ICES Journal of Marine Science, 59: 156–167. 2002
doi:10.1006/jmsc.2001.1126, available online at http://www.idealibrary.com on IDEAL®

Acoustic classification of marine habitats in coastal Newfoundland

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Anderson, J. T., Gregory, R. S., and Collins, W. T. 2002. Acoustic classification of marine habitats in coastal Newfoundland. – ICES Journal of Marine Science, 59: 156–167.

A digital acoustic seabed classification system, QTC View (Series IV) was used in the coastal waters of Newfoundland to characterize and classify marine benthic habitats. The QTC View system was calibrated in Placentia Bay at sites identified independently during a submersible research program. Four different habitats were used for calibration of the QTC View system: mud, gravel, rock, and macroalgae on rock. These different habitats were used as a "training" catalogue for real-time classification of marine habitats carried out in Bonavista Bay. The classification data were based on over 2000 km of survey tracks ranging in depth from approximately 10-m to 220-m depth. Post classification analyses were carried out using data visualization techniques, simultaneously comparing the classification data in mathematical and geographic settings. Following post classification, eight different marine habitats were identified using the acoustic system: mud, loose gravel, gravel, rock, sparse algae/cobble, macroalgae, high relief/deep cobble, and wood chips. Throughout the surveyed area, rock habitat dominated, followed by sparse algae/cobble and high relief/cobble habitat types. The wood chip habitat type was identified within a small area that historically had been associated with logging in coastal Newfoundland.

Keywords: acoustic, classification, coastal, cod, habitats, juvenile, Newfoundland, seabed.

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Introduction

Recent advances in acoustic technologies are offering new opportunities to describe and map marine environments. Multibeam acoustic systems provide complete coverage of bank scale features that can be interpreted in terms of surficial sediment structure (Todd *et al.*, 1999). Multibeam systems require ancillary information to describe geological and biological structure. Acoustic classification of seabed habitats represents a recent development in remote sensing of marine landscapes (Sotheran *et al.*, 1997; Greenstreet *et al.*, 1997). Calibrated acoustic classification systems can represent marine habitats across a range of spatial scales (Anderson, 2001). Once calibrated, these systems are capabile of classifying marine habitats in an objective and timely manner. Ultimately, the integration of different observational systems will significantly advance our description and understanding of marine seabed habitats.

In this study, we describe the use of a digital acoustic seabed classification system, the QTC View Series IV,[1] in the coastal waters of Newfoundland. Our goal was to develop the application of this new technology and demonstrate its capabilities to define marine habitats within the coastal waters of Newfoundland. Our approach was to first develop a comprehensive set of geo-referenced seabed calibration sites over a wide range of depths and marine habitats, based on submersible observations. The submersible dives allowed us to define marine habitats in the context of suitable fish habitats. We combined our observations with published experimental studies linking fish behaviours to preferred habitats as part of our process of defining seabed habitats (Gregory and Anderson, 1997). The seabed calibration sites were used to "train" the QTC View system to classify a set of seabed types. Subsequently, real-time seabed

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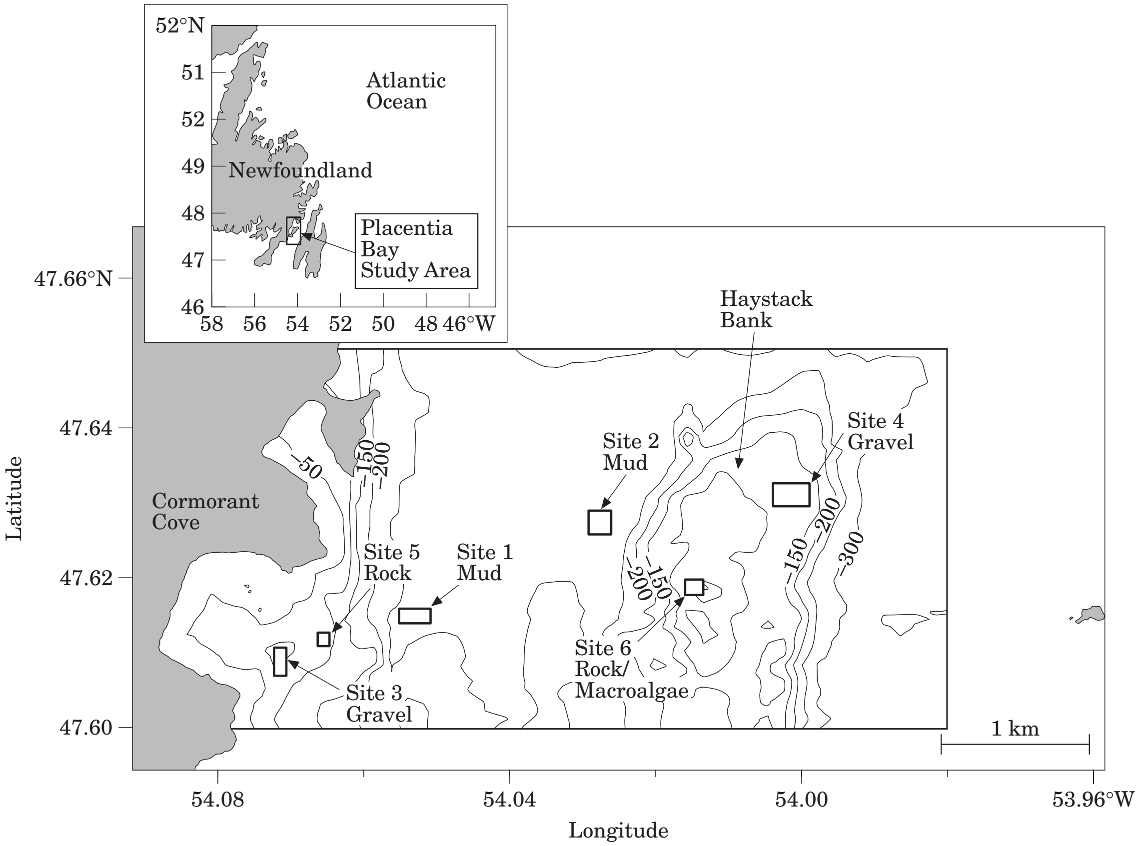

Figure 1. Acoustic seabed calibration sites in Placentia Bay, Newfoundland determined by submersible observation. Contours are depth from surface in 50-m increments.

classifications were carried out over a much broader area in a different coastal area. Finally, we evaluated the real-time classification data with respect to our knowledge of depth, topographic relief and features of marine habitats developed during the submersible program. Post processing of the real-time classification data was facilitated by visual comparisons between a geographic setting, using high resolution digital bathymetric maps, and a mathematical setting, using a three-dimensional surface defined using output data from the QTC View system. The results of the acoustic classifications are discussed in relation to mapping seabed habitats.

Study areas

The initial phase of our work was conducted in Placentia Bay, Newfoundland in 1995 and 1996 (Figure 1). The study area was approximately 24 km^2 and was bounded by a coastal zone on the western side and a fishing bank on the eastern side. These two areas were separated by a deep, flat channel that extended to depths of approximately 300 m. Within the study area, we established seabed calibration sites based on a series of submersible dives in April and October 1995 (Figure 1). These calibration sites included bedrock, cobble, gravel, mud, and marine macroalgae habitats over a range of depths from approximately 20 to 300 m.

The second phase was conducted in Bonavista Bay, Newfoundland in 1997 (Figure 2). Bonavista Bay was chosen as a representative area where we could independently classify seabed habitats and validate the calibration catalogue developed in Placentia Bay. The study area included long narrow sounds, where depths exceed 300 m, open areas where the depths ranged from 20 to 120 m, as well as shallow, low relief bays, shoreline areas, and islands.

Methods

Calibration

A QTC View Series IV system was connected to a Simrad EQ100 38 kHz transducer, hull mounted in the 23-m steel hulled RV “Shamook”. The echosounder had a 10° beam angle and was set with a pulse width of 0.3 ms and 1 pps. Calibration of the QTC View system

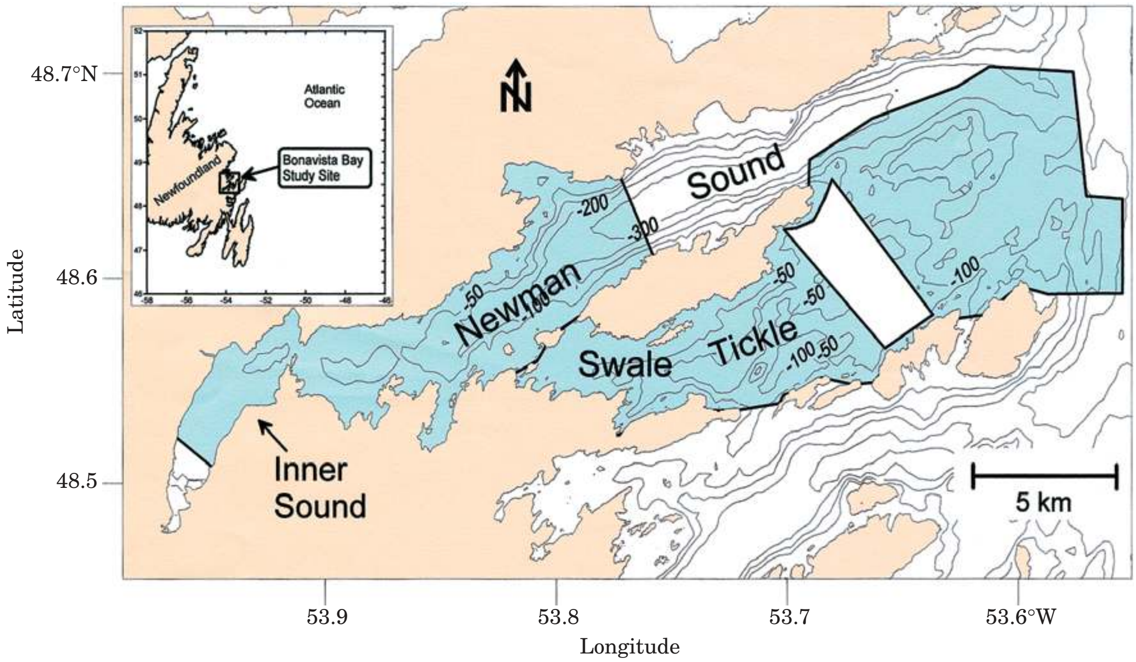

Figure 2. Study area in southern Bonavista Bay, Newfoundland showing Newman Sound and Swale Tickle. Inner Swale Tickle is the western area bounded by land and outer Swale Tickle is to the east. The Inner Sound is a fjord like area at the western most extent of Newman Sound. The blue shaded area outlines the total area surveyed with the QTC View system. The small clear area is the detailed study site in outer Swale Tickle. Contours are depth from surface (m).

Table 1. Seabed habitat calibration sites based on submersible observations in Cormorant Cove and on Haystack Bank and channel, Placentia Bay, Newfoundland.

Type	Depth (m)	Habitat	Description
1	240	Mud	Flat, soft bottom lying in the deep water beyond Cormorant Cove
2	265	Mud	Deep water area beyond Haystack Bank with a soft, low relief bottom
3	100	Gravel	Small gravel basin bounded by the 100-m depth contour within Cormorant Cove
4	123	Gravel	Broad, low relief gravel area on the northeast portion of Haystack Bank
5	58	Rock	Small area near the 100-m depth contour at the top of a rock wall descending to >200 m
6	50	Rock/ Macroalgae	Shallow area of Haystack Bank with both exposed bedrock and bedrock with algae, including Irish moss (*Chondrus crispus*) and *Agarum* sp. kelp

was done in Placentia Bay, Newfoundland during June 1997. We occupied a series of calibration sites established during the submersible phase of our study (Table 1 and Figure 1). At each site, we collected a number of calibration files under a variety of instrument settings. We evaluated three levels of transducer transmit power, 100%, 25%, and 10%, and three range settings for ''virtual'' depth, 37 m, 100 m, and 150 m. Virtual depth is a parameter used as input to an algorithm to compensate for signal spreading with depth.

In calibration mode, the QTC View system digitizes each backscatter signal which is then reduced to 166 discrete variables that are designed to represent different acoustic properties of the acoustic signal. Subsequently, the 166 variables are characterized using Principle Component Analysis (PCA) into the three most significant eigenvalues, expressed here as Q1, Q2, and Q3, respectively. The PCA is a simplified quantitative expression of the complex acoustic properties of the first return echo. These calibration data were visually inspected in

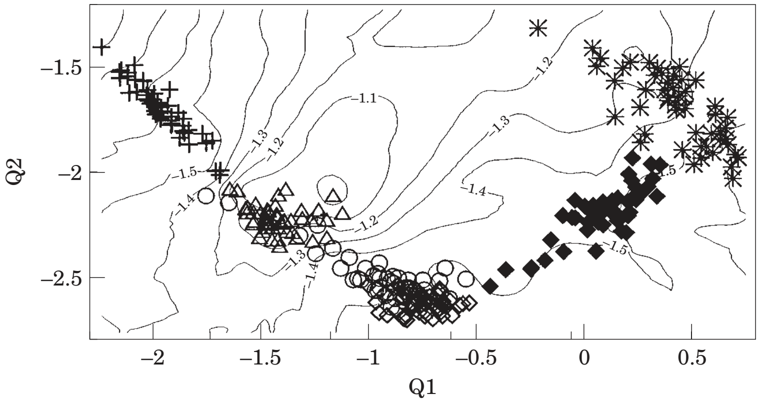

Figure 3. Seabed calibration data collected at six different sites in Placentia Bay, Newfoundland plotted on the Q-Space surface. The x- and y-axes are represented by Q1 and Q2 values while Q3 values are represented by the contoured surface (see the text for details). Symbols are: +, Mud Type 1; △, Mud Type 2; ◇, Gravel Type 3; ○, Gravel Type 4; ◆, Rock Type 5; *, Macroalgae on Rock Type 6.

three dimensional mathematical space (Q-space). We looked for a high degree of data integrity for each calibration file, as evidenced by a tight distribution of the data in Q-Space. Also, we were looking for a relatively high degree of separation in Q-Space among different bottom types from the various calibration sites. A source of variability in some of the calibration data appeared to be related to sites which were relatively small, geographically. It was not always possible to maintain ship position over these sites, even though the data collection period was typically less than five minutes duration.

A total of 43 calibration files were collected and evaluated at the six sites. We determined that the 150-m reference depth gave the overall best result, which was approximately one half the maximum depth of data collection. We also determined that 10% of maximum transmit power gave the best result, where otherwise the transducer transmitted too much power at shallower depths (i.e. <40 m). We created a single calibration catalogue based on the best single data file from each of the six sites. These six files represented four seabed habitats: mud (n=2); gravel (n=2); rock (n=1), and rock with macroalgae (n=1) (Table 1 and Figure 2). There was a progression of the data in Q-space while moving from the mud bottom types (low relief, soft, relatively smooth) through the gravel (low relief, harder, and rougher) to rock (higher relief, hardest, relatively smooth), and finally to macroalgae attached to rock (low-high relief, hard, and rough due to the macroalgae) (Figure 3). The calibration data indicate a high degree of overlap for the two gravel habitats but a significant separation between the two mud habitats. The position of the Mud Type 2 calibration data between Mud Type 1 and the two gravel habitat calibration files suggests that Mud Type 2 was a mixture of mud and gravel. This observation was supported by the extension of four data points of Gravel Type 4 data into the Mud Type 2 area of Q-space. This also demonstrates there was a small degree of contamination of a mud/gravel signal in the Mud Type 2 data file. Overall these calibration data satisfied our requirements for high data integrity and wide separation in Q-Space.

Real-time seabed classification

Real-time seabed classifications using the QTC View system were based on the calibration catalogue of known seabed types. During classification, five consecutive analog signals were averaged into one signal, digitized, and then summarized by PCA into three Q-values. The three Q-values were then compared to the different seabed types represented in the calibration catalogue, which existed as three-dimensional ellipsoids defined by the original calibration data. Classification was based on the closest association in Q-Space with one of the calibration types using cluster analysis. In our study, real-time classification was for one of the six seabed types defined in our calibration catalogue. All data were then logged to a personal computer.

Seabed classifications were carried out in Bonavista Bay during June and October 1997. The research vessel Shamook used a GPS positioning system, assuring positional accuracy to within a few meters. Survey lines were run at 5–6 knots ($\approx 3\ \mathrm{m\ s^{-1}}$) with 150–300 m spacing throughout the surveyed areas to assure a high degree of spatial coverage. In some areas, subsequent survey lines were run orthogonal to the initial lines. In most cases, a survey line was run along the shore as close as possible where water depths were 10 m or more. These along-shore survey lines defined the practical shoreward limit of data collection with the QTC View system.

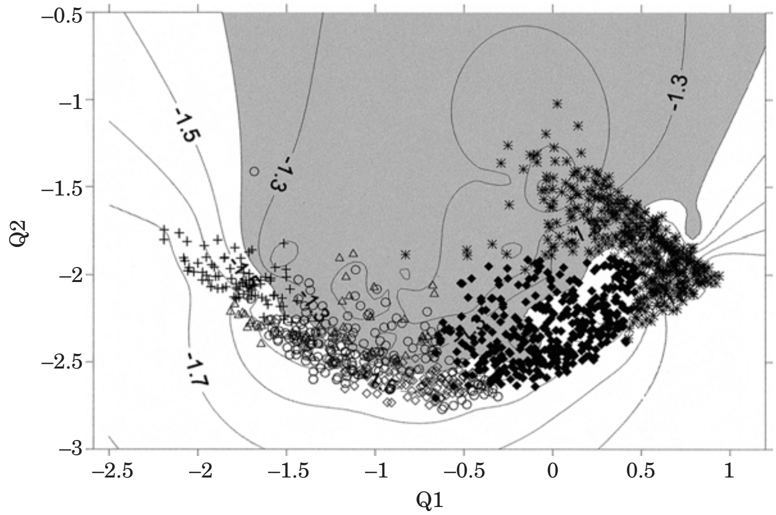

Figure 4. Real-time seabed classification data collected in outer Swale Tickle, Bonavista Bay and plotted on the Q-Space surface. These data were based on the six calibration files collected in Placentia Bay, representing four different seabed habitats. Symbols are: +, Mud Type 1; △, Mud Type 2; ◇, Gravel Type 3; ○, Gravel Type 4; ◆, Rock Type 5; *, Macroalgae on Rock Type 6. The shaded area represents higher Q3 values and is simply for visual interpretation of the plotted data against this third axis.

Results

Real-time seabed classifications

An extensive area was surveyed within southern Bonavista Bay, collecting 142 000 seabed classification observations in an approximately 150 km^2 area (Figure 4). These data were collected over more than 2000 km of linear survey transects. Initially, we grouped the real-time classification data into the four seabed types represented by the calibration catalogue: mud, gravel, rock, and rock with macroalgae. The Rock/Macroalgae seabed type was dominant throughout the surveyed area (Type 6), followed by rock (Type 5), gravel (Types 3 and 4) and then mud (Types 1 and 2). These classification data characterized the seabed as being predominantly hard, where >60% of the bottom was classified either as Rock or Rock/Macroalgae. The real-time classification data were distributed in Q-space similar to the distribution of the original calibration data. However, the real-time survey data included a broader distribution of data over a greater range of values on the Q-space surface, compared to the calibration data (Figure 4). This broader distribution of Q-values was expected, given the extensive area of Bonavista Bay that was surveyed over a wide range of depths.

The real-time classifications were too general to be of practical use in an ecological context. We knew that the four seabed habitats in our calibration catalogue were too simple to represent the coastal environment of Newfoundland. However, the QTC View system was designed to classify each acoustic signal with respect to the bottom types in the calibration catalogue, whether that represented a realistic classification or not. For example, the Rock/Macroalgae classification dominated throughout the surveyed areas, representing 34–46% of the habitat. The Rock/Macroalgae seabed classification occurred from shallow depths, <20 m, up to 200 m deep. We knew from our submersible diving that marine algae did not occur commonly deeper than about 50 m, where most macroalgae was less than 30-m depth (Anderson, 2001). Therefore, Rock/Macroalgae classifications at depths >50 m were not "rock with macroalgae".

Knowledge of seabed habitats and topographic features can provide guidelines for the post classification of QTC View data. For marine algae, we used our knowledge that macroalgae did not occur beyond approximately 50-m depth in Bonavista Bay. Macroalgae also occurred at different densities, from dense beds that covered large areas of the bottom to sporadic occurrence over exposed bedrock. In addition, seabed habitats covary with topography. For example, rough cobble occurred at the bottom of marine slopes and cliffs; gravel was common over flat bottoms exposed to wave action; soft mud occurred within deep sedimentary basins. Our submersible observations also demonstrated that seabed habitats could change at very small spatial scales, such that a bed of gravel could occur between rocky ridges at the scale of meters, or patches of macroalgae could occur interspersed with rock. These observations led us to expect that seabed habitats could be complex at small spatial scales. Finally, we directly compared acoustic seabed classifications with our submersible observations when data collection transects overlapped (Anderson, 2001).

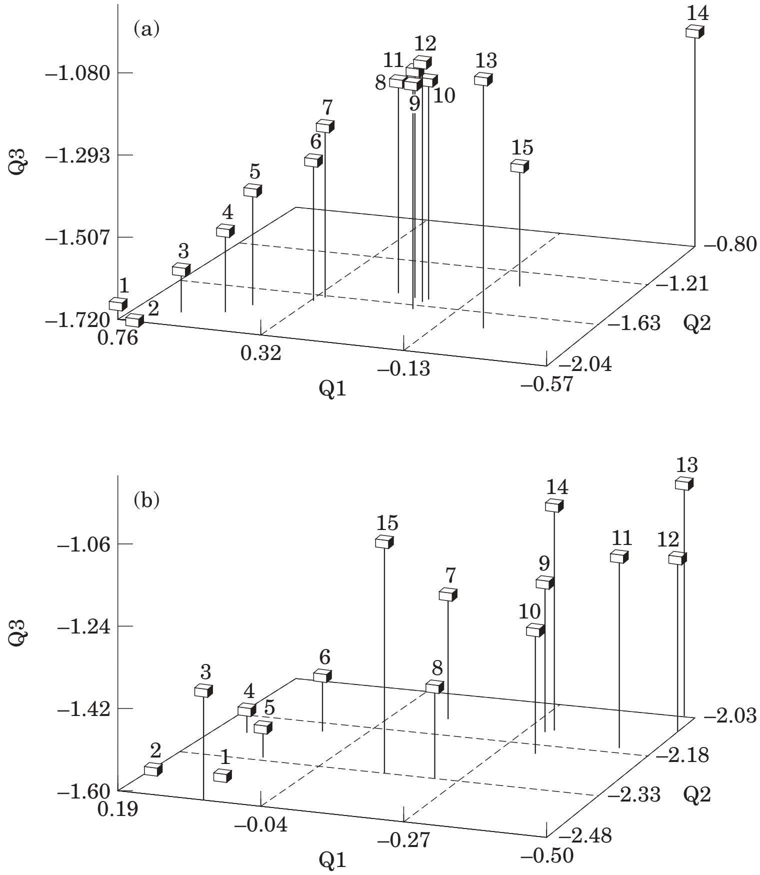

Figure 5. Three dimensional scatter grams of depth dependent changes in real-time classification data for Rock/Macroalgae, Type 6 (a) and Rock, Type 3 (b) seabed type plotted for the Q1, Q2, and Q3 classification data (see the text for details). The numbers associated with each symbol represent depth categories: 1, 0–20 m; 2, 21–40 m; · · ·; 15>280 m.

Post-classification analysis

In the post-classification of the QTC View data, we employed data visualization techniques combined with our knowledge of seabed habitats and topographic features. Data visualization was based on simultaneous comparisons of the classification data in both geographic and mathematical settings. We have gained extensive knowledge of seabed habitats in coastal Newfoundland based on 17 submersible dives during the period 1995–1997 (Gregory and Anderson, 1997; Gregory *et al.*, 1997; Anderson, 2001; R.S.G. and J.T.A., unpublished data). We generated detailed maps of the bottom topography, at various geographic scales, based on modelling high resolution bathymetric data collected by the Canadian Hydrographic Service in Bonavista Bay in the early 1990s. Here, we refer to the mapping of the seabed classification data onto these geographic 3D modelled bottom relief surfaces as "G-space". The mathematical setting was based on the surfaces created by the first three axes of the principal component analysis of the classification data, the Q-values. Here, we refer to the mapping of the seabed classification data onto these 3D modelled surfaces as Q-space. For both bathymetric and classification data, the three-dimensional surfaces were generated using kriging (Surfer, 1999). Definitions of new seabed types, or classes, were based primarily on new boundaries imposed in Q-space and secondly, by limitations based on depth.

To extract a macroalgae signal from the Rock/Macroalgae classification data, we binned data in 20-m depth intervals into 15 depth categories from 0–20 m to >280 m. There was a general relationship between Q-values and increasing depth, where Q-values decreased along the Q1 axis and increased for both Q2 and Q3 (Figure 5). Q-values for depth categories from 0–20 m to 140–160 m changed systematically in Q-space. For depth categories from 160–180 m to 220–240 m there was little change in Q-space. Extreme limits of Q-values for Rock/Macroalgae data were reached for depth category 14 (260–280 m) before returning towards

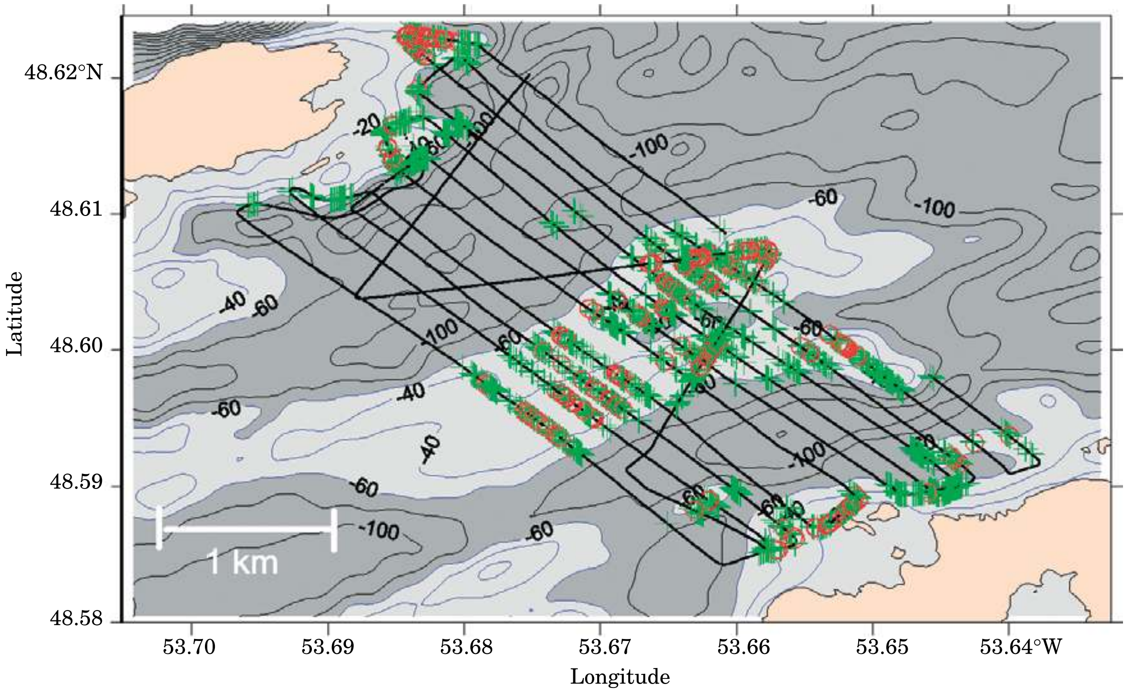

Figure 6. Spatial distribution of post classification seabed types True Algae (○) and Sparse Algae/Cobble (+) data within the detailed study area of outer Swale Tickle. The contoured surface represent water depths in 20-m intervals from the surface. Areas ≤60-m depth are shaded light blue and deeper depths are shaded deep grey. Land is shaded beige.

the Q-Space centre. Q-value data associated with the two shallowest depth categories typically formed a distinct band at maximum Q1 values and minimum Q2 and Q3 values. This was particularly true for data sets isolated from known locations of macroalgae, indicating that classification confined to this area of the Q-space surface could be considered as a true, or maximum, macroalgae signal. Here, we defined a new seabed class for this narrow band within Q-space, based on Q1 and Q2 values, that we refer to as True Algae. When this new class was plotted in G-space we observed that the data occurred in certain areas along the shore in relatively shallow depths <30 m and also in patches at shallow depths associated with shoal areas, or ridges, in offshore areas. There was also a close comparison of the acoustic True Algae data with the occurrence of macroalgae observed by submersible (Anderson, 2001). The distribution of the new True Algae signal is demonstrated for a small area surveyed in outer Swale Tickle (Figure 6).

When we examined Rock/Macroalgae classification data for depths >50 m and plotted these in G-space we noted that a high proportion of these data were associated with areas of high bathymetric relief. We know from our submersible observations that these high relief zones typically have rough cobble and boulders associated with the bottom of the slopes. We also know that side shadowing of the acoustic signals occurs over high relief bottoms. Side shadowing occurs when part of the acoustic signal is reflected back to the surface as it strikes the side of a high relief bottom, before the remainder of the signal strikes bottom. Together, these observations indicate that the QTC View system was classifying a high relief bottom, probably associated with cobble and boulder within a defined region of Q-space. We found that the classification data associated with the highest relief typically occurred for deeper depths and, therefore, was confined to an area of Q-space with high Q2 and Q3 values. Hence, a new classification type was created that we refer to as High Relief/Deep Cobble based on this area in Q-space. Comparison of this new seabed type with relief demonstrated the close association with highest relief areas (Figure 7).

The creation of these two new seabed classes resulted in the remaining Rock/Macroalgae classifications occurring between the True Algae and the High Relief/Cobble data sets in Q-space. These remaining data were plotted onto bathymetric surfaces to reveal that many of the observations were associated geographically with the True Algae signal in G-space. However, some data also occurred deeper than 50-m depth and over high relief areas. These observations indicated that these acoustic signals were probably a combination of macroalgae and cobble habitat types. We know that macroalgae

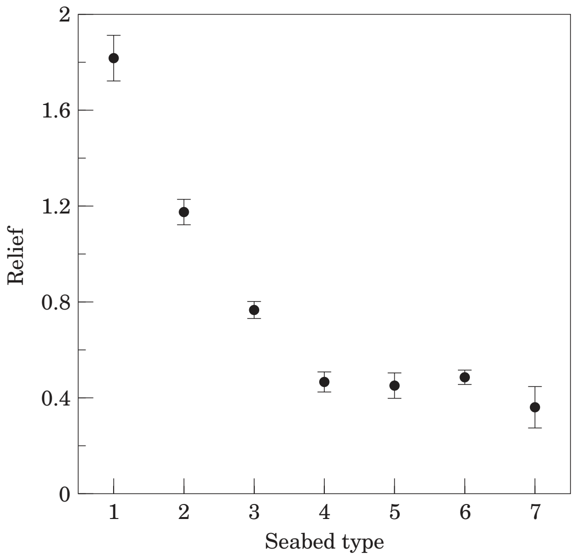

Figure 7. Relationships between bathymetric relief, estimated as change in vertical depth (m) for each 1 m change in horizontal distance, for each seabed post classification type. Seabed types were plotted with decreasing association with high relief: 1, High Relief/Deep Cobble; 2, Sparse Algae/Cobble; 3, Rock; 4, Soft Gravel; 5, True Algae; 6, Gravel; 7, Mud.

occurred at different densities and that it was sometimes associated with broken rock and cobble (Anderson, 2001). We characterized these remaining Rock/Macroalgae data as a new classification we refer to as Sparse Algae/Cobble. This new seabed class was also associated with high relief areas but less so than the High Relief/Deep Cobble class (Figure 7). When this signal occurred in close association with the True Algae at depths <50 m then we generally interpreted the signal to represent macroalgae at lower densities. When deeper than 50 m, then we interpreted this type as a rough, cobble habitat.

The Rock classification demonstrated an association of Q-values with depth, similar to that of the Rock/Macroalgae data but over smaller ranges of Q-values (Figure 5). For Rock classifications, the progression of changing Q-values with increasing depth was less systematic than the Rock/Macroalgae data. Extreme Q-values occurred for the 241–260-m depth interval before returning towards the centre of the Q-space surface. Together, these observations suggest that there was a smaller effect of depth on the acoustic classification data for the Rock data compared to Rock/Macroalgae. The Rock data were also associated with higher relief areas, but these were lower relief areas than either the High Relief/Deep Cobble or the Sparse Algae/Cobble classes (Figure 7). Together, these three seabed types demonstrated a decreasing association with depth and relief moving from the High Relief/Deep Cobble, to Sparse Algae, to Rock classes. The remaining real-time classifications, as well as the post classification True Algae types, did not demonstrate any clear associations with depth or relief (Figure 7). Therefore, we conclude that geographic features of depth and relief were confined to the Rock and Rock/Macroalgae real-time classifications.

We defined a new class, Loose Gravel, based on relatively high Q2 values within the range of Q1 values we knew as gravel. When these data were plotted in G-space we found that the data were typically concentrated within sedimentary basins. We believe this classification represented harder bottom than our true mud signal due to the higher Q1 values. Therefore, we found soft muddy bottoms within sedimentary basins that varied in their degree of compaction, as represented by the Q1 axis. When plotted throughout the survey area, these Mud and Loose Gravel classifications were typically associated with the gravel classification at shallower depths leading up from the sedimentary basins.

Finally, we identified a bottom type specific to inner Newman Sound, a small fjord lying at the inner extremity of Newman Sound (Figure 2). Data from the basin of the inner sound largely occurred in a region of Q-space not represented by any of the original calibration data and only sporadically represented by classification data collected elsewhere. We know from trawling in this area that the bottom is covered by a thick layer of saturated wood chips, present from approximately 150 years of logging and saw mill operations within the Newman Sound area (T. Potter, formerly Terra Nova National Park, Glovertown, NF, pers. comm.). We created a new class we refer to as Wood Chips, defined on the basis of the Q-value data collected within the inner sound at depths ≥40 m.

For real-time classifications greater than approximately 220-m depth the QTC View bottom tracking algorithm had trouble detecting the bottom. These data also tended to have low confidence levels with the QTC View classification catalogue. As configured in this study, the system was probably not reliably classifying the seabed greater than 220 m. Therefore, we ultimately restricted our post-classification data to lesser depths.

Final classification scheme

We expanded the original four seabed types used in our classification catalogue into eight seabed habitats based on post classification analyses (Table 2). The original Rock/Macroalgae class was subdivided into three new classes: High Relief/Deep Cobble; Sparse Algae/Cobble; and, True Algae. Our original Mud (Types 1 and 2), Gravel (Types 3 and 4), and Rock classifications remained largely as defined in the original calibration catalogue. Finally, two new seabed classes, Loose Gravel and Wood Chips, were created for regions within

Table 2. Marine habitat categories based on acoustic classification data collected in Bonavista Bay, Newfoundland. The categories were derived from real-time classification data as well as post classification analyses (see the text).

Bottom type	Source	Description
High Relief/Cobble	New	At depths typically >50 m and highest bathymetric relief; characterized by being hard and rough bottom and includes acoustic side shadowing.
Sparse Algae/Cobble	New	At depths typically <50 m and high relief, but not including the area of Q-space characterized as True Algae.
True Algae	New	At depths <50 m, and confined to the area of Q-space associated with dense macroalgae, such as kelp (*Laminaria* sp. and *Agarum* sp.) as well as Irish moss (*Chondrus* sp.)
Rock	Catalogue	Found over a wide range of depths, representing bedrock, bedrock with boulders and broken rock, some cobble; also some association with high relief.
Gravel	Catalogue	A relatively homogenous gravel bottom found in low relief areas but apparently subject to waves and currents; we expect these bottoms to be non-sedimentary and typically containing epifauna such as crinoids, starfish and sea anemones.
Loose Gravel	New	This bottom appears to be a mixture of mud (soft) and gravel (hard) bottom characteristics, typically low relief and not subject to significant waves and currents.
Mud	Catalogue	A true mud bottom that is soft and easily cored, found in sedimentary basins and usually at depths >100 m.

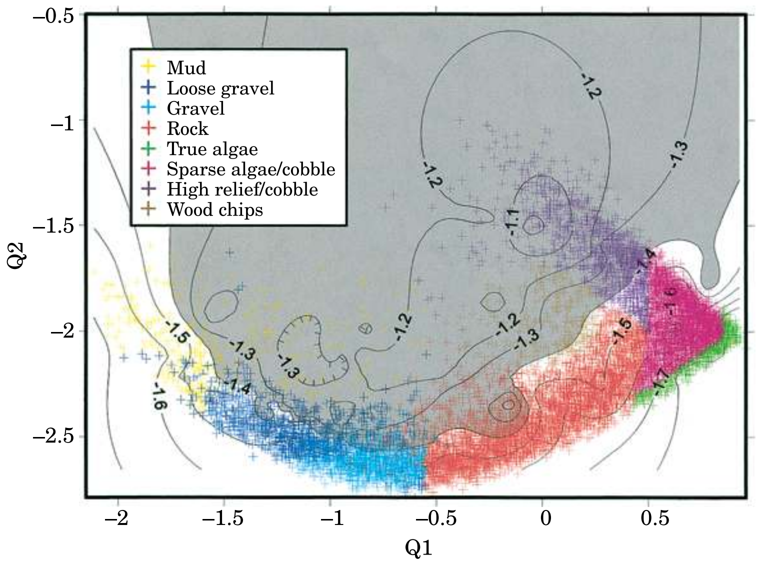

Figure 8. Post-classification data collected in Bonavista Bay, Newfoundland representing eight different seabed habitats, plotted on the Q-space surface. The x- and y-axes are represented by Q1 and Q2 values, while Q3 values are represented by the contoured surface (see the text for details). The shaded area represents higher Q3 values and is simply for visual interpretation of the plotted data against this third axis. The polygon with inward tick marks represents an area of rapid downward change. These data represent about 7% of the data collected in Bonavista Bay and were derived from classification done in outer Swale Tickle.

Q-Space that were not represented by the original catalogue. These data were distributed within unique areas of Q-space (Figure 8). There were areas in Q-space where data from different classes typically overlapped, such as the Rock and Gravel types. Ecologically, overlap between adjacent classification categories was expected, reflecting transition zones. From the entire data set, these transition zones typically accounted for <10% of the data. There was some variation in the proportions of different seabed classes among the three areas, Newman Sound, inner Swale Tickle, and outer Swale Tickle. For example, the High Relief/Cobble class

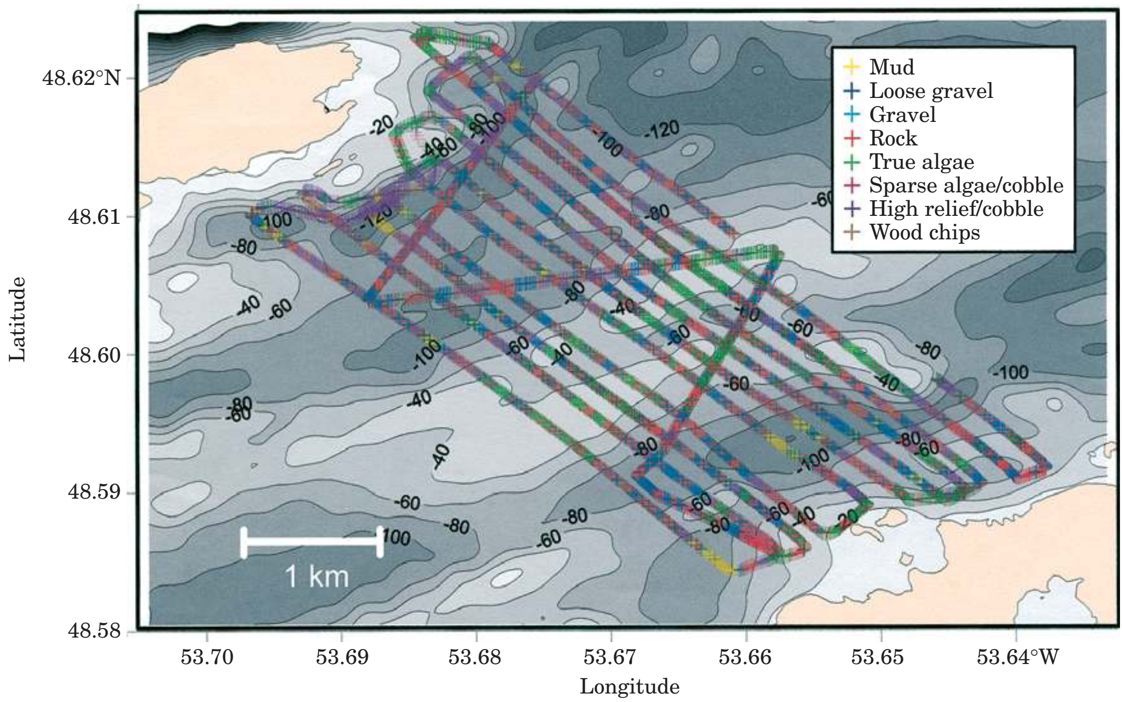

Figure 9. Post-classification data collected in Bonavista Bay, Newfoundland representing eight different seabed habitats. The data are plotted along data collection transects in the detailed study area of outer Swale Tickle (see Figure 2). The shaded contoured surface represent water depths from the surface in 20-m intervals, where darker is deeper. The beige areas represent land.

was more prevalent in outer Swale Tickle (21%) than within Newman Sound (12%). Conversely, the True Algae signal occurred more frequently in Newman Sound (10%) than outer Swale Tickle (2%). Rock was the dominant seabed class in all three areas, ranging from 28 to 34% of all classifications. Gravel ranged from 6 to 9% and Mud from 6 to 10%. Given our knowledge of the seabed in this area, such frequencies were reasonable (Anderson, 2001).

We present an example of the post-classification seabed habitat data for a small area, approximately 15 km^2, within the larger surveyed area (Figure 2). The detailed study area included shoreline on each side and an underwater ridge in the middle which rose to approximately 20-m depth and descended on either side to 100–120-m depth before rising again at the shorelines. The post classification data indicated there were broad areas of common habitat, within which there was a smaller scale variability (Figure 9). Within the detailed study area, True Algae accounted for only 4% of the habitat while the Sparse Algae class accounted for 15%. The Rock habitat type was evident throughout the area and it was the dominant habitat type, accounting for 29% of the habitat. Typically, Rock habitat occurred on the slopes leading down from the shallow areas dominated by the True Algae and Sparse Algae habitat types. Steep slopes were almost always classified as High Relief/Deep Cobble. High Relief/Deep Cobble habitats were common in this study area, occurring in 21% of the surveyed area. The high proportion of Rock and High Relief/Deep Cobble habitat types was consistent with the rough submarine landscape in this area, which contained steep slopes and was exposed to wave action from the Atlantic ocean. The deep, low relief areas were dominated by Gravel, Loose Gravel, and Mud habitat types. The two gravel habitats accounted for 19% of the habitat while mud only accounted for 2%. Superimposed on these broader scale features was small scale variability among seabed habitats.

Discussion

Our evaluation of the QTC View system demonstrated that it is important to collect a representative set of calibration files that broadly represent the seabed habitats to be classified. If calibration catalogues only contain a subset of bottom habitats to be encountered during real-time classification, then it is likely there will be spurious classifications. For example, we did not have a specific calibration file for ‘‘cobble’’ habitat, which we would characterize as areas of large rocks and boulders 0.25–1.0 m diameter. However, we discovered this was an important feature of the seabed landscape in

Bonavista Bay (Anderson, 2001). Alternatively, it may be difficult to initially construct a comprehensive calibration data set for the real-time QTC View classification system at the outset of any survey program. We discovered that the QTC View system was capable of discriminating new bottom types once we examined the distribution of the data in Q-space. Our most striking example of this was the delineation of the Wood Chips bottom type in inner Newman Sound.

The capability of post-classifying the Q-value data sets represents an important step to improve the classification of seabeds, even when initial training data sets are incomplete. In this way, acoustic classifications can be seen to proceed in an iterative fashion where post-classification of new seabed habitats can be used to develop a more comprehensive calibration catalogue for subsequent generations of classification surveys. Development of more comprehensive catalogues will result in less post-classification analyses over time.

We have characterized the seabed classification data into eight different habitat types. Inevitably, this represents fewer categories than actually exist. For example, we know that beds of macroalgae typically consisted of kelp or Irish moss, *Chondrus crispus*. In some nearshore locations *Laminaria laminaria* kelp dominated while kelp areas away from the shoreline were usually *Agarum cribrosum*. In addition, we know from the submersible observations that transitions from one habitat type to another can be frequent. Examination of the classification data indicated some areas of Q-space where two or more classes occurred. These may represent transition zones in the marine landscape. However, such transition zones represented $<10\%$ of all data and we expect such areas are geographically small in area. Alternatively, the small scale variability may indicate some measure of uncertainty in the acoustic classification data along our survey transects. The degree to which the smallest scale variability represents true habitat variation vs. noise associated with acoustic seabed classification remains unknown. Further refinement of acoustic classification to measure more detailed structure of seabed habitats may be achieved through higher resolution acoustics and by comparison of classifications at different acoustic frequencies.

The issue of acoustic seabed classification as a function of bathymetric depth and relief is complex. The QTC View Series IV system compensates for signal attenuation over the range of depths to be encountered during classification surveys. Our work indicated that setting the virtual depth of the QTC View Series IV at approximately one half the maximum collection depth of 300 m gave the best calibration data. However, we did not evaluate the effect of setting the virtual depth beyond 150 m. We expect that setting the virtual depth parameter close to the maximum collection depth will result in better system performance. We demonstrated strong depth dependence in the Q-values for two of our original seabed classification types. Identifying a depth dependent component was critical in establishing new seabed types during post classification analyses. In addition, three post classification categories were interpreted to be a function of both depth and relief. Not only was the QTC View system capable of classifying these depth and relief dependent habitat types into separate classes, we believe these are important habitats for juvenile Atlantic cod. Lastly, specific seabed habitats are dependent on depth and relief. For example, macroalgae will not grow below the photic zone. Low relief areas will be depositional depending on their exposure to ocean currents and wave turbulence, all else being equal. However, low relief areas that are deep will tend to be depositional and will support different biological communities. To a certain degree, the QTC View system appears to combine depth, relief, and substrate type dependencies into single classification types. The degree to which we can regard acoustic seabed classifications as an integration of these three variables in habitat mapping initiatives should be a subject of future research.

Examination of the post-classification data collected along survey transects indicated that both large and small scale features occurred within the detailed study area. For example, the deep basins were dominated by mud habitats while the shallow areas were often dominated by areas of our True Algae classification. Alternatively, there was a high degree of variability in classification types along the acoustic transects. This variability reflects the small scale variation of marine habitats in the study area, which we know to be true from submersible observations (Anderson, 2001). The footprint of the classified acoustic data along track ranged from approximately 11 m at 10-m depth to 17 m at 120 m. Therefore, we generalize that the seabed habitats in our study area were characterized by large scale features of different seabed types (1000s m^2) but embedded within these larger areas was small scale variation (100s m^2). The true dimensions of these habitats remains a fundamental question facing marine ecologists and will only be answered by high resolution studies designed to identify and map marine habitats at appropriate spatial scales.

Acknowledgements

Arnold Murphy operated the QTC View system evaluated in this study. Karl Rhynus and Brad Prager assisted us configuring, calibrating, and understanding the QTC View system. Edgar Dalley was responsible for conducting the seabed classification work in Bonavista Bay. Denise Davis developed the detailed bathymetric data used in the study. Sandy Fraser and Robert Hewitt assisted in the analyses of the QTC View data. The captains and crews of the RV "Shamook" contributed to the success of the project. The officers and crew of the HMCS "Cormorant" provided an unique opportunity to study the seafloor in a safe and productive way. Major sponsors of this work included the Canadian Center for Fisheries Innovation, the Canada/Newfoundland Cooperative Agreement for Fishing Industry Development, the Environmental Innovations Program of Environment Canada, the Newfoundland Department of Fisheries and Aquaculture, the Department of Fisheries and Oceans, and the Department of National Defense.

References

Anderson, J. T. 2001. Classification of marine habitats using submersible and acoustic seabed techniques. *In* Spatial Processes and Management of Fish Populations. Lowell Wakefield Fisheries Symposium. October 27–30 1999. In press.

Greenstreet, S. P. R., Tuck, I. D., Grewar, G. N., Armstrong, E., Reid, D. G., and Wright, P. J. 1997. An assessment of the acoustic survey technique, RoxAnn, as a means of mapping seabed habitat. ICES Journal of Marine Science, 54: 939–959.

Gregory, R. S., and Anderson, J. T. 1997. Substrate selection and use of protective cover by juvenile Atlantic cod (*Gadus morhua*) in inshore waters of Newfoundland. Marine Ecology Progress Series, 146: 9–20.

Gregory, R. S., Anderson, J. T., and Dalley, E. L. 1997. Distribution of juvenile Atlantic cod (*Gadus morhua*) relative to available habitat in Placentia Bay, Newfoundland. NAFO Scientific Council Studies, 29: 3–12.

Sotheran, I. S., Foster-Smith, R. L., and Davies, J. 1997. Mapping of marine benthic habitats using image processing techniques within a raster-based geographic information system. Estuarine and Coastal Shelf Sciences, 44(Suppl. A): 25–31.

Surfer 1999. Surface Mapping System. V7. Golden Software Inc., Golden, Co. USA.

Todd, B. J., Fader, B. G., Courtney, R. C., and Pickrill, R. A. 1999. Quaternary geology and surficial sediment processes, Browns Bank, Scotian Shelf, based on multibeam bathymetry. Marine Geology, 162: 165–214.