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Acoustic detection of a scallop bed from a single-beam echosounder in the St. Lawrence

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Single-beam seabed echoes combined with epi-macrobenthos photographs were used to remotely detect a scallop bed and characterize the specific acoustic signal of Iceland scallop (*Chlamys islandica*). A dense scallop bed was surveyed in 2002, with a QTC VIEW Series IV acoustic ground-discrimination system (AGDS) connected to a 38 kHz, 7° split-beam SIMRAD EK60 scientific echosounder. In 2003, a 50 kHz, 42° single-beam SUZUKI ES-2025 echosounder was connected to a QTC VIEW Series V AGDS. The QTC VIEW data were analysed with QTC IMPACT following the standard procedures and classified into acoustic classes. Several approaches were tested: unsupervised and supervised survey strategies directed to specific benthic communities. The SIMRAD EK60 seabed volume-backscattering strength (S_v) was submitted to a principal component analysis (PCA), before and after removal of a depth trend, and the scores on the first 10 principal components were classed by a K-means cluster analysis. The same seabed S_v data were submitted to stepwise discriminant analysis whose training data sets were defined with the ground-truth photographs using different groupings: biotope types, community types, and finally scallop-density classes. All the QTC AGDS approaches failed to reveal the scallop bed, community structures, or biotopes. The QTC classifications mimicked the bathymetry with a strong correlation of the acoustic classes with depth. The seabed S_v PCA + K-means approach presented similar depth-dependence, but, the PCA + K-means on the S_v residuals revealed the scallop bed. The discriminant analysis was the best solution for the scallop density with a general classification success rate of 75% and up to 91% for the highest density class. The S_v signature of the scallop bed is presented, and the most discriminant part of the acoustic signal is identified.

Keywords: acoustic ground discrimination, benthic biotopes, habitat mapping, QTC VIEW, remote sensing, scallop bed, seabed classification.

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Introduction

Seafloor mapping becomes more and more essential for the effective management of the marine environment and especially for fisheries as the exploitation of marine biological resources increases. Physical-, geological-, and biological-resource maps have proved to be essential aids in sustainable management by allowing the monitoring of environmental fluctuations and the estimation of anthropogenic influence on benthic communities and habitats (Siwabessy *et al.*, 1999; Kostylev *et al.*, 2001). However, accessing submarine landscapes has never been easy as sampling gears are remotely controlled and, consequently, often blind. Traditionally, many of the earlier mapping studies relied on physical sampling, for example with grabs, dredges, or both gears. This approach is not only time consuming and costly, but also highly disturbing for the benthic *biotopes* (i.e. habitats and their associated communities) and provides only separated, discrete data across the study area. Recent improvements in single-beam echosounders, sidescan sonar, swath-bathymetric systems, and signal processing now provide effective tools to explore the seabed as a complement to the physical sampling methods traditionally used to carry out benthic surveys (Kenny *et al.*, 2003). More recently, "acoustic ground-discrimination systems" (AGDS) have been developed to detect the acoustic-reflectance properties of seabeds. Different reflectances are linked to differences in the physical and occasionally biological nature of these seabeds. Indeed, the nature of the bottom echoes is influenced not only by basic sediment grain-size parameters, sediment sorting, microtopography, sediment density, and porosity, but also by the presence, concentration, and type of benthic fauna and flora (Tsemahman and Collins, 1997; Collins and Galloway, 1998; Bornhold *et al.*, 1999; Hamilton *et al.*, 1999; Kloser *et al.*, 2001; Anderson *et al.*, 2002).

RoxAnn (Chivers *et al.*, 1990) and QTC VIEW (Collins *et al.*, 1996) are two widely used AGDSs for surveying biotopes. They extract shape, energy, or both features contained in the bottom acoustic signals (Siwabessy *et al.*, 2000). RoxAnn systems derive two parameters E1 and E2, respectively, the energy of the tail of the first echo, often related to the roughness of the sediment, and the total energy of the second echo, often related to hardness of the sediment (Burns *et al.*, 1989). By associating the relationship between E1 and E2 with a substratum type, distinct bottom types can be mapped. It has been shown that RoxAnn performance is highly dependent on ship speed (Hamilton *et al.*, 1999). In contrast, QTC VIEW systems examine the shape characteristics of the first echo and use a series of algorithms to translate it to an array of 166 descriptive variables (Collins *et al.*, 1996), which are then reduced through principal component analysis (PCA) to three Q-values, Q_1, Q_2, and Q_3 (Collins and McConnaughey, 1998). These three Q-values are plotted in three-dimensional Q-space and then run through a cluster analysis to distinguish acoustically distinct bottom types. The QTC VIEW classification accuracy has been shown to be greatly affected by bottom slopes exceeding approximately 5–8° (von Szalay and McConnaughey, 2002). According to Hamilton *et al.* (1999), QTC VIEW appears to be the more consistent and reliable of the two systems. Compared with traditional physical sampling, acoustic tools permit rapid, broad-scale, and non-intrusive sampling of the seabed. However, resulting AGDS classifications must be ground-truthed with physical sampling to assess their accuracy. In the so-called "supervised" approach, the classification process is trained *a priori* on a ground-truth data set.

Most of the acoustic classifications carried out in previous studies focused on identifying and mapping seafloor sediments, which were then associated with benthic habitats and ground-truthed to establish the distribution of organisms on the seabed (Greenstreet *et al.*, 1997; Siwabessy *et al.*, 2000; Kostylev *et al.*, 2001; Anderson *et al.*, 2002; Ellingsen *et al.*, 2002; Freitas *et al.*, 2003a). However, some studies have clearly identified influences from epi-benthic assemblages (e.g. urchin, cockle) in acoustic backscatter (Jumars *et al.*, 1996; Self *et al.*, 2001). Assuming that dense assemblages of benthic fauna and flora could modify the seabed acoustic backscatter, this study aims at detecting the specific signal of Iceland scallop and a known scallop bed located in the St. Lawrence Estuary, Canada. Several acoustic approaches are compared: QTC VIEW systems (Series IV and V) processing using QTC IMPACT software and custom processing of the SIMRAD EK60 scientific echosounder seabed volume-backscattering strength.

Material and methods

Study area

This study was conducted off Ile Rouge located in the St. Lawrence Estuary, Québec, Canada (Figure 1). The study area is approximately 22 km^2 and the associated Iceland scallop bed is the most upstream one of the St. Lawrence Estuary (Arseneau *et al.*, 2003). This scallop bed is located on Ile Rouge bank, at depths varying between 20 and 60 m. It is bounded by the 250–300 m deep Laurentian Channel in the north and the 100 m deep South Channel in the south. The northern part of the scallop bed is located in the Saguenay-St. Lawrence Marine Park. It has one of the highest scallop densities in the Gulf of St. Lawrence. From dredge samples, the mean density of the scallop bed was estimated at 0.53 scallops m^{-2} and the maximal density was 2.58 scallops m^{-2} (MPO, 2000; Hartog *et al.*, 2001). The bed has been exploited by commercial fishers since 1998, including the part located in the Marine Park (Arseneau *et al.*, 2003).

Acoustic surveys

Two surveys with different acoustic equipment were run over the study area. The first survey occurred on July 15, 2002 aboard NGCC "F.G. Creed", an acoustic SWATH vessel particularly stable and relatively silent. Nineteen survey lines, orientated north/south, were run at an average speed of 16.7 km h^{-1} (4.6 m s^{-1}) (Figure 2a). The acoustic equipment comprised a SIMRAD EK60 echosounder operating at 38, 120, and 200 kHz. Only data from the 38 kHz sounder are presented here. The 38 kHz sounder had a 7° split-beam transducer and was operated with a 1-ms pulse length triggered every second. The navigation system, connected to both the echosounder and the QTC VIEW™ system, was a Differential Global Positioning System (DGPS), providing positional accuracy of $\pm$3 m. A vessel-attitude system (POSMV, Applanix, TX, USA) was connected to the EK60 system, which took the heave into account in bottom-depth measurement. A QTC VIEW Series IV (Collins, 1996) was connected to one quadrant of the split-beam transducer. This system detected, processed, and digitized the raw bottom echo trace read from the transducer cable, and extracted 166 echo-shape features from a five-pings, stacked echo with a series of algorithms for energy and shape characteristics in both frequency and time domains (Collins, 1996; Collins *et al.*, 1996). Preston *et al.* (2004) defined the five algorithm families used to generate the 166 features as following: (i) "cumulative amplitude and ratios of samples of cumulative amplitude"; (ii) "amplitude quantiles"; (iii) "amplitude

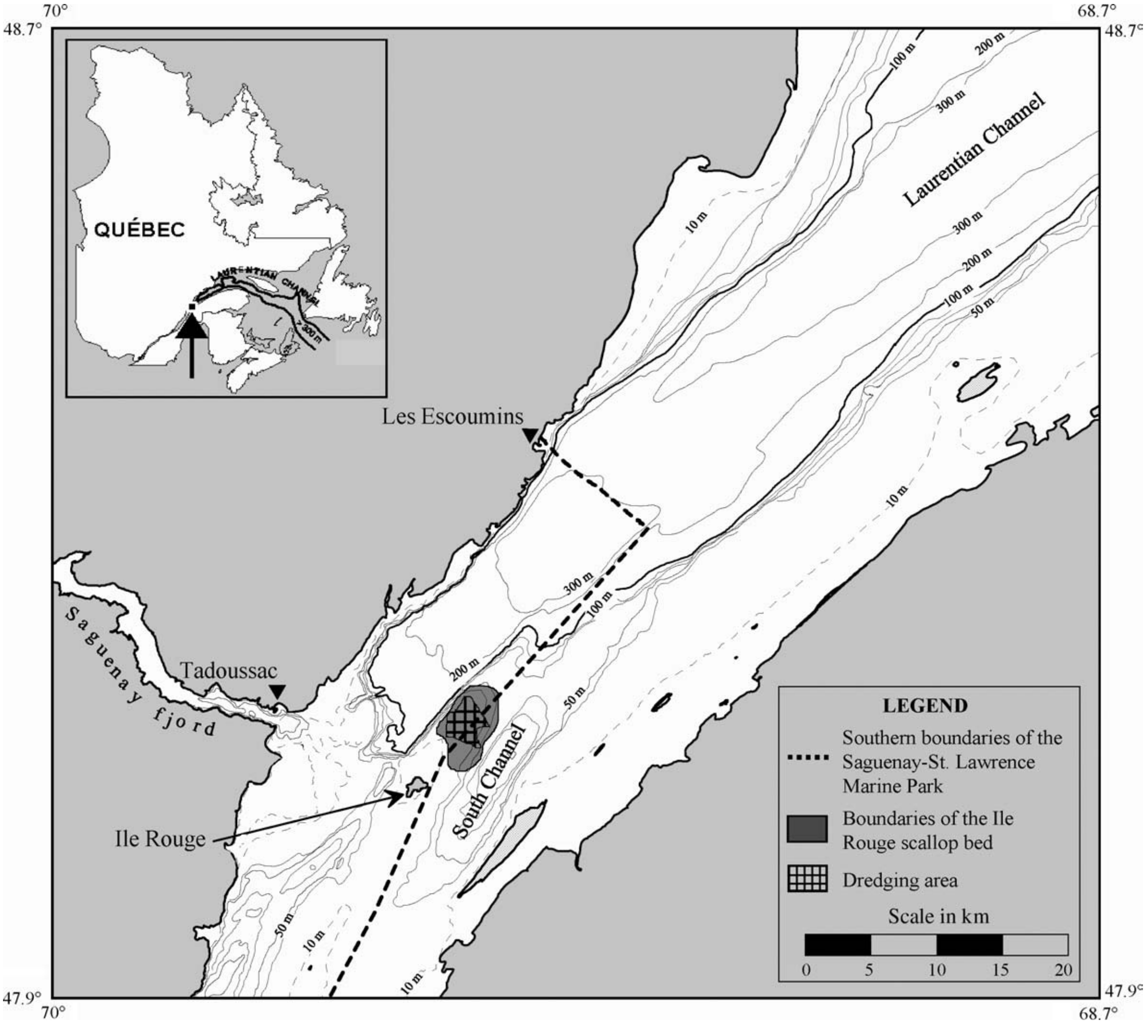

Figure 1. A map of the study area indicating the scallop-bed's location and extent.

histogram"; (iv) "power spectrum", and (v) "wavelet packet transform". Furthermore, conductivity–temperature–depth profiles were made with an SBE-19 CTD (Seabird Electronics Inc.) during the survey to compute the actual sound speed and absorption coefficient profiles for the analysis of the EK60 data.

The second acoustic survey was run in June 2003 aboard the trawler NGCC "Calanus II". Forty transects were surveyed at an average speed of 13 km h^{-1} (3.6 m s^{-1}) (Figure 2b). Some tighter lines were also run in areas known as being representative of a particular bottom type or benthic faunal community (Figure 2c). A SUZUKI ES-2025 echosounder operating at the single frequency of 50 kHz with a 42° single-beam transducer and emitting 0.60-ms pulses every 2 s was used. The QTC VIEW system was the Series V, which achieves faster digitization of the signal with a better resolution and dynamic range (Freitas *et al.*, 2003b), and permit classification over a depth range that includes very shallow waters, according to the manufacturer. In addition, Series V raw data are the full bipolar waveform of the echo trace, while the Series IV raw data are the pre-processed set of echo descriptors. The main differences between the acoustic equipments used for the two acoustic surveys are given in Table 1.

Ground-truth sampling

Biological data were collected in June 2002 aboard the RV "A.C. Horth". Seafloor photographs were taken with a high-resolution (4.2 megapixels) still camera fitted with a wide-angle lens and placed in a waterproof case and remotely controlled from the vessel. Two 250 W light sources allowed adjustment of the illumination according to the water turbidity, the position of the camera to the bottom, or both factors. The system was mounted on a tetrapod frame that included a reference ruler to evaluate the size of material of

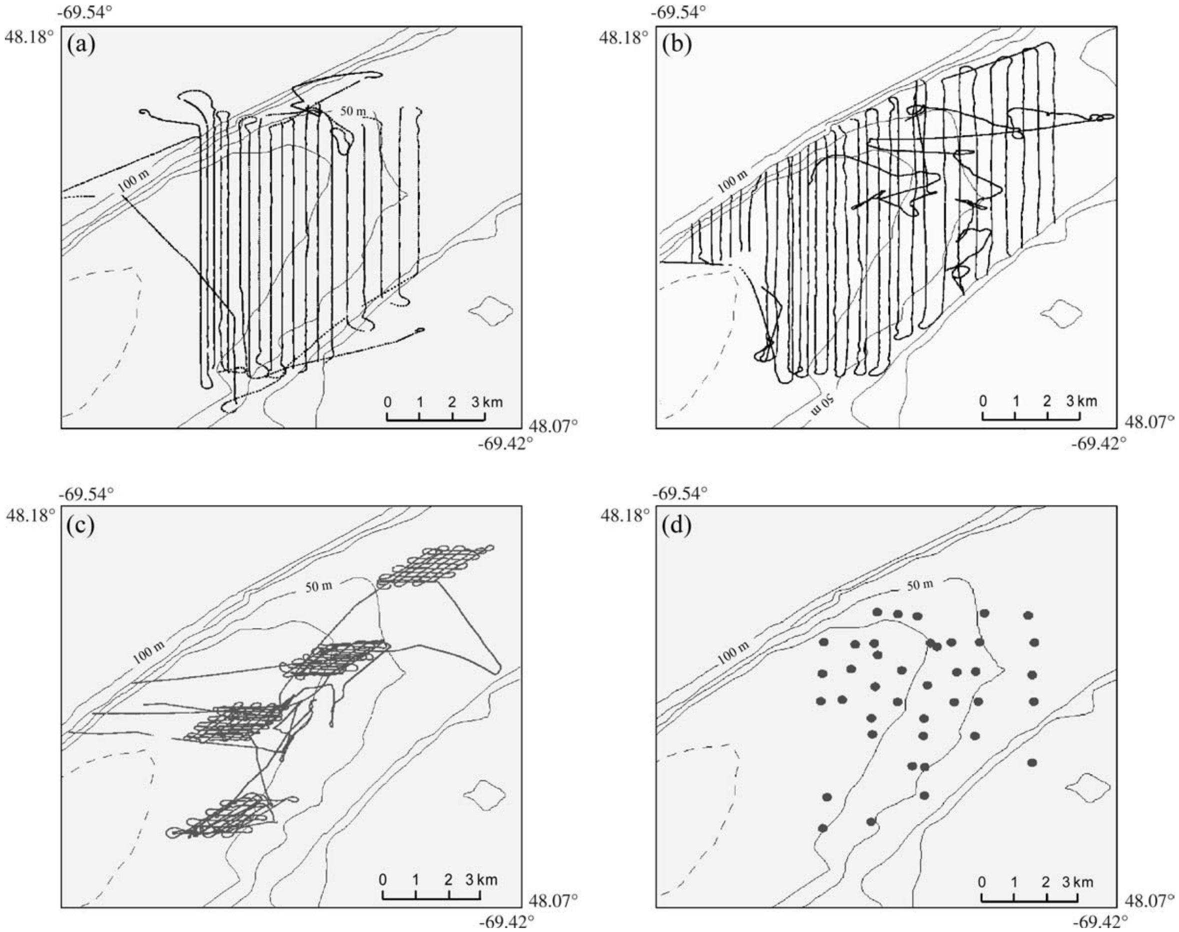

Figure 2. Survey maps. (a) 2002 Acoustic-survey lines; (b) 2003 acoustic-survey lines; (c) 2003 acoustic-survey tighter lines over different benthic-communities areas; (d) 2002 seafloor-photograph stations. Note that the maps in Figures 2–7 are stretched horizontally by a factor of 1.5 for clearer separation of the transect lines; the scale provided is for the horizontal axis.

the seabed. Throughout the study area, 40 stations, located on a regular grid, but actually sampled slightly away from the plan because the ship drifted with the currents, were surveyed (Figure 2d) and, at each station, five 0.25 m^2 images of the seafloor were collected when the camera reached the bottom. Furthermore, Smith-McIntyre grab (0.1 m^2 area) and dredge samples were collected. Granulometry of the sediment was done at each station and used to compare grab samples and seafloor photographs (Arseneau *et al.*, 2002). The grab samples underestimated large boulders and rocks, compared with photographs. Seafloor photographs were, therefore, used here since they are more appropriate to identify the relevant biotope characteristics.

Data analysis

The seafloor photographs were analysed through the image analysis software Image Pro Express v4.0 to quantify the surface covered by the sediment and the epi-macrobenthos. A grid of 100 uniformly distributed points was superimposed on the photographs, and what was under each point was identified to give an estimate of the percentages of the surface covered by each component. This is a modified method of that used by Archambault *et al.* (2001) directly in the field. For each station, these aerial percentages were averaged over the five photographs. For comparison with the acoustic classification, stations were first classed by their dominant organism, which represented more than 50% of the total aerial percentage represented by the macrobenthos. These biological dominance classes were: "scallop", "hydrozoa", "ophiuridae", or "encrusting algae", which were the four most common taxa. When there was no predominance, the station was then assigned to a "non-predominance" class. This allowed the generation of a single map showing the principal biological feature at each station. Furthermore, in the quantification of the epi-macrobenthos, the distinction between live and dead scallops was based on the presence

Table 1. A comparison of the settings for the echosounder and the QTC VIEW systems on the acoustic surveys in 2002 and 2003.

	Setting	
Parameter	2002	2003
Echosounder	SIMRAD EK60	SUZUKI ES-2025
Operating frequency	38 kHz	50 kHz
Beam width	7°*	42°
Footprint diameter and area in 40-m water depth	5 m, 19 m^2, 2.5 m, 5 m^2*	30 m, 741 m^2
Transmit power	2 000 W	100 W
Pulse duration	1 ms	0.60 ms
Ping rate	1 s^{-1}	2 s^{-1}
Time-varied gain	20 log R + 2αR†	20 log (ct/2) + αct‡
Heave-corrected depth	Yes	No
QTC VIEW	IV	V
Sample rate	20 kHz	5 000 kHz
Resolution	8 bits	12 bits
Raw data	Full-features vectors (*.FFV)	Full-waveform features (*.FWF)
Acoustic classification	Real-time and post-processing	Post-processing

*One the four quadrants of the split-beam transducer was connected to the QTC VIEW IV system.
†For the SIMRAD EK60 data, R is the range and α is the absorption coefficient, taking into account the actual sound speed and absorption profiles. For the QTC VIEW IV, see below.
‡Provided by the QTC system, c is a nominal speed of sound in water (1500 m s^{-1}), t is the elapsed time since the transmit pulse (in seconds) and α is a nominal absorption coefficient fixed at 5.5 dB km^{-1} according to QTC (2002a).

of visible ocelli and a non-eroded shell margin. Second, the aerial percentages were submitted to multivariate statistical analyses to classify the stations by their similarity and to compare these results with the acoustic classification. The matrix of 40 stations by 49 variables, corresponding to the species- and sediment-type aerial percentages, was used to compute similarity matrices on selected variables using the Bray−Curtis index (Clarke and Warwick, 1994). The similarity matrices were then submitted to average linkage hierarchical clustering to classify the stations (Legendre and Legendre, 1998). For each resulting classification, the mean relative aerial density and percentage of contribution to within groups similarity were computed for the main components of the group (for details, see Clarke and Warwick, 1994). Third, another classification for comparison with the acoustic classification was based on the aerial percentage of living scallops, which was objectively partitioned in homogenous classes by K-means clustering.

The QTC VIEW full-feature vectors data (FFV) were first analysed using an unsupervised classification method (Bornhold *et al.*, 1999). The 166 variables, resulting from the QTC VIEW echo description, were reduced to three main dimensions (Q_1, Q_2, and Q_3) using principal component analysis (PCA, cf. Legendre and Legendre, 1998) for sorting out the echoes (Collins and McConnaughey, 1998), which generally account for 90% or more of the total variance in a data set (Prager *et al.*, 1995; Legendre *et al.*, 2002). This reduced data matrix was submitted to K-means clustering based on a progressive-splitting process using QTC IMPACT v3.0 post-processing software. The detailed procedure of QTC IMPACT processing is described in Freitas *et al.* (2003b). The decision to split and merge clusters was assisted by provision of statistical information of each cluster, notably the total score and the Cluster Performance Index rate (CPI). The total score corresponds to the sum of the scores of the individual classes, while the individual score of each class is the product of the number of records and a "chi-square" value (χ^2) (Ellingsen *et al.*, 2002). The total score should first decrease rapidly and then stabilize when the optimal split level is reached (QTC, 2002b), but see Legendre *et al.* (2002). The CPI is a measure of the ratio of the distance between the centres of clusters and the extent of the clusters in the Q-space. The CPI rate is defined as $CPI(n) = (CPI(n) - CPI(n-1))/CPI(n-1)$, where n is the split number. The CPI rate tends to be maximum at the optimal split level (QTC, 2002b). These two descriptors were taken into account, as recommended by QTC, to decide how to further subdivide the data set. At the end of the procedure, echoes with similar characters formed clusters that defined acoustic classes, which were mapped throughout the surveyed seabed. In addition, as the QTC classification accuracy can be affected by slopes (von Szalay and McConnaughey, 2002), data records corresponding to steep and moderate slopes at the margin of the study area were trimmed off before the analysis. The analysis was also done with all data and the resulting patterns (not shown here) pointed to similar conclusions. Only depths shallower than 70 m were kept and submitted to cluster analysis.

Following the supervised approach, a specific catalogue, which took into account a set of three, pre-determined seabed classes from the biological samples, was created. The FFV data within 150 m from a ground-truth station were assigned to that station and its dominant macrobenthic group ("scallop", "hydrozoa", and "ophiuridae"). These data were then used through QTC IMPACT to create a catalogue of known seabed classes, which served to classify the whole survey FFV data.

A separate acoustic classification was performed from the EK60 scientific echosounder seabed echo (only available for the 2002 acoustic survey). The volume-backscattering coefficient acoustic metric (S_v, m^{-1}) used in echointegration (MacLennan and Simmonds, 1992) was estimated for 40 intervals of 75 cm around the echo return from the seafloor to get the seabed echo. The echosounder was calibrated with the standard-sphere method (Foote *et al.*, 1987). The EK60 raw data were first converted into standard HAC format through CH1 software (Simard *et al.*, 1998). The S_v seabed-echo shape and amplitude were computed using CH2 (Simard *et al.*, 2000), which took into account a time-varied gain (TVG) correction estimated from the measured sound-speed and absorption profiles. Thus, each ping was described by a multivariable composed of 40 S_v values. The entire study area represented 22 031 pings, which formed a data matrix of 22 031 rows and 43 columns including latitude, longitude, and depth. The 40 S_v variables were log transformed into volume-backscattering strength (S_v, dB re 1 m^{-1}). As for the QTC classification, only depths shallower than 70 m were retained for the analysis. The S_v echo shape was smoothed by a moving average on five pings. Then, this data matrix was submitted to two types of multivariate statistical analyses. First, a PCA was performed on the correlation matrix of the S_v variables. Similarly, these S_v variables were also regressed on depth and the residuals were submitted to a second PCA. Then, the scores on the PCA components representing more than 2.5% (i.e. 1/40) of the total variance were submitted to a K-means cluster analysis. Several acoustic classes were obtained this way. The optimal split level was intuitively determined by the observer as it best matched the biological pattern. The associated acoustic classes were then imported into a GIS and superimposed on the biological results. Second, discriminant analyses (Legendre and Legendre, 1998) were also applied to these seabed S_v data to determine an acoustic-classification solution for a set of pre-determined seabed classes from the biological samples. The pings within 150 m from a ground-truth station were assigned to the macro-benthic class of that station. A new acoustic-station matrix was then generated with the same above 40 S_v variables + 3 columns which included 2105 rows corresponding to the extracted pings. This S_v matrix was subjected to discriminant analysis using a series of pre-determined seabed classes obtained from several different hierarchical and K-means clustering on the ground-truth data set defined above. The classes' assignments were added to the acoustic-station matrix, which then formed the training set for the discriminant analysis. A stepwise analysis was used, in which only those variables which contribute the most to the discriminant function are included, one at a time. The discriminant solutions were then generalized to the whole survey area. The final classifications were mapped and superimposed with biological results.

Results

Ground-truth data

From analysis of the photographs, seafloor sediments on Ile Rouge bank are rather coarse with a dominance of gravel (>2 mm) and medium sands (0.25–0.5 mm). The gravel proportions in sediments decrease downstream from Ile Rouge, from 97% to less than 55%. Big boulders (>40 cm) were common (up to 20%) in the east/southeast of the bank. Scallop shells variably occurred over the study area with a maximum proportion of about 25% in the dredging area. The results of analysis of the photographs are well corroborated by the grab- and dredge-samples analysis, but these observations are not shown here. The sediment inter-sites variability was rather low. Consequently, the sediment pattern itself was not sufficiently variable to compare with an acoustic classification. Several benthic communities were identified from the analysis of the photographs and they tended to be distributed over distinct areas. The most common groups on the bank were ophiuridae, Iceland scallops, calcareous-encrusting algae, and hydrozoa. Two species of Ophiuroidea were observed, *Ophiura robusta* and *Ophiopholis aculeate*. They were combined for the analyses. These species were very abundant, especially in the northern and eastern parts of the bank and commonly in the crevices of rocks among scallops or under rocks and shells. They may form dense beds in high-energy, tidal area. They avoid light and prefer to hide beneath rocks and under shells. They were often observed attached to other animals through their adapted, long, flexible arms. Calcareous encrusting algae were observed on the shallower part of the bank relatively close to Ile Rouge, generally fixed on pebbles and boulders, which are rarely overturned. Hydrozoa, which populated the southern part of the bank, were observed on boulders (10 cm and more) and sometimes attached to living scallop shells. These organisms could be very abundant and reach a height >10 cm above the seafloor. These four groups of organisms were retained to map the macrobenthos dominance from the surveyed stations (Figure 3a).

Among the several similarity analyses and hierarchical clusterings realized with the ground-truth data matrix, only the ones which gave the best similarity with the discriminant analyses of the acoustic data were retained. First, the hierarchical clustering applied to the similarity matrix computed from the combination of sediments and macrobenthos aerial percentages identified five groups and one singleton that are detailed in Table 2 and mapped in Figure 3b. The five groups are actually mainly sorted by their sediment composition. Some of them can be compared with the previously described macrobenthos spatial distribution (Figure 3a) as follows: group 2 can be related to calcareous-encrusting algae habitat, group 4 to ophiuridae habitat, and group 6 to scallop habitat. Second, hierarchical clustering applied to the similarity matrix computed with only the aerial percentages of macrobenthos provides six groups and three singletons (Table 3 and Figure 3c). Those groups are characterized by one dominant taxon (groups 1 and 2) or macrofauna assemblages (groups 4, 6, 8, and 9) but, in this last case, one taxon is always predominant vs. the other taxa of the community. Thus, scallops are

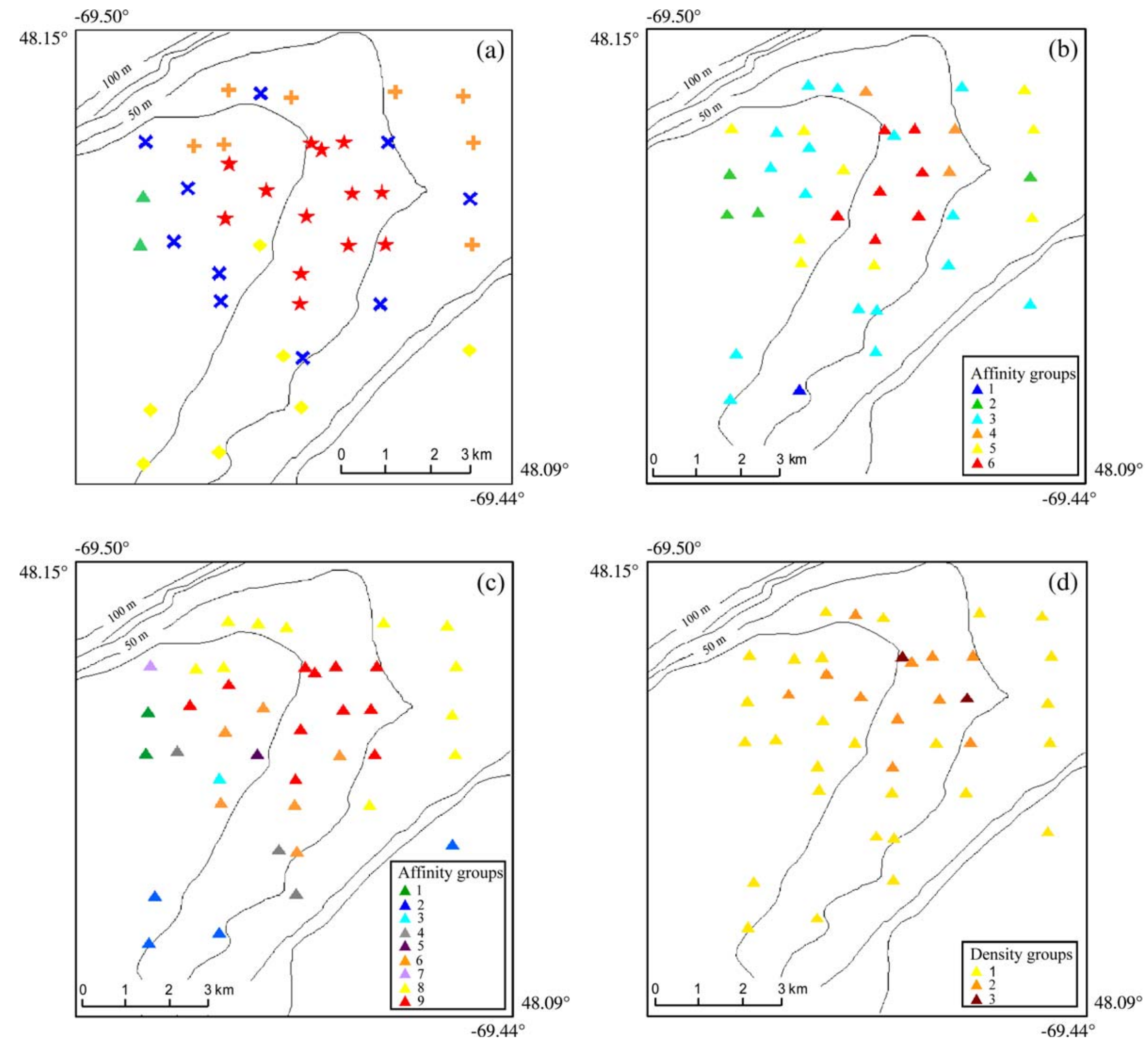

Figure 3. Maps of the ground-truth stations. (a) Map of the macrobenthos dominance over the study area showing the scallop bed: : predominance of ophiuridae; : predominance of scallops; : predominance of encrusting algae; : predominance of hydrozoa; : no predominance. (b) Spatial distribution of the affinity groups identified by hierarchical clustering on the similarity matrix of macrobenthos and sediments combined: five identified affinity groups and one singleton. (c) Spatial distribution of the affinity groups identified by hierarchical clustering on the similarity matrix of macrobenthos only: six identified affinity groups and three singletons. (d) Spatial distribution of the density groups identified by K-means clustering on living scallops aerial percentages: three identified density groups.

predominant in groups 6 and 9 but are also present in groups 4 and 8. In summary, these two cluster analyses gave consistent results that are both interesting to compare with the discriminant analyses applied to the acoustic data to compare the influence of sediments and macrobenthos combined on the one hand, and only macrobenthos on the other hand. In addition, K-means clustering was also applied to the living scallop aerial percentages only to identify scallop density for a third discriminant analysis with the acoustic data. Several density groups were produced, but only the results for three groups were kept because they best matched our prior knowledge of scallop spatial distribution throughout the survey area. These results are shown in Table 4 and mapped in Figure 3d.

Acoustic classifications

The results of the acoustic classifications of both QTC VIEW systems are given in Table 5. The optimal K-means split level of the QTC VIEW IV data unsupervised classification was already reached at the second split, as the total score began to stabilize and the CPI rate was maximal. Only Q_1 and Q_2 components contributed to the classification (Figure 4b). The optimal classification

Table 2. The mean relative aerial density and contribution to within-group similarity for the macrobenthos and sediments aerial percentages in each group identified with hierarchical clustering.

Species	Relative aerial density (%)	Contribution to similarity (%)
Group 1		
One station only	—	—
Group 2		
Boulders 10−80 mm	46.7	52.5
Boulders 1−10 mm	30.2	32.5
Boulders >80 mm and encrusting algae	14.3	7.12
Group 3		
Boulders 10−80 mm	50.1	59.1
Dead shells	15.1	14.4
Boulders 1−10 mm	13.4	13.4
Boulders >80 mm and encrusting algae	6.3	4.6
Group 4		
Dead shells	61.4	73.6
Sand	9.1	9.1
Ophiuridae	8.6	6.4
Living scallops	8.5	5.7
Group 5		
Dead shells	44.6	53.5
Boulders 10−80 mm	23.5	25.6
Boulders 1−10 mm	6.6	16.0
Sand	9.7	5.5
Group 6		
Boulders 10−80 mm	28.5	29.2
Dead shells	24.4	26.7
Sand	21.3	21.8
Boulders 1−10 mm	12.0	12.9

Table 3. The mean relative aerial density and contribution to within-group similarity for the macrobenthos aerial percentages in each group identified with hierarchical clustering.

Species	Relative aerial density (%)	Contribution to similarity (%)
Group 1		
Calcareous-encrusting algae	10.9	97.5
Group 2		
Hydrozoa	17.2	93.9
Group 3		
One station only	—	—
Group 4		
Hydrozoa	4.2	75.8
Scallops	1.1	7.5
Sponges	0.5	7.1
Group 5		
One station only	—	—
Group 6		
Scallops	2.9	67.0
Hydrozoa	0.8	11.3
Ophiuridae	0.7	9.4
Sponges	0.5	6.3
Group 7		
One station only	—	—
Group 8		
Ophiuridae	10.2	65.9
Scallops	2.8	19.7
Urchin	1.0	6.0
Group 9		
Scallops	8.3	69.5
Ophiuridae	3.8	19.7
Urchin	0.8	5.7

solution corresponded to three acoustic classes largely dominated by acoustic class 1. These three acoustic classes are superimposed with the dominance pattern at the biological stations in Figure 4a. This map did not indicate a close correspondence between the acoustic pattern and the main biological assemblages. It rather indicated a correlation of the Q-values with depth, which was significant for the Q_1 and Q_2 components responsible for the classification (Table 6). For the supervised classification, a specific catalogue was created with the selected training FFV data set for three biological dominances, i.e. "scallop", "ophiuridae", and "hydrozoa". The resulting QTC IMPACT specific catalogue was used to classify the whole survey. This supervised classification, also dominated by acoustic class 1 (Figure 4c), appeared as inconclusive as the above unsupervised classification. No correspondence between these QTC acoustic classification and the biological assemblages was found in this way. The results of the QTC VIEW V data classification up to the third split are presented in Table 7a for the 2003 data set. The total score and the CPI rate indicate that the optimal split level was reached at the second split. The QTC VIEW V system provided a classification pattern very similar to that of the QTC VIEW IV, with the same relationship with the bathymetry (Figure 5a). Here again, the Q-values were highly correlated with depth (Table 8). The results for the specific benthic-community area classification up to the third split are given in Table 7b and Figure 5c. The optimal split level was the second. The first class was dominant again, and the third class contained only a few cases. The resulting spatial distribution of this classification does not match the biological pattern either (Figure 5c).

The PCA results for the S_v depth-filtered data set are presented in Table 9. The first 10 principal components explained 76.4% of the total variance. The reduced matrix of the scores on these first 10 principal components was subdivided into groups by K-means clustering in order to produce acoustic classes. The optimal split level was

Table 4. Scallop-density groups defined with K-means clustering on living scallops: aerial percentages for three groups.

	Scallop relative aerial density (%)
Group 1	[0; 3.8]
Group 2	[4.2; 8.8]
Group 3	[14.2; 15]

subjectively determined for K = 4. The resulting acoustic classification did not show any correspondence with the biological pattern (Figure 6a). The map suggested a high correlation of the principal components with depth. This correlation was significant for the 10 principal components. Comparatively, when this depth relation was removed through a regression of S_v variables on depth and the residuals were submitted to PCA, 79.4% of the variance was explained by the first 10 principal components. The scores on these PCA were then separated in groups with K-means. The resulting acoustic classification matched the biological pattern better (Figure 6b). Only the partition with five identified acoustic classes is presented here because this is the one which best fitted the biological classification. The scallop-bed centre appears rather clearly (in red). The few stations with no biological predominance (blue crosses) that are included in this scallop-bed centre were not dominated by scallops but they still hold significant scallop concentrations.

The results of the three best discriminant analyses are summarized in Table 10, which shows the number of samples correctly assigned to each group (in the column assigned the same number as the row), the number of misclassifications (in other columns), and the good classification rates (in the last column). The attributes (i.e. the S_v bins variables) contributing the most to the discrimination between groups were also identified. The 0.75-m S_v bins were numbered from 1 to 40 according to their altitude, the last bins corresponding to the water column. With a mean sound speed of $1470\ \mathrm{m\,s^{-1}}$ at acquisition, each bin corresponds to 5×10^{-4} s. First, Table 10a shows the results for the training data set obtained from the similarity analysis and hierarchical clustering on the sediments and macrobenthos percentages combined. Second, Table 10b shows the results for the training data set obtained from the similarity analysis and hierarchical clustering on the macrobenthos aerial percentages. Three of the first most discriminating variables in this analysis are the same as in the previous analysis (variables 40, 35, and 11), and the others are adjacent, which points towards the same part of the seabed signatures contributing to the discrimination. These two discriminant analyses gave comparable results with a rather good success rate, respectively, 69% and 66%. To classify the whole acoustic data set, the results from Table 10a and b were generalized to the whole survey area and the resulting classifications mapped (Figure 7a and b). Both maps highlighted rather well the centre of the scallop bed, from the acoustic classes 6 and 9, respectively, as well as the general spatial pattern of biotope or macrobenthos. Finally, Table 10c shows the discriminant classification results for the scallop-density, training data set. This is the best scallop classification so far. Altogether, 75% of the members from the three subgroups were correctly classified and 91% from the scallop were the richest group. The generalization to the whole survey area is mapped in Figure 7c. This classification probably gives a good idea of the scallop bed extent as defined by high concentration spots.

The scallop-specific acoustic signature was extracted from the ground-truth training data set comprising the scallop-density classes. Box-plots of the S_v values for each bin are presented in Figure 8 to highlight the seabed echo changes from the lowest to the highest density class to identify the specific "scallop signal" and the "no-scallop signal". The amplitude of the echo largely depends on the beam-pattern of the SIMRAD ES 38B 7° transducer. The peak on each plot (bin 33) corresponds to the backscattering from the surface of the seabed. Before the peak, i.e. just before reaching the seafloor (bin 35), the scallop-signal energy was weaker than the no-scallop signal. The seabed-echo tail is not discriminating between groups until a delay of 6.5 ms (bin 27). As the tail ended its steep decrease, between the time delays for seabed-surface echoe incidences of ∼20–30°, where the most discriminant features are concentrated, the scallop signal held stronger energy content than the no-scallop signal. This situation reverses a little later, at a delay of 9 ms (bin 22), i.e. >30° incidence.

Table 5. QTC IMPACT classification statistics for the 2002 QTC VIEW IV data. Optimal split level in bold.

Split	Total score	CPI	CPI rate	Class	Members	χ^2	Score
0	1 655 404	—	—	1	5 788	286.0	1 655 404
1	134 503	1.8	—	1	4 352	18.3	79 776
				2	1 436	38.1	54 728
2	**69 722**	**10.6**	**4.7**	**1**	**3 613**	**10.3**	**37 245**
				2	**718**	**9.3**	**6 713**
				3	**1 457**	**17.7**	**25 764**
3	47 235	39.2	2.7	1	3 079	8.4	25 866
				2	341	3.8	1 282
				3	858	12.8	10 954
				4	1 510	6.0	9 132
4	30 465	76.2	0.9	1	2 532	6.7	16 856
				2	313	3.4	1 071
				3	514	2.7	1 368
				4	697	6.6	4 585
				5	1 732	3.8	6 586

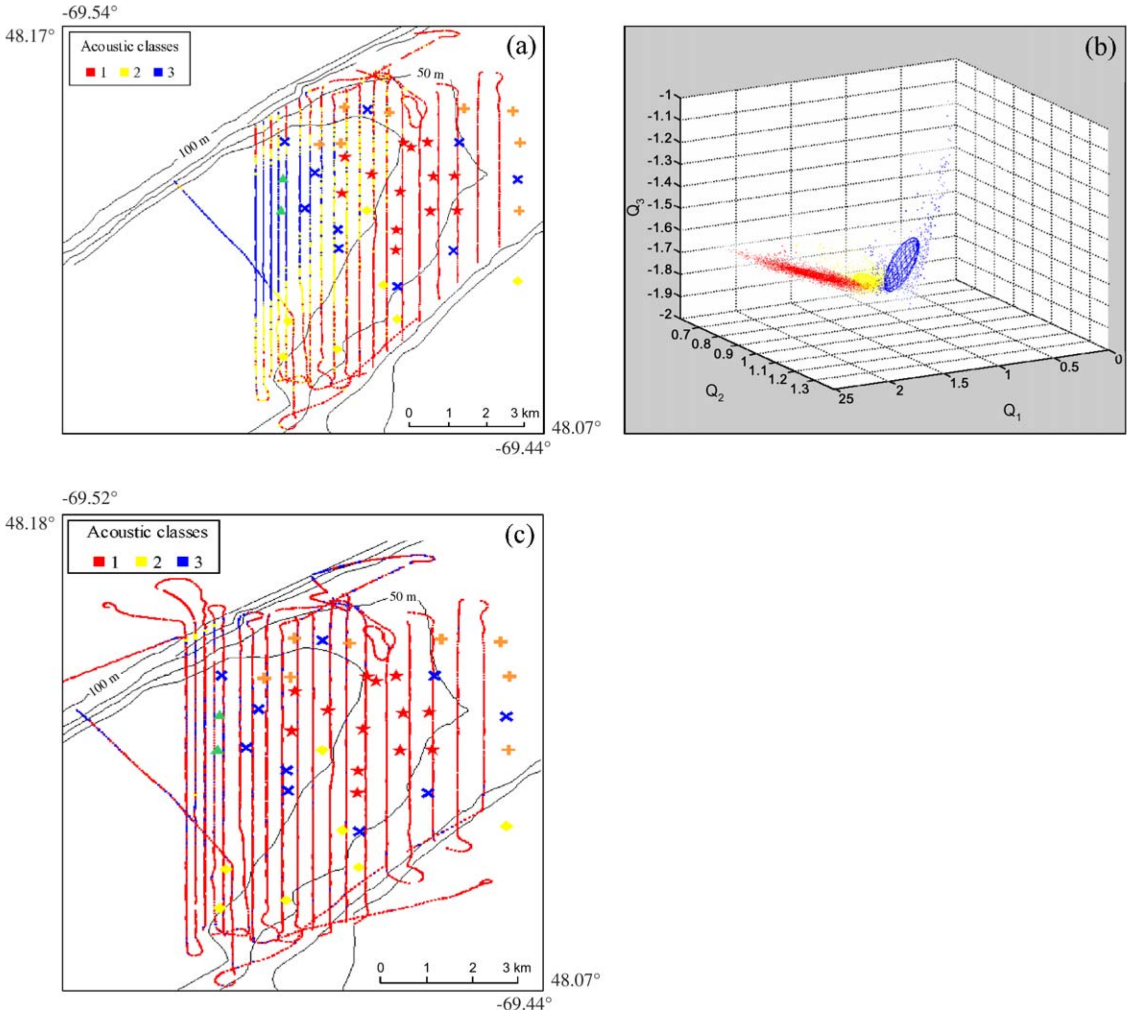

Figure 4. QTC VIEW IV classifications. Maps of the three QTC IMPACT acoustic classes with the biological classification of Figure 3a superimposed. (a) Unsupervised classification with (b) three-dimensional scatter plot of the associated Q_1, Q_2, and Q_3 values, classified into three clusters. (c) Supervised classification.

Discussion

The ground-truth analysis of photographs showed that the inter-site variability of the sediment types was too low to be discriminated acoustically contrary to the benthic-taxa distribution. To a certain extent, however, this substratum pattern determines the benthic-communities distribution as the sediment types (or substrata) are one of the main environmental descriptors that defines benthic habitats and, consequently, influences the composition of the communities. As the species encountered in our study live in preferred sediment types, we assumed that the sediment distribution is implicitly involved in the acoustic discrimination of the benthic communities, but is generally not controlling the observed patterns. Some ancillary factors are also used to characterize a habitat such as water depth, seafloor geomorphology, habitat complexity, current speed, food supply, temperature range, predation pressure, and disturbance by fishing activities (Kostylev *et al.*, 2001, 2003). These environmental factors certainly influence the pattern of scallop distribution and should be taken into account in the interpretation of acoustic classifications. On Ile Rouge bank, scallops were found on areas with strong

Table 6. Pearson correlation coefficients between depth and the three Q-values from QTC VIEW IV. The correlations are all significant ($p < 0.05$).

	Unsupervised classification	Supervised classification
Q_1	−0.77	−0.75
Q_2	0.46	0.24
Q_3	−0.08	−0.28

Table 7. QTC IMPACT classification statistics for the 2003 QTC VIEW V data. Optimal split level in bold.

Split	Total Score	CPI	CPI rate	Class	Members	χ^2	Score
(a) Whole survey area							
0	535 645	—	—	1	13 122	40.8	535 645
1	122 651	1.8	—	1	11 137	10.5	117 048
				2	1 985	2.8	5 603
2	**29 786**	**5.6**	**2.3**	**1**	6 316	1.5	**9 248**
				2	4 861	3.2	**15 681**
				3	1 945	2.5	**4 856**
3	34 975	14.4	0.8	1	6 285	2.2	14 048
				2	4 871	3.1	15 089
				3	543	2.4	1 278
				4	1 423	3.2	4 560
(b) Specific benthic-community sites							
0	85 110	—	—	1	12 054	7.1	85 110
1	35 091	0.7	—	1	8 798	1.2	10 932
				2	3 256	7.4	24 159
2	**25 503**	**3.5**	**3.7**	**1**	9 065	1.2	**10 883**
				2	2 820	5.0	**14 226**
				3	169	2.3	**394**
3	28 825	5.5	0.6	1	8 576	1.0	8 640
				2	1 598	4.3	6 942
				3	193	2.9	569
				4	1 687	7.5	12 673

currents and gravel substratum two factors that are essential for larval dispersion and larval settlement (Bousfield, 1960). The region is also well known as an upwelling region that is very productive (Therriault and Levasseur, 1985) and where concentration processes are very active along topographic features (e.g. Cotté and Simard, in press). This could provide a large source of food for the scallops, and the hydrodynamic regime observed in this area (Simard *et al.*, 2002) could favour the retention of this scallop population in this specific area. The hydrodynamic regime of this region is known to aggregate and retain large biomasses of swimming species such as krill (Lavoie *et al.*, 2000).

The QTC AGDS classifications failed to highlight the benthos distribution. Actually, both QTC-unsupervised classifications were significantly related to bottom depth. But previously, as it was commonly observed that, in general, benthic communities and sediment structure changed with depth. In our case, however, no correlations between sediments or spatial patterns of communities and depth were found in the ground-truth data. Von Szalay and McConnaughey (2002) have shown that even modest bottom slopes could greatly affect the QTC performance. We removed all the data located on steep and moderate slopes from our initial QTC VIEW IV and QTC VIEW V data sets, but the resulting new QTC classifications were still dependent on depth. Similar depth-dependence with QTC AGDS classifications, have been encountered in previous studies. Anderson *et al.* (2002) demonstrated a high "depth-dependence" in the Q-values for some of their classifications, whereas Foster-Smith *et al.* (2004) encountered, in shallow waters, a marked depth trend of Q-values (especially Q_1). This depth-dependence was also mentioned by Greenstreet *et al.* (1997) for the RoxAnn system, the performance of which might be affected by water depth, and by Bax *et al.* (1999), who reported the depth-dependence of the RoxAnn habitat indices E1 and E2. Reporting the case of a study whose first components from the QTC-extracted features were highly correlated with depth, Legendre (2003) interpreted this correlation with depth as being partly related to the QTC IMPACT processing that "only uses three axes in determining its partition [which] makes it especially sensitive to depth". To deal with this specific issue, Legendre (2003) recommended using all the principal components required to explain 95% or more of the variance in the data set. However, Preston (2003) asserted that the QTC IMPACT resampling process to standardize echo duration removes the dependence on depth. Though this may help to align echoes with angles of incidence, the problem of the footprint increasing with depth still remains when the transducer is fixed on the vessel for any acoustic systems, as noted by Morrison *et al.* (2001) and von Szalay and McConnaughey (2002). The QTC process averages the backscatter signal of five consecutive pings to generate a single-record to reduce ping-to-ping variability that may cloak sediment contribution to the echo (Preston *et al.*, 2004). For the SIMRAD EK60 of the 2002 survey, given the vessel speed and the ping rate, this averaged QTC footprint (one quadrant of the 7° split-beam transducer) was equivalent to ~7.3 m^2 in 50-m depths with no overlapping between two individual pings. The equivalent for the SUZUKI ES-2025 echosounder of the 2003 survey was ~1157 m^2 in 50-m depths, i.e. 157 times more than in the 2002 survey, and with a very important overlapping percentage of ~95% between two individual pings. Legendre (2003) stressed that a correlation with depth is "not avoidable because the size of the sonar footprint is a function of depth". The relationship between our QTC classifications and depth might be related to the increasing size of the averaged footprint with depth as the acoustic acquisition of this study was made in a relatively wide range of depths (48−70 m for the depth-filtered data). Large-footprint sizes also hinder the resolution of small-scale patterns in benthos and bottom habitat, thus limiting the ability of the equipment to accurately discriminate, as mentioned by Kenny *et al.* (2003). Moreover, the supervised classification within the QTC VIEW IV data processing was not conclusive either, as the procedure failed to recognize the pre-determined subset of known seabed types in the rest of the survey area. The above dependence on depth of the QTC data is not likely to be one of the reasons behind this misclassification because even data in the same water depth

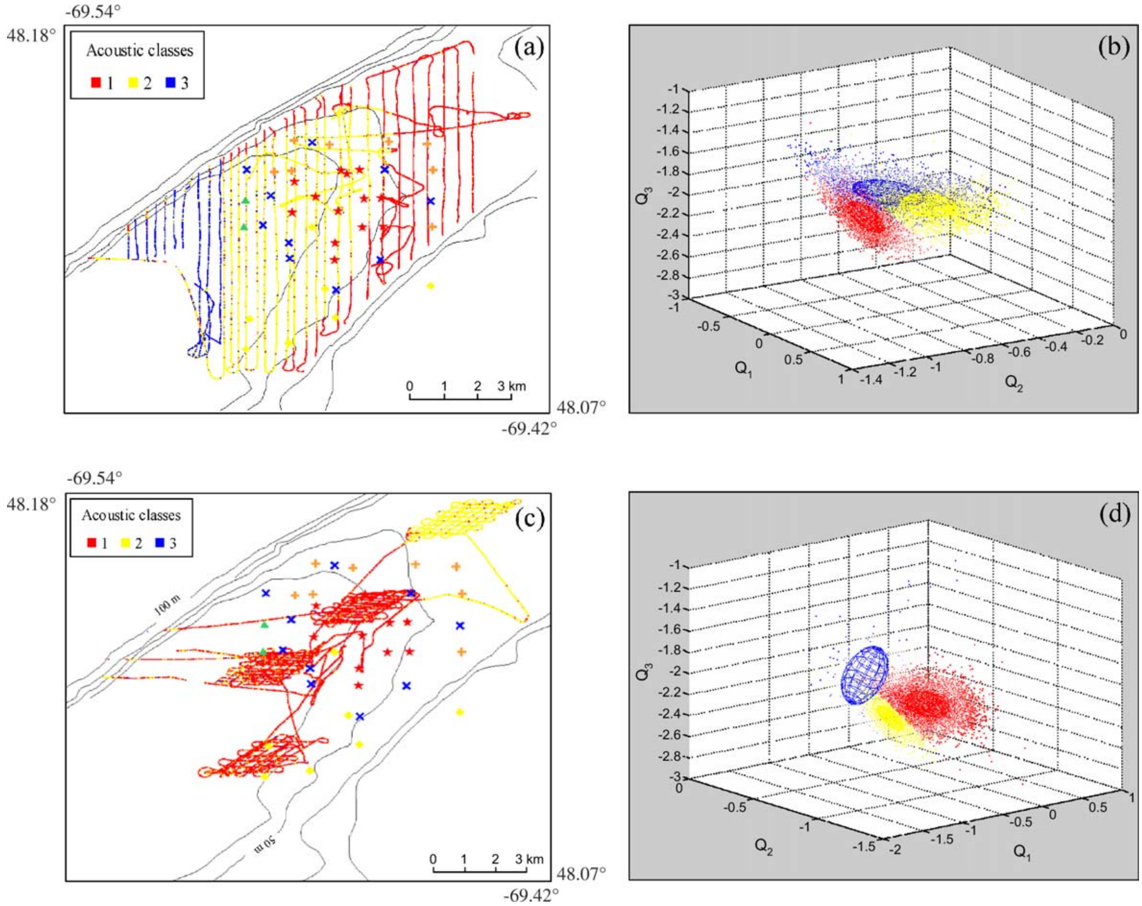

Figure 5. QTC VIEW V unsupervised classification. Map of the three QTC IMPACT acoustic classes with the biological classification of Figure 3a superimposed. (a) Whole survey area with (b) three-dimensional scatter plot of the associated Q_1, Q_2, and Q_3 values classified into three clusters. (c) Specific benthic-communities sites with (d) three-dimensional scatter plot of the associated Q_1, Q_2, and Q_3 values classified into three clusters.

were incorrectly classified. Other influences, such as the use of too small a fraction of total variance with only three principal components, or ineffective extraction of proper discriminant features, might be involved.

The bottom S_v data processing through PCA and K-means clustering first showed a similar dependence of the classification with depth in spite of the accurate TVG of the SIMRAD EK60 echosounder corrected for actual sound speed and absorption profiles, which properly compensated for spreading and absorption losses. Yet, a moving average was also performed on five pings to stabilize the signal (Lurton and Pouliquen, 1992; Sternlicht and de Moustiers, 2003). This finally provided an average footprint per ping of $\sim 29\ m^2$ at 50 m. The comments made earlier on depth-dependence and footprint-size effects also apply here. Removing the depth trend by a regression was effective for the PCA + K-means clustering, and the resulting unsupervised acoustic classification matched rather well the biological classification. This partitioning of the acoustic variability was done with the first 10 principal components, which represented 79.4% of the variability in the data set. This is less than the 95% recommended by Legendre (2003), but all the significant components (eigenvalue > 1) were included. The statistical removal of the masking trend with depth through a regression produced a better classification, but the acoustic interpretation of this filter and its effect on

Table 8. Pearson correlation coefficients between depth and the three Q-values from QTC VIEW V. The correlations are all significant ($p < 0.05$).

	Whole survey area	Specific benthic-community sites
Q_1	−0.26	0.04
Q_2	0.62	−0.18
Q_3	0.27	0.43

Table 9. Bottom S_v PCA results. A: the percentage of total variance explained by the first 10 principal components (PC) and their correlation with depth (all significant, $p < 0.05$), and B: the percentage of total variance explained by the first 10 principal components of the residuals after removal of the depth trend of the S_v data by regression.

	A		B
PC	% Variance	Pearson r with depth	% Variance
1	29.60	0.76	31.21
2	10.79	−0.06	12.41
3	8.21	0.52	9.08
4	6.27	0.39	7.05
5	5.08	0.07	4.92
6	4.59	0.22	4.92
7	3.40	0.14	3.34
8	3.23	0.09	2.08
9	2.70	0.11	2.41
10	2.50	−0.28	1.99
Total	76.40	—	79.40

distorting the seabed-discriminant information are unknown. The unsupervised approach is effective in partitioning the total variability in a study area, but it is not turned to highlight particular habitat or biotope, as our study hoped to do.

The discriminant analyses performed on the bottom S_v data allowed the percentage of classification success and the mean S_v signal of each group to be determined. They also permitted the identification of the variables responsible for the discrimination between the groups in order to help in understanding the relevant acoustic-scattering classification process. They provided the most interesting acoustic classifications. Indeed, the accuracy of this method strongly relies on the presence of discriminant features in the training data set. Several training data sets were tested without success. In descending order, the best correspondence between the resulting discriminant analysis, acoustic classification, and the associated biological classification was found for the three scallop-density classes, then for the six sediment-community classes, and finally for the nine community classes. The number of classes may influence the classification by increasing the overlap between the class signatures. Increasing the range of habitats or biotopes will surely enlarge the possibility of overlapping signatures and consequently reduce the discrimination. The classification accuracy may be improved by grouping habitats or biotopes in broader categories, but with the risk of missing small-scale but significant units (Foster-Smith and Sotheran, 2003). Nevertheless, the information extracted by the discriminant analysis for the three scallop-density classes, with a percentage of correct classification of 91% for the areas that hold the greatest scallop densities, is significant

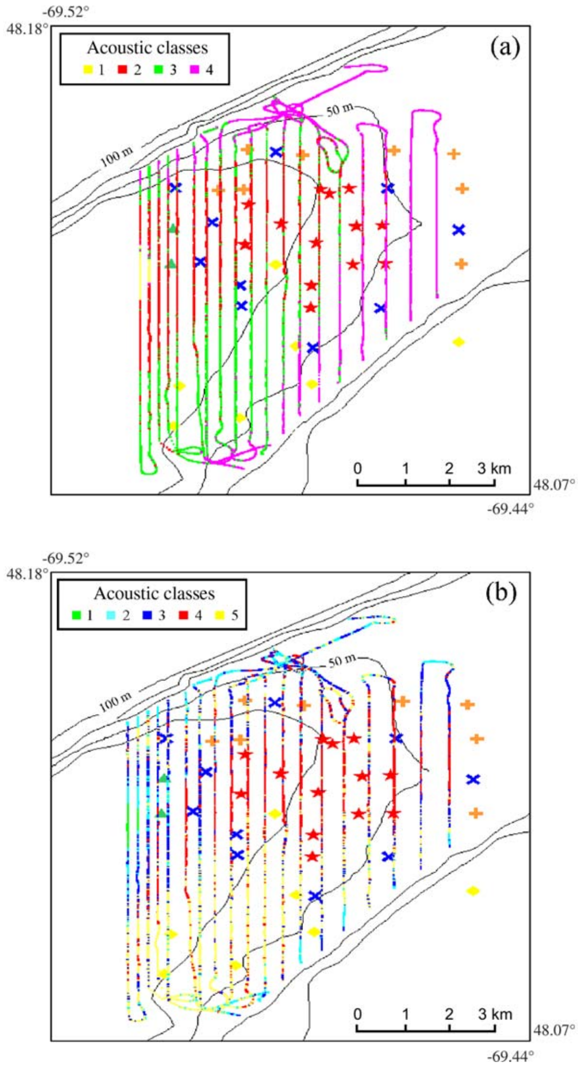

Figure 6. Acoustic classification resulting from the EK60 seabed S_v processing superimposed on the biological classification of the Figure 3a. (a) PCA + K-means clustering: example with four acoustic classes. (b) Regression on depth of the EK60 seabed S_v + PCA on the residuals + K-means clustering on the first 10 principal components: five identified classes retained.

for the objectives of this study. The extent of the scallop bed was thus well defined, revealing patchiness in the distribution with some very high-density spots, essentially in the centre of the bank and extending to the south and west. Actually, commercial-size scallops were very abundant in the surveyed area with a mean dredge density of 0.75 and m^{-2}, higher values in the centre of the bed, whereas in the other parts of the St. Lawrence, the highest density was 0.4 m^{-2} (MPO, 2000). This species is characteristic of cold-water regions (Eckman, 1953). It lives in areas with sediments characterized by a mixture of gravel and <10%

Table 10. Discriminant analysis from EK60 S_v seabed data. Cases in rows classified into columns. The total percentage of correct classification corresponds to the sum of the diagonal of the table over the "sum of the columns" totals.

(a) Classification matrix for the training data set corresponding to the six macrofauna and sediments aerial percentage assemblages

Group	1	2	3	4	5	6	% Correct
1	52	0	2	0	1	0	95
2	0	275	3	0	7	0	96
3	8	59	422	93	187	82	50
4	0	0	10	119	5	21	77
5	7	2	63	9	326	30	75
6	4	0	24	14	28	252	78
Total	71	336	524	235	554	385	69

(b) Classification matrix for the training data set corresponding to the nine dominant taxa groups

Group	1	2	3	4	5	6	7	8	9	% Correct
1	89	0	0	1	1	0	2	0	0	96
2	0	180	5	2	3	16	4	4	0	84
3	0	0	63	0	0	1	0	0	0	98
4	1	4	1	117	0	7	2	12	8	77
5	0	1	0	0	58	6	1	3	1	83
6	2	33	56	22	43	140	2	7	53	39
7	0	3	0	0	0	1	90	10	0	87
8	49	16	1	19	31	13	9	259	38	52
9	8	0	3	54	22	25	1	50	392	71
Total	149	237	129	215	158	209	171	345	492	66

(c) Classification matrix for the training data set corresponding to the three scallop-density classes

Group	1	2	3	% Correct
1	1 083	276	62	76
2	96	421	75	71
3	1	7	84	91
Total	1 180	704	221	75

sand (Fader *et al.*, 1982). Gilkinson and Gagnon (1991) observed a high density of *C. islandica* associated with coarse sediment (dense gravel–cobble). It is generally found attached by byssal threads to coarse substrata in areas with strong currents (Vahl and Clausen, 1980). However, the part of the discriminant information due to the presence of scallop and that attributable to the associated sediment composition remain to be determined. Verifications by additional ground truth at the discontinuities between classes would help validate the generalized classification for the whole survey area. Intense *a priori* and *a posteriori* ground-truthing is essential to verify the effectiveness and accuracy of all seabed acoustic-classification methods.

We can speculate on the causes of the specific scallop acoustic signature and the differences with the no-scallop acoustic signature and infer some characteristics of the scallop biotopes. First, there are only slight differences between the acoustic signatures of the seabed classes in this area, probably because the sediment across the whole area is fairly similar and relatively hard and reflective. The main particularity of the scallop signal vs. the no-scallop signal occurs just before the acoustic pulse encounters the seafloor. In areas with scallops, the slope effect on the signal may be less important than in areas without scallop, thus suggesting a flatter bottom for the scallop-rich areas, as the echo starts to return earlier and lasts longer over sloping bottoms. The roughness of the seabed at a small scale might be smaller in high-density scallop areas, or perhaps the interaction between the slope and the roughness of the seabed differs there. The second particularity occurred in the echo tail when the scallop signal appeared stronger than the no-scallop signal. This may be attributable to stronger interface backscattering detected from the first side-lobes of the SIMRAD ES 38B transducer, suggesting a higher roughness in scallop areas detected at incident angles between 20° and 30°, as the sampling surface becomes larger. Alternatively, this may be linked to the seabed volume backscattering in the presence of scallops that significantly differs from the volume backscattering in coarse sediments (e.g. sand) alone (cf. Sternlicht and de Moustiers, 2003). Finally, the third and last difference identified between the two signals occurred beyond 30° incidences, where higher backscatter was detected for areas with few or no scallops. One reason for this result could be that the sampling surface becomes larger, thus considering roughness variability at broader scales, which can then include boulder occurrence. The observation from ground-truth samples that boulders were more common outside the high-density scallop area is in agreement with this hypothesis. Once again, the potential interaction with volume backscattering at angles $>30°$ cannot be overlooked, and may also contribute to the signal patterns.

In the light of these diverse results, we can draw some conclusions about the relative efficiency of each acoustic approach considered in our study. Both QTC systems (Series IV and V) failed to provide conclusive acoustic classifications compared with our prior knowledge of the benthic characteristics of the surveyed area, and this was the case for both sediment pattern, and for the community pattern. QTC results held a strong depth-dependence, which could not easily be filtered out because of the awkward access to the QTC 166 features. However, both QTC systems used in this study have been shown to be effective in mapping other marine benthic habitats (Collins and Galloway, 1998; Hamilton *et al.*, 1999; Preston *et al.*, 1999; Smith *et al.*, 2001; Ellingsen *et al.*, 2002; Freitas *et al.*, 2003b). Furthermore, as suggested by Hamilton *et al.*

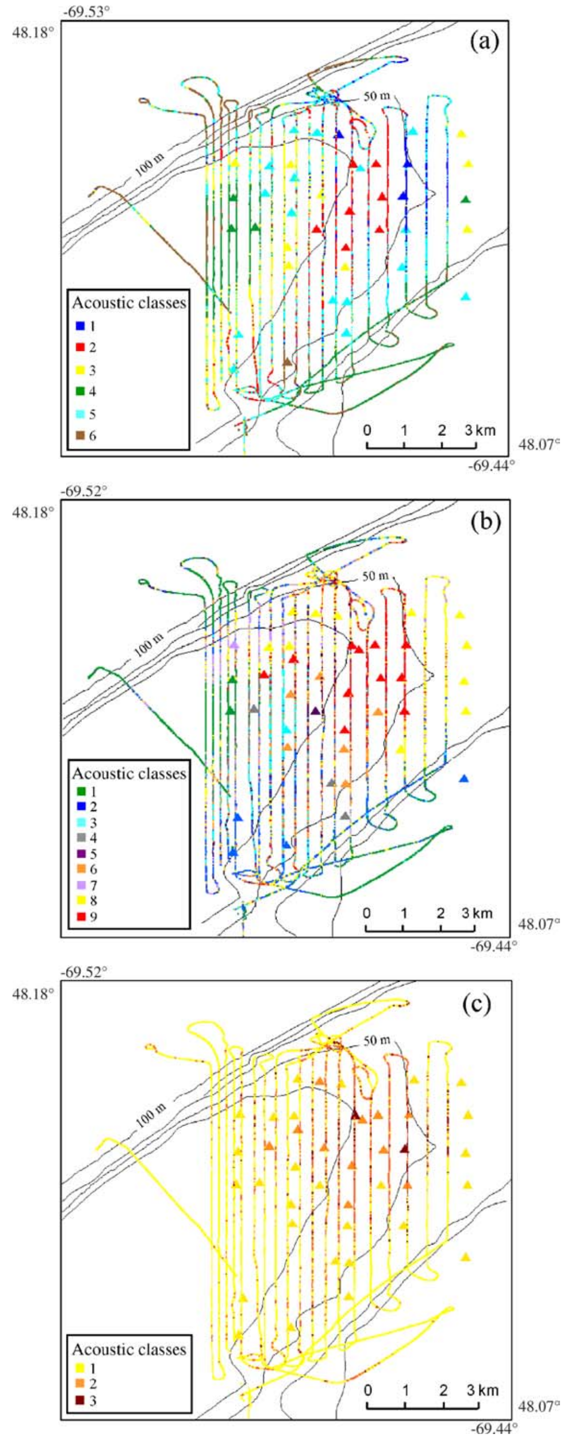

Figure 7. Generalization to the whole survey area of the EK60 seabed S_v discriminant-analysis solutions based on the training data sets defined with a similarity analysis and hierarchical clustering on (a) both macrobenthos and sediments aerial percentages combination; (b) macrobenthos aerial percentages only; (c) scallop-density classes sorted out by K-means clustering. (The corresponding training data set is superimposed on each part figure a, b, and c.)

(1999), who compared the performance of RoxAnn and QTC VIEW and found not only useful results but also misclassifications with the two systems, AGDSs remain empirical systems that may be efficient for some bottoms and inefficient for others. As an alternative to AGDS, the bottom S_v processing provided several different interesting acoustic classifications within the limits of the methods and equipment as mentioned above. The discriminant-analysis approach is attractive because it can be adapted to the specific objective of the classification looked for, such as sediments, communities, biotopes, or even a particular species, by organizing *a posteriori* the training data set accordingly. This is indeed not possible with the unsupervised approaches that are used to partition the total acoustic variability observed in a given area into different groups, or with the *a priori*-defined training data sets. Besides, the discriminant-analysis solution provides the level of uncertainty of the classification, which is not available for unsupervised approaches of the bottom S_v processing. It also identifies the variables that are largely contributing to the discrimination, which is helpful for understanding the related acoustic process. The use of simple acoustic signatures expressed in standard units, such as the S_v used here, is also essential for comparing results with other areas and for generalizing solutions.

In conclusion, the acoustic equipments and processing used in the present study can be of certain efficiency in the remote sensing of the nature of a given seabed. However, as extrapolation to non-surveyed areas is required because the coverage is not 100%, classification uncertainty is unavoidable. AGDS might be expected to detect differences between a limited number of very different biotopes that are well demarcated in space. However, large numbers of subtly different biotopes that merge into each other will be poorly discriminated by such systems (Brown *et al.*, 2001). Given the fairly uniform sediments distribution over the whole study site, the limited resolution of the systems used in this study combined with the partial coverage of the study area might lead to underestimating the small-scale heterogeneity of the benthic habitats. To compensate for the shortcomings of the method using high-resolution acoustics, gears such as sidescan sonar (Brown *et al.*, 2002) or multibeam systems (Kostylev *et al.*, 2003) become more appropriate when looking for a complete coverage of the site. Those systems provide a more precise mapping of the seafloor topography, which could contribute to better estimates of scallop distribution and abundance, as notably shown by Kostylev *et al.* (2003) with a multibeam. The use of such a system is envisaged for future study of this area. However, the distance between the instrument and the seafloor affects spatial resolution for all systems. A constant-altitude platform is required to obtain a constant-sampling resolution. The distinction between the effect of the seabed slopes and the seafloor composition on the strength of the backscatter at different incident angles is another difficulty that is common to all gears.

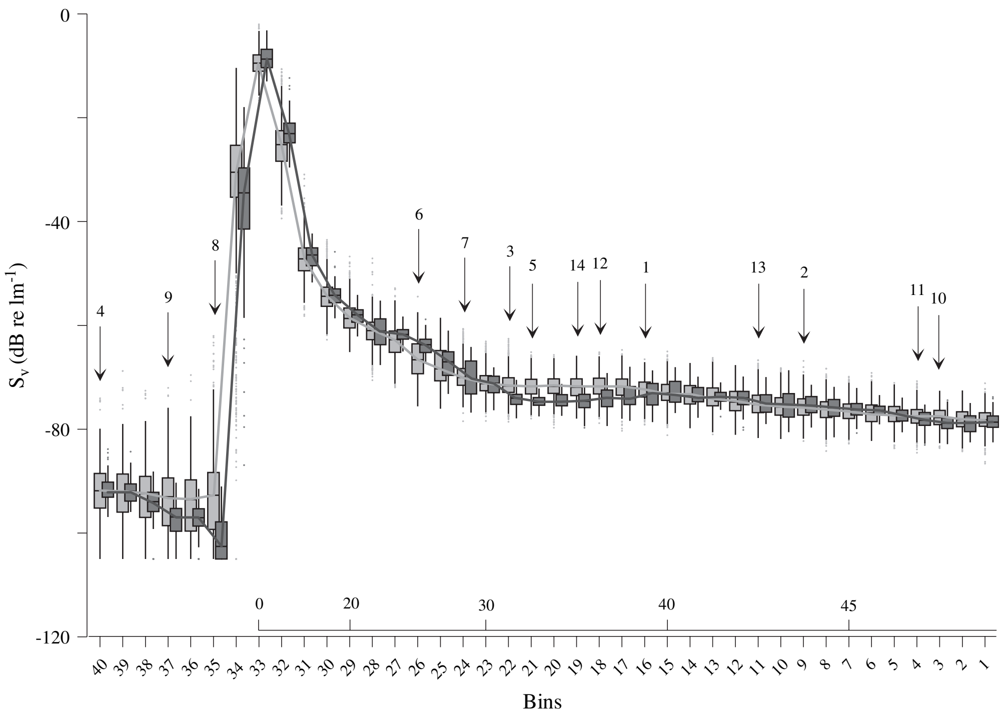

Figure 8. Box-plot of the EK60 bottom S_v signature associated with the densest scallop-density class (in dark grey) compared with areas without significant scallop density (in light grey). Points correspond to outliers. Arrows point at the most discriminant variables (as identified by the discriminant analysis) in decreasing order. The superposed x axis indicates estimated angle of incidence (in degrees). The 0° is given after the complete backscattering of the 1 ms pulse (i.e. 1.5 m).

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