ELSEVIER INSIGHTS

SEAFLOOR GEOMORPHOLOGY AS BENTHIC HABITAT

GEOHAB ATLAS OF SEAFLOOR GEOMORPHIC FEATURES AND BENTHIC HABITATS

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19 Geomorphic Features and Benthic Habitats of a Sub-Arctic Fjord: Gilbert Bay, Southern Labrador, Canada

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Abstract

Gilbert Bay is a shallow-water, low-gradient, sub-Arctic fjord in southeastern Labrador, Atlantic Canada. The bay is composed of a series of basins separated by sills that shallow toward the head. A major side bay with shallow but complex bathymetry includes important spawning and juvenile fish habitat for a genetically distinct local population of Atlantic cod (*Gadus morhua*). Six acoustically distinguishable substrate types were identified in the fjord, with two additional substrate types recognized from field observations, including areas outside multibeam sonar coverage. Ordination and Analysis of Similarity (ANOSIM) of biotic data generalized five habitat types: hard-substrate habitats developed on cobble-boulder gravel and bedrock bottoms; coralline-algae-encrusted hard-substrate habitats; soft-bottom habitats developed on mud or gravelly mud bottoms; current-swept gravel with a unique biotic assemblage; and nearshore ice-scoured gravels in waters shallower than 5 m depth. Greatest within-habitat biodiversity was found in the coralline-algae-encrusted gravel habitat.

Key Words: fjord, fiord, sill, basin, coralline algae, epifauna, infauna, sub-Arctic, Labrador, Marine Protected Area

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Introduction

p0030 Fjords are geomorphic and biological systems of great interest to geomorphology, oceanography, and marine biology. Fjords typically have complex bathymetry and host highly diverse and heterogeneous habitats [1], making them challenging

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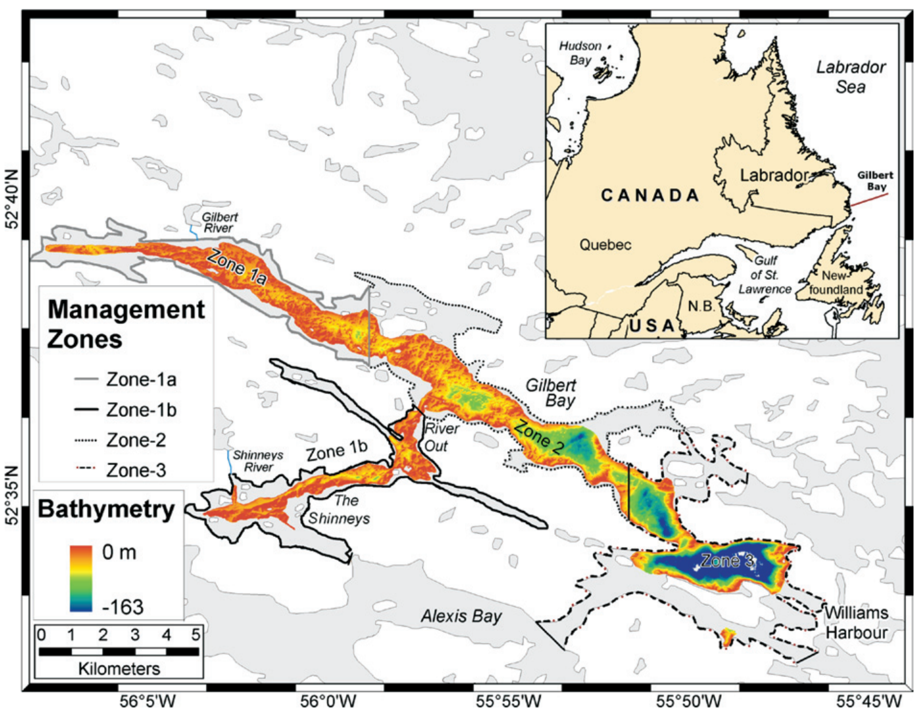
environments for marine habitat mapping using acoustic remote sensing [2]. The fjords of Newfoundland and southern Labrador commonly have relatively low relief, are surrounded by forested watersheds, and exist in boreal to sub-Arctic climatic conditions, making them somewhat different from archetypal fjords of the Canadian High Arctic [3].

p0035 The Gilbert Bay Marine Protected Area (MPA) was gazetted in 2005 to protect the resident Atlantic cod (*Gadus morhua*) stock in the bay. Cod captured in Gilbert Bay display a golden-brown coloration that distinguishes them from other Atlantic cod and earned them the name "golden cod" or "bay cod" [4,5]. Gilbert Bay cod are a genetically distinct population [6] and display high site fidelity within the bay [4,7]. Fisheries and Oceans Canada commissioned habitat mapping research in Gilbert Bay to support management of the MPA.

p0040 Gilbert Bay is a 28 km long, 1–2.5 km wide fjord on the southeastern coast of Labrador, in the boreal to sub-Arctic region of eastern Canada (Figure 19.1). Gilbert Bay is a relatively complex bathymetric system, with seven basins along the length of the fjord separated by six sills [8]. The basins range in depth from 32 m near the head of the bay to 163 m at the mouth. The sills range in depth from 4 to 65 m. The mouth of Gilbert Bay is blocked by islands and is open to the sea through three entrances, all less than 350 m wide. There is a complex of three arms branching to the southwest from the main reach of the bay, at River Out and The Shinneys. These



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f0010 **Figure 19.1** Location map and multibeam sonar-derived bathymetry of Gilbert Bay.

arms contain shallow-water basins, shoals, islands, and tidal channels. The surface of Gilbert Bay is covered by land-fast ice from late November to early May [5]. During the spring and summer, both the Gilbert River and the Shinneys River discharge significant amounts of freshwater from forested watersheds into the bay, turning the sea around the river mouths brown with tannins.

p0045 Most of Gilbert Bay is shallow. On the basis of a multibeam sonar survey [9], slightly more than half of the mapped fjord is shallower than 30 m, only 6% is deeper than 100 m, and the mean depth is 33.2 m [8] (Figure 19.1). Seabed depth and slope increase toward the mouth of the bay. Toward the fjord head, the seabed is flat floored, with less than 5° slope, whereas the margins of the outermost basin have steep slopes up to 68° [8].

p0050 Water clarity in Gilbert Bay is often quite low in the summer—a consequence of tannin-rich runoff from the rivers during spring melt and phytoplankton blooms [5]. The bay has a limited sediment supply; the only sources of mud and sand into the bay are the Gilbert River and the Shinneys River. Most modern sediment is trapped near the mouths of these rivers by shallow sills. The floor of Gilbert Bay reflects its glacial origin. Till composed of mixed sand, gravel, and boulders was deposited as moraines that now form basin sills. Eskers, which are narrow ridges of sandy gravel, are oriented parallel to the fjord coast on the mud basin floors.

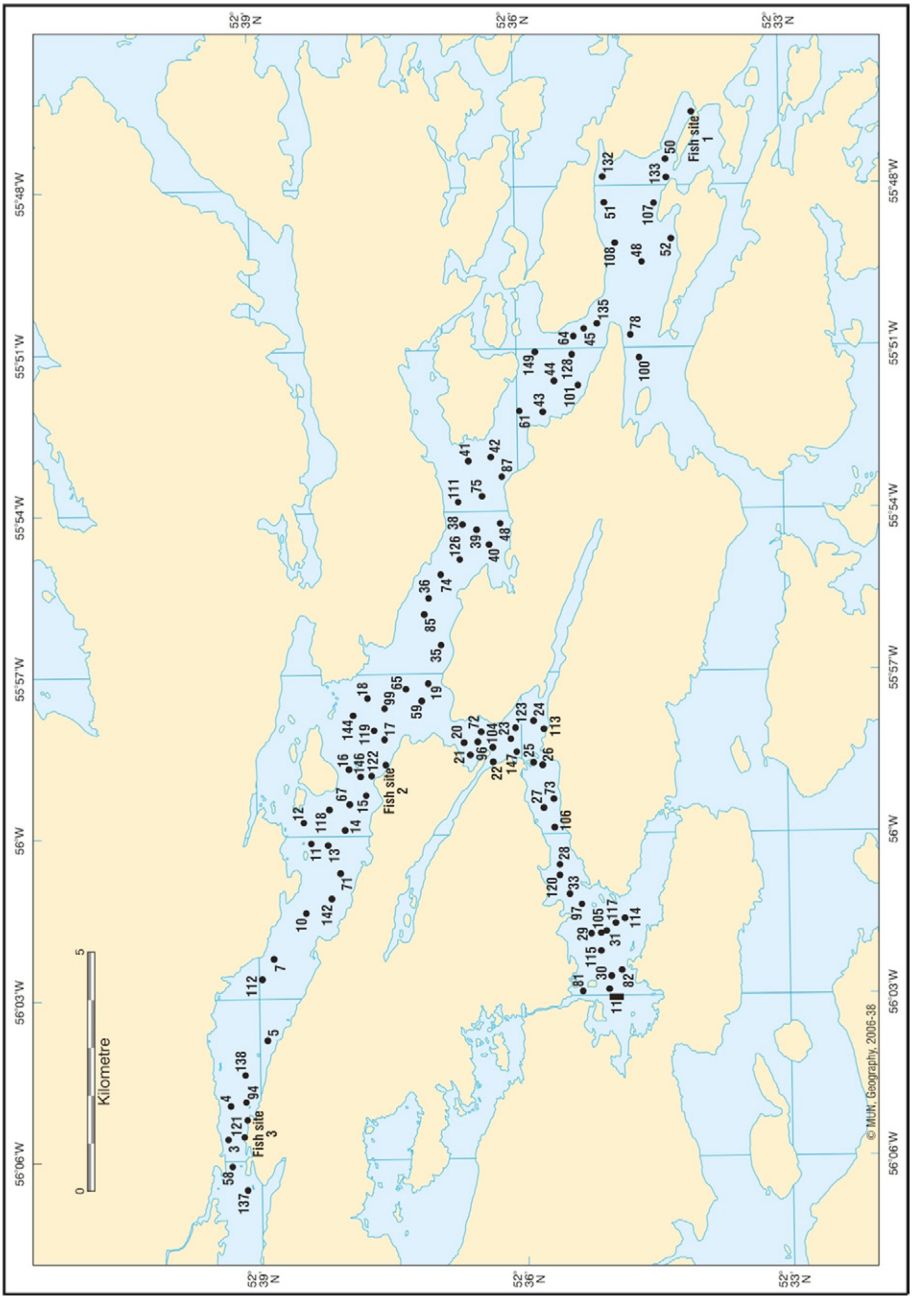
s0015 *Multibeam Sonar Data Acquisition and Ground-truthing*

p0055 The multibeam sonar survey of Gilbert Bay was conducted in 2002 using EM100 and EM3000 transducers. The survey covered 32 km^2 of the total 82 km^2 area of the MPA [9]. There was an extensive littoral gap in shallow areas (mostly <5 m depth) of the bay. Depth and acoustic backscatter values were gridded to 5 m spatial resolution and 0.1 m bathymetric resolution for habitat analyses. Bottom slope angle for each grid cell was calculated from the 5 m bathymetric grid [8].

p0060 The correspondence of depth, slope, and backscatter values to bottom substrate type and benthic biota was determined by extensive ground-truthing using benthic grab samples and bottom video imagery in October of 2006 and 2007 [10,11]. Paired grab samples and drop-video casts were made at 129 stations covering all parts of the bay (Figure 19.2). Position and depth of each grab sample or start and end point of drop-video transect was determined using the boat's GPS and depth sounder, with spatial accuracy better than 3 m and depth resolution of 0.1 m. Twenty-eight drop-video transects of variable length were recorded in shallow water where multibeam sonar data were unavailable.

s0020 *Sediment Sample and Biota Analysis*

p0065 Grab samples were photographed, sub-sampled in duplicate for sediment grain size and organic matter content, and then wet-sieved through 1 mm mesh to recover flora and fauna. Invertebrates and algae present in the washed sample were collected and preserved in 70% ethanol. Video imagery was reviewed, and the percentage of seabed covered by mud, sand, pebble, cobble, boulder, and coralline algae was estimated by the time that each substrate was visible during each video transect [12].



f0015 **Figure 19.2** Distribution of sampling stations from 2006 field season [10]. "Fish sites" 1, 2, and 3 are the standard fish fauna survey sites [26]. Distribution of sampling stations and towed video transects from 2007 field season is indicated in Figure 19.6.

p0070 Grab-sampled biota and biota observed in video were identified to the lowest taxonomic level possible under a dissecting microscope following regional field guides [13,14]. Foraminifera were identified to skeletal type only (calcareous or agglutinated). Organisms recorded in video only were identified by comparison with specimens recovered in grab samples and by reference to published photographs and video footage. Some sponges in video observations were identified to growth form and color only, with a probable species identification indicated.

s0025 *Habitat Classification of Samples and Mapping*

p0075 Field samples of substrates were grouped into habitats by statistical analysis of their biota using multidimensional scaling and Analysis of Similarity (ANOSIM) conducted at the presence–absence level [15]. Substrate classes that had statistically unique biotic assemblages were classified as habitats, while substrate classes with statistically indistinguishable biota were combined into habitats [10,16].

p0080 Supervised classification of depth, slope, and backscatter in the multibeam sonar data set was employed to generate the final substrate and habitat maps [10,11]. Accuracy of the substrate maps was assessed using 20% of the ground-truthing data set reserved for validation.

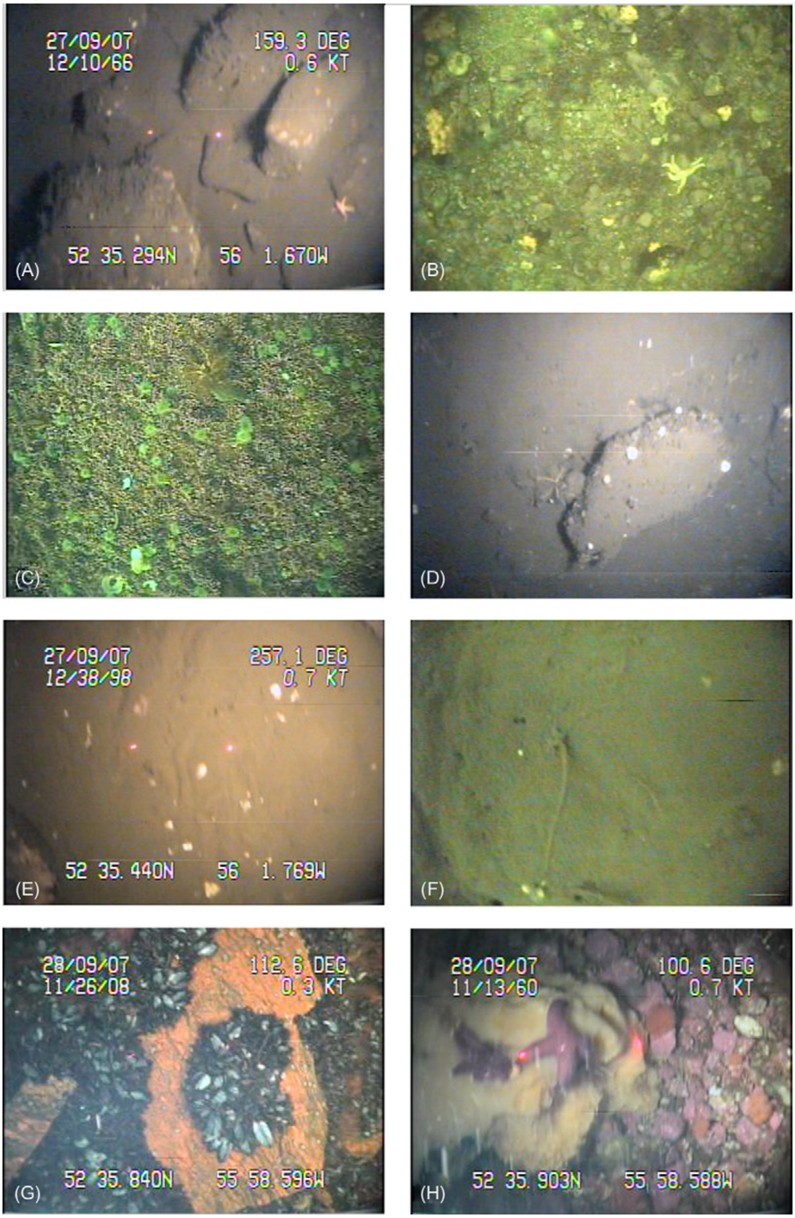
s0030 Geomorphic Features, Substrates, and Habitats

p0085 Nine substrate types were identified in Gilbert Bay, of which six had distinct acoustic characteristics allowing them to be mapped using multibeam sonar.

p0090 *Sills, eskers, fjord walls, and other hard-substrate features*: Three substrates—muddy gravel, sandy gravel, and coralline-algae-encrusted gravel—generally occurred on top of the interbasin sills, along submerged eskers in the basins, or in shallow current-swept or wave-exposed waters. Muddy gravel substrate was characterized by pebble, cobble, and boulder gravel in a mud matrix. The gravel component was either draped by mud or exposed (Figure 19.3A). Sandy gravel substrate also contained pebble to boulder gravel, but in a sand matrix (Figure 19.3B). Pebbles, cobbles, and boulders that were more than 50% covered by branching coralline red algae were classified as coralline-algae-encrusted-gravel substrate. The key features of this class were extensive algal growth and the presence of algae-forming structures, rather than algae simply encrusting the gravel clasts. This class included both algae-coated lithic clasts and rhodoliths lacking a gravel core, which were composed completely of calcium carbonate algal skeletons (Figures 19.3C and 19.4).

p0095 Coralline-algae-encrusted gravel was distributed along the margins of the bay, in the shallow upper part of the bay, and in River Out (Figures 19.5 and 19.6). The nearshore gravel substrate is present in very shallow waters of the bay, where it was mapped by continuous video transects outside the area of multibeam sonar coverage (Figure 19.6).

p0100 Two additional gravel-bottom substrate classes were defined by towed video from The Shinneys and River Out, but were not effectively sampled by grab sampler. The nearshore gravel class (Figure 19.3G) was characterized by pebbles, cobbles, and boulders, the latter in some cases over a meter in diameter, in very shallow water. Mud



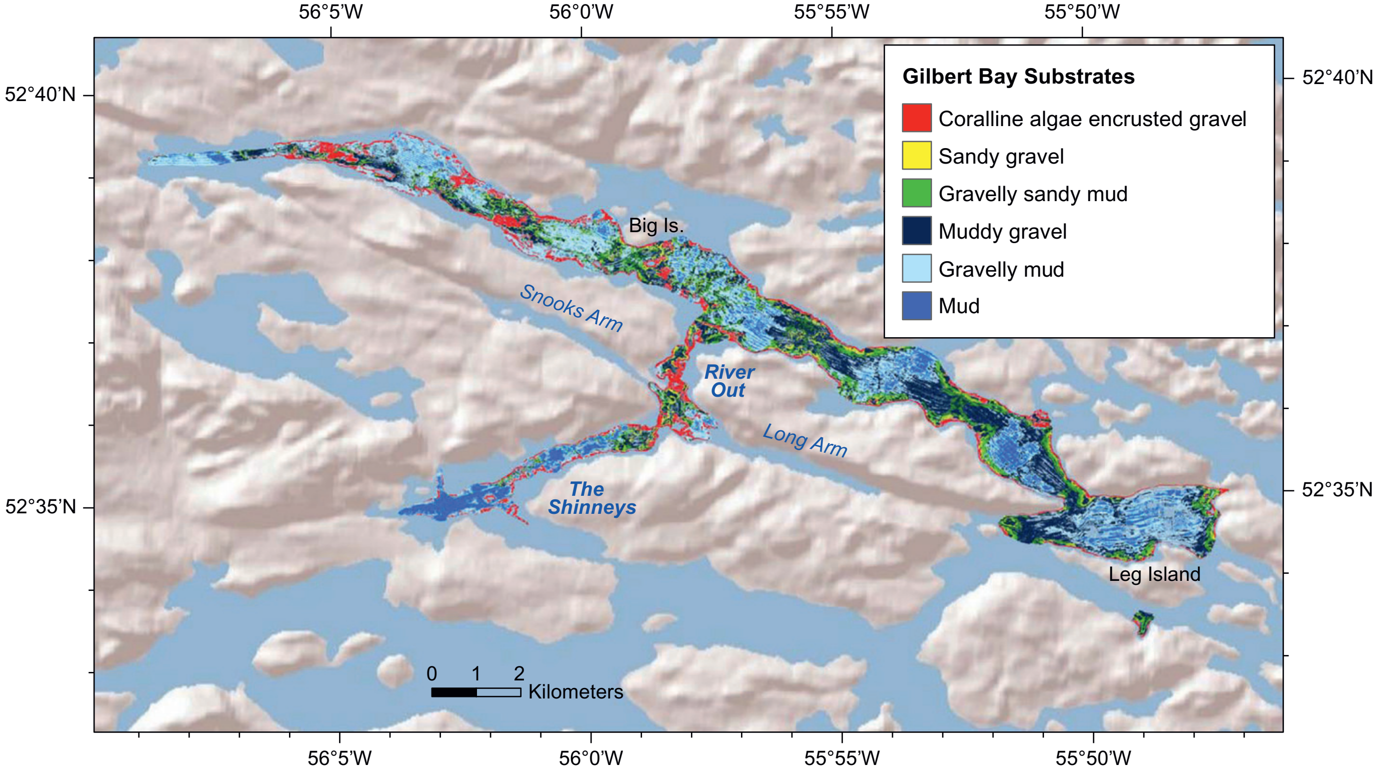
f0020 **Figure 19.3** Photo plate of substrates mapped in Gilbert Bay: (A) muddy gravel; (B) sandy gravel; (C) coralline-algae-encrusted gravel; (D) gravelly muddy sand; (E) gravelly mud; (F) mud; (G) nearshore gravel; (H) current-swept gravel. Red laser points are 10 cm apart but are not clearly visible in all photos. In coralline-algae-encrusted gravel (3C), green objects are echinoids (*Strongylocentrotus droebachiensis*), while red-brown background is rhodolith. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this book).

f0025 **Figure 19.4** Rhodoliths composed of the branching calcareous red alga *Lithothamnion glaciale* sampled from River Out.

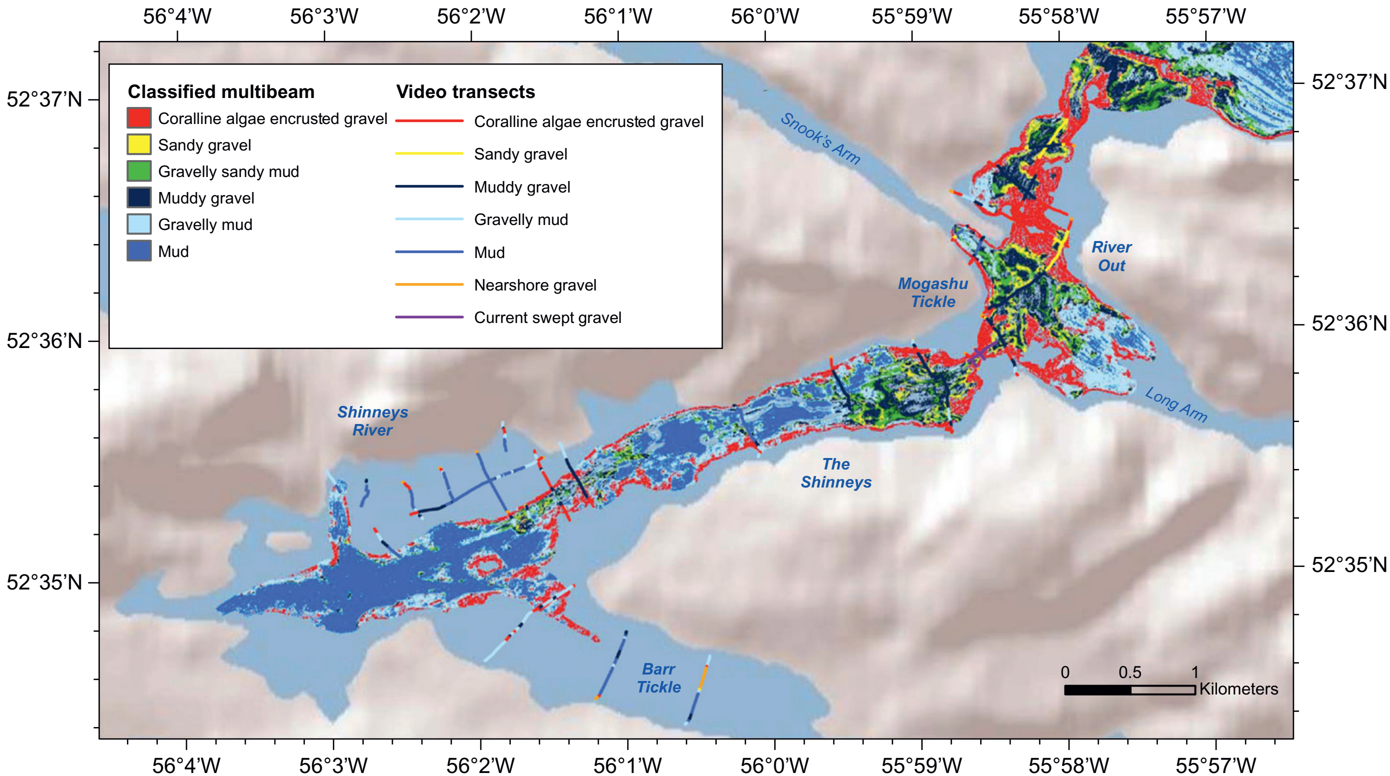
or sand was usually absent, and coralline algae were never observed on this substrate. Finally, the current-swept gravel substrate class (Figure 19.3H) was characterized by sediment-free pebbles, cobbles, and scattered small boulders encrusted by nonbranching coralline algae. This substrate was only found in the high-current channel through Mogashu Tickle (Figure 19.6). Bedrock walls were rare in Gilbert Bay, occurring mostly around the margins of the deepest basin closest to the mouth of the fjord, and were acoustically indistinct from the muddy gravel substrate.

p0105 *Basins*: Finer-grained substrates were generally found in the basins between sills, except for shallow water mud habitat found in The Shinneys. Gravelly sandy mud substrate (Figure 19.3D) was defined by a matrix composed primarily of mud, with 7–41% medium (2ø) to very fine sand (4ø) by weight. This is primarily a poorly sorted, matrix-dominated substrate with scattered gravel clasts. In contrast, the gravelly mud class (Figure 19.3E) had a mostly mud (<4ø) matrix with a small amount of fine sand and isolated gravel clasts. Samples were classified as mud (Figure 19.3F) if their matrix was dominated by silt and clay with no more than 4% fine sand and they contained no gravel. Gravelly mud dominates the shallow basins near the head of the fjord, whereas mud is more common in the deeper basins toward the mouth. The only place where mud was mapped in shallow water was at the head of The Shinneys near the river mouth (Figure 19.6).

p0110 Overall, the mapped seabed of Gilbert Bay was composed of 41% gravelly mud, 38% muddy gravel, 10% each of gravelly sandy mud and mud, 8% coralline-algae-encrusted gravel, and 4% sandy gravel [10]. The area occupied by both current-swept gravel and bedrock walls was less than 1% [11]. Nearshore gravel was not included



f0030 **Figure 19.5** Benthic substrate map of Gilbert Bay created by supervised classification of multibeam sonar data from ground-truth samples collected in 2006. White patches in the map represent islands, shoals, or other gaps in the sonar coverage [10]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this book).



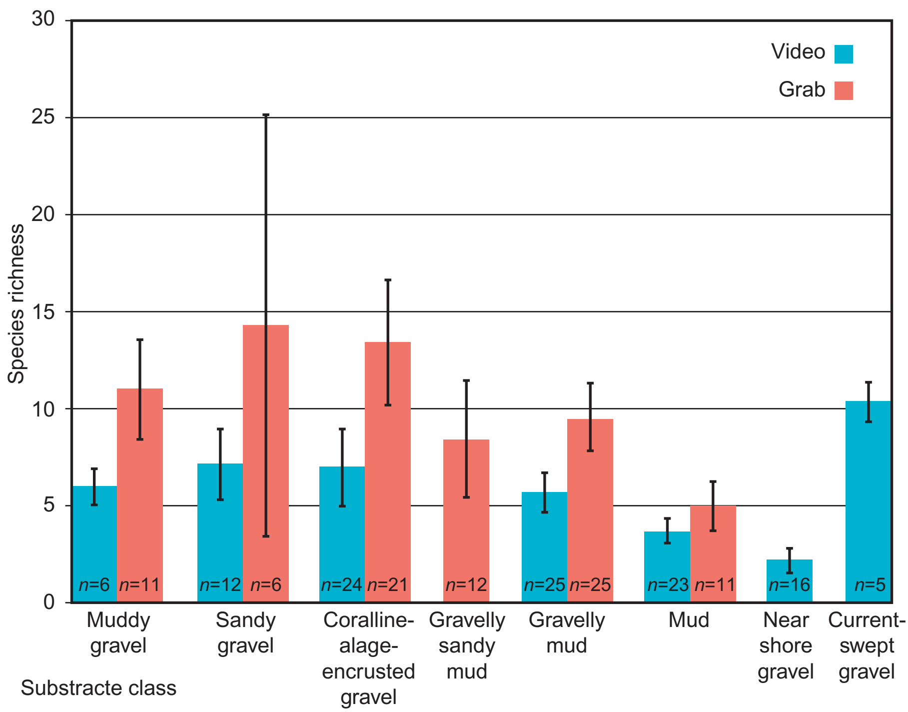
f0035 **Figure 19.6** Substrate map of The Shinneys and River Out portions of Gilbert Bay, with classified video transects collected in 2007 overlain on the multibeam-derived substrate map from 2006 [11].

in the seabed cover estimate because it occupies the littoral gap between the water-depth limit of multibeam coverage and the shoreline. The total classified surface area of the bay is 111% due to classification ambiguity. Whereas 61% of the bay was uniquely classified, 22% met depth, backscatter, and slope criteria for two or three classes, and 16% remained unclassified. Classification accuracy as determined by the test data set was 69%, with 20 of 29 test points correctly classified, 5 incorrectly classified, and 4 unclassified [10].

p0115 Submerged glacio-fluvial features such as eskers and fans were identified in the upper part of the bay and at the mouth of River Out [8,10]. The shallowest parts of these features were dominated by cobble gravel and coralline algae, whereas deeper sections were draped in mud. Winnowing was particularly evident in the tidal rapids in the channel through Mogashu Tickle. With distance from Mogashu Tickle, the current-swept gravel transitioned to sandy gravel, muddy gravel, and soft-bottom substrates (Figure 19.6).

s0035 Surrogacy: From Substrate Maps to Habitat Maps

p0120 Average species richness was higher in the grab samples than in the video transects (Figure 19.7), primarily because of high diversity of polychaete worms in the



f0040 **Figure 19.7** Species richness of substrates sampled in Gilbert Bay. Mean ± 95% confidence interval; number of samples in each substrate type and sample type indicated on bars [11].

bottom grabs. Species richness was generally higher in the gravelly substrates than in the muddy substrates. Among the gravelly substrates, highest species richness was observed in the current-swept Mogashu Tickle gravel, followed by the coralline-algae-encrusted gravel. Lowest species richness was observed in the mud substrate.

p0125 Statistical analysis of the sampled biota using ANOSIM and Percentage Similarity (SIMPER) identified five habitats in Gilbert Bay: (Tables 19.1–19.4)

o0010 **1.** *Gravel bottom habitat*: Gravel bottom habitat combines muddy gravel and sandy gravel substrate classes (Figure 19.3A and B), as they were statistically indistinguishable [10]. Gravel bottom habitat was dominated by epifaunal taxa, such as *Spirorbis* sp., tube worms, bryozoans, chitons, foraminifera, and encrusting sponges. The limited areas of bedrock sampled had biota statistically equivalent to that of the other gravel bottom habitats.

o0015 **2.** *Soft-bottom habitat*: The mud, gravelly mud, and gravelly sandy mud substrates contained a statistically indistinguishable biotic assemblage dominated by polychaetes, particularly

t0010 **Table 19.1** ANOSIM Results Table for Video Data

	Muddy Gravel	Sandy Gravel	Coralline-Algae-Encrusted Gravel	Gravelly Sandy Mud	Gravelly Mud	Mud
Muddy gravel	–					
Sandy gravel	51.5	–				
Coralline-algae-encrusted gravel	1.8	16.0	–			
Gravelly sandy mud	0.1	0.1	0.1	–		
Gravelly mud	0.1	0.1	0.1	41.7	–	
Mud	0.1	0.1	0.1	34.8	47.1	–

Numbers indicate probability of p-values, in percent (i.e., $p = 0.05$ is represented as 5.0) [10].

t0015 **Table 19.2** ANOSIM Results Table for Grab Samples

	Muddy Gravel	Sandy Gravel	Coralline-Algae-Encrusted Gravel	Gravelly Sandy Mud	Gravelly Mud	Mud
Muddy gravel	–					
Sandy gravel	41.5	–				
Coralline-algae-encrusted gravel	0.1	26.7	–			
Gravelly sandy mud	5.5	4.2	0.1	–		
Gravelly mud	0.1	0.1	0.1	9.7	–	
Mud	0.2	2.4	0.1	44.8	47.5	–

Numbers indicate probability of p-values, in percent (i.e., $p = 0.05$ is represented as 5.0) [10].

t0020

Table 19.3 Characteristic Taxa of Each Substrate, Video Transect Data

	Muddy Gravel	Sandy Gravel	Coralline-Algae-Encrusted Gravel	Gravelly Sandy Mud	Gravelly Mud	Mud	Nearshore Gravel	Current-Swept Gravel	Bedrock
1	*Strongylocentrotus droebachiensis* green sea urchin (25.16)	*Leptasterias polaris* polar sea star (20.83)	*Strongylocentrotus droebachiensis* green sea urchin (23.32)	Infaunal bivalve (siphon pits) (23.48)	Burrows (32.84)	Burrows (42.94)	*Strongylocentrotus droebachiensis* green sea urchin (85)	*Henricia* sp. (13)	Bivalve shell hash (59)
2	*Halichondria panicea* sponge (20.19)	*Chlamys islandica* (live) scallop (16.41)	*Leptasterias polaris* polar sea star (22.58)	Trails (18.44)	Infaunal bivalve (siphon pits) (16.46)	Infaunal bivalve (siphon pits) (25.75)	*Mytilus edulis* Mussel (7.6)	*Crossaster papposus* spiny sunstar (13)	Branching bryozoans (27)
3	Bivalve shell hash (12.12)	*Asterias vulgaris* sea star (10.95)	*Chlamys islandica* (live) scallop (10.99)	Ophiuroidea brittle star (16.04)	Trails (7.97)	Trails (18.65)		*Leptasterias polaris* polar sea star (13)	Hydroids (7)
4	*Crossaster papposus* spiny sunstar (11.16)	*Strongylocentrotus droebachiensis* green sea urchin (10.12)	Branching coralline red algae (live) (10.46)	Burrows (15.48)	*Halichondria panicea* sponge (6.95)	Ophiuroidea brittle star (10.40)		*Strongylocentrotus droebachiensis* green sea urchin (13)	
5	*Leptasterias polaris* polar sea star (8.41)	*Halichondria panicea* sponge (9.86)	Encrusting coralline red algae (4.23)	*Halichondria panicea* sponge (11.16)	*Strongylocentrotus droebachiensis* green sea urchin (6.67)			Hydroids (8)	

6	Ophiuroidea brittle star (7.02)	*Crossaster papposus* spiny sunstar (8.53)	Branching coralline red algae (dead) (4.21)	Bivalve shell hash (3.99)	Ophiuroidea brittle star (6.16)		*Halichondria panicea* sponge (8)
7	*Chlamys islandica* (live) scallop (3.82)	Bivalve shell hash (5.09)	Hydroids (4.12)	*Strongylocentrotus droebachiensis* green sea urchin (3.68)	Polychaete tubes (4.62)		Barnacle (8)
8	Branching bryozoan (3.70)	Ophiuroidea brittle star (4.23)	*Crossaster papposus* spiny sunstar (4.10)		Articulated bivalve shell (dead) (3.90)		*Chlamys islandica* (live) scallop (8)
9		Finger sponge (4.23)	*Metridium senile* frilled anemone (3.98)		Branching bryozoan (3.57)		*Gersemia rubiformis* soft coral (4)
10			*Halichondria panicea* sponge (3.09)		*Crossaster papposus* spiny sunstar (3.36)		Encrusting coralline algae (4)

Numbers indicate the percent contribution to within-substrate faunal similarity, computed at presence–absence scale [10,11].

t0025

Table 19.4 Characteristic Taxa of Each Substrate, Grab Sample Data

	Muddy Gravel	Sandy Gravel	Coralline-Algae-Encrusted Gravel	Gravelly Sandy Mud	Gravelly Mud	Mud
1	*Spirorbis borealis* (21.06)	*Spirorbis granulatus* (39.56)	*Anomia squamula* jingle shell (33.35)	Mud polychaete tubes (16.43)	*Thyasira flexuosa* bivalve (20.41)	*Thyasira flexuosa* bivalve (59.32)
2	*Spirorbis granulatus* (8.23)	*Spirorbis borealis* (18.28)	Branching coralline red algae (19.58)	*Thyasira flexuosa* bivalve (14.58)	*Ctenodiscus crispatus* mud star (15.08)	*Ctenodiscus crispatus* mud star (29.66)
3	*Serpula* sp. (7.15)	*Serpula* sp. (8.77)	*Spirorbis granulatus* (13.66)	Unidentified polychaete (14.23)	Mud polychaete tubes (12.56)	*Periploma papyratium* bivalve paper spoon shell (11.02)
4	*Tubulipora* sp. bryozoan (5.51)	*Balanus balanus* barnacle (8.14)	Encrusting coralline red algae (5.25)	*Goniada maculata* chevron worm (10.96)	*Nucula tenuis* nut shell (10.64)	
5	*Stomachetosella sinuosa* (4.99) bryozoan	Encrusting coralline red algae (6.82)	*Tonicella rubra* chiton (5.13)	*Nuculana tenuisulcata* bivalve (7.85)	Unidentified polychaete (9.31)	
6	Muddy polychaete tube (4.75)	*Anomia squamula* (5.80) jingle shell	*Balanus balanus* barnacle (5.07)	*Nucula tenuis* nut shell (4.43)	*Goniada maculata* chevron worm (6.79)	
7	*Nuculana tenuisulcata* bivalve (4.58)	*Escharella immersa* bryozoan (2.32)	*Porella* sp. bryozoan (1.67)	*Pectinaria granulata* (3.49) trumpet worm	Maldanid polychaete (4.81)	
8	*Balanus balanus* barnacle (4.15)	*Tubulipora* sp. bryozoan (2.32)	Calcareous forams (1.52)	*Anomia squamula* jingle shell (3.24)	Sandy polychaete tube (2.54)	
9	*Turritellopsis acicula* (3.53) needle shell		*Tubulipora* sp. bryozoan (2.71)	*Ophiura robusta* (2.86) brittle star	*Nuculana tenuisulcata* bivalve (2.23)	
10	Calcareous foraminifera (3.34)		*Hiatella arctica* (1.29) boring bivalve	*Turritellopsis acicula* (2.58) needle shell	*Pectinaria granulata* (1.71) trumpet worm	

Numbers indicate the percent contribution to within-substrate faunal similarity, computed at presence–absence scale [10,11].

the tube-dwelling Maldanidae family, burrowing bivalves, particularly *Thyasira flexuosa, Nucula tenuis,* and *Nuculana tenuisulcata*, mud stars (*Ctenodiscus crispatus*), and ophiuroids.

o0020 **3.** *Coralline-algae habitat*: The coralline-algae-encrusted gravel substrate supported the most diverse biota within the bay, including hydroids, nestling and boring bivalves, polychaete worms, chitons, sea urchins, bryozoans, and anemones.

o0025 **4.** *Current-swept gravel habitat*: The current-swept gravel in Mogashu Tickle hosted biota rarely sampled elsewhere in Gilbert Bay, including the soft coral *Gersemia rubiformis* and basket star *Gorgonocephalus arcticus*. Other characteristic taxa included filter-feeding epifauna such as hydroids and encrusting sponges, green sea urchins (*Strongylocentrotus droebachiensis*), the sea stars *Henricia* sp., *Crossaster papposus*, and *Leptasterias polaris*, and Iceland scallop (*Chlamys islandica*). The current-swept gravel in Mogashu Tickle could not be mapped through classification of the multibeam sonar data because it did not exhibit unique acoustic characteristics.

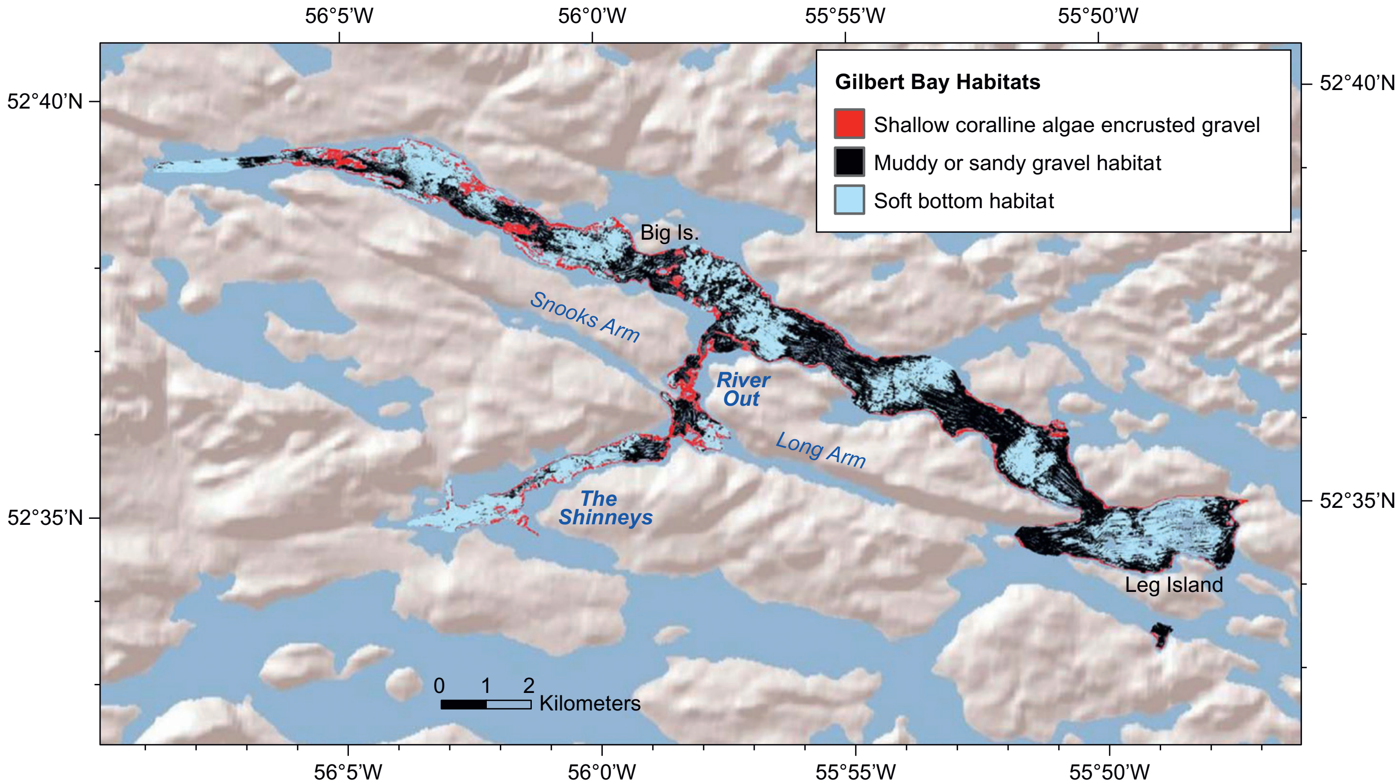
o0030 **5.** *Nearshore gravel habitat*: Nearshore gravel also generated a statistically distinct habitat due to its impoverished fauna. Generally it appeared devoid of attached biota, with the exception of blue mussels (*Mytilus edulis*), which occupied gaps among the gravel (Figure 19.3G). It is likely therefore that this habitat is scoured by land-fast ice during the winter and spring. The only other biota present were large numbers of green sea urchins (*Strongylocentrotus droebachiensis*), which, together with the ice scour, would maintain an algae-free gravel surface.

p0155 The final map of interpreted habitats of Gilbert Bay does not include current-swept gravel, nearshore gravel, or bedrock, because their distributions are quite limited, not acoustically distinct, or not surveyed by multibeam sonar (Figure 19.8). The coralline-algae-encrusted gravel habitat was found along the margins of the bay, especially in River Out and The Shinneys, and on the tops of the sills near the head of the fjord. Closer to the fjord mouth, the sills are too deep to support dense growth of coralline algae.

s0040 Discussion

s0045 *Geomorphic and Biotic Contributions to Habitat*

p0160 The habitats identified in Gilbert Bay were all geomorphic in origin, with the exception of the coralline-algae-encrusted gravel. The current-swept gravel habitat in Mogashu Tickle is unique within the bay, and hosts very high invertebrate abundance, including a high density of scallops [11], and species diversity, including species not sampled elsewhere in Gilbert Bay (Figure 19.7; [11]). The only biologically structured habitat, coralline-algae-encrusted gravel, was found in shallow water areas throughout the bay, but was best developed in River Out and The Shinneys. An extensive rhodolith bed was identified in River Out. The rhodolith bed differed from most other coralline-algae-encrusted gravel habitat in that there was no gravel core to the rhodoliths, and no algae-free gravel was observed in videos. MPA regulations protect the head of the bay, River Out, and The Shinneys from scallop dragging and other fishing.



f0045 **Figure 19.8** Benthic habitat map of Gilbert Bay created by supervised classification of multibeam sonar data from ground-truth samples collected in 2006. White patches in the map represent islands, shoals, or other gaps in the sonar coverage [10]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this book).

p0165 The almost complete absence of large kelp (laminariales) and seagrasses may be a consequence of very high tannin concentrations in the waters of Gilbert Bay during the summer, resulting in a shallow photic zone limit of 7.6–11.5 m [5]. The high tannin concentrations in the water originate from the forested watersheds feeding it and the limited water exchange at the entrances to the bay [5]. The shallow photic zone, combined with extensive ice scour in water shallower than 5 m, likely restricts macroalgal growth, except for coralline red algae, which typically requires less light than most macroalgae [17,18]. Large macroalgae including *Laminaria*, *Saccharina*, *Agarum*, *Alaria*, *Fucus*, and *Ascophyllum* are common on hard-substrate bottoms in the Canadian High Arctic and in boreal and sub-Arctic fjords surrounding the North Atlantic [18,19].

p0170 *Gilbert Bay cod habitat*: River Out and The Shinneys contained extensive areas of coralline-algae-encrusted gravel and sandy gravel, with mud in shallow basins between shoals composed of coralline algae on gravel or bedrock. This area may provide feeding habitat for juvenile Gilbert Bay cod due to the high invertebrate abundance and diversity of potential prey. Benthic invertebrates made up a higher than expected component of the stomach contents of Gilbert Bay cod, particularly in The Shinneys [4].

p0175 The substrate of a known cod spawning site in the Inner Shinneys consisted of coralline-algae-encrusted boulders and silt [20]. Juvenile cod require structured habitat to avoid predation; in other Newfoundland and Labrador bays, this is typically provided by gravel and marine vegetation, including eelgrass (*Zostera marina*; [21–23]) or macroalgae [24]. In Gilbert Bay, the required structured habitat is likely provided by complex bathymetry, coarse gravel, and coralline algae. Geomorphic features, such as moraine-capped sills and eskers, contribute to habitat complexity[25], while coralline algae and gravelly mud likely provide high density of invertebrate food sources.

p0180 The age-specific nature of substrate choices have been documented in other Newfoundland cod populations [23], which is likely the case with Gilbert Bay cod also. Therefore, one single “cod habitat” can likely not be defined for Gilbert Bay, but our work enhances knowledge of the potential habitats available to fish in different parts of the bay [26].

s0050 *Anthropogenic Impacts*

p0185 Coralline-algae-encrusted gravel is the most likely habitat to suffer negative effects from human disturbance. This habitat is vulnerable to disturbance where scallop dragging occurs in the outer two-thirds of the main bay and where dragging depths (8–20 m) coincide with the mapped occurrence of rhodolith and coralline-algae-encrusted gravel habitat (4–15 m water depth). This is cause for concern given the documented impacts that scallop dragging has on coralline-algae-based habitats (*cf.* maerl) in other locations [27].

p0190 Gilbert Bay scallop harvesters reported fishing for scallops primarily on coralline algae, pebble, cobble, and small boulder substrates [20]. Iceland scallops are among the top three taxa contributing to similarity in samples in the sandy gravel and coralline-algae-encrusted gravel substrate classes. Scallops also appeared in the characteristic biota for the muddy gravel class, but were less important. High scallop densities were observed in Mogashu Tickle and immediately adjacent parts of the Outer Shinneys. Analysis of the scallop growth rates and size-frequency distributions in Gilbert Bay in relation to fishing effort strongly suggests that the Gilbert Bay scallop stock is overfished [28,29]. Scallop fishing as historically practiced in Gilbert Bay was incompatible with the habitat conservation objectives of the MPA. As a conservation measure, the spatial footprint of the scallop fishery in Gilbert Bay was limited to a subset of its pre-MPA.

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