Abstract
The Canadian Hydrographic Service (CHS) is systematically mapping bathymetry along the British Columbia coast. The multibeam systems used to measure this high resolution bathymetry also record acoustic backscatter in each of many beams. This backscatter can be classified using commercial software tools to ultimately map detailed seafloor geomorphology. Essentially, CHS bathymetric survey platforms become vessels of opportunity for habitat mapping programs. Acoustic backscatter responds to habitat structure in the benthic area because acoustic echoes are sensitive to variations in geologic and biotic components on (and within) the seafloor. The resulting benthic habitat model is one vital component of the complete ecosystem picture, crucial to modern habitat management philosophy. Segmented backscatter by itself is of limited usefulness but, once calibrated by sediment or benthic population samples, a habitat picture evolves. However, there are scaling and other issues that impact the accuracy with which the acoustic diversity can be used to represent the second layer (seabed type) in an ecosystem. CHS applies sediment grab samples, concurrent seafloor video, and high resolution bathymetry to validate acoustic classes. The Strait of Georgia is the current focus of this habitat mapping program, and four areas corresponding to CHS charts are nearing completion.

Background
CHS conducts surveys primarily to produce hydrographic charts for purposes of safe navigation. Historically, surveys were conducted with single beam sounders and, before that, with traditional leadlines. These historical low resolution data on CHS charts still guide today’s mariners. However, the last decade has witnessed an explosion of sonar technologies that map the seafloor with tremendous resolution. These multibeam sonars are optimized for differing depth regions. There are generally four overlapping depth zones for surveying purposes.

1. Deep ocean: deeper than 1,000 m. CHS Pacific does not have the capability to survey this depth region. However, in a practical sense, there is limited need to survey at this depth on the Pacific Coast at this time.
2. Mid depths: between 1,000 m and 50 m. CHS uses the Kongsberg Maritime EM1002 multibeam sonar, which has the capability to cover most of the BC coast continental shelf.
3. Shallow depths: between 100 m and 10 m. CHS uses the Kongsberg Maritime EM 3002 multibeam sonar.
4. Nearshore region: from 30 m to the beach (in optimal conditions). CHS Pacific has acquired a Benthos C3D bathymetric sidescan sonar (BSS). This new BSS technology is arguably the best tool for surveying this shallow area.
These four sonar technologies each have the capability to measure acoustic backscatter suitable for seafloor habitat classification. Currently, the two EM systems are used for both bathymetry and habitat mapping using acoustic classification methods.

Habitat mapping program
CHS conducts multibeam bathymetric surveys both for clients and for navigational charting needs. As a result of the client-driven process, bathymetric maps for most of southern Strait of Georgia, including the Strait of Juan de Fuca, have been completed in waters deeper than 50 m. However, significant work remains to be done in Hecate Strait, in Queen Charlotte Sound, in all of the outer west coast of BC, and, in particular, much of the nearshore region inside the 30 m contour, or isobath. The deliverable for these client surveys is bathymetry and those data are typically produced shortly after the survey is completed. This quick turnaround of product is possible because the clients in this instance do not require the significantly higher quality (subject to IHO standards) of data necessary for charting purposes.

In addition to bathymetric mapping, CHS is developing acoustic backscatter seafloor classification map products for previously surveyed regions (Galloway 2004). For example, four habitat maps (Fig. 1) that correspond to hydrographic charts are nearing completion for north-central Strait of Georgia.

A client survey recently conducted by CHS Pacific revealed that our client’s primary interest is to understand the geological and biological habitat of the nearshore zone inside 30 m. So, today’s challenge is to map the nearshore zone, which is the most crucial area to an ecosystem-based management model. This challenge can be addressed by using a bathymetric sidescan sonar that can measure bathymetry and backscatter up to twelve times water depth in shallow water, effectively reaching to the beach in optimal

Figure 1. Strait of Georgia multibeam survey habitat chart areas.
nearshore situations. To map the entire nearshore BC coastline (at 45,000 km) however, would be a daunting task that could take as long as 100 vessel-years to survey.

**Acoustic seabed classification**

Acoustic seabed classification methodology measures changes in the acoustic response of the seafloor and surficial substrate. These changes, or diversity, which are quantized in the process, are generally well correlated (ICES 2007) with both geology and those benthic species that are keyed to geologic and biotic components of the seafloor. The assumption here is that acoustically similar seabed structures will be both geologically and biologically similar. Note that this classification process is empirical and does not apply inverse modeling to relate acoustic response to geology.

Software tools for processing the classification information are continually improving, and the current state of the art permits revisiting archived raw data to mine it for future, as yet unknown, needs. In addition to supplementing hydrographic charts, markets for seabed classification products include geomorphological maps, habitat maps for benthic and demersal communities, stock assessment maps, environmental mapping of contaminants, military route survey investigations, and producing visual aids for public information campaigns.

**A classification schema**

CHS uses Quester Tangent’s QTC Multiview™ software, a commercial product that classifies sediments through analysis of amplitudes and statistical properties of multibeam backscatter data. CHS chose QTC Multiview because of successful prior experience with QTC Impact, a classification tool for single beam sounders, and the future potential for classifying bathymetric sidescan sonar backscatter using QTC Sideview. These tools are similar in design and usage so that the learning curve is reduced and the same ISO-based GIS procedures can be applied.

The flow of data through Multiview includes loading backscatter images, applying a quality control process to ensure only high-quality data are used, then dividing the images into a series of rectangles upon which features are calculated using the algorithms of Table 1 (Preston et al. 2004). The rectangle size (typically 16 m by 22 m for the EM1002) is chosen to ensure that adequate classification spatial resolution is achieved and that enough backscatter pixels are captured within the rectangle to allow for effective statistical analysis. Using principal components analysis (PCA), three components (from the possible 132) of these algorithmic features are identified in order of variance. These variances are identified by rotating the axes of multidimensional feature space using PCA to align an axis with the feature that has the largest variance. The next largest variance is identified next, etc. Generally, these first three components (called Q-values) retain most (near 90%) of the estimated variance for the total of 132 features. In Multiview, features from seafloor patches with similar acoustic properties tend to cluster together when plotted in three dimensional Q-space. Each rectangle contributes one Q-space point to an ellipsoid cluster and each unique cluster produces a single class number. The resulting Q-space ellipsoids in Fig. 2 contain a constellation of features with differing distances from the ellipsoid centroid and from other clusters. These properties allow the user to assign relative confidence estimates on the allocation of a feature to a specific cluster. Application of GIS technologies to the resulting referenced numerical classes yields a map of acoustic diversity for the surficial sediments of the seafloor. The challenge then is to relate this interpreted acoustic diversity to variations in sediment facies and/or, to variability within benthic communities. CHS collects seabed samples, photographs, and video targeted specifically to discrete clusters (or classes) as a means of groundtruthing the mapped image.

Table 1. Algorithms that produce the 132 features in Multiview. Each algorithm contributes a number of values to the feature matrix.

<table>
<thead>
<tr>
<th><strong>Multiview™ Image Feature Algorithms</strong></th>
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<tbody>
<tr>
<td>Basic statistics</td>
</tr>
<tr>
<td>Amplitude quantiles and histogram</td>
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<tr>
<td>Power spectra</td>
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<tr>
<td>Ratios based on power spectra (Pace)</td>
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<tr>
<td>Gray-level co-occurrence matrices (Haralick features)</td>
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<td>Fractal dimension</td>
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**Figure 2.** Features and ellipsoids displayed in Q-space. The ellipsoids represent groupings of similar acoustic response of the seafloor, as determined by algorithms applied to backscatter images from a multibeam sonar.
Groundtruthing issues

Results from the Multiview acoustic seabed classification survey consist of measurements of acoustic diversity expressed in discrete numerical “classes” of the seafloor. Our experience shows this clustered measurement usually corresponds directly to unambiguous geology. However, to verify this correlation, physical and/or visual samples of the seafloor need to be taken. Such a sampling program assigns (groundtruths) acoustic classes to seabed types. Validation of acoustic classification diversity measurements with habitat groundtruth information, whether taken from sediment grab samples or from density measurements of benthic communities, is essential. CHS uses sediment samples with coincident seafloor video to validate synoptic classification maps. Here, the Shipek grab is mounted on the same cable but beneath the video camera to permit real time monitoring of the actual grab operation. Standard operating procedure is to situate the groundtruth sites using the processed classification map (ensuring that the grab locations are in an area of locally coherent class), lower a grab to the seafloor, and record the video image along with GPS position on a DVD.

Once the grab sampling process is complete, lift the grab a little and drift for a few minutes to observe the geological consistency of the local area. Although the GPS is actually the vessel location, cable layback is small for the depths and scales of interest so the effective positional error tends to be small (but not negligible). The recovered sediment grab samples are not normally analyzed in the lab for sediment texture or acoustically sensitive factors (e.g., bulk density, X-ray analysis for sediment layering) since, once disturbed, the acoustic properties of the sample are compromised. Rather, a visual and tactile classification is made of the grab material, which assigns an alpha descriptor according to a modified Folk ternary scale; this technique is effective for general classifications where sand-mud-gravel descriptions are sufficient (Folk 1954). Additional alpha descriptors have been added for shell hash and rock. Another groundtruth resource to consider is the extensive existing database of bottom samples taken as a routine part of hydrographic charting and geological surveys’. Caution must be used here, however, because independent visual verification of the bottom type is not generally available for those samples.

An objective, structured, statistical approach using ISO 9001:2000 procedures guides the validation of acoustic classification of surficial geology. A documented, repeatable process is essential to keep the validation of acoustic diversity as objective as possible. A statistical approach, which assigns a class population threshold to a physical sample, helps to manage mismatched sediment and class pairs and can, at least, keep the results consistent.

At a minimum, each grab site has two potential uncertainties.

1. Sediment assessment: The recovered material is visually assessed for sediment content and assigned sand-mud-gravel (and other) alpha descriptors. If the sample has been analyzed for percent content, an alpha descriptor can objectively be applied according to the Folk scale. Otherwise, an expert hands-on assessment is made of the material (and video, if available) and a descriptor is estimated. Of course, assigning a Folk alpha descriptor from a manual assessment of the sample is subject to interpretation errors.

2. Sample position uncertainty: The grab position exhibits an uncertainty that is a function of the vessel positioning system, water depth, vessel wind drag, and the ocean current drag on the cable such that the grab position is contained in an error ellipse. As a consequence, in a complex seafloor scenario, which specific class (within the error ellipse of the presumed grab location) should be assigned to the descriptor may not always be clear. In practice, the grab alpha descriptor is compared to the acoustic classes and a class assignment is made to the material based on class type, quantity of types, and distance from the centroid for each class type within the error ellipse that comes from the grouping of features in Q-space.

Compounding the assessment and positional uncertainty problem is that the acoustic response of the seafloor may dominantly respond to (what are normally) secondary seafloor acoustic factors such as surface texture and biota rather than sediment content. Seafloor acoustic echoes are created by a complex series of impedance mismatches at the water-bottom interface and within the sediment. Of course, this includes biotic content on (and within) the sediment. There are significant spatial issues to consider when attempting to groundtruth acoustic data. Seafloor video, when available, is applied to ensure the grab sample is truly representative of the local region since a grab occupies a very small footprint relative to that acoustic measurement area (EM3002 and EM1002 here) which yields one class value per rectangle. This grab/acoustic footprint ratio can be as much as 1:5000. Fig. 3 demonstrates this disparity. Note the log scales for seafloor penetration and area of coverage. As depicted in Fig. 4, the Shipek grab used by CHS samples only a very small volume relative to acoustic methods, whereas the video samples comparable area relative to acoustics but exhibits little penetration.

As part of the validation process, acoustic classification results can be checked by replaying seafloor video while concurrently showing the camera (vessel, actually) location on a georegistered classification map using Hypack™ navigation software. The result, as in Fig. 5, effectively replays the actual grab sequence post survey showing seafloor video and the image’s specific location on a classification map. This

technique is often used when collecting samples and video (following a classification analysis) to provide real time validation of classification results. Fig. 6 illustrates the great detail possible with a classification map overlaid on 3-D bathymetry. Here, this special test area has numerous grabs to validate the sediment/class relationship.

**Nearshore habitat challenges**

One of the most ecologically sensitive areas in coastal waters and an important area of interest to fisheries and other managers is the nearshore zone, in depths of less than about 30 m. CHS multibeam sonars only operate effectively to 10 m depths and then only in simple contoured areas. However, CHS Pacific has recently acquired a Benthos C3D bathymetric sidescan sonar, which has the capability to measure depth and backscatter right to the beach under optimal conditions. CHS will conduct trials, implement some nearshore surveys, and develop data processing structures with the C3D over the next year. An alternative technology used by NOAA to map nearshore bathymetry is SHOALS LIDAR, an optical airplane-based scanning system capable of mapping the seafloor to a depth of 30 m. QTC is currently developing tools to classify optical backscatter from SHOALS LIDAR systems.

**Future efforts**

CHS Pacific currently conducts multibeam surveys from two vessels. The midwater EM1002 multibeam ship generally has 84 operational 24 hour days each year while the shallow water EM3002 vessel surveys for about 150 operational 9 hour days per year. Surveys occur from the Alaska border to the mouth of Puget Sound, including some surveys in U.S. waters (San Juan Islands). Our short-term objective is to map the coast of BC within the 30 m to 1,000 m depth range. This program is well under way with about 23,700 km² of that depth range now complete. A longer-term objective is to map the nearshore zone of targeted ecologically sensitive areas for the BC coast using bathymetric sidescan sonars. This program will be driven by the need to map ecologically sensitive areas such as potential marine protected areas, regions subject to environmental pollution, high energy transport and sedimentation areas, etc.

**Summary**

CHS is progressively mapping the coast of BC for both high resolution bathymetry and geomorphology derived from acoustic backscatter generated by multibeam sonars that are used to measure this bathymetry. The focus for acoustic habitat classification of the seafloor has been on the Strait of Georgia to date, to be followed by analyzing existing backscatter from Queen Charlotte Sound and Hecate Strait. When available, bathymetric sidescan sonars will be used to map the critical nearshore zone on a priority basis.

This acoustic classification process is empirical, and effective groundtruthing is essential to successful seabed mapping. However, simple validation methods such as grabs
Figure 4. Shipek sediment grab and sample.

Figure 5. Vessel track on acoustic classification map with concurrent video. Green and blue patches in the map image represent medium and fine sand; brown is dominantly gravel. Contours are 10 m increments. Red labels at the grab locations (+) are Folk scale descriptors.
and video are subject to scaling and interpretation issues and do not necessarily provide all the information needed to unconditionally categorize the acoustic maps.

Acknowledgments
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Figure 6. Detailed 3-D map of acoustic diversity overlaid on multibeam bathymetry showing the many bottom grabs (+) for this test area. Green and blue regions in the map image represent medium and fine sand, brown is dominantly gravel, and cyan and light green are different muds. Alpha abbreviations are according to the Folk scale. The high resolution bathymetry and classification were acquired with an EM3000 multibeam sonar and QTC Multiview.

References


