Final Report
DFO Contract to Memorial University of Newfoundland

Habitat Mapping in Gilbert Bay, Labrador - A Marine Protected Area: Phase II Final Report

Marine Habitat Mapping Group
Memorial University of Newfoundland

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**Cover image caption** : Oblique view of the seabed bathymetry of Gilbert Bay, near the mouth of River Out, showing the distribution of benthic substrates (see report for legend). The sharp-crested sinuous ridge (red) running across the mouth of River Out is a submerged glacial esker, which provides an important substrate for coralline algae habitat.

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Overview
The overall goal of Phase II seabed mapping in Gilbert Bay Marine Protected Area was to classify benthic substrate and habitat types from multibeam bathymetric and backscatter data of the seabed. Research included benthic substrate imaging and sampling, sample analysis, data processing and classification, and map production.

Ground-truth sampling conducted in early October, 2006, collected bottom sediment and biotic samples and bottom video segments from 101 sites over seven boat days. Sampling exceeded expected sample recovery by 40%. Bottom video transects were usually four minutes in length, and often entailed enough drift that more than one habitat type was covered by a given bottom video transect. Sediment samples were wet-sieved and classified according to the Wentworth size scale. All biotic samples were identified to the lowest taxonomic level possible (genus or species, family for some of the polychaete worms). Substrates and biota were also identified in video.

Six substrate classes were identified from the sampling program: muddy gravel, sandy gravel, coralline-algae encrusted gravel, gravelly sandy mud, gravelly mud, and mud. The distribution of depth, backscatter, and slope for the pixels represented by the sampling stations were described using Exploratory Data Analysis (EDA). Multibeam supervised classification rules for the six substrate types were developed based upon the EDA. Over 60% of the pixels in the multibeam dataset were uniquely classified, whereas 22% were assigned to either two or three classes. Only 16% of pixels remained unclassified based on our classification rules. Ten percent of the sample points (n=29) were randomly excluded from the supervised classification dataset in order to test the classification accuracy. Of these 29 points, 20 were correctly classified, 5 were incorrectly classified, and 4 were unclassified, according to the supervised classification.

The biota on some of the six substrate classes was statistically identical, such that only three mapable and statistically unique habitat types could be defined for Gilbert Bay: gravel-bottom, shallow coralline-encrusted gravel, and soft-bottom habitats. Soft bottom habitat is restricted to basin floors, both in shallow and deep water. Hard gravel-bottom habitats occur on basin margins and sills. Coralline algae-encrusted gravel habitat is depth-restricted and only occurs in shallow water, whereas muddy or sandy gravel habitat is mapped at a range of water depths from shallow to moderately deep. The following observations on habitat distribution and diversity in Gilbert Bay are highlighted: (i) Areas with multiple habitat types represented in a small area are of greatest biological significance, such as River Out and The Shinneys; (ii) Substrate and habitat units mostly have geological origins, and understanding the recent glacial evolution of Gilbert Bay will be important to understanding the habitats; (iii) Scallop habitat is found on shallow gravel and coralline algae-encrusted gravel bottoms and closely matches those scalloping grounds mapped by traditional ecological knowledge; and (iv) The Gilbert Bay population of Atlantic Cod probably occupies habitat on most of the hard substrates, and areas with closely juxtaposed hard and soft bottoms.
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Research Objectives and Rationale

The overall goal of Phase II seabed mapping in Gilbert Bay Marine Protected Area (MPA; Figure 1) is to classify benthic substrate and habitat types from multibeam bathymetric and backscatter data of the seabed using ground-truth data. Specifically, classification rules developed based on ground-truth data acquired during an underwater video and grab sampling field sampling program in October, 2006. This approach provides an assessment of the accuracy of map products and identifies limitations of the classification procedure.

The ecosystem-based management plan for Gilbert Bay, Labrador, requires information on benthic habitats to generate scientifically-defensible management decisions. For example, the ocean bottom within each of the three management zones must be classified and mapped for habitat monitoring purposes (Anderson et al. 2002). This research directly addresses these scientific requirements through the generation of benthic substrate and habitat maps of Gilbert Bay from available multibeam bathymetric and backscatter data (Phase I; Copeland et al. 2006) and a new seabed sampling and imaging program (Phase II; this report). This research builds on the Phase I results in that it formulates classification rules specifically for benthic mapping in Gilbert Bay and no longer relies on generic rules applied from elsewhere.
Figure 1: Locations of management zones associated with Gilbert Bay Marine Protected Area and place names used in the report.

**Multibeam Sonar Data**

The Canadian Hydrographic Service (CHS) (Newfoundland Office) conducted a multibeam survey of Gilbert Bay between September 30 and October 09, 2002, using CCGS Matthew (EM100) and hydrographic launch Plover (EM3000) (Roy 2002). The multibeam sonar survey covered 32 km² of the bay. Two data types are obtained during a multibeam survey: bathymetry and backscatter intensity. Once cleaned and processed, bathymetric data provides information on water depth, slope angle and attitude, and general physiography of a surveyed basin. Backscatter intensity measures the strength of the acoustic multibeam signal reflected from the
seabed in decibels (dB). The strength and signal characteristics vary depending on the seabed properties and can be used to roughly interpret different classes of bottom substrate types and structure-forming biota. In general, bedrock and coarse (boulder to gravel) substrates reflect most acoustic energy and have high backscatter intensity, while sand and mud absorb most of the acoustic energy and have low backscatter intensity. Seaweeds, seagrass, and branching coralline red algae all have very low density and effectively scatter sound waves, such that habitats with high densities of structure-forming biota can have backscatter intensity much lower than the backscatter intensity of the same physical substrate without the macroalgae.

**Research Approach**

Our benthic habitat classification approach relies on two important assumptions. First, we assume that substrate strongly influences the distribution of benthic biota; a relationship which has been established for nearshore and continental shelf environments elsewhere (Kostylev et al. 2001; Harney et al. 2006). Second, we assume a consistent relationship between substrate and multibeam sonar-derived values of depth, slope and backscatter (Todd et al. 1999; Kostylev et al. 2003; Ferrini and Flood 2006). The operational procedure for conducting the classification is as follows (Copeland 2006):

1. Define major substrate classes from the measured grain-size distribution of grab-sampled sediments and visual texture descriptions of video images. This may be done through either a statistical clustering approach or a visual assessment of plotted data, depending on data formats.
2. Using Exploratory Data Analysis of classified sampling stations, establish the range of backscatter intensities, slope angles and water depths that best characterize each substrate class. This process creates the rules for classifying the entire multibeam dataset.

3. Assign each pixel of the multibeam survey to one of the created substrate classes based on the classification rules for backscatter intensity, slope angle, and water depth values.

4. For those randomly selected sampling stations that were withheld from the classification procedure (10% of available dataset), compare their classified substrate with their sampled substrate to determine the accuracy of the classification rules.

5. Estimate the ambiguity in the classification. Because the classification rules do not necessarily produce unique solutions for each pixel nor do they encompass the entire range of values in the dataset, a certain proportion of pixels may be assigned to multiple substrate classes or remain unclassified, respectively. Calculation of these proportions provides an estimate of the ambiguity in the classification and an indication of those substrate characteristics that were inadequately sampled during fieldwork.

6. Identify indicator species and characteristic biotic components from multivariate statistical analysis of sampled and imaged biota associated with each substrate class.

7. Determine which substrate classes have statistically unique biotic composition, and are therefore mappable habitat units, using further multivariate statistical analyses.
Bathymetry of Gilbert Bay

Water Depth

Most of Gilbert Bay is shallow, with 56% of the area surveyed shallower than 30 m, and a mean water depth in the survey area of 33 m (Table 1). Water depths deeper than 100 m make up only ~ 6% of the total survey area and are found mostly near the mouth of the bay. The maximum depth - 163 m - was recorded in the outermost basin, approximately 500 m north of Fox Cove Head on Leg Island. Gilbert Bay is made up of a number of basins, between 30 and 160 deep, separated by sills between 10 and 30 m deep (Figs. 2 and 3). The sills separating the basins are probably glacial in origin, probably end moraines composed of winnowed till.

Table 1: Summary of water depths in multibeam bathymetric survey

<table>
<thead>
<tr>
<th>Water Depth</th>
<th>Percentage of the Multibeam Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallower than 15 m</td>
<td>16.73 %</td>
</tr>
<tr>
<td>15 to 30 m</td>
<td>39.09 %</td>
</tr>
<tr>
<td>30 to 50 m</td>
<td>18.43 %</td>
</tr>
<tr>
<td>50 to 100 m</td>
<td>20.17 %</td>
</tr>
<tr>
<td>deeper than 100 m</td>
<td>5.59 %</td>
</tr>
</tbody>
</table>
Slope Angle

The floor of Gilbert Bay is relatively gently sloping, with a mean slope value of 8.2° (Fig. 4).

The steepest slope at 68° was found 35 m offshore of Granby Island, opposite Fox Cove Head.
The site, on the north side of the Leg Island basin, is the only place where extensive steep cliffs were found.

### Table 2: Summary of slope values in the multibeam bathymetric survey

<table>
<thead>
<tr>
<th>Slope Angle</th>
<th>Percentage of the Multibeam Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 1°</td>
<td>7.94 %</td>
</tr>
<tr>
<td>1 to 5°</td>
<td>27.54 %</td>
</tr>
<tr>
<td>5 to 10°</td>
<td>33.92 %</td>
</tr>
<tr>
<td>10 to 45°</td>
<td>29.86 %</td>
</tr>
<tr>
<td>steeper than 45°</td>
<td>0.16 %</td>
</tr>
</tbody>
</table>

**Figure 4:** Slope analysis of Gilbert Bay. Most of the bay is gently sloping, except for steep-walled edges of the bay, and around pinnacles, in the outermost bay.

**Backscatter Patterns**

In Gilbert Bay the general backscatter trend is that low backscatter occurs in bathymetric depressions, and higher backscatter is associated with positive relief features and the margins of the bay (Fig. 5). Low backscatter is more closely associated with lower slope angles than high backscatter, and in most cases with greater water depths.
In general, Gilbert Bay contained moderate backscatter values, with a mean value of −24.1 dB. The lowest backscatter value recorded was −61 dB. This value is found 35 m from shore in the surveyed inlet of Williams Harbour Run at a water depth of about 2 m. The highest backscatter was recorded in the Shinneys, where values approaching 0 were returned. This very high backscatter was recorded in water shallower than 5 m adjacent to a gap in the multibeam coverage which is a small island.

**Table 3: Summary of backscatter values in the multibeam bathymetric survey**

<table>
<thead>
<tr>
<th>Backscatter Range</th>
<th>Percentage of the Multibeam Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; −10 dB</td>
<td>0.60</td>
</tr>
<tr>
<td>−10 to −20 dB</td>
<td>25.50</td>
</tr>
<tr>
<td>−20 to −30 dB</td>
<td>52.27</td>
</tr>
<tr>
<td>−30 to −40 dB</td>
<td>21.25</td>
</tr>
<tr>
<td>&lt; −40 dB</td>
<td>0.38</td>
</tr>
</tbody>
</table>

**Figure 5:** Map of multibeam backscatter values for Gilbert Bay. Dark shades represent high values (reflective seafloor), whereas low values (non-reflective seafloor) are shown in light shades.
**Field Component**

The specific goals of the Phase II field program were to conduct grab sampling and video data acquisition at selected stations in the bay representing the full range of depth, backscatter, and slope values. The description of bottom type and dominant biota at these stations are used to develop classification rules for substrate and habitat mapping from the multibeam data. The sampling design covered all predicted substrate types and was roughly divided into two groups: (i) stations for which the substrate has been predicted with high confidence (low ambiguity) from our Phase I analysis, and (ii) stations with high ambiguity, or stations left unclassified in our Phase I maps (Copeland *et al.* 2006). Two substrate types – coralline red algae and cobble gravel – were intensely sampled because of their probable habitat associations with juvenile cod and scallops, respectively.

The fieldwork component of Phase II mapping was carried out over 12 days between October 01 and 12, 2006, and included 7 sampling days in Gilbert Bay. Sampling was conducted from a combination of longliner and speedboat with the help of two boat operators and the local MPA coordinator. Apart from persistent technical problems with one of the camera systems and intermittent weather delays, the sampling effort was conducted at near maximum efficiency. The total number of stations sampled (n=101) exceeded our expectations by up to 40%. The sampling network appears in Figure 6, and the positional data for all stations are listed in Bell *et al.* (2006).
Figure 6: Location map of stations sample during October 2006 fieldwork
Laboratory Component

Laboratory research consisted of textural analysis of sediment samples collected in the field, identification and enumeration of invertebrates collected in the field, analysis of underwater video footage, and statistical analysis of substrate and biological data.

Substrate Classification

Textural Analysis:

Sediment grab samples collected from Gilbert Bay were wet sieved to remove the mud fraction (silt and clay) from the sample. The weight of the mud that was washed out was calculated by weighing the dried sample before and after wet sieving. The remaining coarse material (sand and gravel) was dry sieved through a stack of 7 sieves with mesh sizes of −2, −1, 0, 1, 2, 3 and 4qd. These sieves represent the boundaries of the grain size classes described by Wentworth (1922) which are shown in Table 4. The grain size distribution of the whole sample could then be determined by combining the weight of material in each gravel and sand sieve with the known weight of the mud fraction.

Table 4: Wentworth Grain Size Definitions

<table>
<thead>
<tr>
<th>Phi unit (ø)</th>
<th>Wentworth Grain Size Description</th>
<th>Grain Size (mm)</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;−8</td>
<td>boulder</td>
<td>&gt;256</td>
<td>gravel</td>
</tr>
<tr>
<td>&gt; −6</td>
<td>cobble</td>
<td>63 to 256</td>
<td>gravel</td>
</tr>
<tr>
<td>&gt; −2</td>
<td>pebble</td>
<td>4 to 63</td>
<td>gravel</td>
</tr>
<tr>
<td>−1</td>
<td>granule</td>
<td>2 to 4</td>
<td>gravel</td>
</tr>
<tr>
<td>0</td>
<td>very coarse sand</td>
<td>1 to 2</td>
<td>sand</td>
</tr>
<tr>
<td>1</td>
<td>coarse sand</td>
<td>0.5 to 1</td>
<td>sand</td>
</tr>
<tr>
<td>2</td>
<td>medium sand</td>
<td>0.25 to 0.5</td>
<td>sand</td>
</tr>
<tr>
<td>3</td>
<td>fine sand</td>
<td>0.125 to 0.25</td>
<td>sand</td>
</tr>
<tr>
<td>4</td>
<td>very fine sand</td>
<td>0.0625 to 0.125</td>
<td>sand</td>
</tr>
<tr>
<td>&lt;4</td>
<td>silt and clay</td>
<td>&lt; 0.0625</td>
<td>mud</td>
</tr>
</tbody>
</table>
Textural description of substrate classes:

The results of the grain size analysis of the grab sampled sediments were combined with observations of the seabed from the video imagery to form a complete description of the substrate at each sampling site. These descriptions were then grouped into classes. Three classes of substrates that were primarily soft sediment were described, while three other classes were created of samples from a primarily gravel bottom. The characteristics of samples placed in each of the six substrate classes are described below.

**Muddy Gravel**

This class was characterised by pebbles, cobbles and occasionally boulders, in muddy sediment (Fig. 7). The matrix (the sediment between the gravel) from grab samples in this class contained between 3 and 34% mud grains. Our analysis did not calculate the amount of silt and clay in the mud fraction of any of the substrate classes. Although the gravel was often draped by a thin layer of mud, this is a primarily gravel-bottom substrate.

**Sandy Gravel**

The sandy gravel class was characterised by a matrix containing over 10% sand by weight and little mud. Most of the samples in this class contained sand which fell into the ‘very coarse sand’ (0ø) to ‘medium sand’ (2ø) range on the Wentworth scale. The gravel component of this class was similar to the previous class, and included pebbles, cobbles and angular boulders up to several metres in diameter (Fig. 8). Typical samples in this class include grab 148 which contained 23.4 % sand by weight, including 7% ‘very coarse sand’ which is 1 to 2 mm in diameter (Wentworth 1922).
**Coralline Algae Encrusted Gravel**

This substrate class contained pebbles, cobbles and boulder gravel that was at least 50% covered by coralline red algae and showed some branching (Fig. 9). Coralline algae were observed in the sandy gravel class, but samples with significant branching were placed in the coralline encrusted gravel class. Some samples in this class were in a muddy matrix, while most were in coarse sand or had very little sediment present. Only one sample of true rhodoliths was collected, at station 96 in River Out, so this sample was placed in this class. The rhodoliths collected were densely branched and completely composed of coralline algae.

**Gravelly Sandy Mud**

Samples were placed in this class if they contained scattered gravel on a primarily sediment bottom (Fig. 10). Gravel observed in this class ranged from pebble (<6.4 cm) to boulder size and covered 25% or less of the surface in videos and comprised 5 to 12% of the weight in grab samples. The sediment component of the substrate contained sand between ‘medium sand’ and ‘very fine sand’ on the Wentworth scale. Samples in this class range from 7 to 41% sand. Mud was the most significant component of samples in this class. Grabs contained between 51 and 78% mud by weight. Typical samples in this class include grabs 39 and 40 from the Peckham’s Cove area. Grab 39 contained 11% sand and 77% mud, while 40 contained 15% sand and 76% mud.
**Gravelly Mud**

Samples in this class contained mud, occasionally with a very small amount of fine sand, and scattered gravel. It differed from the previous class by having a finer grain size matrix. Again gravel of all sizes was observed, from small pebbles to boulders, scattered on a primarily mud bottom (Fig. 11). Often a drape of mud covered the surface of the gravel.

**Mud**

Grab samples in the mud class were composed primarily of sediment grains smaller than 0.0625 mm (63μm) which fell into the silt and clay classes of the Wentworth scale. No gravel was observed. Some grab samples contained between 0.5 and 4% fine sand but all of the grabs in this class contained over 94% mud by weight. The only exception was sample 81 from the mouth of the Shinneys River which contained more sand than other members of this class, but no gravel so it was included here. The mud class is shown in Fig. 12.
Figure 7: Muddy Gravel Substrate

Fig. 7A: Muddy gravel substrate with brittle stars, sea urchin and bivalve shells at Kelly's Pt.

Fig. 7B: Muddy gravel with brittle stars and encrusting sponge near Coach Box Point

Fig. 7C: Muddy gravel substrate
**Figure 8: Sandy Gravel Substrate**

**Fig. 8A:** Sandy gravel at Rexon’s Point with crinoids and sea star

**Fig. 8B:** Sandy gravel with polar sea star and sponges in River Out

**Fig. 8 C:** Sandy gravel with encrusting sponges and sea anemone near Mogashu Tickle
Figure 9: Coralline Algae Encrusted Gravel Substrate

Fig. 9A: Coralline algae encrusted pebble and cobble gravel (laser scale is 15 cm apart)

Fig. 9B: Rhodolith substrate with sea urchins, scallops and sea cucumbers in River Out

Fig. 9C: Cobble and boulder gravel with branching coralline red algae at Leg Is.
Figure 10: Gravelly Sandy Mud Substrate

Fig. 10A: Gravelly sandy mud with abundant brittle stars at Rexon’s Cove

Fig. 10B: Gravelly sandy mud with burrows and a sea star off Peckham’s Cove

Fig. 10C: Gravelly sandy mud with brittle stars and epifauna on gravel off Halfway Pt.
**Figure 11: Gravelly Mud Substrate**

*Fig. 11A: Gravelly mud with polar sea star near Middle Is.*

*Fig. 11B: Gravelly mud with bryozoans at the mouth of Long Arm*

*Fig. 11C: Gravelly mud with bivalve shells and anemones on scattered gravel*
Figure 12: Mud Substrate Class

Fig. 12A: Mud with mud star west of Middle Is.

Fig. 12B: Mud with burrows and brittle star

Fig. 12C: Mud with siphons and polychaete tubes
Once all grab and video sample points had been classified, a random number generator was used to randomly exclude 10% of the points from each substrate class. These ‘test points’ were stored to test the accuracy of the final maps (see below). The remaining classified points were used to determine backscatter, depth and slope ranges which were representative of the six substrate classes.

**Multibeam Characteristics of Substrate Classes:**

The multibeam backscatter, depth and slope values of the classified grab and video samples were examined using exploratory data analysis (EDA) in SPSS to determine the statistical distribution of values for each substrate class to be used when creating the substrate map. Box and whisker plots indicated where values for substrate classes overlapped (Figs. 13, 14, and 15). Using these boxplots and knowledge gained from groundtruthing about distribution of substrates within Gilbert Bay, the substrate map was produced in an iterative fashion so that overlap between classes was minimised and total area classified was maximised. Substrate class boundaries were derived from the 95% range limits (whisker), and inter-quartile range limits (box). Numbers of samples in each class, and the final criteria used for defining each class in the multibeam data, are presented in Table 5. The following text explains the classification, and the iterations through which it was derived. The substrate map of the six classes throughout the bay is presented in Figure 16. For detailed substrate maps of individual portions of the bay, see Appendix C.
Figure 13: Box and whisker plot of depth (m) of grab and video samples classified by substrate. Whiskers indicate 95% confidence limits, red boxes indicate the actual range used to map substrates and numbers are sample stations.

Figure 14: Box and whisker plot of backscatter (dB) of grab and video samples classified by substrate. Whiskers indicate 95% confidence limits, red boxes indicate the actual range used to map substrates and numbers are sample stations.
Habitat Mapping in Gilbert Bay Marine Protected Area

Figure 15: Box and whisker plot of slope angle (º) of grab and video samples classified by substrate. Whiskers indicate 95% confidence limits, red boxes indicate the actual range used to map substrates and numbers are sample stations. No slope criteria were used to define the coralline-algae encrusted gravel or gravelly mud classes.

Table 5: Classification Criteria for Substrate Classes

<table>
<thead>
<tr>
<th>Substrate Class</th>
<th>Samples</th>
<th>Depth Range (m)</th>
<th>Backscatter Range (dB)</th>
<th>Slope Range (º)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muddy gravel</td>
<td>78</td>
<td>≤−15</td>
<td>≤−16.9, ≥−26.4</td>
<td>≤29</td>
</tr>
<tr>
<td>Sandy gravel</td>
<td>29</td>
<td>≤−14, ≥−27.8</td>
<td>≤−17, ≥−22</td>
<td>≤15.5, ≥7.5</td>
</tr>
<tr>
<td>Coralline encrusted gravel</td>
<td>41</td>
<td>≤−4, ≥−14.9</td>
<td>≤−9.9, ≥−19</td>
<td>any value</td>
</tr>
<tr>
<td>Gravelly sandy mud</td>
<td>47</td>
<td>≤−18.2, ≥−40.6</td>
<td>≤−19.2, ≥−27.2</td>
<td>≤16, ≥4.8</td>
</tr>
<tr>
<td>Gravelly mud</td>
<td>67</td>
<td>≤−8</td>
<td>≤−23, ≥−32</td>
<td>any value</td>
</tr>
<tr>
<td>Mud</td>
<td>29</td>
<td>≤−5</td>
<td>≤−32</td>
<td>≤10.5</td>
</tr>
</tbody>
</table>
Muddy Gravel
Muddy gravel substrate had a slightly deeper depth distribution than the other substrate classes, which helped to define its distribution. The upper interquartile value for depth was used, which defined the upper limit of this substrate as $-15$ m. Initially, the lower limit was defined by the lower 95% range value of $-88$ m. In the final map, no lower limit was placed on depth for muddy gravel in order to classify more area in the deep Leg Island basin, which we were not able to sample, but where backscatter values suggest this substrate.

The upper interquartile backscatter value of $-16.9$ dB was used to define the upper limit of the backscatter range for muddy gravel. The lower limit ($-26.4$ dB) was defined by the lower 95% range. Four samples in this class appeared as extreme low values for backscatter, and one sample was an outlier (sample 33).

The range for slope was determined by the upper 95% range value, as there were two samples from the Leg Island basin in this class with steep slopes which appeared as extreme high values on the box plot. Initially the lower interquartile value of 4.5° was used to define the lower boundary. On the first substrate map, some areas of the bay in the muddy gravel backscatter range remained unclassified as they were excluded from all classes by slope. Muddy gravel samples had lower slope values than either sandy or coralline encrusted gravel, and mud is most likely to accumulate on a flat bottom, therefore the lower slope limit for muddy gravel was changed to the lower 95% range, which was 0.

The backscatter range used separated muddy gravel from mud and gravelly mud and the depth limits separated it from coralline algae encrusted gravel. Therefore the only potential for overlap is with sandy gravel.
Sandy Gravel
Sandy gravel had a narrow depth range defined by the upper and lower interquartile values. This depth range limits overlap with the muddy gravel class which had similar backscatter values, but a broader and deeper depth range. Backscatter and slope for sandy gravel were defined by the upper and lower interquartile values.

Sandy gravel is distinguished from gravelly mud by its higher backscatter and slope values. The backscatter and slope ranges for sandy gravel are higher than, but overlap with, gravelly sandy mud, so there may be some pixels classified in both these classes.

Coralline Algae Encrusted Gravel
The coralline algae encrusted gravel substrate class is primarily defined by its shallow depth, which distinguishes it from the other five substrates. As coralline red algae are a primary constituent of this substrate, it must occur within the photic zone, so the upper 95% range and lower interquartile values were used to define its depth range. Similarly the upper 95% range and lower interquartile were used to define the backscatter range, thus placing any hard-bottom, shallow-water pixels in this substrate class. Slope was not distinctive for this class so no slope criterion was defined for coralline-algae encrusted gravel.

Gravelly Sandy Mud
The upper and lower interquartile ranges were used to define the classification ranges for all three variables in the gravelly sandy mud class. This substrate combines components of many of the others; therefore it is not surprising that the ranges overlapped. The backscatter range for gravelly sandy mud overlaps with sandy gravel and gravelly mud. The backscatter values for
gravelly sandy mud separate it from mud, which is acoustically the softest class with the lowest backscatter range, and from coralline encrusted gravel which was the class with the highest backscatter. Coralline encrusted gravel is also the only substrate that does not overlap with the depth range for gravelly sandy mud.

**Gravelly Mud**

On the initial versions of the substrate map, the lower depth limit for gravelly mud was the lower interquartile limit which was later revised to classify more pixels without overlapping the mud class. The boxplot for depth showed that samples from at least 3 stations in this class had extreme values for the depth variable. Given that it is only the backscatter range for gravelly mud that overlaps with the mud class, and the depth limit for mud was relatively shallow; the lower depth limit for gravelly mud was not defined in the final map. This allowed deep portions of the bay with low backscatter to be classified as this substrate. The upper limit of the depth range was also revised so that the upper 95% range value (−8m) was used.

The upper and lower interquartile values (7 to 2°) were initially used as the slope range. On the first substrate map portions of the Upper Hummock remained unclassified. Sampling indicated gravelly mud, but using these ranges the area was too flat to be classified as gravelly mud. The slope variable was therefore removed from this class, which successfully classified the Upper Hummock as well as portions of the Leg Island basin.

The backscatter range for gravelly mud was initially set using the upper and lower interquartile values. When the first substrate map was created gaps appeared where substrates that fell between the lower backscatter limit for gravelly mud (−30 dB) and the upper backscatter limit for mud (−32 dB). In order to fill these classification gaps the lower backscatter limit for
gravelly mud was changed to $-32$ dB. Gravelly mud was altered as it was the more likely of the two substrates to occur in the classification gaps given the proximity of the gaps to groundtruthed samples in this class.

**Mud**
The mud substrate class is defined by its backscatter values which were lower than all other substrates. The upper limit of the backscatter range was set at the upper interquartile value for mud, while no lower limit was used. Initially, the upper interquartile depth value was used to constrain depth below $-18$m. This depth limit left areas of the Shinneys, where shallow water mud had been sampled, unclassified. The shallowest mud sampled was at station 81 at the mouth of the Shinneys River, so an upper depth limit of $-5$ m was used in the final substrate map to incorporate this area of mud. The Shinneys was the only region of the bay with very low backscatter in shallow water, so this change successfully mapped the mud here, without causing overlap with other classes.

Sample 48 was shown as an outlier on the depth box plot (Fig.13). As this was the only sample retrieved from the floor of the Leg Island basin it is probably representative of mud at that depth. In order to allow the basin floor to be classified as mud if it fit the backscatter specifications, no lower depth limit was used for mud. Slope was not a defining characteristic of this substrate, so the upper 95% range was used and no lower limit was imposed.
Figure 16: Benthic Substrate map of Gilbert Bay
Substrate Map

Spatial Patterns

The primary pattern in the spatial distribution of benthic substrates in Gilbert Bay (Fig 16) is the occurrence of mud and gravelly mud in basins and other substrate types along the shallow margins of basins or on the shallow sills between basins (Fig 17A). There is a general increase in the proportion of mud to gravelly mud with depth of basin as is observed through the progressive increase in mud-dominated basins toward the mouth of the bay (Fig 17B). The exception to this pattern is the mud-dominated, relatively shallow inner basin of The Shinneys which is only 19 to 24 m deep (Fig 18A). The “streaky” nature of the mud and gravelly mud substrates in Leg Island basin and in Middle Island to Halfway Point basin (Fig 17A) is an artifact of the multibeam survey and data processing and does not represent a true representation of the distribution of these substrates within these basins.

Gravelly sandy mud and muddy gravel make up much of the basin shallows and the deeper sills in the outer half of Gilbert Bay. Much less muddy gravel and more gravelly sandy mud occur on shallow sills in the inner bay. There was also a greater percentage of coralline algae encrusted gravel on sills in the inner bay, which appears to correspond with submerged glaciofluvial eskers and fans (Figs. 19 A and B). Sandy gravel is generally restricted to the edge of the multibeam survey and is therefore restricted to the shallow margins of Gilbert Bay.

River Out contains an interesting diversity of shallow-water benthic substrates, predominantly composed of muddy gravel and coralline algae encrusted gravel (Fig 20A and B). Farther west in The Shinneys, deeper mud-floored basins are separated by shallow rocky ridges which are in places encrusted by coralline algae, or rarely, covered by gravel (Fig 18B).
Figure 17A: Oblique view of substrate classes draped over bathymetry, inner portions of the main axis of Gilbert Bay. Soft substrates (gravelly sandy mud, gravelly mud, and mud) are primarily limited to deeper basins separated by shallow gravelly sills.

Figure 17B: Oblique view of substrate classes draped over bathymetry, outer portions of the main axis of Gilbert Bay. Soft substrates (gravelly sandy mud, gravelly mud, and mud) are primarily limited to deeper basins separated by shallow gravelly sills. As the outer basin is generally deeper than the inner basin, the sills contain more gravelly sandy mud (green) in the outer basin than in the inner basin (fig 17A).
Figure 18A: The muddy basin in the inner part of the Shinneys. The Shinneys was the only shallow water area of the bay with extensive mud. Note the closely interspersed mud and coralline-algae encrusted gravel substrates in the eastern end of the Shinneys.

Figure 18B: Muddy substrate separated by ridges in the central, narrow, portion of the Shinneys. Note the abundance of hard substrates along the edges. Areas of steep unclassified bottom are likely to include exposed bedrock. Note also the sinuous feature along the bottom, possibly a submerged river channel.
Figure 19A: Muddy substrate separated by ridges and plateaus of coralline-algae encrusted gravel associated with eskers and fans, Upper Hummock, inner portion of main axis Gilbert Bay.

Figure 19B: Gravelly and sandy-gravel sills and eskers near the Lower Hummock.
Figure 20A: Coralline algae encrusted gravel atop a drowned esker at the mouth of River Out.

Figure 20B: Coralline algae encrusted gravel in shallow water and muddy or sandy gravel in deeper water in River Out. Steep-walled low backscatter areas near mouth of Snooks Arm are classified as gravelly mud (light blue), but are likely to have dense accumulations of low backscatter biota such as rhodoliths.
The major limitation for soft-bottom substrate in Gilbert Bay is the lack of sediment supply in most parts of the bay. Only two major rivers drain into Gilbert Bay: the Gilbert River and the Shinneys River. Sand and mud from these two rivers is likely trapped close to the river mouths by the multiple sills spanning the bay. Most of the gravel and cobbles in the hard-bottom substrates (i.e. muddy gravel, sandy gravel, and coralline-algae encrusted gravel) is likely derived from \textit{in-situ} winnowing of glacial or glaciofluvial sediments. The limited sediment supply probably also contributes to the scarcity of sandy environments in Gilbert Bay – sands are most extensive close to the two river mouths, and along the eskers and fans, which are glaciofluvial in origin.

\textbf{Table 6: The percentage of each substrate class in each region of the bay}

<table>
<thead>
<tr>
<th>Substrate Class</th>
<th>Gilbert River Basin</th>
<th>Zone 1A</th>
<th>Middle Island to Halfway Pt.</th>
<th>River Out</th>
<th>The Shinneys</th>
<th>Halfway Pt. to Kelly’s Pt.</th>
<th>Kelly’s Pt. to Rexon’s Pt.</th>
<th>Leg Is. Basin</th>
<th>Williams Harbour Run</th>
<th>Gilbert Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muddy gravel</td>
<td>21%</td>
<td>27%</td>
<td>45%</td>
<td>31%</td>
<td>14%</td>
<td>53%</td>
<td>51%</td>
<td>40%</td>
<td>69%</td>
<td>\textbf{38%}</td>
</tr>
<tr>
<td>Sandy gravel</td>
<td>1%</td>
<td>3%</td>
<td>6%</td>
<td>8%</td>
<td>2%</td>
<td>4%</td>
<td>3%</td>
<td>2%</td>
<td>4%</td>
<td>\textbf{4%}</td>
</tr>
<tr>
<td>Coralline encrusted gravel</td>
<td>1%</td>
<td>14%</td>
<td>7%</td>
<td>25%</td>
<td>11%</td>
<td>4%</td>
<td>6%</td>
<td>3%</td>
<td>4%</td>
<td>\textbf{8%}</td>
</tr>
<tr>
<td>Gravelly sandy mud</td>
<td>3%</td>
<td>7%</td>
<td>15%</td>
<td>9%</td>
<td>5%</td>
<td>15%</td>
<td>13%</td>
<td>8%</td>
<td>27%</td>
<td>\textbf{10%}</td>
</tr>
<tr>
<td>Gravelly mud</td>
<td>70%</td>
<td>53%</td>
<td>43%</td>
<td>21%</td>
<td>21%</td>
<td>43%</td>
<td>31%</td>
<td>41%</td>
<td>22%</td>
<td>\textbf{41%}</td>
</tr>
<tr>
<td>Mud</td>
<td>18%</td>
<td>5%</td>
<td>7%</td>
<td>3%</td>
<td>38%</td>
<td>9%</td>
<td>14%</td>
<td>10%</td>
<td>0%</td>
<td>\textbf{10%}</td>
</tr>
</tbody>
</table>

\textit{NB. Totals add to more than 100% because of multiple classification of some cells}
Classification Ambiguity:

Binary grids were created for each of the six substrate classes, where the 5X5 m cells from the multibeam dataset were assigned a value of 1 if they met all the classification criteria for a substrate class and 0 if they did not. Therefore the areas of overlap between the classes could be mapped by adding the grids together and assigning each pixel a new value which corresponds to the number of times it was given a value of 1.

Cells which were not assigned a value on any of the 6 grids, but contained backscatter data were given a value of 0. This step eliminated the holes in the multibeam data set from the calculated percentage of the bay which remained ‘unclassified’.

Using the substrate classification criteria shown in Table 5, 61% of Gilbert Bay could be uniquely classified (Table 7). Future groundtruthing efforts should be directed at the 22% of the bay which was classified as more than one substrate, and the 16% of the bay which was left unclassified by the current scheme (Fig. 21).

Table 7: Percentage of each region that falls in multiple substrate classes

<table>
<thead>
<tr>
<th>Region</th>
<th>1 class</th>
<th>2 classes</th>
<th>3 classes</th>
<th>Unclassified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gilbert River Basin</td>
<td>73%</td>
<td>15%</td>
<td>2%</td>
<td>10%</td>
</tr>
<tr>
<td>Hummocks Zone 1A</td>
<td>65%</td>
<td>15%</td>
<td>4%</td>
<td>16%</td>
</tr>
<tr>
<td>Middle Island to Halfway Pt.</td>
<td>58%</td>
<td>19%</td>
<td>8%</td>
<td>14%</td>
</tr>
<tr>
<td>Halfway Pt. to Kelly’s Pt.</td>
<td>60%</td>
<td>23%</td>
<td>7%</td>
<td>11%</td>
</tr>
<tr>
<td>Kelly’s Pt. to Rexon’s Pt.</td>
<td>60%</td>
<td>20%</td>
<td>6%</td>
<td>14%</td>
</tr>
<tr>
<td>Leg Island Basin</td>
<td>57%</td>
<td>17%</td>
<td>3%</td>
<td>20%</td>
</tr>
<tr>
<td>Williams Harbour Run</td>
<td>49%</td>
<td>22%</td>
<td>13%</td>
<td>15%</td>
</tr>
<tr>
<td>River Out</td>
<td>59%</td>
<td>12%</td>
<td>4%</td>
<td>23%</td>
</tr>
<tr>
<td>The Shinneys</td>
<td>69%</td>
<td>6%</td>
<td>3%</td>
<td>21%</td>
</tr>
<tr>
<td><strong>Gilbert Bay</strong></td>
<td><strong>61%</strong></td>
<td><strong>17%</strong></td>
<td><strong>5%</strong></td>
<td><strong>16%</strong></td>
</tr>
</tbody>
</table>
Figure 21: Map of the number of substrate classes into which cells were classified.
Map Accuracy:

Two types of accuracy are associated with a classified substrate map: the positional accuracy of the map units produced (user accuracy) and the ability of the substrate classes to accurately reflect all substrate types likely to be encountered in the study area (producer accuracy).

In Gilbert Bay the producer accuracy is likely high, as most grab samples were paired with video imagery to give the most complete data possible, and almost all areas of the bay were surveyed. Consultation of people with local knowledge of benthic substrates in Gilbert Bay could also give an idea of the accuracy of the substrate classes produced.

The user’s accuracy was tested with a set of groundtruth samples which has been classified but not used in determining substrate classification criteria; they could therefore be treated as independent test points. In total 29 classified sample points were removed from the data set to act as test points. Of these 29 points, 20 appeared on the correct substrate when plotted on the final map, while 5 of the points were mis-classified (Table 8). Another 4 points appeared on areas of the map which remained unclassified. Three of these unclassified points were from the muddy gravel class but were not correctly classified as their slope values were higher than the classification range for this substrate. These points occurred in high slope areas on the north side of the Leg Island basin and in the centre of the Shinneys.
### Table 8: Results of accuracy assessment of substrate map with test samples

<table>
<thead>
<tr>
<th>Class</th>
<th>Correctly classified</th>
<th>Incorrectly classified</th>
<th>Unclassified</th>
<th>Total test points in class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muddy gravel</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Sandy gravel</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Coralline algae encrusted gravel</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Gravelly sandy mud</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Gravelly mud</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Mud</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td><strong>20</strong></td>
<td><strong>5</strong></td>
<td><strong>4</strong></td>
<td><strong>29</strong></td>
</tr>
</tbody>
</table>

### Habitat Classification

Habitat, used here as the combination of substrate and biota, was mapped as the substrate-biotic units, as defined by samples collected in October 2006. First, the biotic associations with each substrate class were determined based on the samples. Second, the degree of differentiation among the biota associated with each substrate class was assessed using multivariate statistics. Because species can be identified with a different degree of taxonomic precision in grab samples and video data, the two data sources are analyzed separately.

The final habitat map shows the substrate-biotic units that are statistically distinguishable.

**Biotic Associations with Substrate Classes:**

Species composition of the biota (both flora and fauna) was compared among sampled stations in the six substrate types identified using the multivariate statistical techniques similarity percentage (SIMPER) analysis, non-metric multidimensional scaling (MDS), and analysis of similarity (ANOSIM). Inconsistent functioning of the scaling lasers on the underwater cameras precluded absolute measures of organism density from video data. Therefore, analysis of all
biotic data was conducted at the presence-absence level. MDS and ANOSIM analysis rely upon calculation of a Bray-Curtis similarity matrix, in which the similarity of every sample in relation to every other sample is calculated. The MDS ordination plot then shows the relative similarity of all samples; samples that plot close to one another are highly similar, while those plotting far from each other are highly distinct.

**Similarity Percentage Analysis (SIMPER)**

Similarity percentage analysis (SIMPER) calculates the percent contribution of each taxon to the overall internal Bray-Curtis similarity of the biota associated with each substrate class, that is, the taxa that most clearly characterize the biota occupying each substrate. SIMPER also calculates the contribution of each taxon to the dissimilarity between all the substrate classes, but only the contribution to internal similarity is presented here.

**Muddy gravel**

The species contributing the most to similarity of grabs within the muddy gravel class are primarily epifauna present on sampled gravel. These include polychaete worms in calcareous tubes, such as *Spirorbis borealis*, *Spirorbis granulatus* and *Serpula sp*. Other epifauna include encrusting and branching bryozoans, brachiopods and barnacles. Sediment dwelling bivalves, namely the nut shell (*Nuculana tenuisulcata*) and gastropods such as *Turritellopsis acicula*, were also among the top contributors to similarity in muddy gravel grabs. Video samples from the muddy gravel class were dominated by echinoderms such as the green sea urchin, sea stars and brittle stars. The encrusting sponge *Halichondria panicea* was frequently observed on gravel and contributed 20.19% of the similarity within this group of samples (Tables 9 and 10). Iceland
scallops (*Chlamys islandica*) contributed 3.82% to similarity, indicating muddy gravel provides habitat for scallops.

**Sandy gravel**

Like muddy gravel, the grabs from the sandy gravel class were characterised by epifauna present on the gravel component of the substrate. These included the calcareous tube worms *Serpula sp.*, *Spirorbis granulatus* and *Spirorbis borealis*, two species of encrusting bryozoans, barnacles and jingle shells (*Anomia squamula*). Encrusting coralline red algae contributed 6.82% to similarity of grabs in this substrate class. This is a reflection of the relatively shallow water depths where sandy gravel occurred.

Video samples in the sandy gravel class contained sea stars, sea urchins, brittle stars and encrusting and erect sponges. Notably, live Iceland scallops (*Chlamys islandica*) were the second highest contributor to similarity (16.41%) and are characteristic of this substrate.

**Coralline algae encrusted gravel**

SIMPER analysis of biota from grab samples in the coralline encrusted gravel class indicated that the biotic assemblage of this substrate is characterised by branching coralline red algae and small epifauna associated with it. The highest contributor to group similarity was the jingle shell (*Anomia squamula*) which was particularly numerous among the branches of coralline algae. The red chiton (*Tonicella rubra*) and arctic boring clam (*Hiatella arctica*) were also particularly numerous within densely branched coralline algae, the latter making a significant contribution to shell hash in this habitat. Other epifauna associated with this substrate are similar to those found on other types of gravel, namely encrusting bryozoans and foraminiferans.
The green sea urchin, (*Strongylocentrotus droebachiensis*) was particularly abundant on substrates with significant coralline algae such as those in River Out. Again, large sea stars such as *Leptasterias polaris* and *Crossaster papposus*, and Iceland scallops were characteristic of this habitat. Coralline encrusted gravel was the only substrate where cnidarians were commonly observed. Both hydroids and the frilled anemone (*Metridium senile*) were significant contributors to similarity of samples in this substrate class.

As predicted by Copeland et al (2006), the coralline-algae encrusted gravel habitat held among the highest diversity of the habitats sampled in Gilbert Bay. Analysis of variance found the highest species richness among video samples in the sandy gravel and coralline-algae encrusted gravel habitats (1-way ANOVA, $F_{(5,73)} = 3.29$, $p<0.01$). Species richness among grab samples was also highest in the sandy gravel and coralline-algae encrusted gravel habitats, but patterns were not statistically significant (1-way ANOVA, $F_{(5,74)} = 1.75$, $p=0.13$).

The sandy gravel and coralline-algae encrusted gravel habitats together comprise the cobble-gravel environment identified as high quality habitat for scallops, as predicted by Copeland et al. 2006 (Wroblewski et al. submitted). Coarse gravel substrates are among the highest quality habitats for scallops (Schneider et al. 1987). Scallop habitats have been mapped successfully on the Scotian Shelf using multibeam acoustic data (Kostlyev et al. 2003). The distribution of sandy gravel or coralline-encrusted gravel habitat substantially overlaps with the distribution of fishing effort for scallops in the main arm of Gilbert Bay (Wroblewski et al. submitted).
**Gravelly sandy mud**

Similarity within the gravelly sandy mud substrate class was mostly due to the presence of soft bottom fauna, with the exception of jingle shells (*Anomia squamula*) in the grabs and encrusting sponges in the videos. The primary inhabitants of this substrate were tube dwelling and errant polychaetes, such as the chevron worm (*Goniada maculata*). Infaunal bivalves were also characteristic, particularly the cleft clam (*Thyasira flexuosa*) and nut clams (*Nuculana tenuisulcata* and *Nucula tenuis*). Video samples from this substrate showed bivalve siphon pits and shell hash, indicating that larger bivalves are also present. Bioturbation of the substrate was observed in videos in the form of trails along the surface (likely from echinoderms such as mud stars and brittle stars) and burrows.

**Gravelly mud**

The biotic assemblage of the gravelly mud class was dominated by deposit feeding, infaunal species, such as mud stars, bivalves and brittle stars. The highest contributors to similarity in grab samples from this class were the mud star (*Ctenodiscus crispatus*), cleft clam (*Thyasira flexuosa*) and smooth nut clam (*Nucula tenuis*). The surface of the sediment observed in videos showed large burrows, which were abundant at times, as well as siphon pits and other signs of bioturbation. Polychaete tubes were observed protruding from the sediment, which are likely the same muddy tubes which appear as the third contributor to class similarity in the grab samples. SIMPER analysis showed the encrusting sponge *Halichondria panicea* to be a contributor to similarity in this class. Like the gravelly sandy mud class, this was the only truly gravel-associated species that contributed to internal similarity of the gravelly mud substrates.
**Mud**

In videos the surface of mud substrates showed evidence of biological activity such as trails on the surface, likely from mud stars, burrows and bivalve siphon pits. Mud bottoms were primarily inhabited by infaunal bivalves, deposit feeding mud stars (*Ctenodiscus crispatus*) and brittle stars. Bivalves which appeared as significant contributors to similarity in the mud class from grab samples include the paper spoon shell (*Periploma papyratium*) and the cleft clam (*Thyasira flexuosa*), which alone contributed over half the biotic similarity of grabs in this class.

The only shallow water area to have extensive sand and mud habitat was in the Shinneys. The Shinneys River mouth is one of the few areas of Gilbert Bay that could host seagrasses or other marine vegetation, which have been identified as important habitat for juvenile cod in other regions (Cote et al., 2004). Investigation of the Shinneys River mouth found abundant rockweeds (*Fucus* spp.), and less abundant *Chorda filum* and other seaweeds, but no eelgrass or other seagrasses. The river mouth is probably rarely if ever exposed at low tide, and is not a salt marsh according to either geomorphic or biological definitions.
Table 9: The top contributing taxa from grab sampled biota and their percent contribution to similarity within each substrate class

<table>
<thead>
<tr>
<th></th>
<th>Muddy Gravel</th>
<th>Sandy Gravel</th>
<th>Coralline Algae</th>
<th>Gravelly Sandy Mud</th>
<th>Gravelly Mud</th>
<th>Mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Spirorbis borealis</em> (21.06)</td>
<td><em>Spirorbis granulatus</em> (39.56)</td>
<td><em>Anomia squamula</em> jingle shell (33.35)</td>
<td><em>Mud polychaete tubes</em> (16.43)</td>
<td><em>Thyasira flexuosa bivalve</em> (20.41)</td>
<td><em>Thyasira flexuosa bivalve</em> (59.32)</td>
</tr>
<tr>
<td>3</td>
<td><em>Serpula sp. (7.15)</em></td>
<td><em>Serpula sp. (8.77)</em></td>
<td><em>Spirorbis granulatus</em> (13.66)</td>
<td>Unidentified polychaete (14.23)</td>
<td>Mud polychaete tubes (12.56)</td>
<td><em>Periploma papyratium</em> bivalve ‘paper spoon shell’ (11.02)</td>
</tr>
<tr>
<td>4</td>
<td><em>Tubulipora bryozoan</em> (5.51)</td>
<td><em>Balanus balanus barnacle</em> (8.14)</td>
<td>Encrusting coralline red algae (5.25)</td>
<td><em>Goniada maculata ‘chevron worm’</em> (10.96)</td>
<td><em>Nucula tenuis ‘nut shell’</em> (10.64)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td><em>Stomachetosella sinuosa</em> (4.99)</td>
<td>Encrusting coralline red algae (6.82)</td>
<td><em>Tonicella rubra</em> chiton (5.13)</td>
<td><em>Nuculana tenuisulcata bivalve</em> (7.85)</td>
<td>Unidentified polychaete (9.31)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Muddy polychaete tube (4.75)</td>
<td><em>Anomia squamula</em> jingle shell (5.80)</td>
<td><em>Balanus balanus barnacle</em> (5.07)</td>
<td><em>Nucula tenuis ‘nut shell’</em> (4.43)</td>
<td><em>Goniada maculata ‘chevron worm’</em> (6.79)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td><em>Nuculana tenuisulcata bivalve</em> (4.58)</td>
<td><em>Escharrella immersa</em> (2.32)</td>
<td><em>Porella sp. bryozoan</em> (1.67)</td>
<td><em>Pectinaria granulata</em> (3.49) trumpet worm</td>
<td>Maldanid polychaete (4.81)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td><em>Balanus balanus barnacle</em> (4.15)</td>
<td>Tubulipora bryozoan (2.32)</td>
<td>Calcareous foraminifera (1.52)</td>
<td><em>Anomia squamula jingle shell</em> (3.24)</td>
<td>Sandy polychaete tube (2.54)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td><em>Turritellopsis acicula</em> (3.53) needleshell</td>
<td><em>Tubulipora bryozoan</em> (2.71)</td>
<td><em>Ophiura robusta</em> brittle star (2.86)</td>
<td><em>Nuculana tenuisulcata bivalve</em> (2.23)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Calcareous foraminifera (3.34)</td>
<td><em>Hiatella arctica</em> (1.29) boring bivalve</td>
<td><em>Turritellopsis acicula</em> (2.58) needleshell</td>
<td><em>Pectinaria granulata</em> (1.71) trumpet worm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 10: The top contributing taxa from video sampled biota and their percent contribution to similarity within each substrate class

<table>
<thead>
<tr>
<th>Muddy Gravel</th>
<th>Sandy Gravel</th>
<th>Coralline Algae Encrusted Gravel</th>
<th>Gravelly Sandy Mud</th>
<th>Gravelly Mud</th>
<th>Mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Strongylocentrotus droebachiensis urchin (25.16)</td>
<td>Leptasterias polaris polar sea star (20.83)</td>
<td>Strongylocentrotus droebachiensis urchin (23.32)</td>
<td>Infaunal bivalve (siphon pits) (23.48)</td>
<td>Burrows (32.84)</td>
<td>Burrows (42.94)</td>
</tr>
<tr>
<td>2 Halichondria panicea sponge (20.19)</td>
<td>Chlamys islandica (live) scallop (16.41)</td>
<td>Leptasterias polaris polar sea star (22.58)</td>
<td>Trails (18.44)</td>
<td>Infaunal bivalve (siphon pits) (16.46)</td>
<td>Infaunal bivalve (siphon pits) (25.75)</td>
</tr>
<tr>
<td>3 Bivalve shell hash (12.12)</td>
<td>Asterias vulgaris sea star (10.95)</td>
<td>Chlamys islandica (live) scallop (10.99)</td>
<td>Ophiuroidea brittle star (16.04)</td>
<td>Trails (7.97)</td>
<td>Trails (18.65)</td>
</tr>
<tr>
<td>4 Crossaster papposus spiny sunstar (11.16)</td>
<td>Strongylocentrotus droebachiensis urchin (10.12)</td>
<td>Branching coralline red algae (live) (10.46)</td>
<td>Burrows (15.48)</td>
<td>Halichondria panicea sponge (6.95)</td>
<td>Ophiuroidea brittle star (10.40)</td>
</tr>
<tr>
<td>5 Leptasterias polaris polar sea star (8.41)</td>
<td>Halichondria panicea sponge (9.86)</td>
<td>Encrusting coralline red algae (4.23)</td>
<td>Halichondria panicea sponge (11.16)</td>
<td>Strongylocentrotus droebachiensis urchin (6.67)</td>
<td></td>
</tr>
<tr>
<td>6 Ophiuroidea brittle star (7.02)</td>
<td>Crossaster papposus spiny sunstar (8.53)</td>
<td>Branching coralline red algae (dead) (4.21)</td>
<td>Bivalve shell hash (3.99)</td>
<td>Ophiuroidea brittle star (6.16)</td>
<td></td>
</tr>
<tr>
<td>7 Chlamys islandica (live) scallop (3.82)</td>
<td>Bivalve shell hash (5.09)</td>
<td>Hydroids (4.12)</td>
<td>Strongylocentrotus droebachiensis urchin (3.68)</td>
<td>Polychaete tubes (4.62)</td>
<td></td>
</tr>
<tr>
<td>8 Branching bryozoan (3.70)</td>
<td>Ophiuroidea brittle star (4.23)</td>
<td>Crossaster papposus spiny sunstar (4.10)</td>
<td></td>
<td>Articulated bivalve shell (dead) (3.90)</td>
<td></td>
</tr>
<tr>
<td>9 Finger sponge (4.23)</td>
<td>Metridium senile frilled anemone (3.98)</td>
<td></td>
<td>Branching bryozoan (3.57)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Halichondria panicea sponge (3.09)</td>
<td></td>
<td>Crossaster papposus spiny sunstar (3.36)</td>
<td></td>
</tr>
</tbody>
</table>
Defining Mappable Habitat Types

Mappable habitat types were defined by separating the substrate-biotic associations that were statistically distinct, and combining the substrate-biotic associations that were statistically identical. The statistical techniques used to make this determination were multidimensional scaling (MDS) and analysis of similarity (ANOSIM).

Ordination Using Multidimensional Scaling (MDS)

Ordination using multidimensional scaling illustrates the degree of difference in species composition among samples. Ordination of the species composition data from video samples (Fig. 22) clearly shows a separation between the biota of the hard substrates (muddy gravel, sandy gravel and coralline encrusted gravel) and the soft substrate environments (gravelly-sandy mud, gravelly mud, and mud), with a stress value of 0.12, indicating a highly reliable analysis (verified by ANOSIM, see below). Ordination of the species composition data from grab samples (Fig. 23) shows a clear separation between the fauna of the shallow hard substrate samples (sandy gravel and coralline-algae encrusted gravel) and the soft substrates (gravelly-sandy-mud, gravelly mud, and mud), but the muddy gravel substrate (blue triangles) was highly variable, and overlapped its composition with samples from both hard and soft substrates. The stress value of the analysis of the grab sample data (0.15) indicates a fairly reliable analysis, in which differences in biotic composition among substrate classes are slightly less clear than in the video data.
Figure 22: 3-dimensional multidimensional scaling (MDS) plot of video sampled biota

Figure 23: 3-dimensional multidimensional scaling (MDS) plot of biota from grab samples.
Analysis of Similarity (ANOSIM)

Analysis of Similarity (ANOSIM) is a non-parametric test that determines the degree of similarity in species composition among replicate samples in all the substrate-biotic associations. The results of ANOSIM analysis showed that the fauna of the six substrate classes could be divided into three groups: shallow hard substrate biota, (coralline-algae encrusted gravel) deep hard substrate biota (below photic zone, sandy gravel – muddy gravel), and soft substrate biota (gravelly sandy mud, gravelly mud, and mud) (Tables 11 and 12). The biota of the muddy gravel substrates (deep hard substrate) and coralline-alga encrusted gravel (shallow hard substrate) were statistically distinct, but the species composition of the biota on sandy gravel substrates, which were intermediate in depth between the deeper muddy gravel and the shallower coralline-encrusted gravel, did not differ significantly from either of the other hard substrate classes. The biota of the gravelly sandy mud, gravelly mud, and mud substrate classes were statistically indistinguishable from each other in both grab and video data, but all differed from the biota of the hard substrate classes at a probability of p<0.001).
Table 11: ANOSIM results table for grab samples. Numbers indicate probability of p-values, in percent, i.e. p=0.05 is represented as 5.0.

<table>
<thead>
<tr>
<th></th>
<th>Muddy gravel</th>
<th>Sandy gravel</th>
<th>Coralline algae encrusted gravel</th>
<th>Gravelly sandy mud</th>
<th>Gravelly mud</th>
<th>Mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muddy gravel</td>
<td>–</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy gravel</td>
<td>41.5</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coralline algae encrusted gravel</td>
<td>0.1</td>
<td>26.7</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravelly sandy mud</td>
<td>5.5</td>
<td>4.2</td>
<td>0.1</td>
<td>9.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravelly mud</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>44.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mud</td>
<td>0.2</td>
<td>2.4</td>
<td>0.1</td>
<td>47.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 12: ANOSIM results table for video data. Numbers indicate probability of p-values, in percent, i.e. p=0.05 is represented as 5.0.

<table>
<thead>
<tr>
<th></th>
<th>Muddy gravel</th>
<th>Sandy gravel</th>
<th>Coralline algae encrusted gravel</th>
<th>Gravelly sandy mud</th>
<th>Gravelly mud</th>
<th>Mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muddy gravel</td>
<td>–</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy gravel</td>
<td>51.5</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coralline algae encrusted gravel</td>
<td>1.8</td>
<td>16.0</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravelly sandy mud</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>41.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravelly mud</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>34.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mud</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>47.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Definition of Habitat Map Units

Multivariate statistical analysis suggested three mappable habitat types in Gilbert Bay; shallow-hard bottom habitat, hard bottom habitat in deeper water below the photic zone and soft bottom habitat (Table 13, Figure 24).

The shallow-water hard bottom habitat corresponded directly to the coralline algae encrusted gravel substrate class. This habitat is characterised by shallow depth and hard substrate
which allow branching coralline red algae to grow, creating small-scale habitat complexity. Biological diversity and individual abundance within the branched coralline algae was higher than in any other sampled habitat in Gilbert Bay. The shallow coralline algae encrusted gravel habitat was mapped using the same criteria as the coralline algae encrusted gravel substrate class (Table 13).

The deeper, sandy and muddy gravel habitat was inhabited by a combination of infaunal species living in the sediment matrix between the gravel, and epifauna attached to the gravel. Coralline algae were present in the shallower portions of this habitat, but extensive branching was not observed. This habitat was mapped by combining the criteria that defined the muddy gravel and sandy gravel substrate classes (Table 13).

Soft bottom habitat was composed of a primarily muddy substrate with associated infauna, particularly deposit feeding species. This habitat was mapped using the criteria for the gravelly sandy mud, gravelly mud and mud substrates (Table 13).

<table>
<thead>
<tr>
<th>Table 13: Criteria used to map habitats</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Habitat</strong></td>
</tr>
<tr>
<td>---------------------------------------</td>
</tr>
<tr>
<td>Shallow coralline algae encrusted gravel</td>
</tr>
<tr>
<td>Muddy or sandy gravel</td>
</tr>
<tr>
<td>Soft bottom</td>
</tr>
</tbody>
</table>
Figure 24: Benthic habitat map of Gilbert Bay
Habitat Map

Soft bottom habitat in Gilbert Bay is restricted to basin floors, both in shallow and deep water (Fig. 24). Hard bottom habitats occur on basin margins and sills. Coralline algae encrusted gravel habitat is depth-restricted and only occurs in shallow water, whereas muddy or sandy gravel habitat is mapped at a range of water depths from shallow to moderately deep. The final habitat map produced for Gilbert Bay shows a remarkably limited range of habitats within the bay, with distributions governed almost exclusively by depth and substrate type. There appears to be relatively little biologically-constructed habitat, although the coralline-algae encrusted gravel habitat is biologically-modified, probably in fairly important ways.

Much of the biological pattern in Gilbert Bay may result from habitat variation on the 10s to 100s of metres scale, for example, the juxtaposition of substrates and habitats in confined areas. The Shinneys, for example, hosts coralline-algae encrusted bedrock ridges close to shallow water mud basins (Fig. 18A and B); the rock ridges and biota on them may provide shelter for juvenile fish, including juvenile Gilbert Bay cod, while the nearby mud bottom habitats may provide additional food sources, particularly for feeding at night when predation risk is low. Management plans for protecting habitat in Gilbert Bay will be most efficient if they focus on areas with multiple substrates, and multiple habitats, found within relatively small areas.

Bottom Habitats at Fish Faunal Survey Sites

Wroblewski et al. (in press) described finfish biota at three repeatedly sampled sandy gravel sites, among the only sites in Gilbert Bay that could be sampled successfully with beach seine nets (Fig. 6). All three sites extend from the waterline to 100 m from shore, in depths between 15 and 25 m. Fish Faunal Survey Site 1 (FFS-1) was not covered by multibeam sonar at all, while FFS Sites 2 and 3 received multibeam sonar coverage at depths greater than 5m only.
At FFS Site 1, the subtidal zone within 30 m of the shoreline is relatively flat, with a bottom depth of about 1 m. Starting from 40 m off the shoreline, the bottom drops off sharply, then tends to be flat again between 70 m and 100 m from shore (Figure 25). The slope of the subtidal zone at FFS Site 2 is steeper than at Site 1. The bottom drops off quickly 40-70 m from the shoreline (Figure 26). FFS Site 3 has the most steeply sloped subtidal zone of the three sites (Figure 27). The slope is relatively constant out to 100 meters from the shoreline.

The bottom substrates at the three sites are different, although all sites show a trend of decreasing bottom hardness with increasing depth (Table 14, Figures 25-27). The hardness of the bottom was highest at Site 1 and lowest at Site 3. Benthos common to all three sites were sea urchin, blue mussel, coralline algae, and unidentified burrowing organisms (Hu 2007).

At Site 1, the bottom substrate shallower than 1.5 m depth is composed of pebble gravel populated by blue mussels (<4 cm in length). Coralline algae were found growing on cobbles where the water depth is greater than 5 m.

Cobble or pebble gravel with coarse sand was the main substrate in shallow water (<1.5 m) at Site 2. Blue mussels were abundant in this area. Branching coralline algae was abundant at the bottom at depths of 5-7 m. The bottom substrate at depths 10-15 m was muddy sand with scattered cobbles.

The substrate in shallow water (<1.5 m) at Site 3 was composed of pebble gravel with a small percentage of sand. Branching and encrusting coralline algae on boulders were common at depths 3-5 m. The bottom substrate deeper than 15 m was sandy mud and mud with scattered cobbles.
Table 14: Habitat classes at Site 1, Site 2, and Site 3 observed by drop down video at 10m interval from the shoreline.

<table>
<thead>
<tr>
<th>Habitat class</th>
<th>Site 1 (Distance seaward from shoreline, m)</th>
<th>Site 2 (Distance seaward from shoreline, m)</th>
<th>Site 3 (Distance seaward from shoreline, m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Boulders and cobbles on pebble gravel</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pebble gravel with scattered cobbles, high coverage of mussels and shells</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pebble gravel</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pebble gravel with high coverage of mussels and shells</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Pebble gravel on sand with scattered cobbles</td>
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<tr>
<td>Pebble gravel on sand with scattered cobbles covered with coralline algae</td>
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<tr>
<td>Pebble gravel on sand, high coverage of coralline algae</td>
<td></td>
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<td>X</td>
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<tr>
<td>Muddy sand with pebbles and cobbles covered with coralline algae, shells</td>
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<tr>
<td>Pebbles on sandy mud, some coralline algae</td>
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<tr>
<td>Pebbles with thin mud veneers and scattered cobbles on sandy mud, some coverage of coralline algae</td>
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<tr>
<td>Sandy mud with lone cobbles covered with coralline algae, burrows</td>
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<tr>
<td>Sandy mud with burrows and shells</td>
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<tr>
<td>Mud with burrows and scattered cobbles with bryozoans/coralline algae growing on the surface</td>
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Figure 25: Subtidal zone profile, substrates, and benthos at Fish Faunal Survey Site 1.
Figure 26: Subtidal zone profile, substrates, and benthos at Fish Faunal Survey Site 2.
Figure 27: Subtidal zone profile, substrates, and benthos at Fish Faunal Survey Site 3.
Figure 28: Photographs of substrates at FFS Site 1 captured from video data. a) About 10m from the shoreline; b) The rocky bar at 40m from the shoreline; c) About 50m from the shoreline. Scaling lasers are 15 cm apart.

Figure 29: The pictures of substrates at FFS Site 2 captured from video data. d) About 10m from the shoreline; e) About 50m from the shoreline.
Scallop Habitat in Gilbert Bay

Live Iceland scallops (*Chlamys islandica*) were collected in two of the grab samples and several videos recorded during groundtruthing in Gilbert Bay. The results of SIMPER analysis indicated that scallops were significant contributors to similarity in the shallow gravel classes (Table 10). Scallops were the second highest contributing taxa in the sandy gravel class (contributing 16.4%) and third highest in the coralline algae encrusted gravel class (10.99%). A map of potential scallop habitat in Gilbert Bay was generated by plotting the sandy gravel and coralline algae encrusted gravel substrates using the classification criteria shown in Table 5 (Fig. 31).
Figure 31: The distribution of potential scallop habitat in Gilbert Bay
Study Highlights and Future Research

Several areas of Gilbert Bay emerged as regions of key importance for marine habitats, all of which require further exploration and analysis. Some areas are narrowly defined geographically (e.g. River Out, the Shinneys), while others are defined based on their origins (e.g. the sills along the main axis of the bay). These areas are briefly described below.

River Out – Mogashu Tickle – Outer Portions of the Shinneys

Among the most topographically and biologically complex areas in Gilbert Bay is the narrow passage connecting The Shinneys to the main part of Gilbert Bay, known as River Out and Mogashu Tickle. This area has tidal rapids, with extremely strong current flow observed at ebb and flood tide, and thus extensive filter-feeding epifauna such as anemones and sponges. Much of the area just SW of Mogashu Tickle, in the narrow entrance to Shinneys, probably consists of bedrock ridges with coralline algae, sponges, and other hard-substrate fauna that thrive in areas of strong currents. Unfortunately, this area was not thoroughly explored during the 2006 field work due to time, camera, and boat limitations. These areas should be studied further in future field work to characterize fauna and the relationships between biota and the geological and oceanographic features defining habitat.

Rhodoliths and Coralline Algae Encrusted Gravel Habitat

Rhodoliths are formed when coralline red algae encrust loose gravel, shells or the calcium carbonate skeletons of other coralline algae. The algae grow on top of this core material, usually in areas of moderate current which helps keep them from being smothered by sediment.
Habitat Mapping in Gilbert Bay Marine Protected Area

(Bosence 1983). The current also rolls the rhodoliths over periodically, enabling algae to grow on all surfaces of the core material. Rhodoliths are therefore commonly spherical (Bosence 1983). Rhodoliths were recorded from a shallow fjord sill with strong tidal currents in Bonavista Bay (Copeland et al. 2005). Similar current action in shallow water is likely in narrow sections of River Out and possibly the Narrows in the upper bay; therefore the formation of rhodoliths is possible in these areas. Rhodoliths were observed at two stations in River Out during the groundtruth sampling in 2006 (Fig. 32).

In Gilbert Bay, gravel substrate in shallow water was commonly encrusted with branches of coralline algae; however, these are not true rhodoliths as the core material is not completely covered by branched algae and they are not free to move. This coralline algae encrusted gravel substrate does provide habitat for a diverse biological assemblage (Tables 9 and 10), and likely extends into shallow water areas not covered by the multibeam, particularly in the Shinneys. Therefore coralline algae encrusted habitat in Gilbert Bay should be the subject of further study, especially its relationship with scallops and juvenile cod (see below).

**Inner Portions of the Shinneys**

Ground-truthed multibeam mapping identified much of the Shinneys as mud bottom. The Shinneys has also been identified as important spawning grounds for Atlantic cod, and probably as important habitat for juvenile cod, yet these features are not expected on mud bottoms. This apparent contradiction may be explained by the areas of bedrock ridges which are encrusted by coralline algae and other hard-substrate biota, and which create near-vertical exposures of rock wall habitat. These bedrock ridges appear as near-linear raised features on the multibeam
Figure 32: The distribution of coralline algae encrusted gravel in Gilbert Bay, mapped from the classification criteria found in table 5. Inset map shows the location of rhodoliths sampled in River Out.
classification draped over bathymetry image. Much of the area that might constitute key habitat for juvenile cod may occur in the nearshore areas of the Shinneys that are less than 5 m deep (the minimum depth surveyed by the multibeam launch). Further biological characterization of these shallow water areas of the Shinneys should be a research priority.

**Glacially-derived Sills and Scallop Habitat in Gilbert Bay**

Although glacial landforms are rare above the waterline in Gilbert Bay, many of the habitat-generating features in the bay are glacial or glaciofluvial in origin. The multiple sills defining basins along the main axis of the bay are composed of muddy gravel, and probably derived from moraines. The coralline-algae encrusted gravel habitat in the main axis of Gilbert Bay is found primarily on top of these sills, and the sills are the principle origin of the scallop habitat fished in Gilbert Bay Management Zones 2 and 3 (Fig. 31). Further understanding of the glacial history of Gilbert Bay will help to explain the nature of these sills and their origin.

**Submerged Glaciofluvial Landforms in the Central and Upper Bay**

Another submerged glacial landform is a long esker (a glaciofluvial feature) that runs along the southwestern margin of the main axis of the bay. This esker includes two large fans exposed above the waterline as the Upper and Lower Hummocks. The esker, composed dominantly of sand and gravel, has been winnowed to expose a gravelly substrate which has since been colonized by coralline algae, much like the coralline-algae encrusted gravels atop the moraines (sills). Further understanding of the glacial history of the Gilbert Bay region will help elaborate
the origin of the eskers, the Upper and Lower Hummocks, and that habitats associated with these features.

**Steep Rock Walls in Leg Island Basin**

Leg Island Basin is the only portion of Gilbert Bay characterized by deep steep rock walls, a type of environment often found in fjords that typically forms a distinctive habitat (Haedrich and Gagnon 1991). Such areas are often difficult to sample, because grab samplers typically do not successfully retrieve samples from steep hard substrates, and downward pointing video cameras similarly do not sample such areas effectively. Furthermore, video assessment of this environment during the 2006 field season was cut short when the underwater camera was fouled in abandoned fishing gear. The steep rock wall habitats of Leg Island basin merit further exploration.

**Juvenile Cod Habitat in the Shinneys and the Main Arm of Gilbert Bay**

The survival of juvenile cod is the most important parameter governing the population dynamics of Atlantic cod in Gilbert Bay, according to the thesis research of Liuming Hu (2007). Unlike coastal Newfoundland where eelgrass is important juvenile cod habitat, in Gilbert Bay structured hard-bottom substrate is likely the habitat for juvenile cod. We have found no eelgrass habitat in Gilbert Bay. To escape predation, juvenile cod hide in structured habitat. In Gilbert Bay that structured habitat is likely provided by branching coralline algae growing on cobble-boulder gravel. Our observations to date indicate suitable habitat for juvenile cod may occur at specific locations in The Shinneys (e.g. Mogashu Tickle) and River Out, and in specific locations in the
upper, middle and lower regions of the bay. During the standardized fish fauna survey of Gilbert Bay conducted in 2004, Wroblewski et al., (2007) found no juvenile cod in shallow waters which could be seined (and had little bottom structure). But Wroblewski (unpublished data) did collect juvenile cod in The Shinneys and in the main arm of Gilbert Bay with small-mesh gillnets which could sample the water column above structured bottom habitat. Areas of Gilbert Bay which have significant beds of coralline algae and boulder-cobble gravel should be studied further in future field work. To understand and realistically model the population dynamics of Atlantic cod in Gilbert Bay, it is very important to determine the habitat of post-settlement juvenile cod in Gilbert Bay. This may be critical habitat which governs the survival of young cod, and therefore determines the growth (or not) of the local cod population in the MPA.

Summary

Phase II of marine habitat mapping in Gilbert Bay, Labrador, found the following key results.

1. Six substrate types were sampled during ground-truthing field work in October, 2006: muddy gravel, sandy gravel, coralline-algae encrusted gravel, gravelly sandy mud, gravelly mud, and mud.

2. The biota on some of these substrates is statistically identical, such that only three mappable and statistically unique habitat types could be defined: gravel-bottom, shallow coralline-encrusted gravel, and soft-bottom habitats.

3. Areas with multiple habitat types represented in a small area are of greatest biological significance, such as River Out and The Shinneys.
4. Substrate and habitat units mostly have geological origins, and understanding the Quaternary geology of Gilbert Bay will be important to understanding the habitats.

5. Scallop habitat is found on shallow gravel-bottom and shallow coralline-algae encrusted gravel bottoms. The distribution of scalloping grounds mapped by traditional ecological knowledge and these habitat types are closely matched.

6. The Gilbert Bay population of Atlantic Cod probably occupies habitat on most of the hard substrate bottoms, and areas with closely juxtaposed hard and soft bottoms.
References


Hu, L. 2007. Modeling the resident fish production, the ecosystem carrying capacity and population dynamics of Atlantic cod (Gadus morhua) in Gilbert Bay, Labrador: A Marine Protected Area. MSc. Thesis Environmental Science Programme, Memorial University.


Appendix A: Invertebrate Taxa Recorded in Grab and Video Samples

**Annelida: Polychaeta**
- *Pectinaria granulata* — trumpet worm
- *Nothria (Onuphis) conchylega* — tube worm
- *Harmothoe imbricate* — Fifteen scaled worm
- *Lepidonotus squamatus* — Twelve scaled worm
- *Pherusa plumosa*
- *Nereis sp.* — clam worm
- *Nephtys sp.* — Red lined worms
- *Diopatra cuprea* — Plumed worm
- *Spirorbis borealis* — hard tube worm
- *Spirorbis spirillum* — hard tube worm
- *Spirorbis granulatus* — hard tube worm
- *Serpula sp.* — hard tube worm

**Arthropoda: Pycnogonida**
- *Anoplodactylus lentus* — Lentil sea spider

**Arthropoda: Crustacea**
- *Balanus balanus* — Rough barnacle
- *Ampithoe rubicata* — Tube building amphipod
- *Leptocheirus pinguis* — Tube building amphipod
- *Gammarus sp.* — Amphipod
- *Casco bigelowi* — Amphipod
- *Hyas araneus* — Toad crab
- *Pagurus acadianus* — Hermit crab
- *Spirontocaris spinus* — Caridean shrimp
- *Lebbeus sp.* — Caridean shrimp
- *Diastylis quadrispinosa* — Cumacean

**Brachiopoda**
- *Hernithyris psittacea* — Parrot beak lampshell

**Bryozoa**
- *Membranipora sp.*
- *Stomachetosella sinuosa*
- *Escharella immerse*
- *Smittina sp.*
- *Eucratea loricata*
- *Flustra foliacea*
- *Porella sp.*
- *Tubulipora sp.*
- *Lichenopora sp.*
- *Scrupocellaria scabra*
Chordata: Ascidiacea
Styela partita – Rough sea squirt  
Didemnum albidum – White crust Ascidian  

Cnidaria: Anthozoa
Metridium senile – Frilled anemone  

Cnidaria: Hydrozoa
Sertularia pumila  
Campanularia sp.  
Abietinaria sp.  

Echinodermata: Asteroidea
Crossaster papposus – Spiny sun star  
Henricia sp. – Blood star  
Hippasteria phyrgiana – Horse or cushion star  
Leptasterias polaris – Polar sea star  
Asterias vulgaris – Northern or common sea star  
Ctenodiscus crispatus – mud star  

Echinodermata: Crinoidea
Hathrometra sp.  

Echinodermata: Echinoidea
Strongylocentrotus droebachiensis – Green sea urchin  

Echinodermata: Holothuroidea
Cucumaria frondosa – Orange-footed sea cucumber  

Echinodermata: Ophiuroidea
Ophiura sarsi – Boreal brittle star  
Ophiura robusta – Brittle star  
Ophiopholis aculeata – Daisy brittle star  

Foraminiferans
Calcareous foraminiferans  
Agglutinating foraminiferans  

Mollusca: Bivalvia
Clinocardium ciliatum – Iceland cockle  
Anomia squamula – Prickly jingle shell  
Astarte undata – Waved Astarte  
Cyclocardia borealis – Northern cardita  
Nuculana tenuisulcata – Elongate nut clam  
Hiatella arctica – Arctic rock borer or Arctic saxicave  
Yolida sp.
Nucula tenuis — Thin nut shell
Crenulla glandula —
Mya truncata — Truncate soft-shelled clam
Macoma balthica — Baltic macoma
Thyasira flexuosa — Cleft clam
Periploma papyratium — Paper spoon shell
Chlamys islandica — Iceland scallop
Cerastoderma pinnulatum — Little cockle
Mytilus edulis — Blue mussel

Mollusca: Gastropoda
Margarites helicinus — Smooth top shell
Margarites costalis — Ridged top shell
Turritellopsis acicula — Needle shell
Puncturella noachina — Noah’s punctured shell
Acmaea testudinalis — Tortoise shell limpet
Velutina laevigata — velvet shell

Mollusca: Polyplacophora
Tonicella rubra — Red chiton
Ischnochiton albus — White chiton

Porifera
Halichondria panicea — Breadcrumb sponge
Scypha ciliata — Vase sponge
Finger sponge (possibly Haliclona oculata)
Orange sponge
White sponge
Appendix B: Detailed Bathymetry and Backscatter Description for Gilbert Bay

For the purpose of this report, Gilbert Bay is sub-divided into 9 regions, which are physiographically or administratively distinct (Figure B1). These regions are: Gilbert River Mouth, Upper and Lower Hummock, River Out, The Shinneys, Big Island to Halfway Point, Halfway Point to Kelly’s Point, Kelly’s Point to Rexon’s Point, and Leg Island Basin. Gilbert River Mouth, Upper and Lower Hummock, River Out, and The Shinneys are all in zone 1 of the Marine Protected Area, Big Island to Halfway Point, Halfway Point to Kelly’s Point are in zone 2, and Kelly’s Point to Rexon’s Point, and Leg Island Basin are in zone 3. An additional area analyzed is part of Williams Harbour Run, an area locally known as Capt. Jack’s Cove, also in Zone 3. Appendix B provides a detailed description of the bathymetry and backscatter patterns of each of these regions.

Figure B1: Location of informal divisions of Gilbert Bay used for analysis and description of bathymetry, backscatter and substrate.
**Gilbert River Basin**

*Bathymetry*

The Gilbert River Basin is an oblong basin at the head of Gilbert Bay, where the Gilbert River meets the sea (Fig. B1). This basin is separated from the main arm of the bay by an approximately 12 m deep sill. The basin inside the sill is shallow with a mean depth of 23.75 m. Most of the basin floor is flat (≤ 2°). The only bathymetric feature inside the basin is a scarp slope marking the northern most location of the Gilbert River fault in the bay. The water at the base of this slope is 34 m deep, making it the deepest point in the upper part of the bay (Fig. B2).

*Backscatter*

The general trend in this basin, as with Gilbert Bay in general, is that backscatter mirrors bathymetry (Fig. B4). The lowest backscatter values were found in deep water, while shallow areas reflected higher backscatter. The flat floor of the basin had low backscatter values ranging from −23 to −36 dB. The deepest point in the Gilbert River Basin is the Gilbert River fault trough, which also had the lowest backscatter in the basin (−43 dB). Higher backscatter was found near the mouth of the Gilbert River. A few areas of moderate backscatter (−6 to −15 dB) were recorded in this basin, and these were associated with positive relief features.
**Figure B2:** Map of multibeam bathymetry for the Gilbert River Basin sun illuminated from the east. A profile along the line indicated is shown in Fig. B3.

**Figure B3:** Bathymetric profile of Gilbert River Basin from west to east showing the Gilbert River fault scarp.

**Figure B4:** Multibeam backscatter of Gilbert River Basin.
The Hummocks - Zone 1A

Bathymetry

The Narrows is a 450 m wide channel connecting the Upper Hummock to the Gilbert River basin. A sinuous channel can be seen running along the seabed between the mouth of the Gilbert River, through the Narrows into the Upper Hummock (Fig. B5). The channel is visible for about 3 km. The bottom of this channel reaches depths between 24 and 30 m, while depths between 5 and 18 m are more typical of the surrounding rough seabed. The margins of the channel have slope angles between 5 and 30°.

The margins of the bay in the Upper Hummock are undulating, with two particularly complex regions just outside the Narrows, and between Upper and Lower Hummock. At the centre of the Upper Hummock the bay is shallow (15 to 21 m) and very flat (2 to <1°). The largest expanse of flat seabed in Gilbert Bay is found in the centre of the Upper Hummock.

An area of complex bathymetry separates the flat floor of the Upper Hummock from a smaller flat area of similar depth at the start of the Lower Hummock (beginning about 4km on Fig. B6). Here the rough seafloor has shallower water depths, particularly on the northern side of the bay where depths range from 6 to 12 m and the seabed is very rough. On the south side of the bay the seafloor is less rough and water depths range from 21 to 30 m.
Figure B5: Bathymetry of Upper and Lower Hummock (Zone 1A) sun illuminated from the east. A profile along the line indicated is shown in Fig. B6.

Figure B6: Bathymetric profile of the Upper and Lower Hummock.

Figure B7: Multibeam backscatter values for the Upper and Lower Hummock showing extensive moderately reflective seafloor.
Between the Lower Hummock and the western side of Big Island, the general bathymetric trend is a seaward deepening of the bay from about 20 m near the Lower Hummock to about 35 m near Big Island. There are numerous round depressions with diameters between 45 and 70 m in this basin. The bottoms of these depressions are 3 to 6.5 m below the level of the seafloor (Fig. B6). The centre of the bay in this location reaches 53 m, at the bottom of a depression west of Big Island. These round depressions are probably gas escape features, commonly found on post-glacial mud in productive environments like estuaries.

Southwest of Big Island, just west of the boundary of MPA zone 1A, lies a linear high relief ridge. This feature rises 3 to 8 m high off the seabed at water depths from about 8 to 21 m. A similar linear raised feature can be seen near River Out. The top of this ridge is 5 to 15 m deep, while the surrounding seafloor is 16 to 27 m deep. Sinuous raised features northwest and southeast of Lower Hummock are probably eskers. The remainder of the area between Big Island and River Out contains rough seabed, which is deeper to the west of Big Island than to the east.

**Backscatter**

The positive relief hills and complex bathymetry in the Narrows reflected slightly higher backscatter values than flatter seafloor. The highest backscatter in this region of the bay occurs in the Narrows on the edges of the multibeam coverage ranging from $-12$ to $-18$ dB. These values are associated with the sloping edges of the bay (with angles up to 27º) in shallow water. In general rough bathymetry in the Narrows reflected backscatter between $-10$ and $-20$ dB, while the slightly deeper and flatter areas reflected $-20$ to $-30$ dB (Fig. B7).

Just as the bathymetry becomes less complex toward the middle of the Upper Hummock, so too does the backscatter pattern. Backscatter intensity reflects bathymetry very closely in this
part of the bay. Most of the flat central part of the Upper Hummock reflected backscatter values between $-23$ and $-33$ dB. The few isolated hills in the Upper Hummock reflected stronger backscatter, (typically $-11$ to $-18$ dB) and can be clearly seen in the backscatter data. The slope up to the island in the Upper Hummock also reflected high backscatter, as did a small ridge on the southern side of the Upper Hummock ($-6$ and $-5$ dB respectively).

The backscatter values from the shallow, complex bathymetry between the Upper and Lower Hummock are higher than those found in the basins on either side. The larger basin has backscatter ranging from $-23$ to $-33$ dB, while the values for the smaller basin range from $-24$ to $-31$ dB. Backscatter from the rough seafloor between the basins ranges from $-11$ to $-25$ dB with slightly higher values in the shallow water on the north side (Fig. B7).

The smaller basin is bounded to the southeast by complex bathymetry which occurs between two points of land on the south and north sides of Gilbert Bay at the Lower Hummock. This area of complex bathymetry in the Lower Hummock contains some small areas which reflected backscatter between $-25$ and $-30$ dB, while the rest of the area reflected values between $-9$ and $-20$ dB. Again the higher backscatter was associated with the shallowest depths.

Southeast of this complex bathymetry at the Lower Hummock is another basin lying west and south of Big Island and the boundary line for MPA zone 1A passes through it. The floor of this basin is non-reflective with backscatter values between $-26$ and $-33$ dB. The edges of this basin display a mottled pattern of moderate ($-15$ to $-19$ dB) to low ($-28$ to $-33$ dB) backscatter. The most striking features in this basin are the linear and sinuous ridges on the southern side of the basin. These ridges appear in the backscatter as lines of high values surrounded by low values (Fig. B7). Values for the ridge range from $-7$ to $-18$ dB, indicating a reflective substrate. High backscatter values on these ridges are consistent with the sand and gravel composition of eskers.
Big Island to Halfway Point

Bathymetry

Southeast of Big Island the seafloor is very complex and rough with numerous hummocks and depressions; it is very similar to the slightly deeper seabed to the east which ranges from about 20 to 40 m (Fig. B8), and reflected a mottled backscatter pattern, dominated by low values. The moderate backscatter (−14 to −26 dB) appears associated with positive relief while most of this basin is between −25 and −36 dB. This complex bathymetry continues east to the mouth of River Out. The sinuous ridge at the mouth of River Out reflected slightly higher backscatter than the surrounding seabed. Values on the ridge range from −12 to −21 dB. This ridge is 650 m northeast of the MPA zone 1B – zone 2 boundary at River Out (Fig. B8).

On the profile at 4 km a basin can be seen between the mouth of River Out and Halfway Point on Rexon’s Island (Fig. B9). The deepest part of this basin is in the centre where it reaches 61 m. This basin is separated from the next basin by a rough sill at Halfway Point. The shallowest point on this sill is 14 m deep, and most of it is shallower than 30 m.
Figure B8: Bathymetry between Big Island and Halfway Point sun illuminated from the east. A profile along the line indicated is shown in Figure B9.

Figure B9: Bathymetric profile from MPA Zone 2 boundary at Big Island to Halfway Point.

Figure B10: Multibeam backscatter values between Big Island and Halfway Point showing reflective seabed in shallow water and non-reflective seabed on the basin floor.
Backscatter

Southeast of Big Island there is a zone of moderate backscatter which corresponds to positive bathymetric relief at depths of 20 m or less. There is a small island in the centre of this shallow-water reflective seabed. Water depths here range from 8 to 20 m and backscatter values from $-10$ to $-20$ dB. The highest backscatter value in this region of the bay, +2 dB, was recorded southeast of this small island (Fig. B10).

The south side of the basin between River Out and Halfway Point is fairly flat with portions $<5^\circ$ in $<-40$ m water depth. Here the substrate is non-reflective with backscatter values between $-23$ to $-42$ dB. The basin floor in general is non-reflective with backscatter $-22$ and $-40$ dB. Also the lowest backscatter value between Big Island and Halfway Point, $-45$ dB, is found on the floor of this basin.

The sill at Halfway Point is composed of reflective substrate with backscatter values between $-13$ and $-28$ dB. A small patch of very reflective ($-5$ to $-10$ dB) seabed can be seen on the north side of the bay on a slope of $25^\circ$.

River Out

Bathymetry

The region of the bay between The Shinneys and Rexon’s Island is known as River Out. River Out lies immediately inshore of the boundary line for MPA zone 1B. This region is mostly quite shallow, with hummocky bathymetry, generally between 10 and 25 m deep (Fig. B11). The exception is the scarp of the Gilbert River fault, where water depth reaches 45 m (Fig. B12). This steeply sloping (up to $47^\circ$) scarp is the primary bathymetric feature in this part of the bay.
Figure B11: Multibeam bathymetry of River Out sun illuminated from the west. A profile along the line indicated is shown in 18.

Figure B12: Bathymetric profile of River Out from south to north showing the Gilbert River fault scarp.

Figure B13: Map of multibeam backscatter for River Out showing mostly reflective seafloor.
Two narrow inlets, Snook’s Arm and Long Arm, follow the orientation of the Gilbert River fault which runs in a northwest-southeast direction parallel to the main arm of Gilbert Bay (Fig. B11). Snook’s Arm is a steep sided, U-shaped inlet with a maximum surveyed depth of 45 m. In contrast the surveyed portion of the entrance to Long Arm is very flat. The Gilbert River fault is less defined at the mouth of Long Arm so no U-shaped valley exists, and the water is shallow with a maximum depth of 25 m. Only the entrances to these areas were covered by the multibeam survey.

**Backscatter**

The seabed at River Out reflected moderate backscatter in a narrow range between −15 and −21 dB, producing a fairly homogenous pattern over most of the region (Fig. B13). Slightly lower backscatter was recorded at the entrance to both Snook’s Arm and Long Arm. The side walls at the entrance to Snook’s Arm are very steep and highly reflective. The highest backscatter value in the River Out region, −2 dB, was found here. Low backscatter values were found at the mouths of Long Arm and Snook’s Arm where the slope angle is low. At Long Arm backscatter ranging from −28 to −35 dB is found on slopes of 5° or less. The lowest backscatter value in River Out, −45 dB, was recorded here in 15 m of water. Similarly, at Snook’s Arm values from −26 to −32 dB were found in the deepest part of the inlet.
The Shinneys

Bathymetry

The mouth of the Shinneys is a 280 m wide channel with a small island in the centre. The multibeam survey covered the channel to the west of the island, which is 130 m wide and 6 to 18 m deep. The Shinneys, inside this point, is 7.7 km$^2$ of which 3 km$^2$ was surveyed with multibeam.

The Shinneys is a narrow (~0.5 km wide), U-shaped channel which opens into a larger basin near the mouth of the Shinneys River (Fig. B14). The floor of the channel contains several depressions which become successively shallower towards the mouth of the Shinneys River. The deepest point in the Shinneys, 56 m, was recorded at the bottom of a depression in the channel.

At the western end of the channel there is a particularly shallow bathymetric feature, which is likely a shallow shoal or submerged rock. The shallowest water depth surveyed in the Shinneys, 1m, was recorded here. This bathymetric feature marks the end of the channel through the Shinneys. Just west of this point, near the mouth of the Shinneys River, the channel opens out into a basin which shallows gradually towards the west (Fig. B15). This inner part of the Shinneys is very flat and 19 to 24 m deep.

Backscatter

A higher number of low backscatter (less than $-30$ dB) values were recorded in the Shinneys than any where else in Gilbert Bay. In general the backscatter values decrease away from the main arm of Gilbert Bay, towards the Shinneys River (Fig. B16).
Habitat Mapping in Gilbert Bay Marine Protected Area

Figure B14: Map of multibeam bathymetry from The Shinneys sun illuminated from the north. A bathymetric profile along the line indicated is shown in B15.

Figure B15: Bathymetric profile of The Shinneys showing the gently sloping inner basin.

Figure B16: Multibeam backscatter values for The Shinneys showing extensive non-reflective seafloor.
An area of moderate backscatter between −15 and −25 dB was recorded near the mouth of the Shinneys. The only other extensive area of moderate backscatter occurred in a heterogeneous area midway between the mouth and head of the Shinneys. Here small patches of high backscatter up to −1 dB, and low backscatter to −43 dB are interspersed with moderate −13 to −23 dB. High backscatter occurred on the edges of the surveyed area in the Shinneys, associated with steep slopes. The north side of the Shinneys reached slope angles up to 54º and had backscatter values to −2 dB, while the south side had slopes up to 57º and backscatter to −8 dB.

There is also moderate and high backscatter associated with bathymetric highs in the inner part of the Shinneys, such as the hill opposite the mouth of the Shinneys River which reaches 3 m depth with backscatter from −24 to 0 dB.

The floor of the inner part of the Shinneys is very flat compared to the rest of Gilbert Bay with extensive area less than 1º slope. The substrate here is non-reflective, with most of the floor of this area having low backscatter between −29 and −59 dB.

**Halfway Point to Kelly’s Point**

*Bathymetry*

Seaward of the sill at Halfway Point is a larger, deeper basin extending from Halfway Point to the western side of Kelly’s Point on Rexon’s Island (Fig. B17). This basin reaches a maximum depth of 94 m. This depth was recorded at the bottom of a depression aligned along the axis of the inlet at Deer Park, which is possibly a fault (Fig. B18).

There are two sills radiating from Kelly’s Point forming a double sill separating the basin at Halfway Point from another at Rexon’s Point. The branch of this sill closer to the head of the bay (the western arm) completely crosses the bay from Kelly’s Point on the south side northwards
Figure B17: Bathymetry from Halfway Point to Kelly’s Point sun illuminated from the southeast. A profile along the line indicated is shown in Figure B18.

Figure B18: Bathymetric profile from Halfway Point Sill to western Kelly’s Point sill showing the deep basin at the mouth of the Deer Park.

Figure B19: Multibeam backscatter values from Halfway Point to Kelly’s Point showing higher values associated with the sills and lower values in the basin.
toward Deer Park. The top of the western arm of Kelly’s Point sill ranges in depth from about 7 m near the shore on the south side to 40 m on the north side of the bay. The seaward branch of the sill is 7 to 36 m deep and extends eastward towards Winnard Tickle (Winter Tickle). This seaward extension does not completely bisect the bay.

**Backscatter**

The basin between the Halfway Point sill and Kelly’s Point sill, off Peckham’s Cove, displays low backscatter on the basin floor and more moderate values on the margins of the basin (Fig. B19). The basin floor ranges from $-18$ to $-35$ dB. There is a lot of low backscatter (less than $-25$ dB) in the deepest part of this basin at 60 to 70 m, which may be a fault scarp at the mouth of Deer Park. Some cells here had values from $-38$ to $-43$ dB. The remainder of the basin floor, to the east towards Kelly’s Point, reflected backscatter between $-15$ and $-25$ dB.

The eastern part of the Halfway Point to Kelly’s Point basin floor and both arms of the Kelly’s Point sill reflected similar backscatter values. The sill at Kelly’s Point reflected backscatter between $-15$ and $-25$ dB with small patches of lower backscatter in the deeper water between the two arms of the sill. There is also a small amount of $-10$ to $-3$ dB near to shore at Kelly’s Point. The slope here is up to $37^\circ$. 
Kelly’s Point to Rexon’s Point

Bathymetry

A 2.5 km long basin was surveyed between Kelly’s Point and Rexon’s Point on the eastern tip of Rexon’s Island (Fig. B20). As with the previous basins, the general trend here is increasing depth seawards. The maximum depth of this oval basin is 99 m. The seafloor topography east of Kelly’s Point is less complex than in the upper parts of Gilbert Bay. The edges of this basin are steep, reaching a maximum value of 58º near Rexon’s Point. Shallow-water (3 to 20 m) surveyed between Point of the Bay and Point of the Island contained a 70 m-wide channel running into Winnard Tickle which is potentially a fault (Fig. B21).

Backscatter

The lowest backscatter value observed in this basin (−50 dB) was found at the bottom of the basin between Kelly’s Point and Rexon’s Point at 73 m water depth. The floor of this basin contains a unit of low backscatter (−25 and −37 dB) found at depths between 55 and about 75 m on a gentle slope (<6º). The sills at either end of this basin both have backscatter values between −8 and −15 dB, indicating more reflective substrate than the basin floor (Fig. B22).

There is high backscatter, −8 to −14 dB, associated with two parallel hills between Point of the Bay and Point of the Island. There is also moderate backscatter in the deepest part of this basin near Granby Island north of Rexon’s Point. Here values from −22 to −11 dB were recorded with small areas reflecting as high as −2.5 dB. This high backscatter does not appear to be associated with bathymetric features and should be investigated.
Figure B20: Bathymetry between Kelly’s Point and Rexon’s Point. A profile along the line indicated is shown in Figure B21.

Figure B21: Bathymetric profile from Kelly’s Point to Rexon’s Point.

Figure B22: Multibeam backscatter from Kelly’s Point to Rexon’s Point.
**Rexon’s Point Sill and Leg Island Basin**

**Bathymetry**

Between Rexon’s Point and western Granby Island the bay is only 500 m wide. Here a circular basin with a diameter of 400 m occurs 100 m off Rexon’s Point. The deepest point of this depression is 65 m deep. The depression is on the seaward side of the Rexon’s Point sill, and the deepest part of the sill is 38 m deep (Fig. B23).

The outer-most basin covered in the multibeam survey is bounded to the south by Leg Island, to the west by Rexon’s Island, and to the north and east by Granby Island. This basin is the deepest and largest surveyed (Fig. B24). The steepest slope angle recorded in Gilbert Bay, 68º, is found on the north side on a cliff off Granby Island.

The most remarkable feature in this basin is the Gilbert River fault which follows the axis of the basin from Red Bay to Rexon’s Cove. The fault appears as a trough on the floor of the basin, which reaches depths over 150 m in several places. The deepest depth in the Gilbert Bay bathymetric survey, 163 m, was found here.

**Backscatter**

The sill at Rexon’s Point reflected a fairly homogenous backscatter pattern with values between −8 to −22 dB. Small areas around −10 dB were found close to shore at the sill. The moderate backscatter of the sill continues into the Leg Island basin to a depth of about 60 m (Fig. B25).

The Leg Island basin reflected moderate backscatter values similar to those of the adjacent Rexon’s Point sill. At Rexon’s Cove, near Bald Island, the backscatter pattern was heterogenous. The cove and nearby basin floor are dominated by moderate
Figure B23: Bathymetry of the Leg Island Basin sun illuminated from the northeast. A profile along the line indicated is shown in Figure B24.

Figure B24: Bathymetric profile of the Leg Island basin. No data location is a gap in the multibeam coverage in the deepest part of the basin.

Figure B25: Multibeam backscatter of Leg Island basin.
backscatter values, $-13$ to $-22$ dB, but patches of low ($-25$ to $-37$ dB) and high ($0$ to $-10$ dB) backscatter also occur on the margins of the basin near Rexon’s Point and Leg Island. The very high backscatter along the southern side of Rexon’s Point, particularly values around 0, correspond to steep slope angles between 48 and 58° (Fig. B25).

The Gilbert River fault runs through the Leg Island basin. It enters shallow water at Rexon’s Cove. The bathymetry associated with this fault at Rexon’s Cove is an H-shaped hill at 19 to 35 m water depth. This hill reflected backscatter values between $-14$ and $-25$ dB.

The depressions in the floor of the basin reflected backscatter values ranging from $-14$ to $-30$ dB. The hill on the basin floor had slightly higher values, from $-7$ to $-22$ dB. In general the bottom of the Leg Island basin, besides Rexon’s Cove and the margins near the walls, is non-reflective with values between $-17$ and $-40$ dB. The wall of Granby Island is very steep, with values of $55^\circ$ and backscatter values to $+3$ dB.

**Williams Harbour Run**

*Bathymetry*

The multibeam survey covers an embayment on the north side of Denbigh Island in Williams Harbour Run. The surveyed area covers a 0.175 km$^2$ U-shaped valley. The sides of the valley are very steep – up to $49^\circ$, while the valley floor slopes gently into deeper water to the northeast away from shore. The floor of the valley is 33 to 35 m deep (Fig. B26). The valley truncates suddenly and hangs off the side of the wall of the main arm of Williams Harbour Run which runs perpendicular to the long axis of the surveyed valley.
Habitat Mapping in Gilbert Bay Marine Protected Area

Figure B26: Bathymetry of Capt. Jack’s Cove in Williams Harbour Run. A profile along the line indicated is shown in Figure B27.

Figure B27: Bathymetric profile from Denbigh Island into deeper water in Williams Harbour Run.

Figure B28: Multibeam backscatter map of the survey inlet in Williams Harbour Run.
The water depth at the bottom of the side wall of Williams Harbour Run is 50 m so the valley mouth is about 15 m above the seabed (Fig. B27).

**Backscatter**

The sides of the valley reflected moderate backscatter values (−14 to −23 dB) with small patches of high backscatter (−7 to −10 dB) in shallow water on the tops of the side walls (Fig. B28). The valley floor reflected low backscatter from −23 to −30 dB, at the base of the walls and slightly more reflective −18 to −23 dB in the centre of the valley floor.

Interestingly a very small area (31 m$^2$) of very low backscatter from −40 to −61 dB was recorded in 3 m of water at the shore-ward edge of the multibeam survey area. This is the lowest backscatter in the Gilbert Bay data set, and is possibly related to vegetation as it is in such shallow water. The surveyed part of the floor of the main part of Williams Harbour Run reflected backscatter from −11 to −23 dB (Fig. B28).

**Summary**

In general backscatter values mirrored bathymetry in Gilbert Bay, with low values recorded in deep water, particularly in bathymetric depressions and low slopes. The accumulation of non-reflective, fine sediment in these locations is the likely cause of this pattern. High backscatter was associated with steep slopes which are often composed of reflective substrates such as exposed bedrock. High backscatter was also associated with positive relief features such as islands and sills which are also likely composed of bedrock. A summary of the three acoustically derived variables – depth, slope and backscatter intensity - for each region of the bay are presented in Table B1.
Table B1: Summary table of the bathymetric and backscatter trends in the 9 regions of Gilbert Bay

<table>
<thead>
<tr>
<th></th>
<th>Gilbert River Basin</th>
<th>Zone 1A Hummocks</th>
<th>Big Is to Halfway Pt.</th>
<th>River Out</th>
<th>The Shinneys</th>
<th>Halfway to Kelly's Pt.</th>
<th>Kelly's to Rexon's Pt.</th>
<th>Leg Is Basin</th>
<th>WH Run</th>
<th>Whole Gilbert Bay</th>
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<td>1</td>
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Appendix C: Substrate and Habitat Maps of the 9 Regions of Gilbert Bay

Figure C1: Substrate map of the Gilbert River Basin

Figure C2: Habitat map of the Gilbert River Basin
Figure C3: Substrate map of MPA Zone 1A

Figure C4: Habitat map of MPA Zone 1A
Figure C5: Substrate map of the Big Island to Halfway Point region

Figure C6: Habitat map of the Big Island to Halfway Point region
Figure C7: Substrate map of the Halfway Point to Kelly’s Point region

Figure C8: Habitat map of the Halfway Point to Kelly’s Point region
Figure C9: Substrate map of the Kelly's Point to Rexon's Point region

Figure C10: Habitat map of the Kelly’s Point to Rexon’s Point region
Figure C11: Substrate map of the Leg Island Basin

Figure C12: Habitat map of the Leg Island Basin
Figure C13: Substrate map of Captain Jack’s Cove in Williams Harbour Run

Figure C14: Habitat map of Captain Jack’s Cove in Williams Harbour Run
Figure C15: Substrate map of River Out

Figure C16: Habitat map of River Out
Figure C17: Substrate map of the Shinneys

Figure C18: Habitat map of the Shinneys