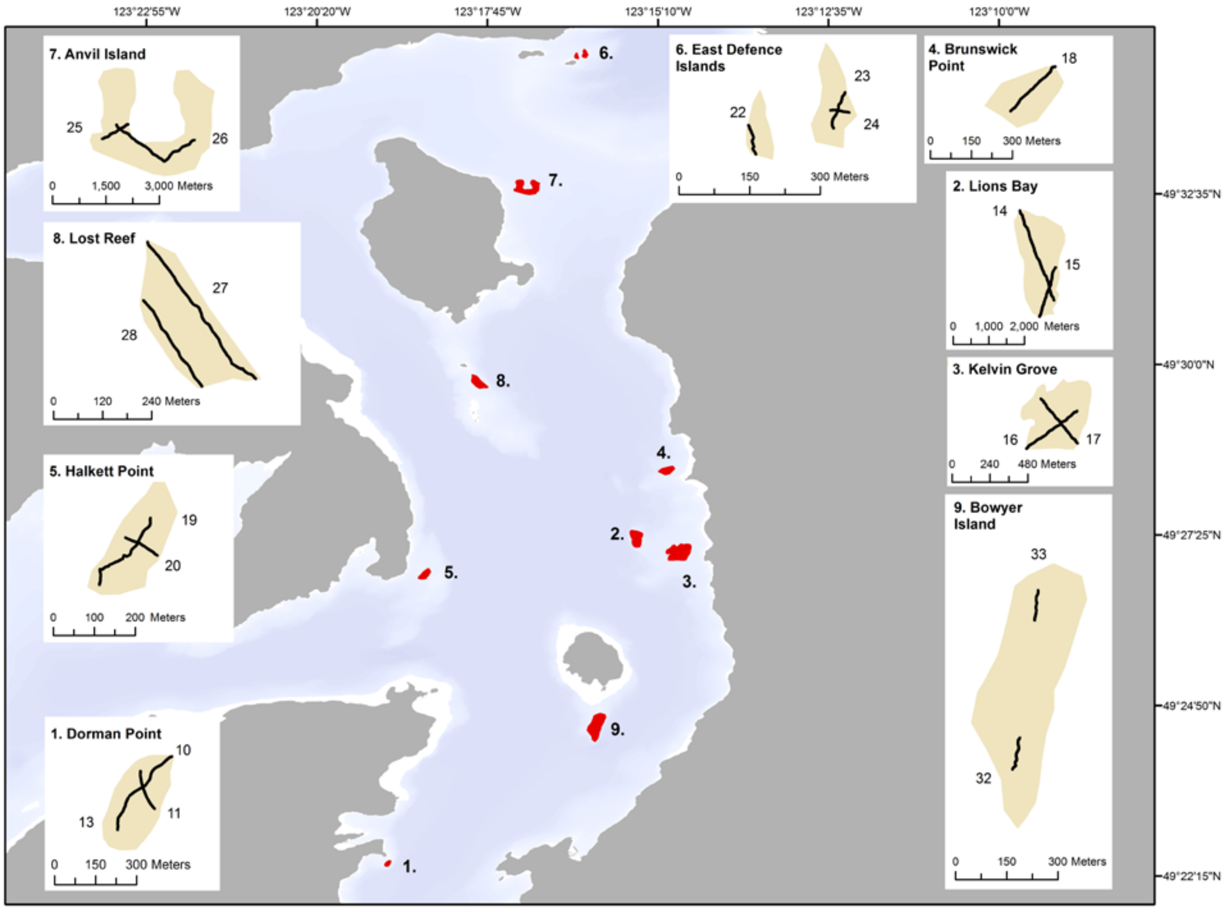


Figure A2-1. ROV transects completed by DFO Science in 2016 (cruise PAC2016-063).

Table A2-1. Summary of reef sizes and spatial coverage of ROV survey transects.

Reef complex	Total reef area, m²	Centroid coordinates (DDM)		PAC2016-063 ROV transect #	Reef area surveyed, m²	Reef area surveyed, %
		Latitude	Longitude			
Dorman Point	9,578	49°22.439'N	-123°19.262'W	10, 11, 13	425	4.4
Lions Bay	72,394	49°27.366'N	-123°15.495'W	14, 15	2026	2.8
Kelvin Grove	150,287	49°27.153'N	-123°14.844'W	16, 17	2014	1.3
Brunswick Point	38,224	49°28.394'N	-123°15.03'W	18	571	1.5
Halkett Point	31,682	49°26.818'N	-123°18.698'W	19, 20	742	2.3
East Defence Islands	17,772*	49°34.694'N	-123°16.328'W	22, 23, 24	546	3.1
Anvil Island	98,138	49°32.676'N	-123°17.148'W	25, 26	1313	1.3
Lost Reef	50,552	49°29.726'N	-123°17.893'W	27, 28	1990	3.9
Bowyer Island	135,225	49°24.523'N	-123°16.102'W	32, 33	547	0.4

*Calculated as a sum of both reef polygons within this complex.

Table A2-2. Qualitative observations of reef composition and reef-building sponge morphology observed during MLSS drop camera and SCUBA surveys and during DFO Science ROV survey Pac2016-063.

Reef complex	Description
Dorman Point	Large patches of dense *A. vastus* / *H. calyx* of white and yellow color growing on dead sponges. Areas of dead sponge between large areas of no visible sponge reef. MLSS noted areas with close to 100% live sponge cover and observed damage from prawn traps. High density of squat lobster, perch and rockfish. Dominated by *A. vastus.*
Lions Bay	Small-to-large patches of *A. vastus* / *H. calyx* mostly white and cream in color with some yellow sponges. MLSS observed patchy sponge aggregations with dense, healthy areas of sponge where no seabed is visible and then expanses of mud or silted over, dead sponge. High densities of squat lobster and many Rosselid (boot) sponges observed. Dominated by *A. vastus.*
Kelvin Grove	Large, wide patches and mounds of abundant and tall *A. vastus* / *H. calyx* of white and yellow color growing on dead sponges. Dense areas of sponge interrupted by dead and broken sponge reef and expanses of mud or silted over, dead sponge. Many squat lobsters observed and damage from traps recorded by both MLSS and DFO.
Brunswick Point	Wide patches of *A. vastus* / *H. calyx* mostly white and cream in color with some yellow sponges. Large areas of dead and broken reef structure. ROV surveys observed smaller reef with dense sponge aggregations and a high density of squat lobster.
Halkett Point	Small patches with dense sponge cover and isolated small-to-large *A. vastus* / *H. calyx* growing on dead sponge and bedrock; mostly white and cream in color. Broken sponge observed by MLSS in March 2016.
East Defence Islands	Patchy sponge distribution with large patches of small-to-large *A. vastus* / *H. calyx* growing on dead sponge mostly white and cream in color with some yellow sponges. Isolated sponges observed growing on bedrock along transects in the sponge reef polygon on the left.
Anvil Island	Many large patches of dense sponge growth of *A. vastus* / *H. calyx* of white and yellow color growing on dead sponges. Densest sponge growth between 80-100 m depth. Areas of visible dead sponge between large areas of no visible sponge reef. Tall sponges and large oscula observed along with high densities of squat lobster. Dominated by *A. vastus.*
Lost Reef	Small patches with dense sponge cover and isolated small-to-large *A. vastus* / *H. calyx* growing on bedrock; mostly white and cream in color with some yellow sponge. Dominated by *A. vastus* and infrequent but established growth of *H. calix.* Many areas covered by MLSS have healthy, live sponge. Damage from fishing line observed by MLSS.
Bowyer Island	Patchy sponge growth with areas of dense *A. vastus* / *H. calyx* sponges. Sponges are mostly white and cream in color with some yellow sponge. Healthy sponges observed along eastern and western ridges of the northern polygon. Dominated by A. vastus.

Table A2-3. Anthropogenic objects observed along the DFO ROV transects (note that these numbers are per area surveyed which covered 0.4-4.4% of reef area; MLSS observed additional anthropogenic objects, such as car tires and prawn traps within the reef footprints).

Reef complex	Total number of objects observed	Object types
Dorman Point	13	Unidentified object (3), glass bottle (10)
Lions Bay	0	None observed
Kelvin Grove	1	Unidentified object
Brunswick Point	1	Unidentified object
Halkett Point	1	Glass bottle
East Defence Islands	5	Marker (5)
Anvil Island	1	Trap
Lost Reef	2	Glass bottle (1), log (1)
Bowyer Island	0	None observed

Appendix 3. Latitude and longitude coordinates (DDM) for simplified four-sided polygons encompassing full known aggregation extents.

Table A3-1. Latitude and longitude coordinates (DDM) for simplified, four-sided polygons encompassing full known reef or aggregation extents. Grey shaded cells denote areas requiring further ground-truthing.

Dorman Point		Lions Bay		Kelvin Grove	
Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
49°22.485'N	-123°19.259'W	49°27.483'N	-123°18.66'W	49°27.268'N	-123°15.047'W
49°22.472'N	-123°19.191'W	49°27.499'N	-123°18.594'W	49°27.29'N	-123°14.639'W
49°22.391'N	-123°19.268'W	49°27.239'N	-123°18.7'W	49°27.036'N	-123°14.715'W
49°22.416'N	-123°19.321'W	49°27.227'N	-123°18.823'W	49°27.032'N	-123°15.037'W
Brunswick Point		**Halkett Point**		**East Defence Islands (right)**	
Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
49°28.384'N	-123°15.181'W	49°26.912'N	-123°18.66'W	49°34.77'N	-123°16.312'W
49°28.479'N	-123°14.987'W	49°26.879'N	-123°18.594'W	49°34.77'N	-123°16.261'W
49°28.417'N	-123°14.87'W	49°26.722'N	-123°18.7'W	49°34.647'N	-123°16.214'W
49°28.315'N	-123°15.038'W	49°26.771'N	-123°18.823'W	49°34.648'N	-123°16.311'W
East Defence Islands (left)		**Anvil Island**		**Lost Reef**	
Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
49°34.716'N	-123°16.43'W	49°32.79'N	-123°17.343'W	49°29.801'N	-123°18.059'W
49°34.717'N	-123°16.384'W	49°32.788'N	-123°16.955'W	49°29.857'N	-123°17.957'W
49°34.633'N	-123°16.372'W	49°32.572'N	-123°16.978'W	49°29.651'N	-123°17.737'W
49°34.641'N	-123°16.425'W	49°32.574'N	-123°17.345'W	49°29.633'N	-123°17.885'W
Bowyer Island		**Ellesmere Creek**		**Christie Islet**	
Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
49°24.737'N	-123°16.113'W	49°35.472'N	-123°15.243'W	49°30.116'N	-123°18.04'W
49°24.676'N	-123°15.911'W	49°35.281'N	-123°15.283'W	49°30.118'N	-123°18.133'W
49°24.274'N	-123°16.106'W	49°35.293'N	-123°15.763'W	49°30.208'N	-123°18.156'W
49°24.403'N	-123°16.282'W	49°35.583'N	-123°15.643'W	49°30.208'N	-123°18.07'W
September Morn Beach		**Langdale**		**Carmelo Point**	
Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
49°24.737'N	-123°19.868'W	49°25.599'N	-123°28.178'W	49°27.187'N	-123°23.313'W
49°24.676'N	-123°19.687'W	49°26.181'N	-123°27.506'W	49°27.11'N	-123°23.018'W
49°24.274'N	-123°19.757'W	49°26.113'N	-123°26.888'W	49°26.107'N	-123°23.639'W
49°24.403'N	-123°19.957'W	49°25.436'N	-123°27.073'W	49°26.191'N	-123°23.839'W
Collingwood Channel		**Mariners Rest**		**Alberta Bay**	
Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
49°23.497'N	-123°24.861'W	49°27.612'N	-123°27.363'W	49°28.04'N	-123°14.918'W
49°23.425'N	-123°24.678'W	49°27.422'N	-123°27.046'W	49°28.043'N	-123°14.749'W
49°22.896'N	-123°25.333'W	49°27.334'N	-123°27.155'W	49°27.606'N	-123°14.624'W
49°23.03'N	-123°25.525'W	49°27.516'N	-123°27.512'W	49°27.59'N	-123°14.928'W
NW Queen Charlotte Channel		**NE Queen Charlotte Channel**		**SE Queen Charlotte Channel**	
Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
49°20.857'N	-123°18.953'W	49°20.875'N	-123°18.142'W	49°20.288'N	-123°18.03'W
49°20.859'N	-123°18.626'W	49°20.875'N	-123°17.855'W	49°20.288'N	-123°17.775'W
49°20.563'N	-123°18.624'W	49°20.636'N	-123°17.855'W	49°20.051'N	-123°17.775'W
49°20.561'N	-123°18.951'W	49°20.636'N	-123°18.142'W	49°20.051'N	-123°18.03'W

Appendix 4. DFO Science Pac2016-063 ROV survey results: full taxonomic list

Table A4-1. Fish and invertebrate taxa observed along ROV transects (video and still image observations combined). "x" denotes presence, "-" denotes absence. Identifications were made to the lowest taxonomic level possible. DP = Dorman Point, LB = Lions bay, KG = Kelvin Grove, BP = Brunswick Point, HP = Halkett Point, EDI = East Defence Islands, AI = Anvil Island, LR = Lost Reef, and BI = Bowyer Island.

Phylum **Class** **Order** **Family**	**Species**[1]	**Common Name**	**Reef complex**								
			DP	**LB**	**KG**	**BP**	**HP**	**EDI**	**AI**	**LR**	**BI**
Porifera	Unidentified species	Sponges	x	x	-	-	-	-	-	-	-
Hexactinellida	*Aphrocallistes vastus* or *Heterochone calyx*	Cloud or Goiter Sponges (reef-building species)	x	x	x	x	x	x	x	x	x
Lyssacinosida Rossellidae	*Rhabdocalyptus* spp.	Boot Sponges	x	x	-	x	x	-	-	x	x
	Staurocalyptus spp.	Lipped Boot Sponges	-	x	x	x	-	-	x	x	x
Demospongiae	Unidentified species	Demosponges	x	x	x	x	x	x	x	x	-
Clionaida Clionidae	Unidentified species	Clionid Sponges	-	x	x	-	x	x	-	x	-
Poecilosclerida Acarnidae	*Lophon* spp.	Gnarled Finger Sponges	x	-	-	-	-	x	-	-	x
Suberitida Halichondriidae	*Hymeniacidon* spp.	Hymeniacidon Sponges	x	x	x	x	x	x	x	x	x
Bryozoa	Unidentified species	Bryozoans	x	-	x	-	-	-	-	-	-
Gymnolaemata Cheilostomatida Cellariidae	*Cellaria diffusa*	Spindly Rabbit-Ear Bryozoan	x	-	-	-	-	x	-	-	-
Cnidaria Anthozoa Actiniaria	Unidentified species	Anemones	x	x	-	-	-	x	-	x	-
Actiniidae	*Cribrinopsis fernaldi*	Crimson Anemone	-	x	-	-	-		-	x	-
	Urticina spp.	Urticina Anemones	-	-	-	-	-	x	-	x	-
Metridiidae	*Metridium farcimen*	Plumose Anemone	x	-	-	-	-	x	-	-	-
Spirularia Cerianthidae	*Pachycerianthus fimbriatus*	Tube-dwelling Anemone	x	x	x	x	x	x	x	x	x
Zoantharia Epizoanthidae	*Epizoanthus* spp		x	-	x	-	-	-	-	-	-
Pennatulacea Virgulariidae	*Halipteris willemoesi*	Sea Whip	x	-	-	-	-	x	-	-	-
Hydrozoa	Unidentified	Hydroids	x	x	x	-	x	-	x	-	-
Annelida Polychaeta	Unidentified species	Feather Duster Worms	x	x	x	x	x	x	-	x	x

Phylum Class Order Family	Species[1]	Common Name	Reef complex								
			DP	LB	KG	BP	HP	EDI	AI	LR	BI
Sabellida Sabellidae											
	Bispira spp.	Twin-eyed Feather Duster Worm	-	-	-	-	-	x	x	x	-
Serpulidae	Unidentified species	Calcareous Tubeworms	x	-	x	x	x	-	x	x	-
	Protula pacifica	White-crowned Calcareous Tubeworm	-	x	x	-	-	x	-	x	-
Brachiopoda	Unidentified species	Lamp shell	-	x	x	-	-	x	-	x	-
Rhynchonellata Terebratulida Laqueidae	*Laqueus californicus*	California Lamp shell	-	x	x	x	x	-	-	x	-
Mollusca Bivalvia	Unidentified species	Bivalve mollusks	-	x	-	-	-	-	-	-	-
Pectinida Pectinidea	*Chlamys rubida*	Swimming scallop	-	-	-	-	x	-	-	-	-
Cephalopoda Octopoda	Unidentified species	Octopod mollusks	-	x	-	x	-	-	-	-	-
Sepiida Sepiolidae	*Rossia pacifica*	Stubby Squid	-	-	-	-	-	-	x	-	-
Teuthida	Unidentified species	Squids	-	-	-	-	-	-	x	-	-
Gastropoda Littorinimorpha Cymatiidae	*Fusitriton oregonensis*	Hairy Triton	-	-	x	-	-	-	-	-	-
Lepetidae	Unidentified species	Limpets	-	-	-	-	-	x	-	x	-
Nudibranchia Discodorididae	*Peltodoris lentiginosa*	Giant Freckled Dorid	x	-	-	-	-	-	-	x	-
Dorididae	*Doris odhneri*	Giant White Dorid	x	-	-	-	x	-	-	-	-
Arthropoda Malacostraca Decapoda	Unidentified species	Decapod crustaceans	-	-	-	-	x	-	-	-	-
Cancridae	*Metacarcinus magister*	Dungeness Crab	-	-	-	x	-	-	-	-	-
Epialtidae	*Chorilia longipes*	Longhorn Decorator Crab	x	x	x	x	x	-	x	x	x
Galatheidae	*Munida quadrispina*	Squat Lobster	x	x	x	x	x	x	x	x	x
Hapalogastridae	*Acantholithodes hispidus*	Spiny Lithode Crab	-	x	x	-	x	-	x	-	-
Pandalidae	*Pandalus borealis*	Pink Shrimp	-	-	x	x	x	-	x	x	x
Pandalidae	*Pandalus danae*	Coonstripe Shrimp	-	-	x	-	-	-	-	-	-
Pandalidae	*Pandalus platyceros*	Spot Prawn	-	x	x	x	-	-	x	-	x
Suborder Dendrobranchiata	Unidentified species	Shrimps	x	x	x	x	x	x	x	x	x
Isopoda	Unidentified species	Isopods	-	-	-	-	-	-	x	-	-

Phylum Class Order Family	Species[1]	Common Name	Reef complex								
			DP	LB	KG	BP	HP	EDI	AI	LR	BI
Echinodermata Asteroidea	Unidentified species	Sea Stars	x	-	x	-	-	-	x	-	x
Forcipulatida Asteriidae	*Leptasterias* spp.	Six Ray Stars	-	-	-	-	-	-	x	-	-
Paxillosida Radiasteridae	*Gephyreaster swifti*	Gunpowder Star	x	x	-	-	-	-	-	-	-
Spinulosa Echinasterida	*Henricia* spp.	Blood Stars	x	x	x	-	-	-	x	x	-
Valvatida Asteropseidae	*Dermasterias imbricata*	Leather Star	-	-	-	-	x	-	-	-	-
Goniasteridae	*Ceramaster patagonicus*	Cookie Star	x	-	-	-	-	-	-	-	x
	Mediaster aequalis	Vermillion Star	x	-	-	-	-	-	-	-	-
Velatida Pterasteridae	*Pteraster tesselatus*	Cushion Star	-	-	-	-	x	-	-	-	-
Holothuroidea Aspidochirotida Stichopodidae	*Apostichopus californicus*	California Sea Cucumber	-	-	x	x	x	-	-	x	-
Dendrochirotida Psolidae	*Psolus chitonoides*	Armoured Sea Cucumber	-	-	-	-	x	x	-	x	-
	Psolus squamatus	Scaly Sea Cucumber	-	-	x	-	-	-	-	-	-
Ophiuroidea	Unidentified species	Brittle Stars	x	-	-	-	-	-	-	-	-
Ophiurida Ophiuridae	*Ophiura luetkenii*	Grey Brittle Star	x	-	-	-	x	-	x	x	-
Chordata **Subphylum Tunicata**	Unidentified species	Tunicates	-	x	x	x	x	-	x	x	-
Ascidiacea Stolidobranchia Pyuridae	*Halocynthia hilgendorfi*	Spiny Sea Squirt	-	x	x	-	-	-	-	-	-
Styelidae	*Cnemidocarpa finmarkiensis*	Shiny Orange Sea Squirt	-	-	-	-	x	x	-	-	-
Subphylum Vertebrata (Fish) Actinopteri	Unidentified species	Ray-finned fishes	x	x	x	x	x	x	x	x	-
Gadiformes Gadidae	*Theragra chalcogramma*	Alaska Pollock	-	-	x	x	-	-	-	-	x
Perciformes Bathymasteridae	*Ronquilus jordani*	Northern Ronquil	x	-	x	-	x	-	-	x	-
Embiotocidae	*Cymatogaster aggregata*	Shiner Perch	x	-	-	-	x	-	-	-	-
Stichaeidae	Unidentified species	Pricklebacks	-	-	-	x	-	-	x	-	-

Phylum Class Order Family	Species[1]	Common Name	Reef complex								
			DP	LB	KG	BP	HP	EDI	AI	LR	BI
Zoarcidae	*Lycenchelys* spp.	Eelpouts	x	-	-	x	x	-	-	-	-
Pleuronectiformes	Unidentified species	Flatfishes	x	x	x	-	x	x	-	x	x
Pleuronectidae	*Hippoglossus stenolepis*	Pacific Halibut	x	-	-	-	-	-	-	-	-
	Lepidopsetta bilineata	Rock Sole	x	-	-	-	x	-	-	-	-
	Lyopsetta exilis	Slender Sole	-	-	x	-	x	-	x	-	x
	Microstomus pacificus	Dover Sole	-	x	x	x	x	-	-	-	-
	Parophrys vetulus	English Sole	-	x	x	-	x	-	-	x	-
Scorpaeniformes Agonidae	Unidentified species	Poachers	x	x	x	-	x	-	-	-	-
Cottidae	Unidentified species	Codfishes	x	x	x	x	x	x	-	x	-
Hexagrammidae	*Hexagrammos decagrammus*	Kelp Greenling	-	-	-	-	-	x	-	-	-
	Ophiodon elongatus	Lingcod	-	x	-	x	x	x	-	x	-
Psychrolutidae	*Psychrolutes paradoxus*	Tadpole Sculpin	-	x	-	-	-	-	-	x	-
Sebastidae	*Sebastes* spp.	Rockfishes and thornyheads	-	x	x	x	x	-	x	x	x
	Sebastes brevispinis	Silvergray Rockfish	-	-	-	-	-	-	x	-	-
	Sebastes elongatus	Greenstriped Rockfish	-	x	x	x	-	-	x	x	x
	Sebastes maliger	Quillback Rockfish	x	x	x	x	x	x	x	x	x
	Sebastes proriger	Redstripe Rockfish	x	x	x	x	x	-	x	-	x
	Sebastes ruberrimus	Yelloweye Rockfish	x	-	-	-	-	-	-	-	-
	Sebastes wilsoni	Pygmy Rockfish	x	x	x	-	-	-	x	-	-
	Sebastes zacentrus	Sharpchin Rockfish	x	x	x	x	-	-	x	-	-

[1]"spp" is used when number of species is unknown (≥1).

Appendix 5. Detailed methods for filtration capacity estimates

Filtration capacity of the nine Howe Sound reefs was estimated via Monte Carlo methods. All variables were drawn from theoretical distributions either fitted to empirical data gathered from ecological dataset #2 or taken from the published peer review literature. Equations 1-6 were repeated 1000 times per reef to generate an estimate of error.

Variables:

- Oscula density (***od***, oscula/m^2): oscula were counted in all still images in ecological dataset #2. Oscula density was then calculated as the number of oscula per area of the still image. An exponential distribution was used to estimate oscula density as the distribution was right skewed (Fig. A5-1).
- Oscula area (***oa***, cm^2): 150 camera-facing oscula were randomly selected from images in ecological dataset #2 and their area was measured using ImageJ. A Weibull distribution was fitted to the observed oscula areas for each reef as the dataset was continuous and heavily right skewed (Fig A5-2).
- Reef area (***ra***, m^2): This was calculated in ArcGIS based on the sponge reef extent polygons presented in Figs. 3-11.
- Pumping rate (***pr***, cm/sec): Pumping rate was drawn from a truncated normal distribution (bounded at 0 on the negative side) with a mean of 2.8 and standard deviation of 1.4. These values are pumping rates of *A. vastus* collected in the Strait of Georgia reported in Leys et al. (2011).
- Filtration rate (***fr***): The percent of water pumped by the sponge from which all bacteria are removed was drawn from a truncated normal distribution (bounded at 0 on the negative side) with a mean of 0.786 and a standard deviation of 0.032. These values were measured on *A. vastus in situ* in the Strait of Georgia and reported in Kahn et al. (2015).
- Bacterial concentration (***b***, cells/ml): Bacterial concentration was drawn from a truncated normal distribution (bounded at 0 on the negative side) with a mean of 6.73×10^7 and a standard deviation of 3.5×10^4. These values were measured *in situ* on a glass sponge reef in the Strait of Georgia and reported in Kahn et al. (2015).
- Bacterial carbon (***bc***, g/cell): Bacterial carbon was drawn from a truncated normal distribution (bounded at 0 on the negative side) with a mean of 3.02×10^{-14} and a standard deviation of 1.23×10^{-14}. These values were reported in Fukuda et al. (1998).
- Bacterial nitrogen (***bn***, g/cell): Bacterial carbon was drawn from a truncated normal distribution (bounded at 0 on the negative side) with a mean of 5.8×10^{-15} and a standard deviation of 1.5×10^{-15}. These values were reported in Fukuda et al. (1998).
- Sponge ammonium excretion (***SpNex***, g/ml): Grams of nitrogen excreted by sponges as ammonium waste was drawn from a truncated normal distribution (bounded at 0 on the negative side) with a mean of 2.38×10^{-9} and a standard deviation of 2.8×10^{-10}. These values were measured *in situ* from *A. vastus* in the Strait of Georgia and reported in Kahn et al. (2015).

Equations:

Equation 1: $Total\ Number\ of\ Oscula(TO) = \sum_{i=1}^{ra} round(od_i)$

Equation 2: $Total\ water\ pumped\ (ml)\ per\ day\ (TP) = 86400 * \sum_{i=1}^{TO}(oa_i \times pr_i)$

Equation 3: $Total\ water\ filtered\ (ml)\ per\ day\ (TF) = 86400 * \sum_{i=1}^{TO}(oa_i \times pr_i \times fr_i)$

Equation 4: $Bacteria\ removed\ per\ day\ (TB) = TF \times b$

Equation 5: $Carbon\ removed\ per\ day\ (TC) = TB \times bc$

Equation 6: $Nitrogen\ removed\ per\ day\ (TN) = (TB \times bn) - \sum_{i=1}^{TO}(oa_i \times pr_i \times fr_i \times SpNex_i)$

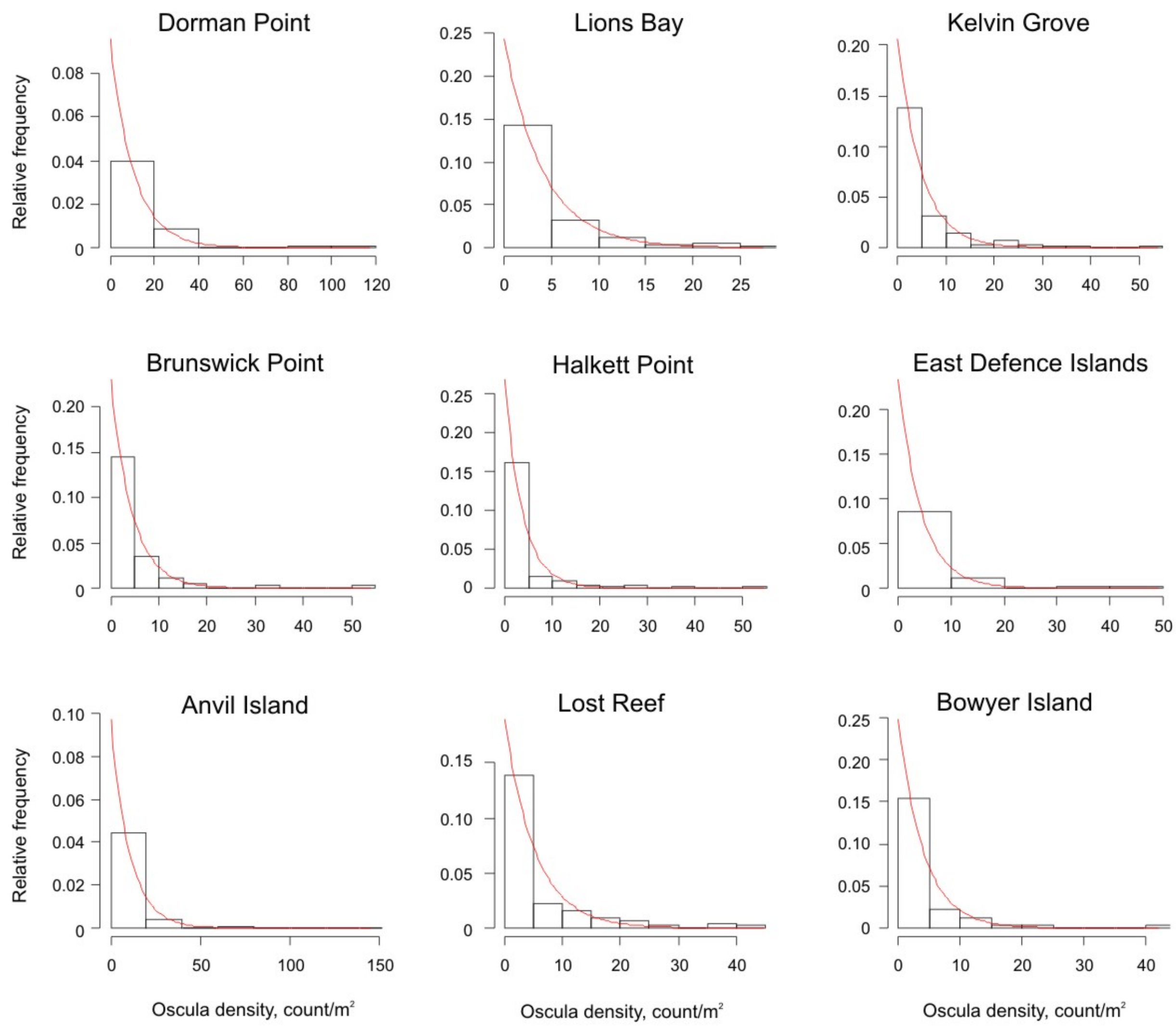


Figure A5-1. Empirical distribution of oscula densities and fitted exponential function (red) for each reef.

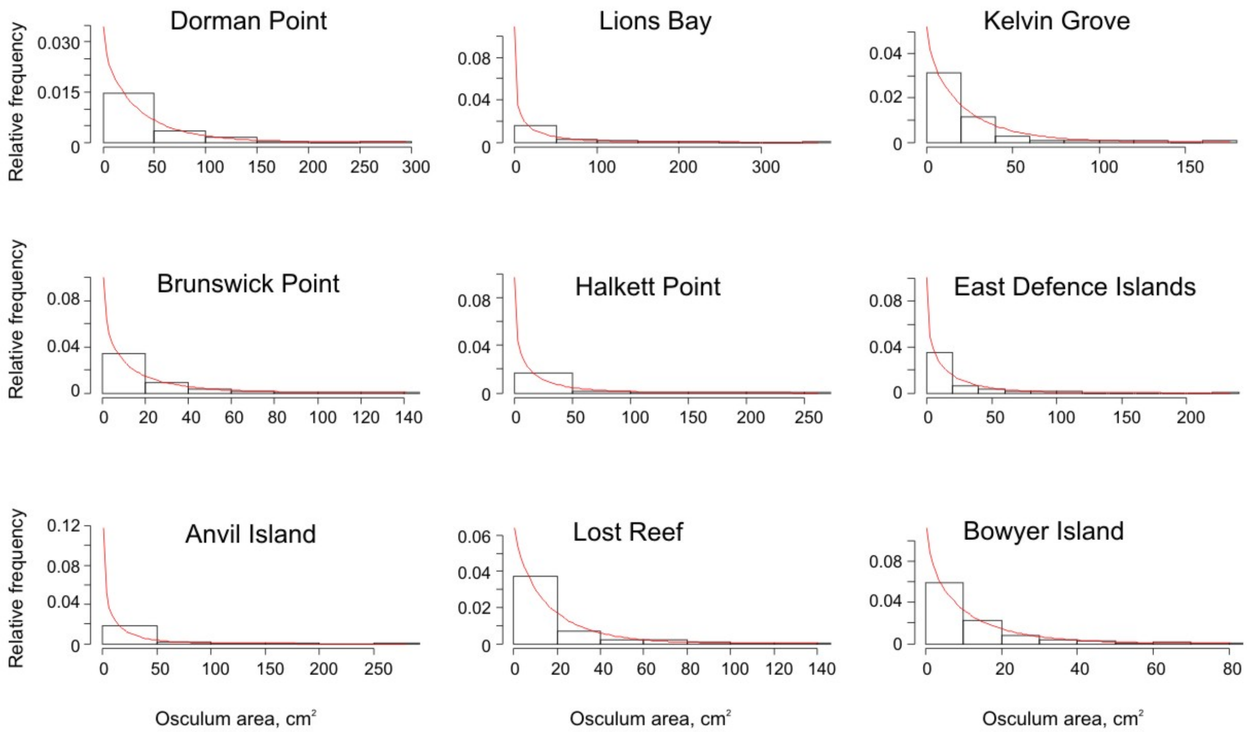


Figure A5-2. Empirical distribution of osculum areas and fitted Weibull distribution (red) for each reef.

Appendix 6. Comparison to other reefs in the Georgia Basin

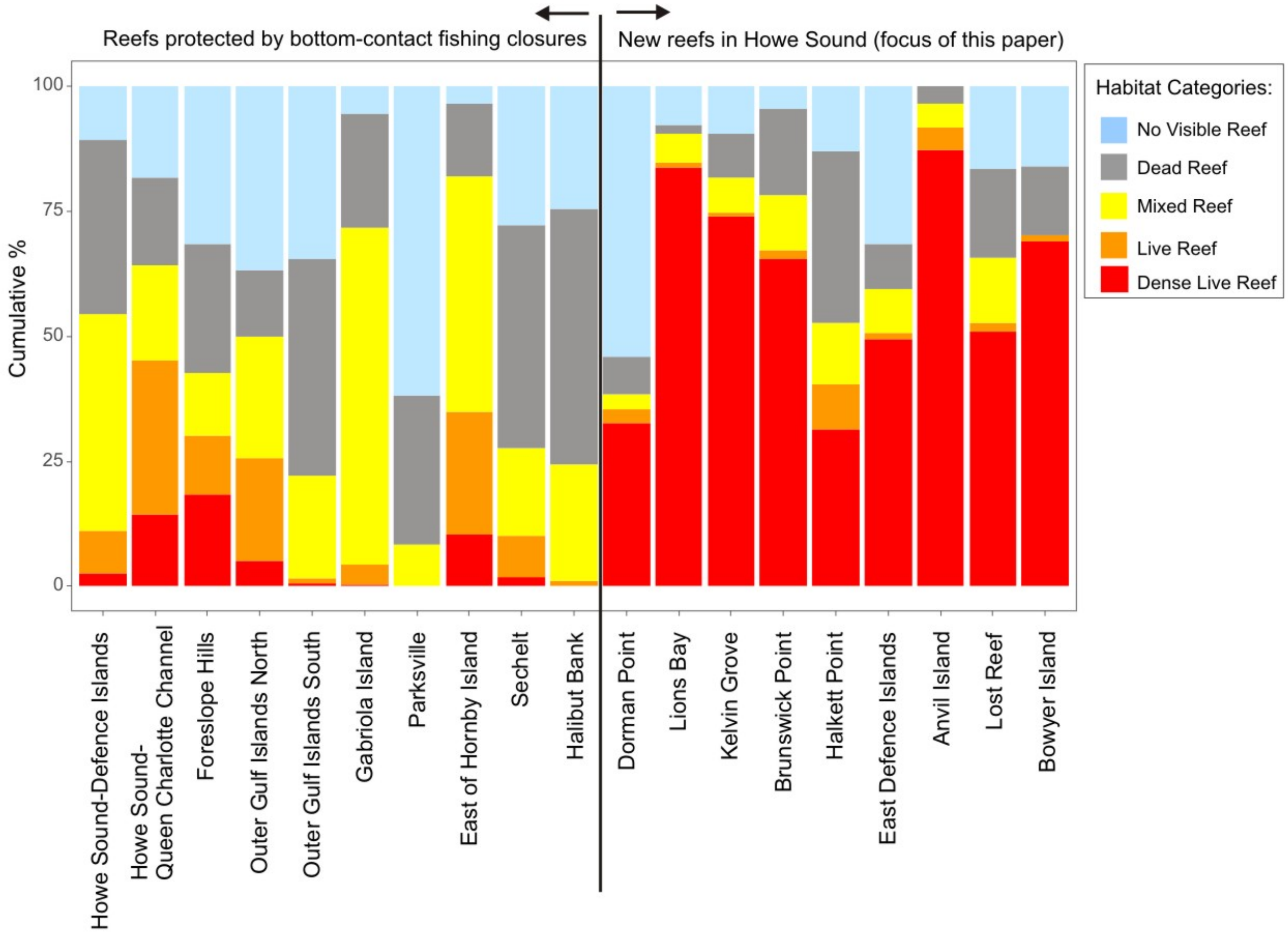
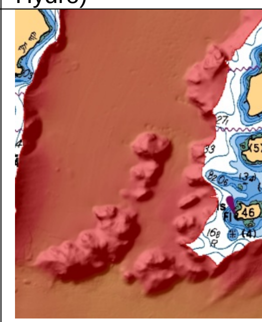
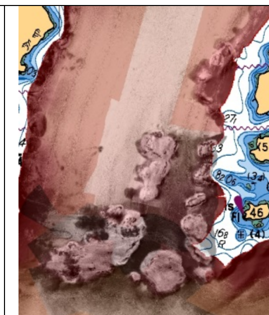
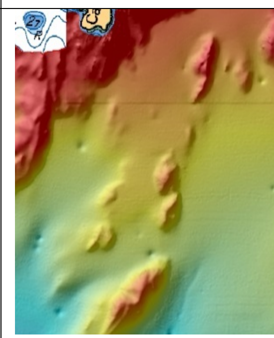
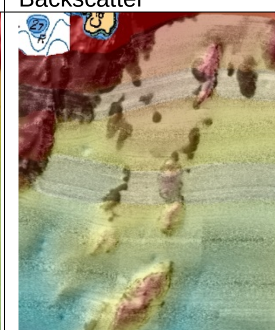


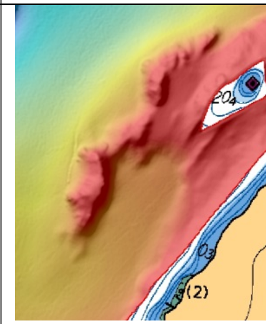
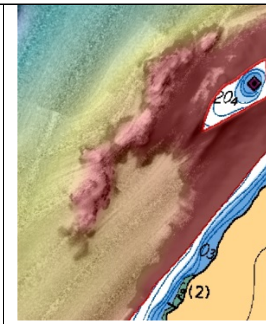
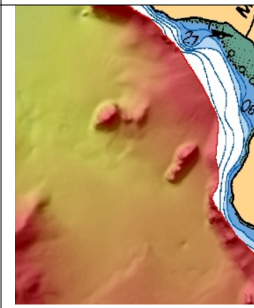
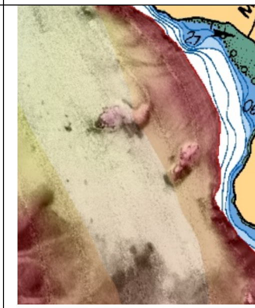
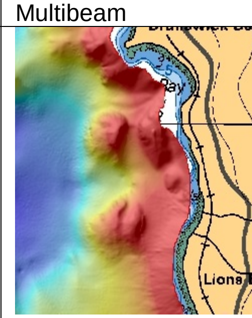
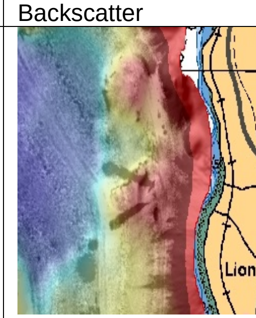
Figure A6-1. Frequency of occurrence of habitat categories: comparison of nine new reefs in Howe Sound with other reefs in the Georgia Basin (already protected by the bottom-contact fishing closures). Note considerably higher proportion of dense live reef habitat (shown in red) within area surveyed.

Appendix 7. Sponge aggregations requiring further ground-truthing and research

Table A5-1. Sponge aggregations supported by either geological or ecological evidence and requiring further ground-truthing and research efforts.

Name	Status, condition	Evidence	Notes	Supporting images
Ellesmere Creek	Reef evidence not detected	Ecological	MLSS survey results indicate reef structure presence with dead and flattened sponge observed. Live reef-building glass sponges not observed. The reef is located on a pinnacle and may be too small to produce a clear geological signature. Recent genetics work (Brown et al. 2016) suggests that genetic mixing occurs among sponge reefs in the Strait of Georgia through larval dispersal; it is possible this area will recover if old reef structure remains intact. Recommendation: Re-visit with drop camera and/or ROV for signs of recovery.	Not available
Christie Islet	Status unknown, live	Ecological	MLSS surveys (dive and drop camera) indicate a sponge aggregation located on a shallow (32 m) rock knoll on the North – Northeast end of the plateau, adjacent to a steep wall. This area is unlikely to be a reef. Recommendation: Continue research on ecological importance of non-reef sponge aggregations (gardens).	Not available

Name	Status, condition	Evidence	Notes	Supporting images	
September Morn Beach	Status unknown, live	Ecological	ROV assessment in June 2017 by Terra Remote and Lake Trail Environmental Consulting for BC Hydro identified a glass sponge aggregation with reef-like appearance. This aggregation may be a reef (too small and/or patchy to produce a clear geological signature) or a sponge garden. Recommendation: Further visual ground-truthing with drop camera and/or ROV. Continue research on ecological importance of non-reef sponge aggregations (gardens).	 Image courtesy of Lora McAuley (Lake Trail Environmental Consulting) and Rob Sicotte (BC Hydro)	
Langdale	Reef, condition unknown	Geological	Clear multibeam and backscatter signatures, good agreement between the two. Good example of what geological reef evidence typically looks like. Recommendation: Survey with drop camera and/or ROV to determine live sponge cover. Glen Dennison, with MLSS, observed glass sponge growing in low density and in large, clumped crowns during dive surveys over the far South East end of the reef. The bottom depth of the dive was around 80 feet deep.	 Multibeam	 Backscatter
Carmelo Point	Reef, condition unknown	Geological	Clear multibeam and backscatter signatures, good agreement between the two. Note 'snow drift' appearance; compare to adjacent rocky knolls that are reflective and therefore a darker colour than the sponge reef. Recommendation: Survey with drop camera and/or ROV to determine live sponge cover.	 Multibeam	 Backscatter

Name	Status, condition	Evidence	Notes	Supporting images	
Collingwood Channel	Reef, condition unknown	Geological	Clear multibeam and backscatter signatures, good agreement between the two. Recommendation: Survey with drop camera and/or ROV to determine live sponge cover. Glen Dennison, with MLSS, noted there are deep sponge gardens on the west side of Bowen Island and shallow gardens on the east side of Keats Island.	 Multibeam	 Backscatter
Mariners Rest	Reef, condition unknown	Geological	Clear multibeam and backscatter signatures, good agreement between the two. Sharp profiles with non-reflective, white colour at highest points. 10-15 m of reef on top of knoll. Recommendation: Survey with drop camera and/or ROV to determine live sponge cover.	 Multibeam	 Backscatter
Alberta Bay	Reef, condition unknown	Geological	Multibeam and some backscatter evidence. Recommendation: Survey with drop camera and/or ROV to determine live sponge cover. May fall within the buffer zone for the Lions Bay, Kelvin Grove, and Brunswick reef complexes. MLSS surveyed the pinnacle with a drop camera and no sponge was observed at the top, around 75 m deep. No dead sponge or old bioherm observed with the drop camera.	 Multibeam	 Backscatter

Name	Status, condition	Evidence	Notes	Supporting images	
Queen Charlotte Channel – additional polygons (outlined in black in supporting images)	Reef, condition unknown	Geological, with some ecological evidence	Multibeam and backscatter evidence. Geological reef polygons were identified as having snow drift morphology typical of a glass sponge reef. MLSS surveyed area with drop camera and SCUBA. Sponge was observed in the northwest polygons but may be already within sponge protected areas. Parts of the north and south-east polygons were surveyed and no sponge reef was observed. Recommendation: Survey with drop camera and/or ROV to determine live sponge cover.	 Multibeam	 Backscatter

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