Acoustic mapping of benthic sediments

Mikkel R. H. Petersen

Cand. Scient. thesis

Universitetet i Oslo
Biologisk Institutt
Avdeling for marinbiologi og limnologi
Våren 2007

FORORD

Først vil jeg takke min veileder John Gray for å ha gitt meg, som orientalerne kaller det, en interessant oppgave. Frode Olsgaard og Kari Ellingsen som har vist meg hvordan det meste skulle gjøres, gutta på Braarud for å gjøre det de kan best (alltid en fornøyelse), Jane Indrehus, uten deg hadde jeg aldri blitt ferdig med artsbestemmelsen. Rita og Sidsel for å bistå meg med alt av materiell og for å ha holdt ut med min til tider manglende ordenssans. Hilde, for å ha vært så snill og venta med hovedfaget sitt så vi kunne bli ferdige samtidig. Alle på DNV, for selv om jeg rømte fra hovedfaget og over til dere har dere lært meg mye som jeg har tatt med videre inn i oppgaven. Foreldrene mine for støtte og mas. Og selfølgelig Karl Inne Ugland som på slutten plukket meg opp som en liten oljedrukna sjøfugl og børsta meg ren. Men mest av alt vil jeg takke min farmor for alle turene til akvariet og Århus Naturhistoriske museum, en marinbiologs fødsel.

CONTENTS

SUMMARY

There is an increasing demand for knowledge of habitats, communities and distribution patterns of the seafloor for impact assessment, conservation and ecological studies. The European Union Water Framework directive will require a lot of effort to be met. In this study acoustic mapping of benthic communities and the factors that may influence the acoustic data has been examined, as well as the usage of sediment profile images (SPI). The survey area is located outside the town of Drøbak in the Oslofjord. An acoustic map of the area was made and four different acoustic classes were detected. Sampling of sediment and fauna from three of the four classes was made. SPI pictures were also taken from three of the classes. Sediment composition seemed to have no apparent affect on the acoustic data, the high concentration of organic carbon suggests that it might be the infauna that is the biggest contributor to the differences in the acoustic data. The faunal composition had a high similarity between the stations, but there was spread that followed the acoustic classes to some degree. Some of the shortcomings of the acoustic method have also been noted, and steps to compensate for this in the future are mentioned. The SPI pictures were in accordance with pictures made by others from the same area. Both SPI and acoustic mapping are cost effective methods for remote sensing of the seabed, but they will not replace traditional ground truthing, merely compensate and improve it.

INTRODUCTION

There is an increased need for developing techniques for mapping marine habitats. The Mareano project (www.mareano.no), led by the Norwegian Institute of Marine Research (IMR) and the Norwegian Geological Survey (NGU), maps bathymetry, geology, biology and contaminants in Norwegian waters. The European Water Framework Directive (WFD) establishes a framework for the protection and improvement of all European surface and ground waters, including transitional and coastal waters (Borja *et al*., 2007). The WFD member states are required to monitor and asses the ecological status of water bodies; traditional methods will not be sufficient, but need to be supported by newer techniques that can cover larger areas.

Technologies that have emerged for habitat mapping are acoustic seabed classification, sidescan sonar, sediment profiling imagery (SPI camera), underwater video, remotely operated vehicles (ROV), GIS-modeling techniques and even satellites. These are not meant to replace existing "ground truthing" techniques; they will complement them and make it possible to asses a much larger area.

Sonar systems were first primarily used by hydrographers and geophysicists for large-scale habitat mapping. However, increasing technological development and availability have made them usable for a variety of applications. Now it is possible to obtain multivariate acoustic data responding differentially to the nature of different seabed types like rock, sediment types, and fixed life forms like algae, sea grass and invertebrate beds (Bale & Kenny, 2005).

The first commercial seabed classification system was the *RoxAnn* single-beam hydroacoustic system, developed in the 1980s (Solan *et al.,* 2003). Other single-beam Acoustic Ground Discriminating Systems (AGDS) include Echo*Plus* and QTC VIEW. Multi-Beam Echo Sounders (MBES) and sidescan sonar are also used in seabed classification. Sidescan sonar provides wide-area images of the seabed, and with its wide beam width (compared to the other systems) it is more useful for object detection, particularly when the objects are <1m in diameter (Bale & Kenny, 2005). Single-beam and multi-beam systems generate quantitative bathymetric data that are amenable to classification and image processing.

To provide better understanding, these types of habitat mapping can be combined with technologies such as acoustic mapping and satellite photos (Riegl & Purkis, 2005; Riegl *et al*., 2007). Combinations of various AGDS like QTC VIEW and Echo*Plus* was performed by Riegl *et al*. (2005 & 2007) to map distribution and seasonal change of macroalgae. Supplying acoustic mapping with underwater photography and/or video for better classification of acoustic classes (Kloser et al., 2001). Hewitt *et al*. (2004) combined sidescansonar, single-beam sonar and video for a bottom up approach for integrating acoustic data with quantitative assessments of subtidal soft-sediment epibenthic communities. Sidescan sonar and QTC VIEW was used by Wienberg and Bartholma (2004) to monitor dredging and dredge spoil disposal. Mapping the seafloor and classifying it into different substrates allows us to relate patterns in these substrates to fish distribution, abundance, mortality and production of the benthos (Rooper & Zimmerman, 2007).

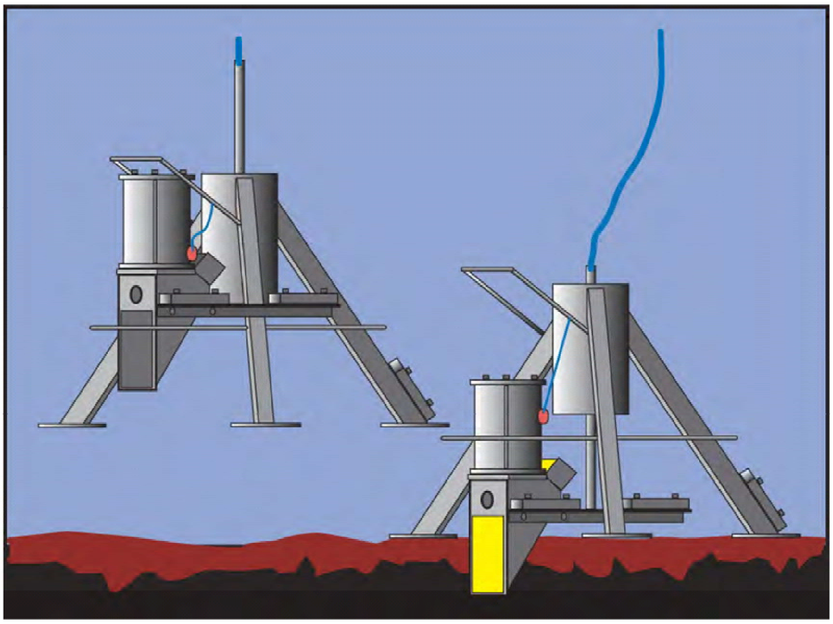


Figure 1 *Illustration of a SPI camera, showing how the prism is lowered into the sediment before pictures are taken. Illustration is from Nillsson and Rosenberg (2006).*

SPI

Sediment Profile Imaging (SPI) with a shipboard-deployed sediment profile camera was introduced by Rhoads and Cande (1971). This technique utilizes a wedge-shaped prism (figure 1) that penetrates into the sediment to obtain undisturbed images of the upper 20cm of the sediment column. Gray (1974) and Rhoads (1974) undertook highly influential studies of organism-sediment relationships that emphasized the mechanisms of biogenic activity. This was followed by documentations of temporal changes in faunal composition following physical disturbance (Rhoads *et al*., 1978), and changes in faunal composition over a spatial distance from a point source of organic pollution (Pearson & Rosenberg, 1978). An "interesting parallel" (Rhoads *et al*., 1978) between disturbance- and pollution-induced changes in faunal structure was noted from these studies, and it provided the appropriate ecological context for the interpretation of SPI images (Rhoads & Germano, 1982). Using post hoc computer-aided image analysis on the sediment images increased analytical efficiency and revolutionized the image interpretation beyond the qualitative judgment of the operator (Rhoads & Germano, 1986; Valente *et al*., 1992). By combining these two techniques, salient undisturbed structural features of the sediment profile could be remotely quantified (Diaz & Schaffner, 1988) and interpreted within a conceptual framework, as dictated by ecological models and opinions of the day (Rhoads & Germano, 1982, 1986; Valente *et al*., 1992; Nilsson & Rosenberg, 1997) and considering specific cases or regions (Rumohr *et al*., 1996).

In this study an easier method will be attempted to make SPI pictures: round multicorer tubes, that have been made into half circle tubes, these will have a flat side which can be taken pictures of on land.

Objectives of this study:

1) Make a detailed acoustic map of the sediments in the area south of Kaholmene inside the submarine wall outside Drøbak with the QTC VIEW system
2) See what causes the different sediment types. Several possibilities include:
   a) Sediment composition: does the grain size and/or the amount of carbon content alter the acoustic properties?
   b) Faunal composition: does the presence of different bioturbators alter the acoustic properties of the sediments?
3) Will our applied method for SPI pictures work, and if, how do they correspond with the acoustic map?

METHODS

Location

The target area is a secluded spot in the inner Oslofjord; it lies south of Kaholmene and just inside the Drøbak Sill (figure 2). The maximum depth is 75 meters; the area is surrounded by islands, skerries and a submarine wall that lies at 1 meters depth. This creates quite strong currents (1/2 to 1 knots) in the upper layers of the water column. The area may be slightly polluted due to the proximity to the city of Oslo; contamination stems from eutrophication and organic enrichment as well as elevated levels of heavy metals (Olsgaard, 1999).

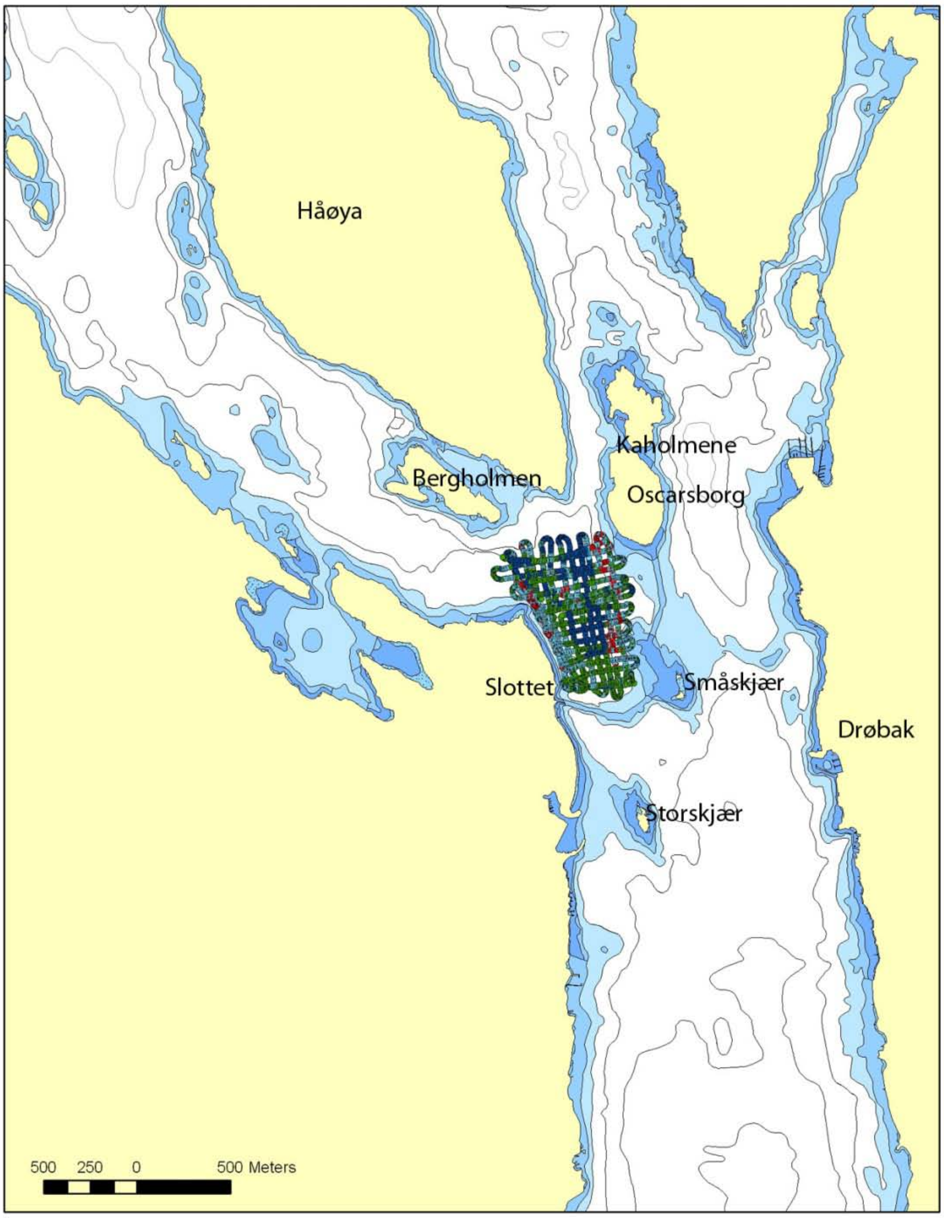


Figure 2 *Location of the survey area in the inner Oslofjord. The survey transect is marked with the different acoustic classes shown in figure 8.*

Field sampling

Samples were collected from the 17th to the 26th of March 2003 and the 13th of January 2004 from the University of Oslo research vessel F/F *Trygve Braarud*. The acoustic mapping was done during the first three days. Fauna and sediment were sampled the following week. Subsequent sampling of sediment and sediment profile images were done in 2004.

Acoustic mapping (QTC)

Data for two acoustic maps was collected. For the acoustic mapping, the 120 kHz echo sounder of the vessel was used. The 50 kHz echo sounder on the vessel was switched off for some time due to interfering noise. The transducer was mounted on an over-the-side strut on the vessel. It was connected to the differential Global Positioning System (dGPS) on the vessel and position was logged continuously along with acoustic data and depth. Settings for the echo sounder were the same for the entire survey; alteration of parameters would have caused changes to the nature of the signal and affected the classification (Ellingsen *et al*., 2002). The reference depth in the QTC software was set to 50 m, compensating for changes in the acoustic signal caused by variation in water depth (Quester Tangent Corporation, 1997). The sea was calm during both surveys; the vessel speed was 3-4 knots due to the strut. Vessel speed between 3 and 12 knots has no significant effect on classification performance (von Szalay *et al*., 2000). Figure 2 shows the survey tracks from both surveys; there were approximately 50m between each survey line. A reference depth of 50m for the QTC software (CAPS) was chosen as the expected average depth of the survey area. This compensated for changes in the acoustic signal due to variations in water depth (Quester Tangent Corporation, 1997). The QTC VIEW can be used in a supervised and an unsupervised mode. The supervised classification requires the collection of a calibration data set from predetermined sites with known seabed features (Collins & Lacroix, 1997). Seabeds along the vessel track will then systematically be compared to the acoustic-calibration data set. This depends on how well the calibration sites are selected. Unsupervised classification uses post-processing analysis of the acoustic data.

The QTC VIEW data acquisition is illustrated in figure 3. When encountering the seafloor, the echo sounder pulse is reflected and scattered at the seabed-water interface, and then by the material of the immediate sub-bottom. The transducer acquires the returned pulse, and transfers it to QTC VIEW (the data acquisition software), where it is merged with the position data and transmitted to the computer for display and post-processing. Five consecutive echo returns create one averaged echo that is automatically computed and a single output record is generated. This reduces the processing load and stabilizes the signals (Lurton & Pouliquen,, 1992; Prager *et al*., 1995). During the survey the echo trace was checked periodically to ensure the signal was clean and noise-free. QTC VIEW analyses the averaged echoes with a series of algorithms, for energy and shape characteristics in frequency and time

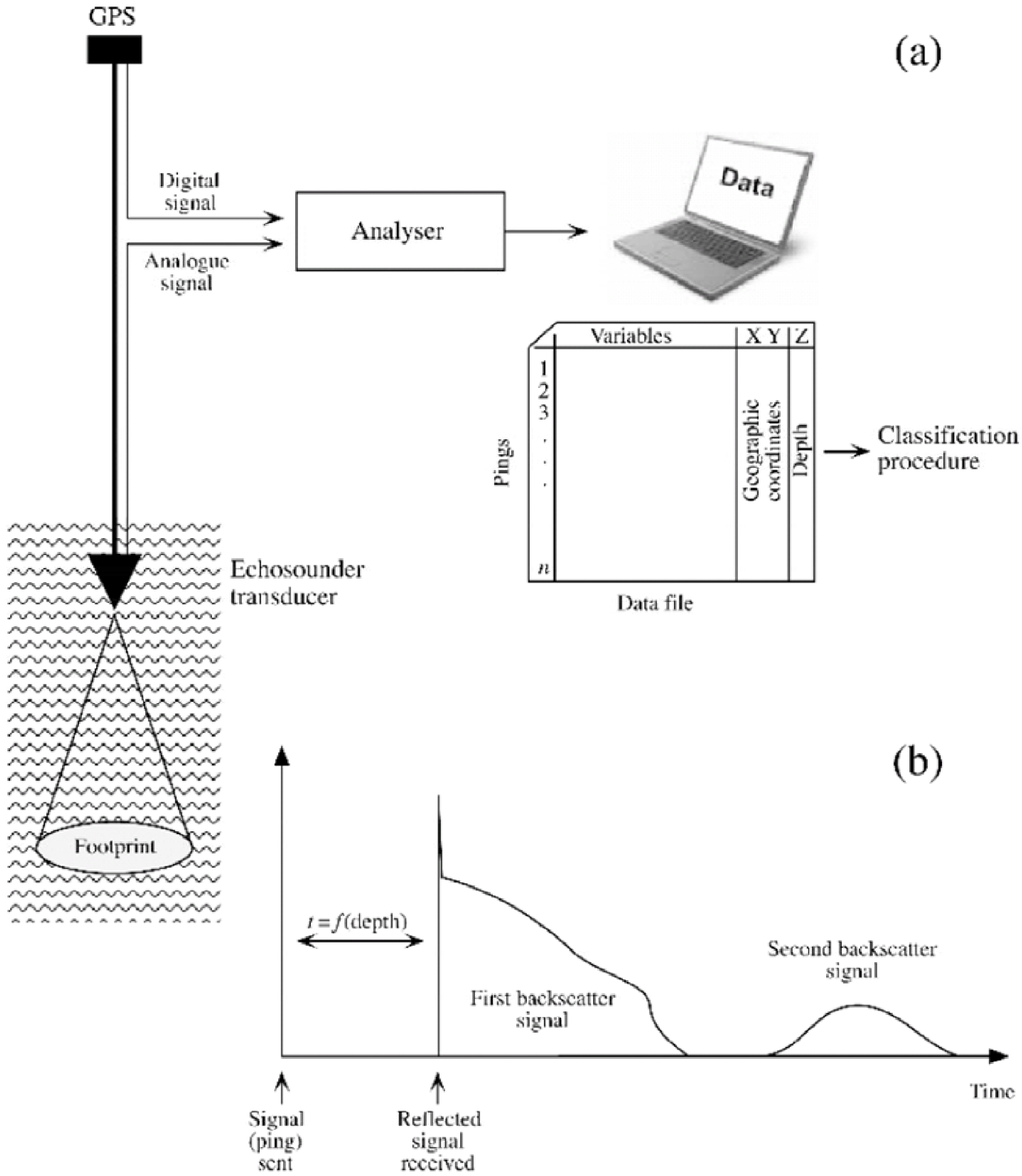


Figure 3 *Data acquisition (a): the echosounder signal is decomposed mathematically into a number of variables that will be used for classification. Each acoustic record is referenced by GPS for mapping. Analogue signal from the echosounder (b): The first backscatter portion of each "ping" is analyzed in this thesis. Figure from Legendre et al. (2002).*

domains (Collins, 1996). This results in a digital description of the echo consisting of 166 variables with their physical and mathematical meaning unknown to the user (Collins *et al.*, 1996). False indications of the bottom can be produced by reflection of the acoustic pulse due to the presence of fish or water column stratification (Collins & Rhynas, 1998). Excessive vessel speed and maneuvering, like sharp turns, can affect the quality of the acoustic data. The data files can also contain erroneous data due to "interrupt failure" in the hardware (Ellingsen *et al.* 2002). Incorrect depth values or omission of some of the 166 echo shape features resulted in manual deleting of the truncated records.

The acoustic data was analyzed with the software packages CAPS and QTC IMPACT (Quester Tangent Corporation, 1999). The data acquisition is illustrated in figure 3. Principal Component Analysis (PCA) determines the best combination of the 166 parameters of the echo returns. Most of the 166 variables have small variance, and?there is a small covariance of any individual parameter with the other (Prager *et al.*, 1995). Generally, the first three components account for more than 95% of the covariance produced from thousands of pings from a wide variety of seabed types (Prager *et al.*, 1995). The 166 variables are reduced to these three principal components, which are referred to as Q1, Q2 and Q3 (Collins & Lacroix, 1997). The rest of the information is not used in the classification. With the QTC software the Q-values can be plotted in a three-dimensional graph in Q-space along the three principal components (figure 7). The clustering analysis starts with one initial class of acoustic data that is subdivided into two clusters by having the program split the data into two classes.The "Class Statistic" window provides a series of statistical measures for each class; these are used to decide how to further subdivide the data set. The "split level" is the number of acoustic classes defined minus one. The "score" is the product of the number of records and a "chi-square" value (χ^2). In the QTC program the chi-square statistic measures how far the observed distribution of records in each cluster deviates from a normal distribution (Ellingsen *et al.*, 2002). For a perfect fit, the chi-square value is as small as zero, or very large for a poor fit (Zar, 1984). The sum of the individual class scores for the given level of splitting is the "total score". Generally the class with the highest score will be the next class split, according to the manual (Quester Tangent Corporation, 1999). A lower total score value indicates that more of the data fit the model than if the same data have a higher total score. When the classes are subdivided, tighter clusters (small χ^2) with smaller number of records results in a decrease in the total score. Beyond a point, further splits have little or no impact on the value of the total score, and this inflection point indicates the most parsimonious number of distinct acoustic classes within a data set (Quester Tangent Corporation, 1999).

The version of the QTC software used in the study is limited to 3-4000 points for the clustering analysis. For very large datasets, calibration is made by generating reference clusters through a grouping of some regularly spaced subset data from the whole survey area. One echo out of six was included in the calibration data set in this study. Extra data records that have not been included in the clustering process can be classified at the end. Each record is classified by using its position in the three-dimensional graph (Q-space) with respect to the set of reference clusters where each echo is classed the same as the nearest reference cluster (Collins & Lacroix, 1997; Galloway & Collins, 1998). A confidence estimate of each echo classification is provided by the software.

Figure 4 *Top picture shows the UiO multicorer used for sediment and faunal sampling. Below are two pictures of the multicorer tubes with sediment samples. The left shows a sample from the green/turquoise acoustic class area with gravel, rocks and a sea urchin. The right one is from the blue acoustic class area, soft sediment with no gravel and worm tubes.*

Sediments

Sediment was sampled from three (blue, green and turquoise) of the four QTC color-zones. The University of Oslo (UiO) multicorer (figure 4) was used for sampling 0-10cm of the sediment. The sediment samples were tested for grain size and carbon contentand were wet sieved through 2mm, 1mm, 0,5mm, 0,25mm, 0,125mm and 0,063mm sieves. The remaining sediment (< 0,063mm) was run through a sedigraph, and measured down to 1µm. The weights of all fractions were calculated as a proportion of total sediment weight. Total organic carbon was found by combustion and by titration.

Fauna

Four areas (1, 2, 4 and 7) in the different acoustic classes (blue, green, turquoise and red) were selected for multicorer sampling. 13 cores, the equivalent area of one boxcorer sample (0.1 m^2), were sampled from each color-area. Altogether 4 stations in area blue1 and 5 in areas blue2, green4 and turquoise7 were sampled. Due to the nature of the sediment in the turquoise QTC area, fauna samples had to be taken on the border of the green QTC area, resulting in samples from both zones in area turquoise7. Strong currents made positioning difficult resulting in station 4_1 and 4_4 being in the blue acoustic class instead of green class (figure 9). Fauna samples were sieved using 2.0 and 0.5 mm round holed screens and treated with 4% formaldehyde and rose bengal. In the laboratory the samples were sieved with a 0.25 mm sieve to make sure no animals were lost. The animals were sorted first into 5 groups: polychaetes, crustaceans, molluscs, echinoderms and varia. Then they were identified down to species wherever it was possible and preserved with 70% ethanol.

Sediment Profile Images (SPI)

SPI pictures were first attempted with multicorer tubes, modified to be only half tubes with one flat side for photography. Only one sample was successful. Pictures were taken back on land. In 2004 a boxcorer was used, and then we simply used the modified multicorer tubes on the boxcorer sample. The tubes were placed in a rack where pictures were taken on the vessel with a Nikon 4500 CoolPix camera. The images were classified with the Benthic Habitat Quality (BHQ) index (figure 5) according to the parameters presented in table 1. Figure 6 provides an illustration to how the SPI pictures should be interpreted.

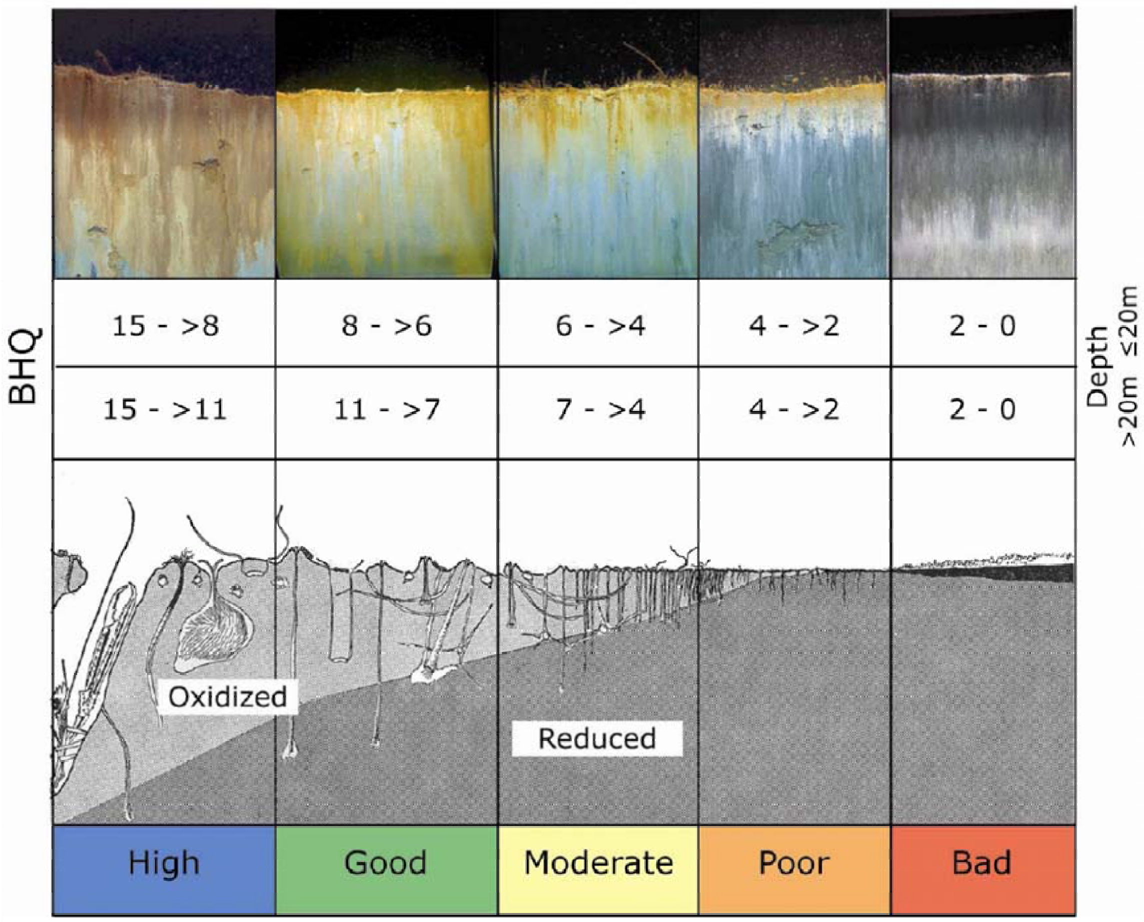


Figure 5 *Model of the faunal successional stages along a gradient of increasing disturbance from left to right. Sediment profile images (color enhanced) are displayed at the top where brownish color indicate oxidised conditions and black reduced conditions, and the benthic habitat quality (BHQ) indices (Nilsson & Rosenberg, 1997) are presented for depths >20m and ≤20m. Picture copied from Rosenberg et al. (2004). This figure has been modified from the earlier version (Nilsson & Rosenberg, 1997) with 4 successional stages to 5 so it will fit with the regulations of the WFD, dividing coastal environmental status into 5 categories for each coastal area based on the typology of the area. This model is for the Kattegat/Skagerak area, other locations will need their own models based on the conditions of the area.*

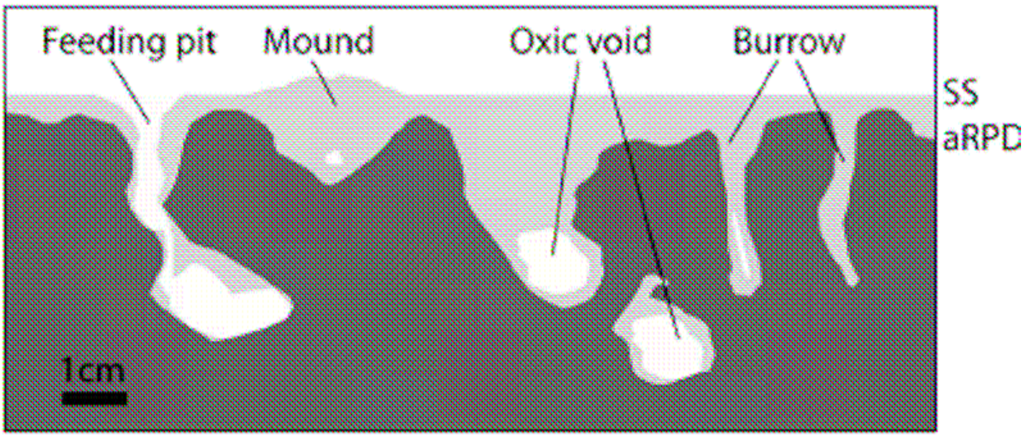


Figure 6 *Line drawing of different features. White = water or pore water, light grey = oxic sediment and dark grey = anoxic sediment. Pits and mounds have often a void in connection to the feature – the total feature will just score 2 points for 'Mound' and not for oxic void in such cases. Picture taken from Nilsson & Rosenberg (2006).*

Table 1 *Calculation of Benthic Habitat Quality (BHQ) index from the sediment profile images. Numbers at the right are point values assigned to features. Table is copied from Nilsson and Rosenberg (2006).*

A: Surface structures		Feacal pellets		1
		Tubes ≤2 mm in diameter and ≤30 mm in length		1
	Or	Tubes >2mm in diameter or >30 mm in length or brittle star arm		2
		Pit or mound		2
B: Subsurface structures		Infauna		1
		Burrows	# 1 - 3	1
	Or	Burrows	# > 3	2
		Oxic void at	≤ 5 cm depth	1
	Or	Oxic void at	> 5 cm depth	2
C: Mean depth of apparent RPD			0 cm	0
			0.1 - 1.0 cm	1
			1.1 - 2.0 cm	2
			2.1 - 3.5 cm	3
			3.6 - 5.0 cm	4
			> 5 cm	5

RESULTS

Acoustic mapping (QTC)

The “Class Statistics” window in the QTC Impact program showed the score value which was used to determine which class should be split next in the clustering analysis of the calibration data set. The total score determined the optimal level of class splitting (table 2). Subdividing the classes decreased the total score. Further splits beyond split level three, which means four acoustic classes, had little impact on the total score. This inflection point was used as an indication of the optimal number of acoustic classes. Four acoustically distinct seabed types were identified in the survey. These four classes are shown in a three-dimensional graph in figure 7. Adjacent classes represent seabeds with more identical acoustic characteristics than cluster pairs farther apart. Each record from the total data set was then classified using its position in the three-dimensional plot with respect to the four reference clusters.

The acoustic data were first divided into two clusters, one consisting of the blue and green acoustic classes, and the other consisting of the red and turquoise classes. Then the blue and green clusters were further divided into two separate clusters at the second split. At the third split (table 2) the red and turquoise classes were separated. The results from the acoustic seabed classification of the whole dataset from the survey are shown in figure 7.

Table 2 *Summary of split statistics using the post-processing software QTC IMPACT. A calibration data set of Q-values describing every sixth record has been sub-divided four times (split levels 1-4). Total score is the sum of the individual class scores given in table 3 for a given level of splitting. Optimal split level is 3.*

Split level	Total score
1	57900.18
2	26304.18
3	**14383.40**
4	16045.55

Table 3 *Class specific characteristics for the 4 acoustic classes, from the three splits of the calibration data set in table 2 as well as the resulting classification of the total data set. χ^2 is the chi-square statistic, a measure of the extent of a cluster in Q-space (figure 7). Score is the product of the number of records and the χ^2 value.*

Class number	No. of records	χ^2	Score
1 (Red)	303	4.03	1221.02
2 (Green)	895	4.93	4410.11
3 (Blue)	754	2.98	2233.19
4 (Turquoise)	782	3.14	2459.27

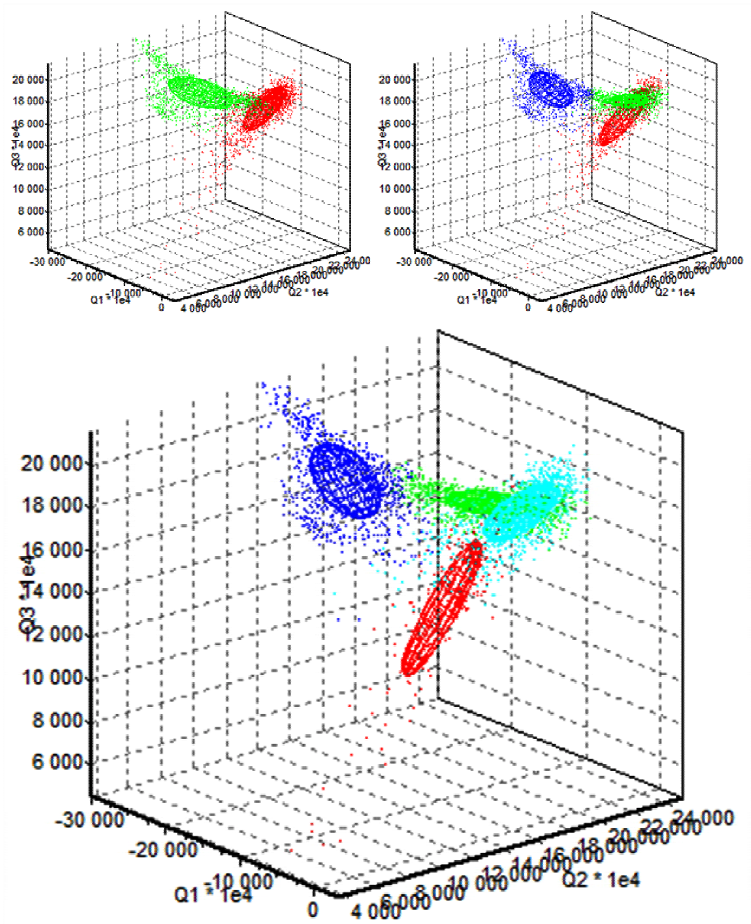


Figure 7 *The reference clusters are shown in a three-dimensional graph. Q1-Q3 are the first three principal components from the principal component analysis. Standard deviation ellipsoids indicate the position of the cluster means and the size of the clusters along the three principal axes. The top left chart shows the first cluster split: the green represents the green and blue areas and the red is the red and turquoise areas from figure 9. The top right shows the second split, the former green cluster has been split and now the green and blue areas are separated. The bottom shows the third and final split of the former red cluster into red and turquoise clusters from the two graphs above. The nearer the clusters are one another, the more they have in common, like the green and turquoise clusters.*

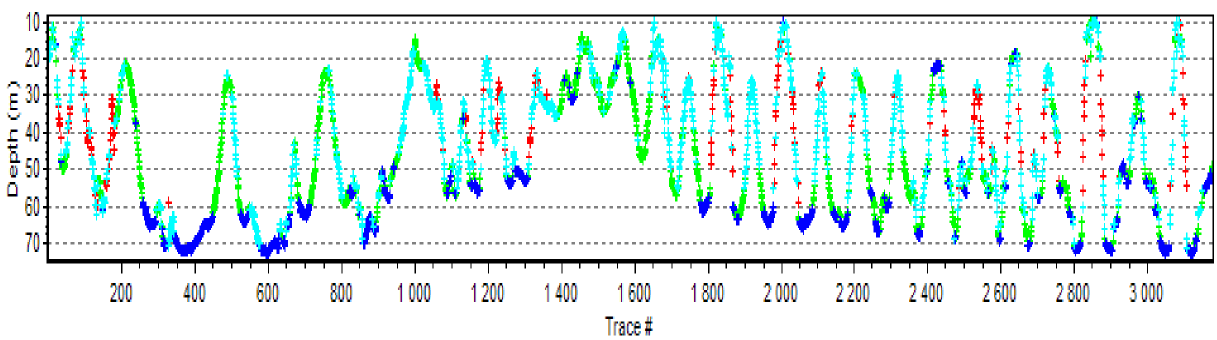


Figure 8 *Bathymetry of the survey line the research vessel followed (figure 9) showing depth and the number of pings received from the echosounder.*

The blue class was found mainly at the deepest sites (figures 8, 9 & 10) consisting mostly of mud and some pebbles (table 4).

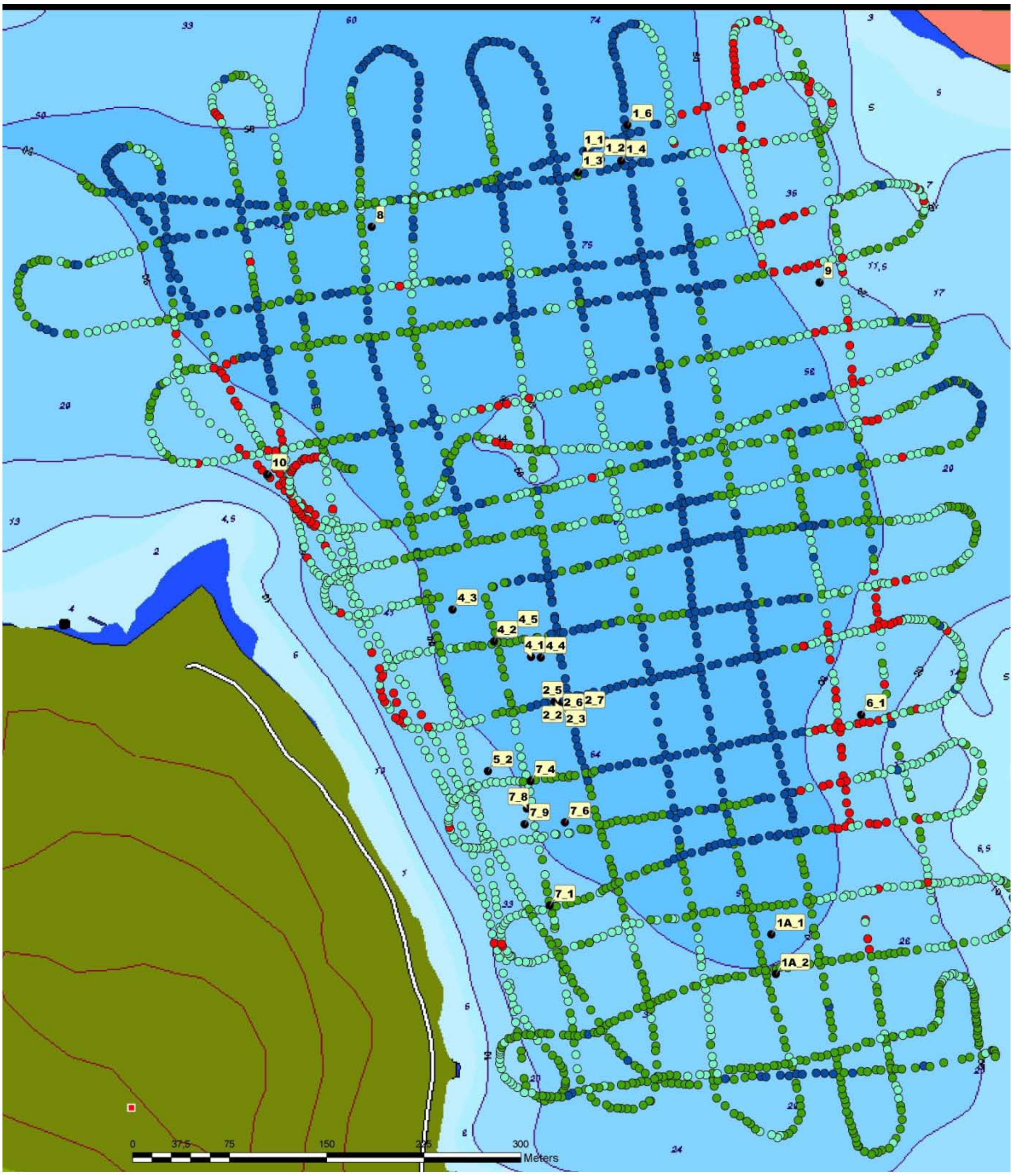


Figure 9 *Map of the different acoustic classes from the survey and sampling stations. Red represents rock, blue is mud and pebbles, green is sand with pebbles and turquoise is clay and pebbles.*

The green class, according to figure 8, was mainly sloped terrain. This class is closely related to the blue class, but even more to the turquoise class (figure 7). The sediment consisted mainly of sand and some pebbles, but it is more shallow than the blue class (figures 8, 9 & 10).

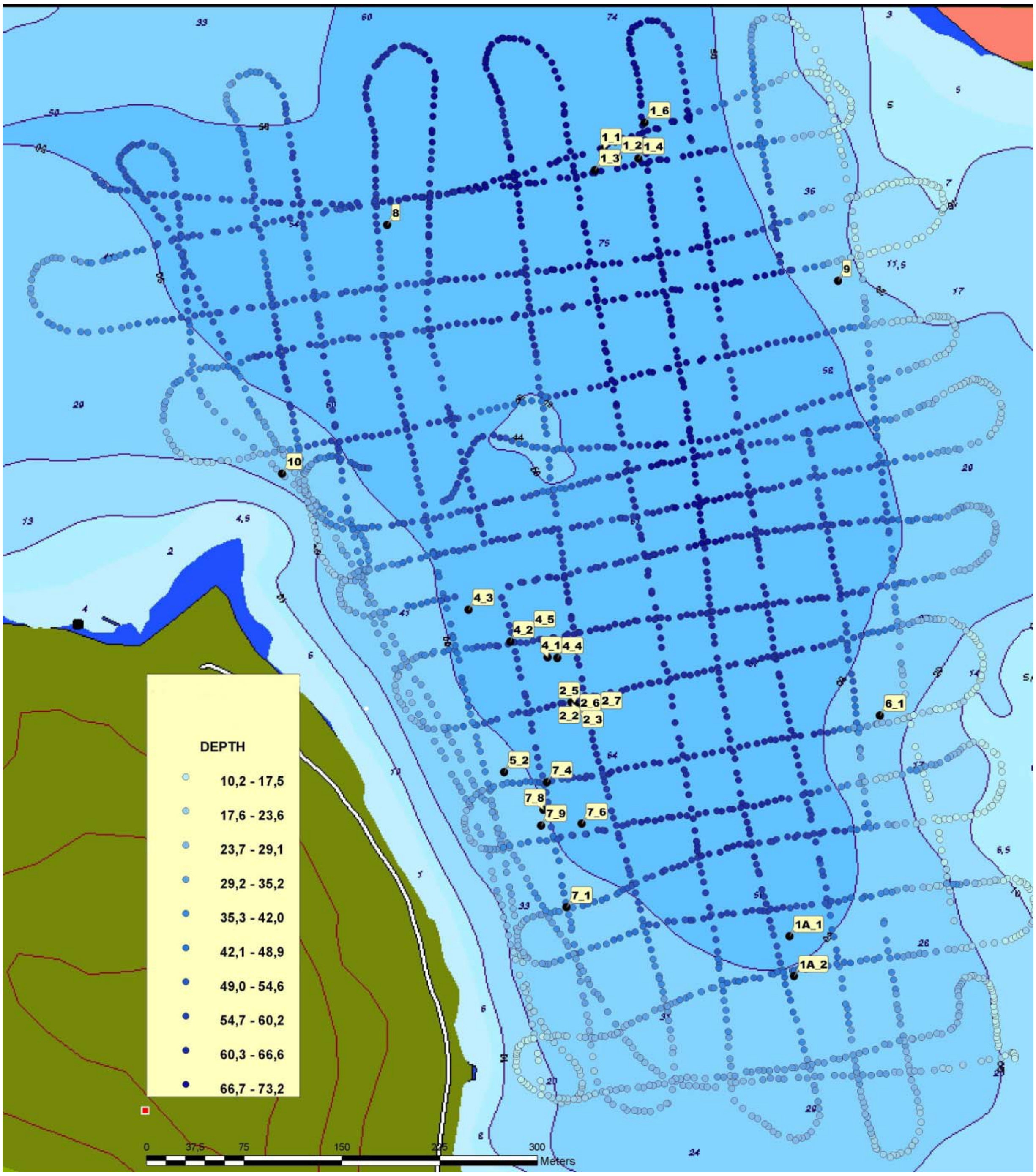


Figure 10 *Map showing bathymetry the survey track with sampling stations.*

The turquoise class was most abundant along the shoreline and like the green class, was found on slopes. The sediment was characterised by some clay and manypebbles, and the multicorer tubes were not able to penetrate deeply into the sediment.

The red class was rock and was found along the shore and underwater slopes (figures 8, 9 & 10).

Table 4 Water depth, acoustic classification (QTC), number of cores for fauna, and sediment samples. Sediment Profile Images (SPI) and description of all sampling sites. All samples were taken with multicorer. Asterisk (*) are for samples taken in 2004. Some classes were hard to associate with one acoustic class as they were taken on borders between two areas.

Site	Depth (m)	QTC class	Fauna	Sediment	SPI	Description
1A_1	52.6	Green		1		Hard sediment, gravel with
1A_2	47.3	Green				mud, pebbles (1-4cm) on top
1_1	74.1	Blue	3			Coarse sand in mud
1_2	73.9	Blue	4			
1_3	73.9	Blue	3			
1_4	74.1	Blue	3	1		
1_6	72.8	Blue		1		Weak H_2S smell
1_9	73.8	Blue		1*	1+4*	
2_1	65.2	Blue	2			Pebbles (0.5-1cm), mud
2_2	64.0	Blue	3			Soft sandy mud, pebbles
2_3	64.2	Blue	3			Mud, pebbles
2_4	64.0	Blue	3			Mud, some pebbles
2_5	64.0	Blue	2			
2_6	64.5	Blue/Green		1		
2_7	65.0	Blue		1*	2*	
4_1	62.5	Blue/Green	2			Mud, few pebbles
4_2	60.0	Green	3			Sand, pebbles under
4_3	53.4	Green	3			Fecal pellets, sand
4_4	62.6	Blue/Green	3			
4_5	60.5	Green	2	1+1*	4*	
5_2	44.8	Turquoise		1		Slope, sandy clay, gravel
6_1	28.8	Red				Rock
7_1	41.5	Green/Turquoise	1			Clay with pebbles
7_4	53.3	Green/Turquoise	4	2*	4*	Pebbles, silty clay, rocks
7_6	54.3	Green/Turquoise	4			
7_8	45.0	Green/Turquoise	2			
7_9	45.0	Green/Turquoise	2			
8_1	61.5	Green				
9	30.0	Red				Rock
10	31.0	Red				Rock

Sediment

The sediment analysis does not show any clear pattern between the different acoustic class areas sampled when it comes to parameters like grain size and carbon content (Table 4). The only feature that distinguishes the stations from the different acoustic classes is the depth gradient (figure 11).

Table 5 Grain-size analysis expressed as percent of total sediment dry weight, divided into sand, silt and clay. Median value in phi (*Φ)* units. Asterisk marks samples taken in 2004.

Site	Sand	Silt	Clay	*Φ*	Kurtosis	Sorting	Skewness	Depth	OC	TOC
1A_1	85.94	4.78	9.28	0.26	1.65	2.86	0.91	56.2	1.92	29.3
1_4	53.56	18.11	28.33	5.48	1.08	4.51	0.66	74.1	3.84	31.8
1_6	41.57	22.20	36.22	6.50	0.73	3.93	0.08	72.8	2.58	24.6
1_9*	76.38	9.21	14.41	3.69	1.66	2.72	0.61	73.8	3.96	47.2
2_6	48.94	19.40	31.66	5.44	0.82	4.05	0.08	64.5	4.06	52.9
2_7*	81.21	3.38	15.41	1.61	1.27	3.97	0.93	65.0	2.41	28.7
4_5	37.14	19.49	43.37	6.71	0.64	3.54	-0.19	60.5	2.64	49.5
4_5*	59.28	15.06	25.65	4.33	0.64	3.00	0.60	60.5	4.21	46.1
5_8	66.21	9.80	23.99	3.65	0.69	4.88	0.42	44.8	4.00	35.4
7_4a*	38.17	21.29	39.54	5.87	0.74	3.16	-0.24	53.3	2.53	42.0
7_4b*	57.89	9.68	32.42	3.88	0.68	4.65	0.26	53.3	4.22	45.4

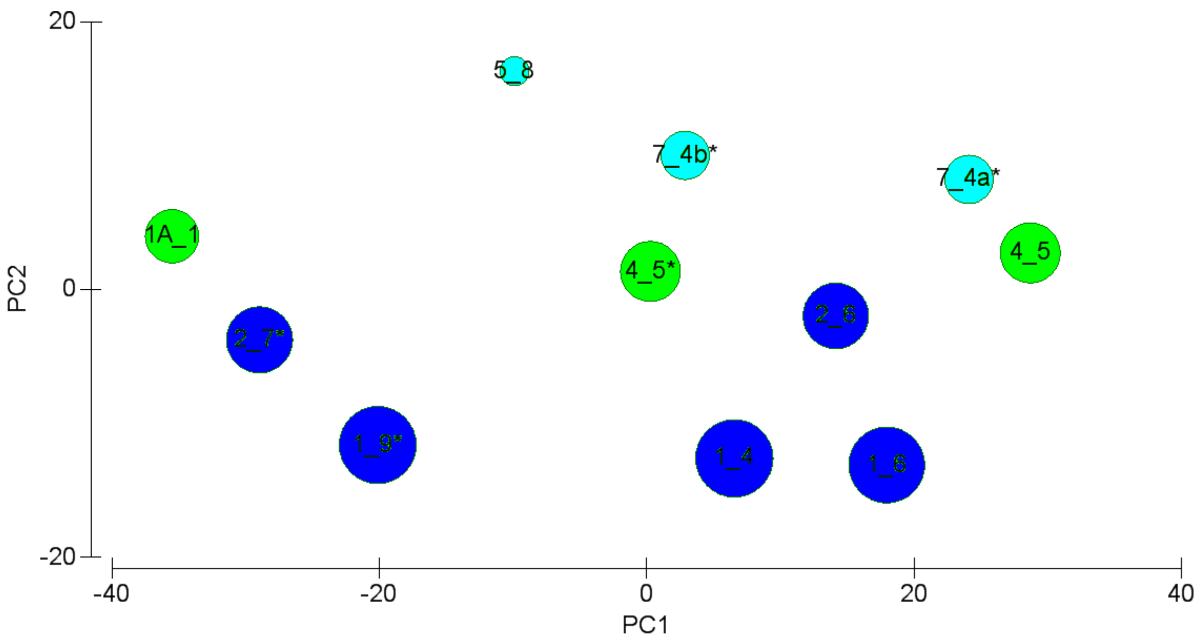


Figure 11 *Principal Components Anlysis of the sediment data. Depth has been emphasized with bubbles and the samples been colored by their respective acoustic class.*

Fauna

A total of 88 taxa were recorded, with Polychaeta as the dominant taxa, followed by Mollusca as a minor contributor; Echinodermata and Crustacea are almost nonexistent. The faunal composition at the different sites is remarkably uniform. Because the number of cores sampled at each station varied from 1 to 4, each station was expressed as one core sample (the average if multiple cores were present). The Primer (PRIMER 2006) software was used for analysis. Multi-Dimensional Scaling (MDS) is useful to analyze similarity between benthic communities (Gray *et al.*, 1988).On the first MDS plot (appendix A), station 7_1 was clearly defined as an outlier and removed from the dataset.

Four different clusters can be seen from the cluster analysis and MDS plot (Figure 12). 1-stations from the blue acoustic class are clearly defined as a separate cluster. The next blue area consists of 2-stations and two 4-stations (4_1 and 4_4), both taken in the blue acoustic class area (Table 4). Only two stations from the green acoustic class area are classified as a separate cluster (4_2 and 4_5). The 7-group of stations from the green–bordering-turquoise area is grouped with station 4_3, which may result from the fact that this station is at 53,4m compared to the 60-62m in that group (Table 4).

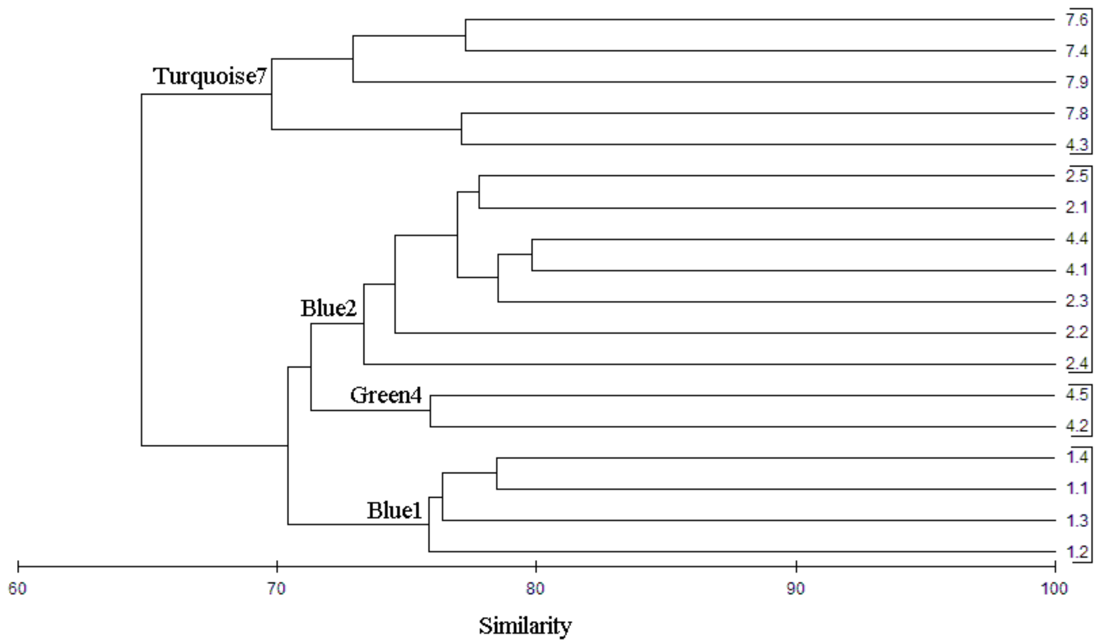


Figure 12 *Fauna stations (each station consists of 2-4 cores) at the sampling site. Tree shows cluster analysis with all sampling sites excluding site 1_7. Each station shows one average corer sample.*

The MDS plot (Figure 13) shows the spread of the stations and the clearly defined groupings explained in the cluster analysis. The 4 groups vary from 5 to 18 multicorer samples, making the species count much higher in the groups with higher number of samples than the ones with few. To get a more detailed view, only the 5 closest aligned corer samples from each cluster group (appendix A) were used in a new cluster analysis (Figure 14) and MDS plot (Figure 15). The new cluster analysis and MDS plot show the similar results to the previous ones.

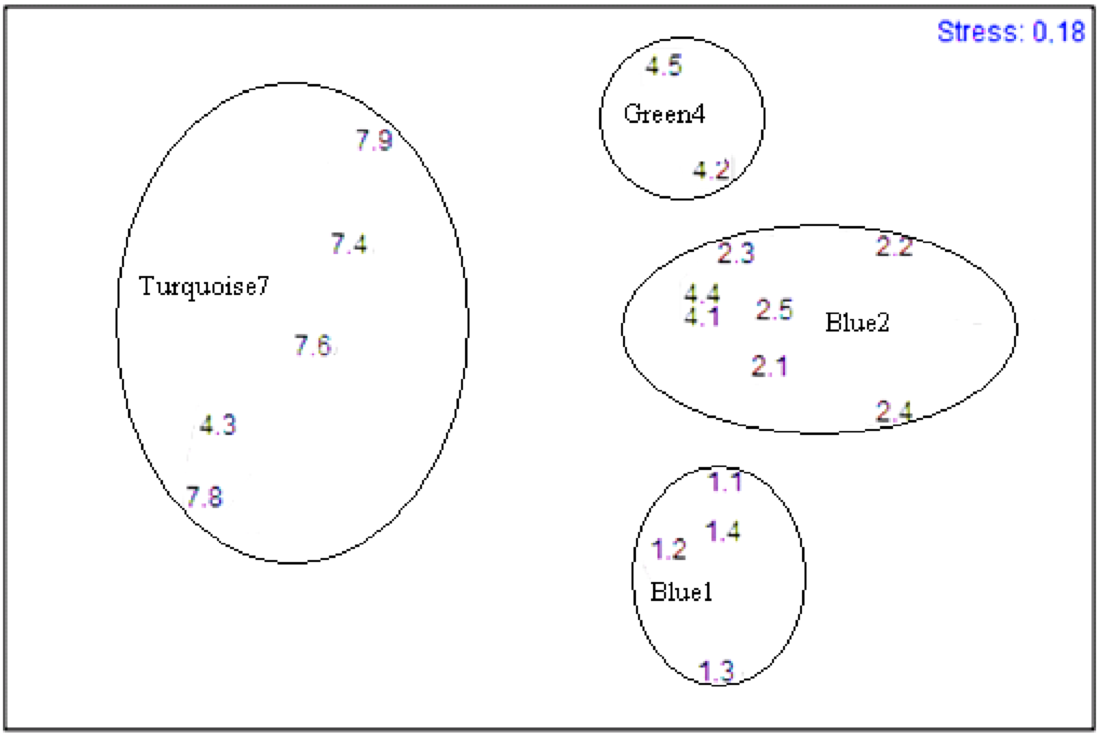


Figure 13 *MDS showing the affinity groups among the fauna samples from figure 12.*

Table 6 *List of the species making up more than 3% of the abundance at each affinity group (figure 13), represented as the average of one multicorer tube (A/0.8m²). Shaded values indicate the higher abundance value for each species.*

Species	Blue1	Blue2	Green4	Turquoise7
Chaetozone setosa	64.9	56.0	53.9	17.6
Mediomastus fragilis	19.4	25.0	16.8	5.9
Pseudopolydora paucibranchiata		13.5	12.2	10.4
Heteromastus filiformis	9.0	11.1	9.2	3.3
Nemertini			5.9	2.6
Cossura longocirrata	14.1	22.7	28.0	12.0
Pholoe sp.	6.0	7.4	12.9	10.0
Nuculoma tenuis				3.0

Table 6 show the species dominance within the affinity groups in figure 13, the turquoise7 group is more diverse than the other groups, and is also the only one to have a bivalve species represented.

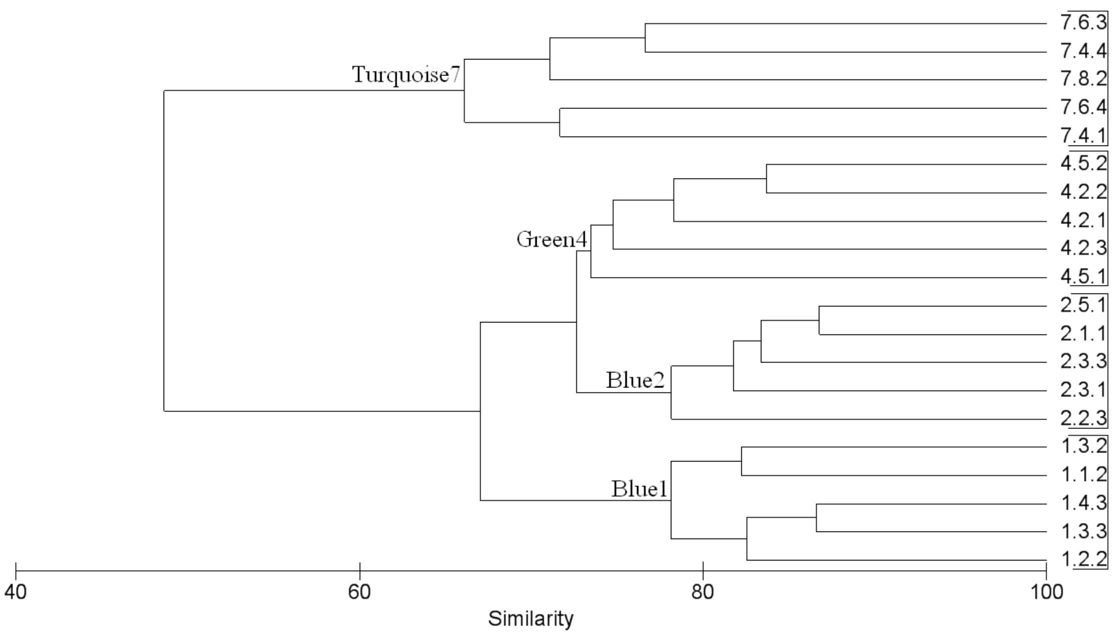


Figure 14 *Cluster analysis of 5 corer tubes from each of the groupings represented in figure 13 and 14. The first number is station area, followed by station and corer tube last.*

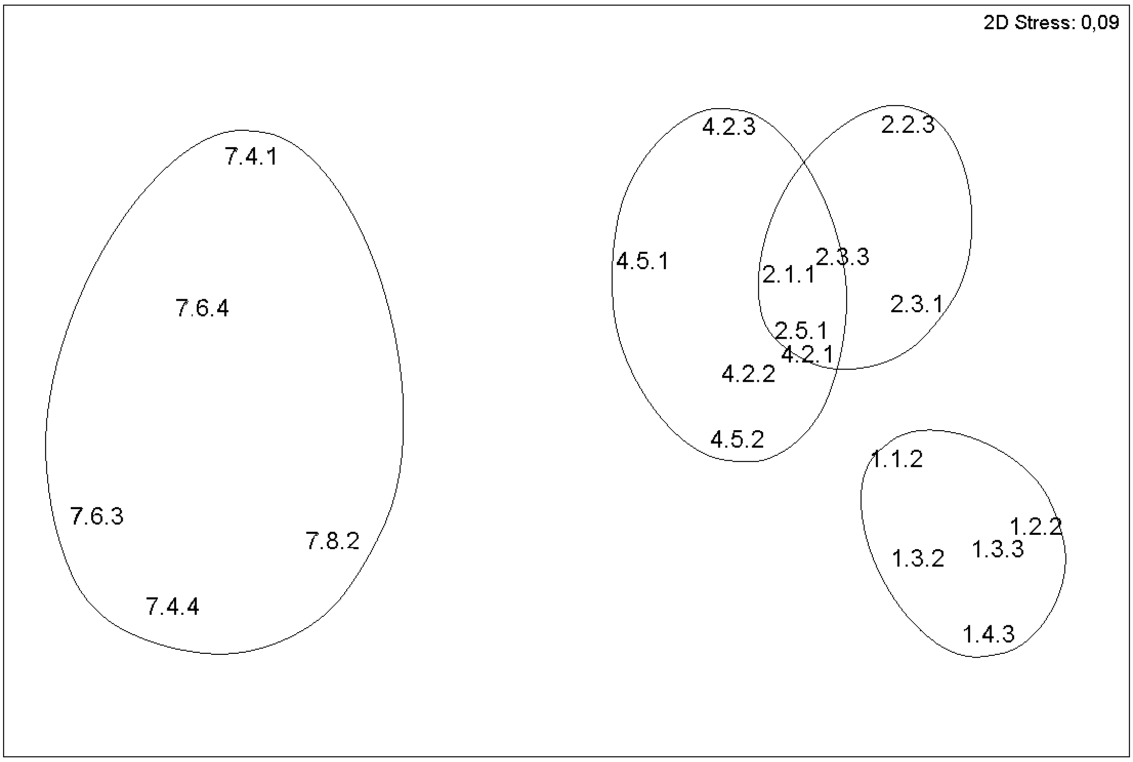


Figure 15 *MDS plot showing the affinity groups among the 5 corer tubes from each station area.*

The diversity indices show no major differences between the area class groupings (table 7). The differences are small, and this is also reflected in the similarities, from the simper analysis provided by the PRIMER software, within and between the groups in table 8. This also reflects the results in the cluster analysis (figure 14).

Table 7 *Univariate diversity indices for the average of the 5 cores from the different acoustic classes. Number of species (S), number of individuals (N), species richness (*d*), Shannon-Wiener diversity index (J'), Hurlberts rarefaction ($ES_{(50)}$) and Eveness (H').*

Sample	S	N	d	J'	$ES_{(50)}$	H'(loge)
Blue1	34	120	6,891	0,5001	9,289	1,763
Blue2	32	179	5,973	0,5929	9,621	2,055
Green4	43	166	8,218	0,6163	12,38	2,318
Turquoise7	38	84	8,342	0,6657	10,92	2,421

Table 8 *Similarity within and between the groups from the cluster analysis in figure 14.*

	Similarity within group	**Similarity between groups**			
Group		Blue1	Blue2	Green4	Turquoise7
Blue1	80.24%		68.07%	65.94%	41.66%
Blue2	81.13%			72.61%	50.51%
Green4	75.82%				53.63%
Turquoise7	68.70%				

Table 9 *Listing the RPD (mean RPD layer) and the BHQ values for the BHQ index for the SPI pictures.*

Station	RPD	RPD value	Surface structures	Sub-surface structures	BHQ index
1.9*	3,6	4	2	2	8
1.9 r1	6	5	2	2	9
1.9 r2	6	5	2	2	9
1.9 r3	6,5	5	2	2	9
1.9 r4	6	5	2	2	9
2.7 r1	3	3	2	2	7
2.7 r2	4	4	2	2	8
4.5 r1	2,7	3	2	1	6
4.5 r2	2,5	3	2	2	7
4.5 r3	2,6	3	2	2	7
4.5 r4	2,2	3	2	2	7
7.4 r1	1,6	2	2	1	5
7.4 r2	1,8	2	3	1	6
7.4 r3	2	2	3	2	7
7.4 r4	2,1	2	2	2	6

SPI

The Sediment Profile Images (SPI) was classified according to table 1 the results are listed in table 9. The highest Benthic Habitat Quality (BHQ) values are found in the blue acoustic class areas, with decreasing values in the green class area followed by the turquoise class area. The blue and green areas within the "good" BHQ value (except from 4.5 r1), while the turquoise area falls within the "moderate" BHQ value (table 8). These low values are mostly related to average depth of the RPD layer (figure 16, bottom pictures).

Figure 16 *SPI pictures from the survey area. Station 1_9 (upper right) from 2003 with features used for BHQ assessment outlined. From 2004; station 1_9 r1 (upper left), station 7_4 r1 (lower right) and station 7_4 r4 (lower left),*

DISCUSSION

The focus of this research has been remote sensing of benthic habitats, and how it may supply and help traditional "ground truthing". Acoustic mapping provides information on the structure and composition of benthic habitats. The spatial distribution and size of habitats in a landscape play an important role in the functioning and structure of marine communities (Ellingsen & Gray, 2002; Hewitt *et al.*, 2002). Acoustic mapping can improve sampling design, as compared to sampling "blind", and can describe larger areas of seabed than is possible or cost effective with traditional sampling. SPI is used for assessment of benthic quality. The analysis of SPIs is more cost-efficient and many more samples than grab samples can be obtained over the same time, and the analysis is rapid (Rosenberg *et al.,* 2004). SPI is cheap compared to identification of species which requires skilful taxonomists, is laborious and tedious as well as expensive.

This study found four different acoustic classes at the optimal split level (table 2) in Oslofjord (figure 9). The sediment composition follows a depth gradient as well (figure 8, 9 & 10): the different acoustic classes are coarse in the shallow areas (turquoise class), followed by more sand mixed with gravel (green class) and in the deepest areas (blue class) mostly mud. This reflects the current in the area (personal comment from captain of research vessel and local scuba-divers), as a strong current in the upper water layers means less sedimentation and more sediment transport (Briggs, 1977). Thus it supports the different classes found with the QTC VIEW software.

Bottom roughness and density differences between the sediment surface and the overlying water is the primary influence on the QTC VIEW classification system according to Collins and Lacroix (1997). Hamilton *et al.* (1999) found a relationship between the acoustic pattern and variation in sediments according to their grain size and texture properties. Four geotechnical variables were found by Preston *et al.* (1999) to have the highest correlation with acoustic classes: surface grain-size, porosity, shear strength and bearing strength. Ellingsen *et al.* (2002) and Freitas *et al.* (2003) found correlations between grain-size and acoustic classes. Microtopography and ripple marks have been shown to influence the acoustic echo (Collins *et al.*, 1996); some infaunal and epifaunal species can also affect single-beam acoustic backscatter as well as seaweed and seagrass (Collins *et al.*, 1996; Collins & Galloway, 1998; Self *et al.*, 2001). The grain-size did not show any correlation with the acoustic classes (figure 11). Stations like 1A_1 and 1A_2 had rocks and pebbles on top of the sand (table 4), while the other stations from the green acoustic class area had none on top, but deeper down in the sediment. Nearly all the green areas were found in slopes (figure 8), and QTC VIEW have problems with the larger acoustic footprint created by this (von Szalay *et al.*, 2000). The large amounts of organic carbon may indicate that the infauna is the biggest contributor to the different acoustic classes detected by the QTC software in this survey.

The faunal diversity indices (table 7) show very little difference between the acoustic classes. Both the cluster analyses of the fauna (figure 12 & 14) and the MDS plots (figure 13 & 15) do however show the different stations have increased similarity within groups. Stations 4_1 and 4_4 ended up in the blue acoustic class with the blue2-stations in the cluster analysis (figure 9). These were sampled in the blue area, due to strong currents. Therefore the figure follows the acoustic classes. Station 4_3 is from the green acoustic class area (figure 9) but cluster analysis (figure 12) puts it with samples from the turquoise7 class area. The station is further from the other green4-stations and also more shallow (table 4), 10m more than the others. Station 7_1 has only half the animals (44) than the other stations in that class area and a slightly different species composition, marking it as an outlier (appendix A). It is located a bit further from the other turquoise7-stations (figure 9) and also a bit shallower (table 4). The cluster analysis (figure 13) shows that the samples from the turquoise and to some degree, the green acoustic class area, are more diverse than the ones from the blue class area. Since these two acoustic classes are mainly found in slopes (figure 8) and the QTC VIEW is known for having classification problems with slopes, it may be that these have various sediment compositions, but they are identified as the same by the QTC software.

The low number of crustaceans in the sample is most likely due the equipment used. The initial disturbance from the arrival of the multicorer on the bottom, along with the small delay from the impact to the insertion of the cores in the sediment, would give motile species time to scurry away.

The eight species that compose more than 3% of the fauna (table 6) are all highly tolerant species according to Rygg (1995). All of the 6 polychaetes are also described as special decisive indicators of pollution with *C. setosa*, *H. filiformis* and *P. paucibranchiata* as highly opportunistic species. The Oslofjord is affected by eutrophication and organic enrichment (Olsgaard, 1999), and this may be the cause of the dominance of tolerant and opportunistic species throughout the survey area. Slightly polluted areas create a dominance of some species, compared to unpolluted areas (Mirza & Gray, 1981).

The mathematical or physical meaning of the 166 echo shapes is unknown to the user of the QTC VIEW software. This reduces the user's understanding of the processes of the software, and ultimately the interpretation of the acoustic data. Reducing the 166 values to the first three principal components in the multivariate PCA analysis may not be adequate. The splitting process (table 2) can have difficulties deciding when to stop (Ellingsen *et al.*, 2002), thus the decision is subjective. Furthermore, if two classes have almost the same score, choosing which to split can be difficult. Legendre *et al.* (2002) proposed a different method by which to analyze the QTC data, based on K-means and a criterion to decide on the best numbers of clusters to retain. This has been criticized by Preston and Kirlin (2003) and defended by Legendre (2003). Further splits or use of the method proposed by Legendre *et al.* (2002) might have provided more acoustic classes and helped explain more of the properties of the "slope classes" (green and turquoise) in this study.

Both the sediment and fauna data could have benefited from increased sampling. More sediment samples would have helped in understanding the effects of the "slope class" on the acoustic mapping. A more complete examination of the sediment, looking at porosity, shear strength and bearing strength, could perhaps have explained more of the acoustic data collected. Replicate fauna samples from other areas within the different acoustic classes could help explain the similarities between the classes. The blue2 samples (figure 14, table 8) are more similar to the green4 samples than the blue1 group from the same acoustic class. Blue2 and green4 are located very close to each other (figure 9) and they are also similar in depth (table 4) compared to the 10 meter deeper blue1 group.

The Sediment Profile Images (SPI) are in accordance to the findings of Nilsson (2007) in the same area,although the turquoise7 station show a lower BHQ index (table 9) of around 6 compared to the average of 8 found by Nilsson. The RPD layer has the same score, but there were less infaunal activity registered. The stations were classified with good BHQ according to the scale in picture 2, except for the turquoise which fell in the moderate category. The low score on the turquoise class stations comes from the shallow apparent RPD layer; this is mainly because this area had silty clay (table 4).

As shown by this project and others (Ellingsen *et al.*, 2002; Hewitt *et al.*, 2004; Rooper & Zimmermann, 2006), remote sensing will not be able to replace traditional "ground truthing"; rather, it is best used as a reconnaissance tool. It provides the opportunity to collect information on physical and biological habitats over larger areas than traditional methods with random sampling. Remote sensing will indicate how representative samples taken with traditional methods are for the area from which they are taken. That is, remote sensing can verify whether the samples represent the larger area or just the small area sampled. This is especially important in coastal waters where the benthic composition differs more than offshore due to bathymetry, currents, tides and runoff from land (Mann, 2000). Misclassification does occur with acoustic mapping, with some bottom types being acoustically deceptive (Hamilton *et al*., 1999). Some bottoms may have similar acoustic signatures for a particular AGDS but are not geologically similar. Sediment samples and underwater video will help rule out these faults. As well as functioning as a reconnaissance tool, remote sensing is also a cost effective way to relate fish distribution to their habitats (Mackinson *et al*., 2003; Rooper & Zimmermann, 2007). Finally, remote sensing is desirable because it does not affect the habitat in the same way as traditional 'ground truthing', which removes a piece of the bottom and kills all the animals.

Acoustic mapping can discover different habitats and make sampling more efficient with the revelation of different sediments that can affect faunal composition. This is important for commercial fisheries as well as monitoring the environment.

There are many new types of equipment and techniques to monitor and map the benthic environment, two of which have been presented here. The key is to know which to use or which combination to use for given study goals. Quoting Redfield (1958): "The problem must dictate the methods to be employed for its solution, not the reverse". With increased use, the more it will evolve, and new technology will be created as well, increasing our knowledge and understanding of the seabed.

REFERENCES

Bale, A. J. and A. J. Kenny 2005. Sediment Analysis and Seabed Characterisation. In: Eleftheriou, A. (ed.), Methods for the Study of Marine Benthos, *Blackwell Science Ltd***,** pp. 43-86.

Borja, A., Josefson, A. B., Miles, A., Muxika, I., Olsgard, F., Philips, G., Rodriguez, J. G. & Rygg, B. 2007. An approach to the intercalibration of benthic ecological status assessment in the North Atlantic ecoregion, according to the European Water Framework Directive. *Mar. Poll. Bull.* 55: 42-52.

Collins, W. Gregory, R. & Anderson, J. 1996. A digital approach to seabed classification. Habitat assessment for juvenile is just one application of this acoustic method. *Sea Technology.* 39: 45-49

Collins, W. & Lacroix, P. 1997. Operational philosophy of acoustic waveform data processing for seabed classification. *Proceedings of Oceanology International '97*, 1: 225-234.

Collins, W. & Rhynas, K. P. 1998. Acoustic seabed classification using echo sounders: operational considerations and strategies. *Canadian Hydrographic Conference '98. CHS, Victoria, British Columbia, Canada*.

Collins, W. T. & Galloway, J. L. 1998. Seabed classification with multibeam bathymetry. This 'tool of choice' for marine surveys adds layer of acoustic data for multidisciplinary mapping at only incremental expense. *Sea Technology.* 39: 45-49.

Diaz, R. J. & Schaffner, L. C. 1988. Comparison of sediment landscapes in Chesapeake Bay as seen by surface and profile imaging. In: Lynch, M. P. Krome (Eds.), Understanding the Estuary: Advances in Chesapeake Bay Research. *Publication 129, CBP/TRS 24/88. Chesapeake Research Consortium, Solomons, MD*, pp. 222-240.

Eleftheriou, A. & McIntyre, A. D. 2005. Methods for the Study of Marine Benthos, *Blackwell Publishing Ltd.*

Ellingsen, K. E., Gray, J. S. & Bjørnbom, E. 2002. Acoustic classification of seabed habitats using the QTC VIEW™ system. *ICES Journal of Marine Science.* 59: 825-835.

Ellingsen, K. E. & Gray, J. S. 2002. Spatial patterns of benthic diversity: is there a latitudinal gradient along the Norwegian continental shelf? *Journal of Animal Ecology*. 71: 373-389.

Freitas, R., Rodrigues, A. M. & Quintino, V. 2003. Benthic biotopes remote sensing using acoustics. *J. Exp. Mar. Biol. Ecol.* 285-286: 229-353.

Galloway, J. L. & Collins, W. T. 1998. Dual frequency acoustic classification of seafloor habitat using QTC VIEW. *Oceans'98. IEEE, Nice, France.*

Gray, J. S. 1974. Animal-sediment relationships. *Oceanogr. Mar. Biol. Ann. Rev.* 12: 223-261.

Gray, J. S., Aschan, M., Carr, M. R., Clarke, K. R., Green, R. H., Pearson, T. H., Rosenberg, R. & Warwick, R. M. 1988. Analysis of community attributes of the benthic macrofauna of Frierfjord/Langesundfjord and in a mesocosm experimental. *Mar. Ecol. Progr. Ser.* 46: 151-165.

Hamilton, L. J. Mulhearn, P. J. & Poeckert, R. 1999. Comparison of RoxAnn and QTC-View acoustic bottom classification system performance for the Cairns area, Great Barrier Reef, Australia. *Continental Shelf Research*. 19: 1577-1597.

Hewitt, J. E., Legendre, P., Trush, S. F., Cummings, V. J. & Norkko, A. 2002 Integrating results from different scales: a multi-resolution study of the relationships between *Atrina zelandica* and macrofauna along a physical gradient. *Mar. Ecol. Progr. Ser.* 239: 115-128.

Kloser, R. J., Bax, T. R., Williams, A. & Barker, B. A. 2001. Remote sensing of seabed types in the Australian South East Fishery; development and application of normal incident acoustic techniques and associated 'ground truthing'. *Mar. Freshwater Res.* 52: 475-489.

Legendre, P., Ellingsen, K. E., Bjørnbom, E. & Casgrain, P. 2002. Acoustic seabead classification: improved statistical method. *Can. J. Fish. Aquat. Sci.* 59: 1085-1089.

Legendre, P. 2003. Reply to the comment of Preston and Kirlin on "Acoustic seabead classification: improved statistical method". *Can. J. Fish. Aquat. Sci.* 60: 1301-1305.

Lurton, X. And Pouliquen, E. 1992. Automated sea-bed classification system for echo-sounders. *IEEE Oceans'92 Conference Proceedings*, pp. 317-321.

Mackinson, S., Freeman, S., Flatt, R. & Meadows, B. 2003. Improved acoustic surveys that save time and money: integrating fisheries and ground-discrimination acoustic technologies. *J. Exp. Mar. Biol. Ecol.* 305: 129-140.

Mann, K. H. 2000. Ecology of Coastal Waters. With Implications for Management, *Blackwell Science, Inc.*

Mareano. Samler kunnskap om havet. [online] Acces: http://www.mareano.no/ [sited 24.04.2007]

Mirza, F. B. & Gray, J. S. 1981. The fauna of benthic sediments from the organically enriched Oslofjord, Norway. *J. Exp. Mar. Biol. Ecol.* 54: 181-207.

Nilsson. H. C., & Rosenberg, R. (1997). Benthic habitat quality assessment of an oxygen stressed fjord by surface and sediment profile images. *Journal of Marine Systems.* 11:249-264

Nilsson, H & Rosenberg, R. 2006. Collection and interpretation of Sediment Profile Images (SPI) using the Benthic Habitat Quality (BHQ) index and successional models. *NIVA report*, O-25072.

Nilsson, H. 2007. Grunnkart-SPI. *NIVA report*, O-25093.

Olsgard, F. 1999. Effects of copper contamination on recolonisation of subtidal marine soft sediments – an experimental field study. *Mar. Poll. Bull.* 38: 448-462.

Pearson, T. H. & Rosenberg, M. R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Ann. Rev.* 16: 229-311.

Prager, B. T., Caughey, D. A. & Poeckert, R. H. 1995. Bottom classification: operational results from QTC VIEW. OCEANS'95, *Challenges of our changing global environmental conference, San Diego, CA USA*, pp 1827-1835.

Preston, J. M., Collins, W., Mosher, D. C., Poeckert, R. H. & Kuwahara, R. H. 1999. The strength of correlations between geotechnical variables and acoustic classifications. Proceedings of IEEE Oceans '99. 3: 1123-1127.

Preston, J. M., and Kirlin, T. L. 2003. Comment on "Acoustic seabed classification: improved statistical method". *Can. J. Fish. Aquat. Sci*. 60: 1299–1300.

PRIMER (Plymouth Routines in Multivariate Ecological Research) 1994. Computer software package, version 6.1.6, *Plymouth Marine Laboratoy*, UK.

Quester Tangent Corporation 1997. Operator's Manual & Reference. Seabed Classification. *Quester Tangent Corporation, Canada.*

Quester Tangent Corporation 1999. CLUSTER Operator's Manual. 24 March 1999. *Quester Tangent Corporation, Canada.*

Redfield, A. C. 1958. The inadequacy of experiment in marine biology. In: Buzzati-Traverson, A. A. (Ed.), Perspectives in Marine Biology. *University of California Press, Berkley, CA*, pp. 17-26.

Rhoads, D. C. & Cande, S. 1971. Sediment profile camera for in situ study of organism-sediment relations. *Limnol. Oceanogr*. 16: 110-114.

Rhoads, D. C. 1974. Organism-sediment relations on the muddy sea floor. *Oceanogr. Mar. Biol. Ann. Rev.* 12: 263-300.

Rhoads, D. C., McCall, P. J., & Yingst, J. Y. 1978. Disturbance and production on the estuarine seafloor. *Am. Sci.* 66: 577-586.

Rhoads, D. C. & Germano, J. D. 1982. Characterization of organism-sediment relations using sediment profile imaging: an efficient method of Remote Ecological Monitoring of the Seafloor (REMOTS® System). *Mar. Ecol. Progr. Ser.* 8: 115-128.

Rhoads, D. C. & Germano, J. D. 1986. Interpreting long-term changes in benthic community structure: a new protocol. *Hydrobiologia.* 142: 291-308.

Riegl, B. M. & Purkis, S. J. 2005. Detection of shallow subtidal corals from IKONOS satellite and QTC View (50, 200 kHz) single-beam sonar data (Arabian Gulf; Dubai, UAE). *Remote Sensing of Environment.* 95: 96-111.

Riegl, B. M., Moyer, R. P., Morris, L. J., Virnstein, R. W. & Purkis, S. J. 2005. Distribution and seasonal biomass of drift macroalgae in the Indian Rivaer Lagoon (Florida, USA) estimated with acoustic seafloor classification (QTCView, Echo*plus*). *J. Exp. Mar. Biol. Ecol.* 326: 89-104.

Riegl, B. M., Halfar, J., Purkis, S. J. & Godinez-Orta, L. 2007. Sedimentary facies of the Eastern Pacific's northernmost reef-like setting (Cabo Pulmo, Mexico). *Marine Geology.* 236: 61-77.

Rooper, C. N. and Zimmermann, M. 2007. A bottom-up methodology for integrating underwater video and acoustic mapping for seafloor substrate classification. *Continental Shelf Research.* 27(7): 947-957.

Rumohr, H., Bonsdorff, E. & Pearson, T. H. 1996. Zoobenthic succession in Baltic sedimentary habitats. *Arch. Fish. Mar. Res.* 44(3): 179-214.

Rygg, B. 1995. Indikatorarter for miljøtilstand på marin bløtbunn. Klassifisering av 73 arter/taksa. En ny indeks for miljøstand, basert på innslag av tolerante og ømfintlige arter på lokaliteten. *NIVA rapport*, LNR 3347-95.

Self, R. F. L., A'Hearn, P., Jumars, P. A., Jackson, D. R., Richardson, M. D. & Briggs, K. B. 2001. Effects of macrofauna on acoustic backscatter from the seabed: field manipulations in West sound, Orcas Island, Washington, U.S.A. *J. Mar. Res.* 59: 991-1020.

Solan, M., Germano, J. D., Rhoads, D. C., Smith, C., Michaud, E., Parry, D., Wenzhöfer, F., Kennedy, B., Henriques, C., Battle, E., Carey, D., Iocco, L., Valente, R., Watson, J. & Rosenberg, R. 2003. Towards a greater understanding of pattern, scale and process in marine benthic systems: a picture is worth a thousand worms. *J. Exp. Mar. Biol. Ecol.* 285-286: 313-338.

von Szalay, P. G. & McConnaughey, R. A. 2000. The effect of slope and vessel speed on the performance of a single beam acoustic seabed classification system. *Fisheries Research.* 54: 181-194.

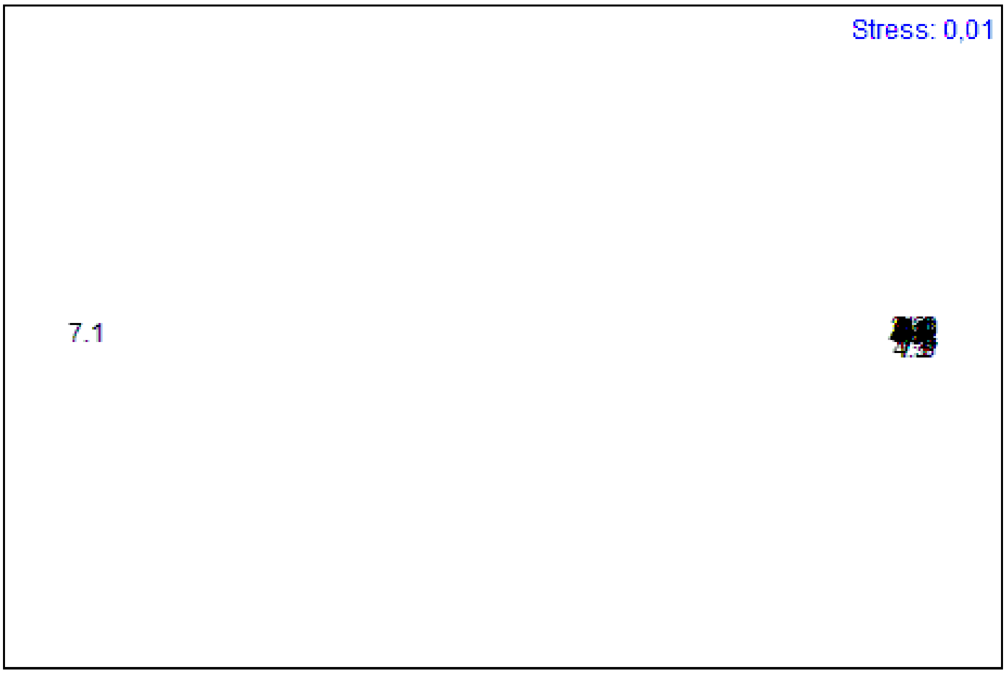
Valente, R. M. Rhoads, D. C. & Cabelli, V. J. 1992. Mapping of benthic enrichment patterns in Narragansett Bay, Rhode Island. *Estuaries*. 15(1): 1-17.

Wienberg, C. & Bartholomä, A. 2005. Acoustic seabed classification in a coastal environment (outer Weser Estuary, German Bight)-a new approach to monitor dredging and dredge spoil disposal. *Continental Shelf Research.* 25: 1143-1156.

Zar, J. H. 1984. Biostatistical analysis, Second Edition. *Prentice-Hall International, Inc., New Jersey*. 718 pp.

Appendix A

MDS plot of all the stations, marking 7_1 as an outlier.



Cluster analysis of all the multicorer tubes.