DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2008/19

The BALANCE project: Benthic marine habitat mapping and modelling in the Kattegat, Denmark

Mapping of hard bottom and sandy habitats and modelling seaweed forest on hard stable substrate

Karsten Dahl, Jørgen O. Leth,
Zyad Al-Hamdani, Jacob Carstensen,
Steffen Lundsteen &
Dennis Anthony

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2008/19

The BALANCE project: Benthic marine habitat mapping and modelling in the Kattegat, Denmark

Mapping of hard bottom and sandy habitats and modelling seaweed forest on hard stable substrate

Karsten Dahl, Jørgen O. Leth,
Zyad Al-Hamdani, Jacob Carstensen,
Steffen Lundsteen &
Dennis Anthony

A joint project between:
Geological Survey of Denmark and Greenland
The National Environmental Research Institute
The Royal Danish Administration of Navigation and Hydrography

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

CONTENTS

1. Introduction

This report summarises the benthic marine habitat mapping and modelling that took place in Kattegat as part of the activities within the BALANCE project funded by the BSR INTERREG IIIB Programme. The actual mapping project was carried out as a co-operation between The Geological Survey of Denmark and Greenland (GEUS), The National Environmental Research Institute (NERI) and The Royal Danish Administration of Navigation and Hydrography (FRV). The report presents the adopted methodology for detailed mapping of the seabed using the advanced acoustic techniques that can cover a large area of the seabed at relatively short time with high accuracy, on condition that it is combined with ground truthing by sampling and diving.

The quality of seabed habitat mapping on deeper waters was previously governed by the number of samples taken, their spatial coverage and density as well as the limitation of the available technology. Single beam echosounder systems that were available at that time provided limited information and coverage of the seabed, as the area they mapped was very small. Interpreted habitat maps were produced by extrapolating between tracks and the risk of overlooking important habitats was high.

New technologies such as multibeam sonar and high-resolution sidescan sonar available today enable us to construct detailed images of the sea floor in a considerably shorter period and to discriminate objects on the sea floor of decimetre size. The area can be surveyed acoustically with 100% coverage, which enables a full picture of the investigated area to be drawn. Both bathymetric as well as backscatter image of the seabed can be obtained now using only one survey system such as the multibeam echosounder.

The present knowledge of the biological components inhabiting the geological features of the seabed in open waters nearly all derives from small spots with a scale ranging from a core samplers to a relatively short transects of diver investigation or video inspection. Each of those small bits of information is often subjected to different but important structuring factors operating both on spatial scales from cm to many km as well as in time varying from hours (storm events) to year.

Identification and verification of key elements suitable to describe the present habitats in a robust manner in a given scale of space and time could provide a very useful tool for large scale spatial planning. The concept underlying this approach is that certain environmental factors needed to host specific species assemblages or communities.

The new acoustic mapping technologies combined with predictive models describing important key biological elements will have a wide range of applicability for the management of offshore resources as it will be demonstrated in the present case study.

1.1 Marine habitats and structuring factors

What is to be considered as a habitat depends on the organism or groups of organism that actually uses it. Hard substrate is the habitat for non-epiphytic macroalgal species and many sessile fauna organisms by itself. Epiphytic algal species use other organisms as substrate and fish species might use the entire seaweed forest including the substrate as their habitat. In this context, we have chosen the broad interpretation and considered the agglomerate of the surface sediment and biota as habitats.

The same type of sediment might encounter different habitat types due to differences in the physical environmental factors structuring the bio-geographical distribution of habitats. E.g. the sediment dynamic is an important controlling factor forming the overall way of living "on the sea bed" or "in the seabed" favouring "opportunistic" or "long living" lifestyles as well as effecting the overall species composition.

Solar radiation is another important factor controlling growth and production of seaweed forests. Light at the seabed depends not only of the actual water depth but also of the water quality. Substantial year to year changes in the development of total macro algal cover have been documented in the national Danish monitoring programme as a consequence of changing in nutrient loads (Dahl et al., 2005).

Salinity play a crucial role determining the number of species (Nielsen et al., 1995) as well as their spatial dominance of species (Dahl et al., 2001) found on a given location. The Baltic Sea is characterized by vertical and horizontal salinity gradients, which are especially profound in the Danish Straits. Effects of current velocities are also likely to structure the biological communities in open waters although it is not very well documented.

Finally, human disturbances from fishery or pollutants as well as stochastic differences in recruitment of species changing the community structure are factors that can change one type of habitat to another.

1.2 The geographic scope and geology

The case study areas are located in BALANCE pilot area 1 in Kattegat between the islands of Læsø and Anholt and the Swedish west coast (figure 1). The study area (a) is bordered by a flat seabed of 5m to 10m water depth to the northwest south of Læsø Island. To the north and east the depth increases considerably to 50m with a series of shallow grounds and intersections of canyon and valley like structures. The bathymetry map obtained from the multibeam survey reviles valleys with variable depths (up to ~120m) and of distinctive bifurcating characteristics. Within the study area (a) high-resolution studies have been performed in a sub-area named "*Den Kinesiske Mur*" (figure 2). The name of this sub-area refers to the characteristic presence of a distinct spectacular morphological feature elevating 8-10m from the surrounding seabed.

Study area (b), Lille Middelgrund, is a shallow ground in the Swedish Kattegat with water depths decreasing form 55m to 6m. The seabed is a complex of hard bottom (boulders, stones and gravel) and soft clayey and sandy sediments.

In the southern and central Kattegat the major geological architecture is dominated by the tectonically active Fennoscandian Border Zone, which has been recurrently active since Early Palaeozoic time (Liboriussen et al., 1987). Registration of present earthquake activity along this zone and the relationship to recent geological motion proves that it is still an active zone (Gregersen et al., 1996). During the Late Quaternary the northern Denmark and the Kattegat formed a structurally determined northwest-southeast trending basin parallel to the Fennoscandian border Zone (Lykke-Andersen, 1987). In this basin, most likely generated by subsidence, marine sediments have been deposited from the Saalian to the Holocene period. Seismic investigations suggest that the Quaternary deposits of the Kattegat possibly might be up to 250m thick.

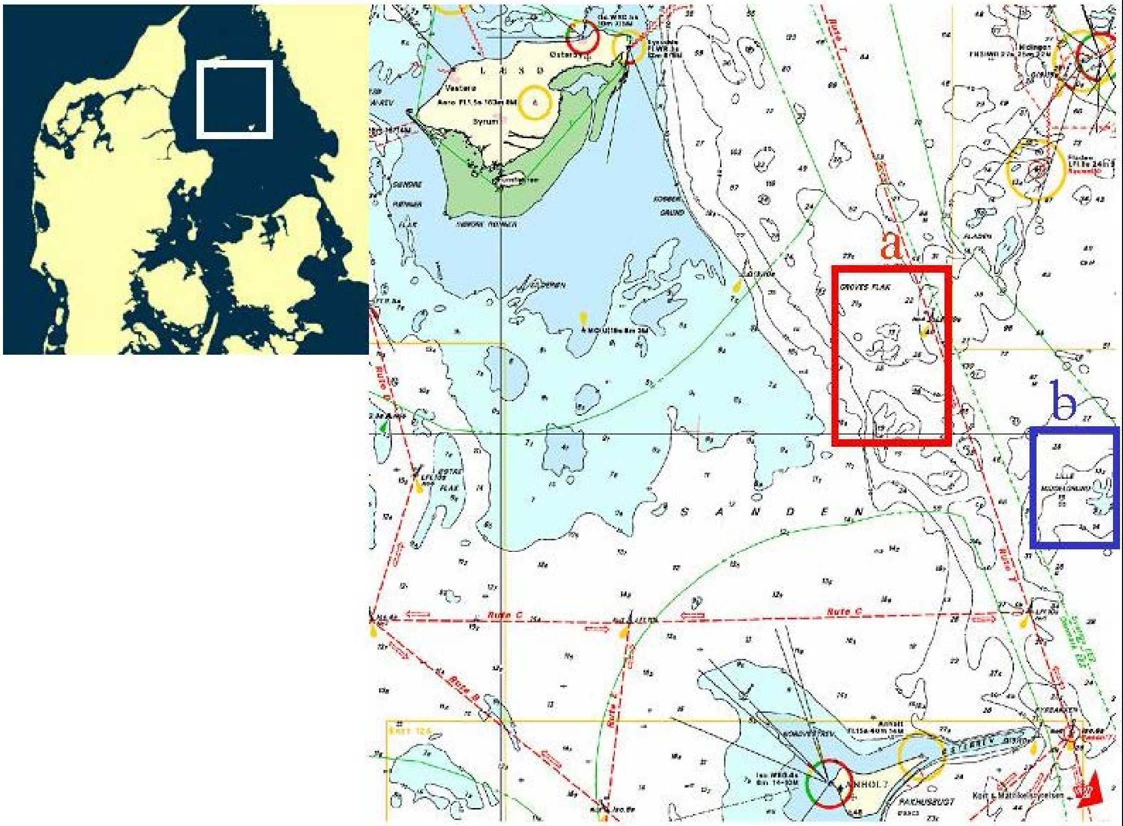


Figure 1. Case study areas within BALANCE pilot area 1 investigating hard bottom flora and fauna and sediment. Study area (a) at water depth between 14 and 120m (red box), and study area (b) Lille Middelgrund in Swedish waters at water depths between 15 and 50m (blue box). By permission of KMS: A.200/87.

Large parts of the southern Kattegat were deglaciated between 14.000 and 13.500 BP (Lagerlund & Houmark-Nielsen, 1993). At that time the Kattegat basin was relatively open towards the west and northwest, but later it became narrower as a result of the isostatic uplift (Bergsten & Nordberg, 1992). After the deglaciation, large areas were covered by marine water and fine grained sediments accumulated. The maximum inundation occurred between 13.500 – 13.000 before present (BP). A fjord-like estuary developed about 12.000 BP while large areas in the western part remained above sea level until middle Holocene. The distribution of Late Weichselian and Holocene sediments in the Kattegat is very uneven.

The Kattegat is located in the transition zone between the Baltic and the North Sea. It forms a relatively protected environment only little affected by tides. During the Holocene the hydrographic conditions changed several times, the most drastic change probably being the opening of the Danish Straits around 9.900 BP (Christiansen et al., 1993).

Like that the present structure of the southern Kattegat including the study area (figure 1) reflects the tectonic and glacial history. It is relatively shallow and can be regarded as a drowned glacial landscape. The presence of deeply incised valleys most likely is caused by a remnant of a river system draining the Kattegat to the north during late glacial period. It cuts into the surrounding seabed of glacial and late glacial sediments forming a non-depositional feature resulting from the permanent exchange of water between Kattegat and Skagerrak.

The distribution of reefs is directly linked to the complex deglaciation history and shoreline displacement of the Kattegat during the Late Weichselian period. After the maximum extension of the Late Weichselian ice sheet it retreated towards the northeast (Lagerlund & Houmark-Nielsen, 1993) leaving a series of recessional ice border stages behind. On the Kattegat sea floor the ice recession continued in the same direction, which explains the geographical distribution of morphological elements as been observed from the present study. However, the presence of the piles of boulders found in the Kattegat area is still a matter of discussion amongst geologists (e.g. Novak & Pedersen, 2000).

1.3 Aims

The aim of this work is to map is benthic habitats on hard substrate in selected case study areas within pilot area 1. The work is based on acoustic mapping methods focusing on the top layer of the sediment combined with extensive ground truthing made by video transects and diving, registering different seabed and biota elements. The applicability of the different biotic elements in space and time will be evaluated based on selected key biotic elements. The chosen elements represent increasing levels of biological information from empirical models describing the structural complexity of the seaweed forest expressed by vegetation cover in the photic zone to more complex community structure expressed by use of multivariate statistics of species composition. GIS maps will be produced showing the spatial distribution of key elements suitable to describe the benthic habitats within the scales of the selected case study areas.

2. Methodology

The National Environmental Institute (NERI) and The Geological Survey of Denmark and Greenland (GEUS) have jointly indulged in a field work campaign for mapping the designated area in pilot Area 1 of the BALANCE project (figure 1). Different geophysical remote sensing instruments were deployed in the acoustic mapping part and a suite of standard methods and procedures was followed in collating biological and sediment samples that range from core sampling to diver's observations and video footage. Additional data sets were acquired from different sources for the area of interest.

Subsequently, the fieldwork results were applied to the modelling of key biological elements and hard bottom habitats as well as to the preparation of seabed habitat maps.

2.1 Acoustic data acquisition

A bathymetry map of the study area (a) was obtained from The Royal Danish Administration of Navigation and Hydrography (figure 2). The map was produced from high-resolution multibeam echosounder data (figure 3) acquired in the survey area. The seabed topography and detailed structures can be observed very clearly from this map. This will aid the seabed classification endeavour together with the other remote sensing methods. Technical descriptions of the latter instruments are published in Dahl et al. (2006) and Leth & Al-Hamdani (2006).

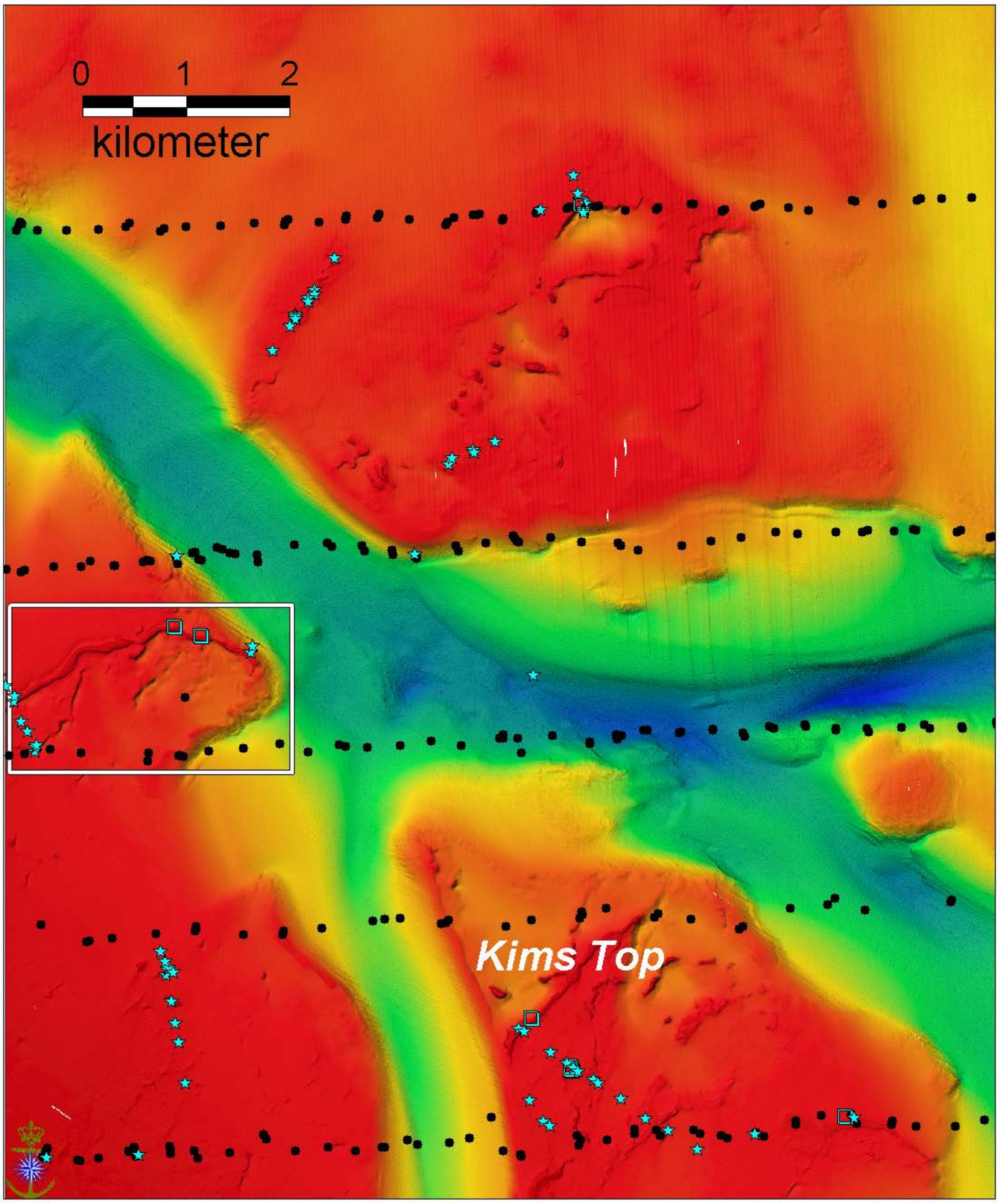


Figure 2. Multibeam bathymetry map of the study area (a) (figure 1) from The Royal Danish Administration Navigation and Hydrography showing sediment sampling stations (blacks dots), diving locations (open blue squares) and video transect stations (light blue stars). The white box shows the so-called "Kinesiske Mur" area where detailed studies have been performed. The reef area Kim's Top is also shown on the map.

Acoustical remote sensing data was also acquired during survey work in the designated area. The principle of the multibeam sonar is shown in figure 3. A digital sidescan sonar system with two frequency channels was used to map the upper layer of the seabed. The sonar was towed behind the survey ship and weighed to sink approximately one meter below the sea surface to avoid the ambient noise. This high-resolution sidescan sonar system (figure 4) produces a very narrow beam of 2º in the along-ship direction capable of producing a detailed image of the mapped seabed. The spacing between the survey lines was chosen to give 120% coverage of the surveyed area. This will ensure a full coverage of the seabed and enables the mapping of small objects from different aspect angles.

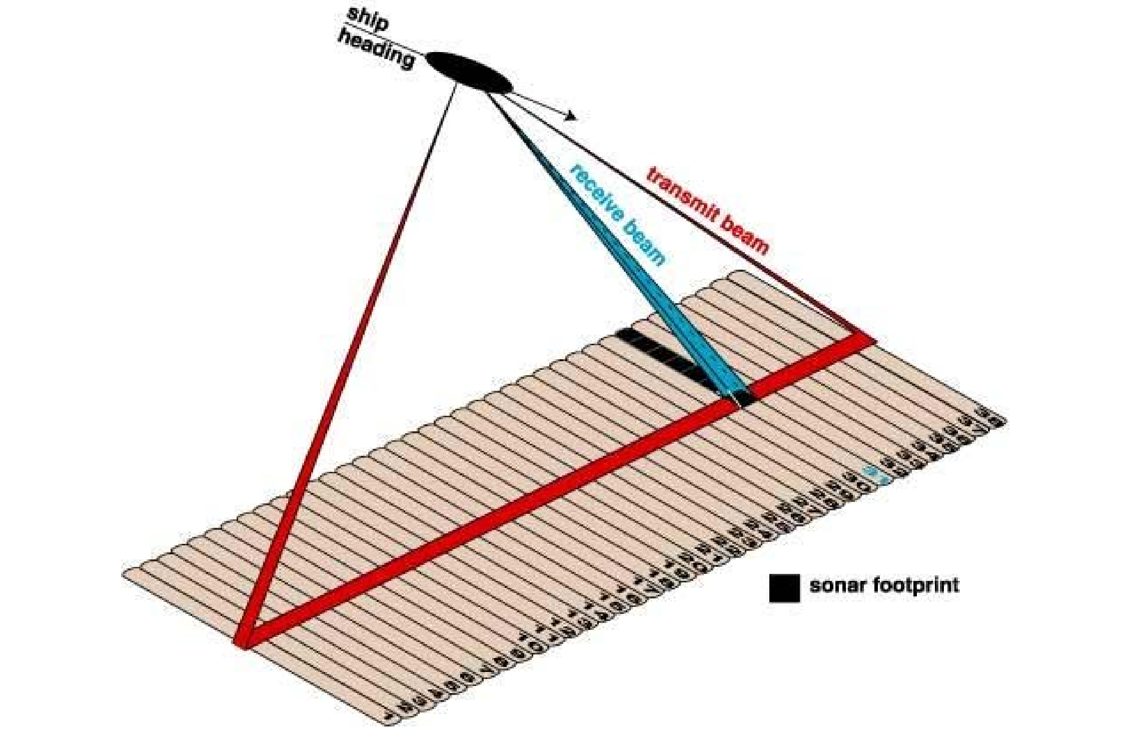


Figure 3. Schematic diagram of the multibeam echosounder operation principle.

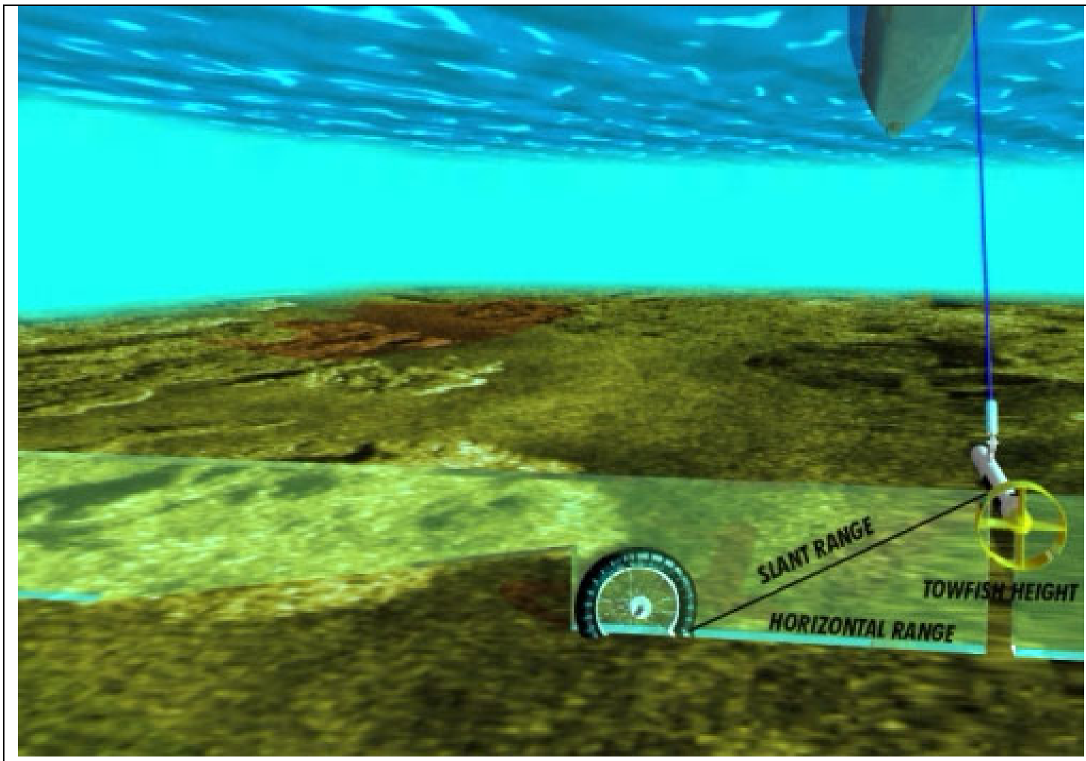


Figure 4. Schematic diagram of sidescan sonar operation. Source: l3Klein.

A seismic sparker system was also deployed during the fieldwork. This acoustic system maps the layers to about 50m depth below the seabed. It is a very useful tool for providing information on the seabed topography, the layers succession and continuity and seabed segmentation.

Information on the seabed sediments from pilot area (b) has been set at the disposal of The Geological Survey of Sweden (SGU) (figure 5). This map compiled by SGU is based on acoustic and seismic data combined with multiple ground truth data points. In addition to the sediment map SGU also provided the project with copies of the original sidescan data, which added essential information on the seabed structures and morphology. These combined data sets made up the basis for planning the video inspections of the sediment and the biota in the pilot area (b).

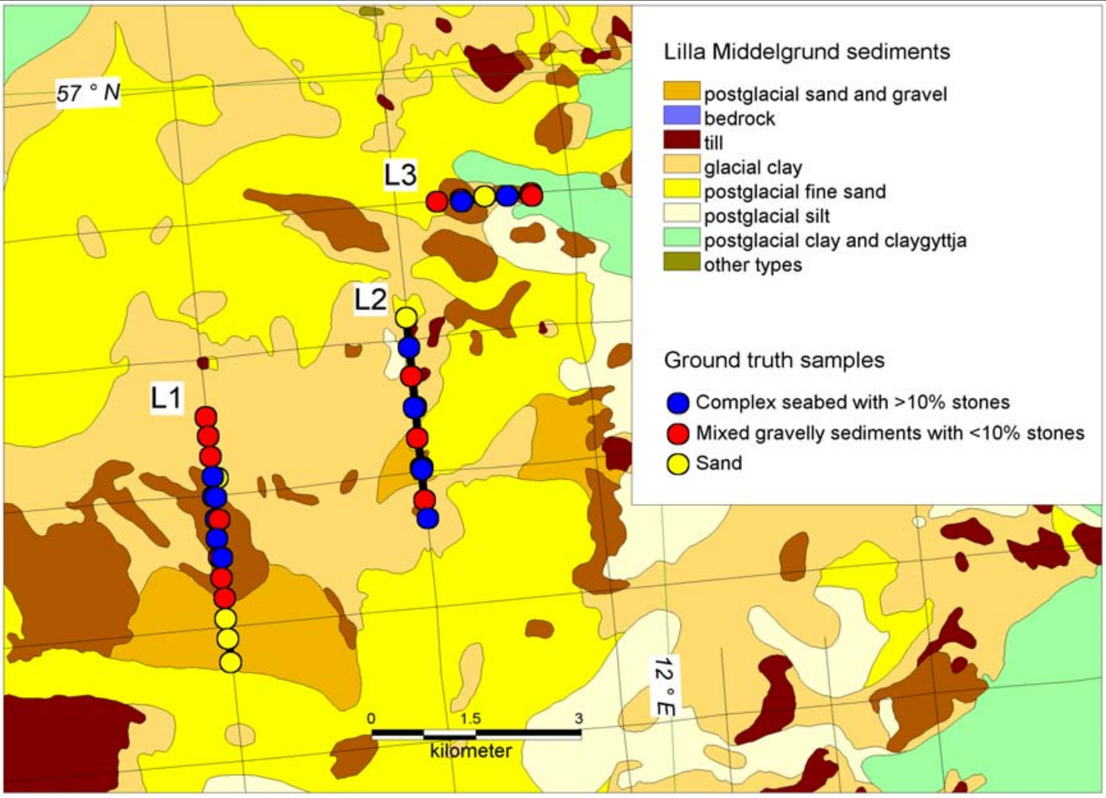


Figure 5. Investigations in the Swedish part of pilot area 1 at Lille Middelgrund, study area (b). The sediment distribution map is by courtesy of SGU. Full lines show the survey lines. The video stations are indicated by dots with colours following the newly classified sediment classes. Apparently there is a very nice correlation between the Swedish sediment classes and the ground truth information provided by the present study. "Complex seabed" ground truth sample overlay the "till", which is a complex glacial sediment normally with a high content of stones. The ground truth sample 'Mixed gravelly sediment' overlays partly the "postglacial sand and gravel", and partly the "glacial clay" with a surficial substrate apart from consolidated clay also consists of sand and boulders. The ground truth samples "sand" overlay nicely "sand and gravel" seabed types.

2.2 Biological data acquisition

2.2.1 Core sampling

Sediment samples for ground truthing purposes were collected at 310 stations along five transect lines in case study area (a) (figure 2) (Dahl et al., 2006). Subsequently these samples were analysed for grain size.

2.2.2 Video inspection

Furthermore, visual descriptions of the seabed sediment and biota were done along 9 video inspections transects in both case study areas (figure 2 and 5). The video inspection was carried out with a submerged video camera held just above the sea bed while drifting (figure 6). In situ description of sediment and biota was made directly watching a monitor onboard. Artificial light mounted on the video rig was used when necessarily. All sequences were recorded on DVD discs.

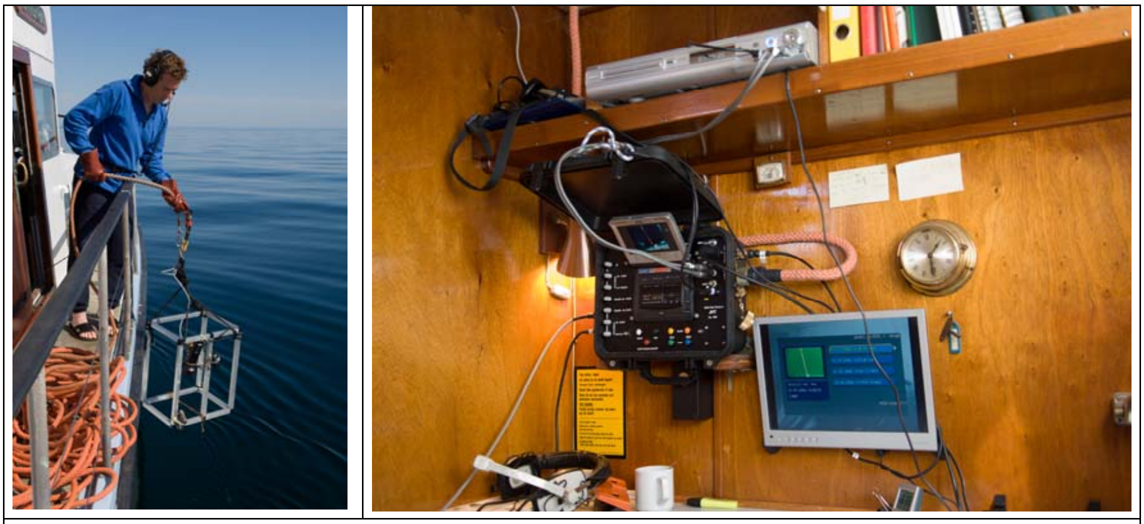


Figure 6. Underwater video system with monitor and hard disk/DVD recorder.

The video transects were planned based on

- The preliminary interpretation of the bathymetric map of the Royal Danish Administration Navigation and Hydrography covering case story area
- Point locations where the softbottom sampler failed (annex 1) with the aim to work in the parallel investigation performed by (NERI) in the Danish area
- Existing bathymetry and geological maps from SGU at study area (b), Lille Middelgrund.

The underwater inspection focused on a rough description of the average sediment structure between obviously changing types of sea beds as well as the general vegetation cover, cover of red and brown algal species and cover of larger recognizable algae and epifauna species. The covers of each of those groups were given in accordance to the substrate type on which they were registered. Cover of per-annual algal species and sessile fauna organism were given for stable hard substrate, opportunistic algal species and small per-annual algal species for unstable hard substrate and *Astropecten irregularis* for soft sediment, just to mention some examples.

The chosen nine transects were split into 60 sub-transects. On each sub-transect the seabed was observed during the drifting of the vessel of approximately 100m. If the seabed changed during the 100m then the sub-transect was further split in part *a* and *b*. Separate sediment descriptions were made for each part as well as the positions were registered whenever the seabed surface sediment changed composition (figure 7).

In addition seven points from the “soft bottom” transects were inspected where sampling failed to get sediment in the core. Furthermore two stations were inspected based on the bathymetric expression of the multibeam data indicating the presence of hard substrate.

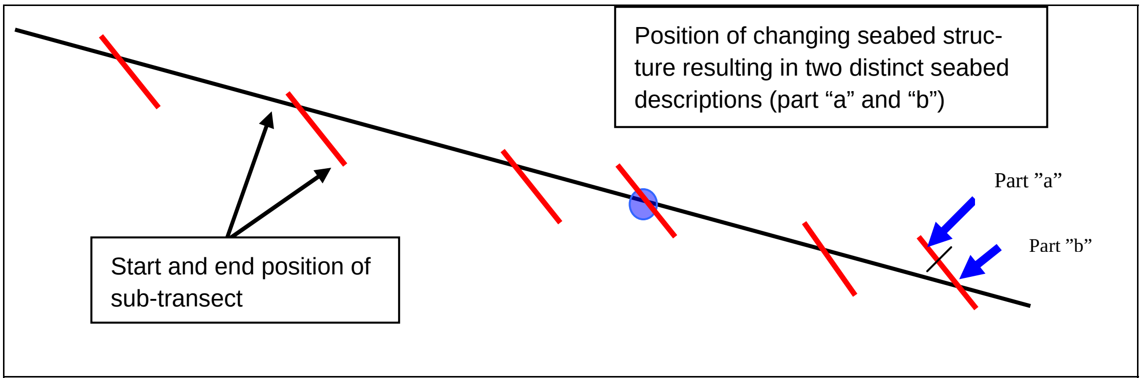


Figure 7. Example on transect with 6 sub-transects were television inspection took place (red color) and a dive investigation indicated by a blue point. One transect is divided in “part a” and “part b” due to changing seabed surface sediment composition.

2.2.3 Dive sampling

In addition, five dives took place at boulder reefs to gather detailed information on species composition of epifauna and macroalgae vegetation. Material was gathered from four of them. The data sampling followed the guidelines for the Danish National Monitoring programme (Krause-Jensen et al., 2004 and Lundsteen et al., 2004). The exact diving locations were planned during the cruise based on information gathered by the video inspection. Dive locations are shown in figure 2 and 5.

2.2.4 Additional data

Existing data on macroalgae and fauna of reefs sampled within as well as outside the case study area as part of the Danish National Monitoring Programme were included in the overall dataset for comparison. Macroalgae data from 2006 were used for more detailed analysis and comparison of the community structure.

A longer time series of macroalgae data from 1993 to 2006 were used for development of habitat models based on establish cause-relationships between marine benthic algal vegetation and different types of pressure elements.

For this part of the work physico-chemical data from monitoring stations in the vicinity of the stone reefs were extracted from the Danish National Marine Database (MADS) and included salinity, temperature, dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), total nitrogen (TN), total phosphorus (TP), chlorophyll-a (CHLA) and secchi depths. Sampling and chemical analysis were performed according to common standard guidelines (Kaas & Markager, 1999). Average concentrations of nutrients and Chlorophyll-a were calculated for the upper mixed layer (0-15m) whereas temperature and salinity were average over depths from 10 to 20m representing the typical depths of macroalgae point samples. The light extinction coefficient (Kd) was also measured at monitoring stations associated with nine out of the 22 reefs and less frequent than the other physico-chemical data.

Nutrient inputs (total nitrogen and total phosphorus) to the Kattegat, The Sound, and the Belt Sea from Denmark and Sweden were compiled from the Danish National Aquatic Monitoring and Assessment Program (DNAMAP) and the Swedish Agricultural University (www.slu.se). Nutrient inputs were aggregated for two periods prior to the macroalgae sampling: 1) January-June and 2) July-December in the previous year. Wind speed observations were obtained from two separate and partly overlapping time series at Sprogø located in the middle of the Great Belt (data source: Sund & Bælt Holding A/S) and Risø near Roskilde Fjord (data source: Dept. of Wind Energy, Risø National Laboratory). Irradiance data were obtained from the HC Ørsted Institute, Copenhagen University. Wind speed and irradiance observations were averaged for May-July, i.e. the primary productive period prior to monitoring.

2.3 Data analysis, sediment classes and habitat modelling

2.3.1 Analysing remote sensing data

The primary data set normally used for seabed discrimination and sediment mapping is the backscatter data obtained from the sidescan sonar system. This data set contains information on the type of the sediment which it reflects or is “scattered” from. It is well known that each sediment type constituting the seabed has certain characteristic acoustic impedance with respect to the incoming acoustic signal which makes discrimination from other sediment types possible. Then inspecting the backscatter image of the seabed can revile information on the type of the sediments whether they are “hard” or “soft” or sometimes “mixed” by nature. This information is manifested by the “brightness” or “darkness” of the grey tone backscatter image.

Another advantage of using the sidescan sonar system for seabed mapping is the shadow effect it produces as acoustic signal map the seabed. By the very nature of the side-looking sonar systems the incident angle of the acoustic beam is always inclined with respect to the seabed. So if there exists a large boulder or other seabed structures like a dune this will cause the formation of a shadow in the resulting image, and this can be readily interpreted by an experienced eye.

Dedicated software was used for sidescan data analysis and presentation, where the survey lines are geo-referenced and combined together. The combination process is called mosaicing and is an important step in the interpretation process.

The multibeam bathymetry dataset provides information on the seabed topography and elevation. Large boulders or reef structures can be observed with this type of data. So combining these two sources of information can yield a seabed map which is fairly reliable especially when mapping and interpretation is performed by an expert's judgement.

Apart from the multibeam bathymetry data the multibeam backscatter data has been used for a broadscale classification of the entire study area (a). After processing the backscatter values they were imported into GIS, from which the values were presented as a gray shaded plot/backscatter image. The newly classified sediment information was overlaid on the backscatter map to test if the backscatter picture can be used to predict the actual sediment type. Areas of fine-grained sediments (mud) have been delineated due to the low reflectivity and by that light colours. For the sandy seabed types it was not possible to differentiate between different grain sizes. Therefore, this seabed type was merged into one class called sand. Areas of mixed sediments can be delineated from the backscatter picture. Areas of high reflectivity expressed by dark colours in the backscatter picture coincide with ground truth samples where the stone coverage of the seabed is more than 10 %. The resulting map of this broadscale classification is presented in fig. 13.

In addition to the mentioned acoustic data sets newly acquired seismic data was used to support the interpretation of the sub-bottom structures and large morphological features on the seabed.

2.3.2 Seabed sample analysis and classification

The following chapter describes briefly sediment classes used in the two ground truth data sets for classification.

Seabed classification used for the video inspection and dives:

- Mud with few (< 10 % cover) of small stones.
- Coarse sand (2 - 20mm).
- Coarse sand (2 - 20mm) with few (< 10 % cover) stones or boulders.
- Gravel (dominance of smaller stones 20m-100mm). In general this is unstable substrate for epibenthos.
- Reef (≥80% seabed covered with stable hard substrate usually boulders of more than 10cm in diameter but it might be 5cm at the deepest locations with less physical stress.

- Reef with 10 - 80% hard stable substrate and > 20% coarse sand
- Reef with 10 - 80% hard stable substrate and > 20% sand
- Sand (0,2-2mm)
- Sand (0.2 - 2mm) with few (< 10 % cover) stones
- Sand and coarse sand 0,2-20mm

These classifications take into the account the sediment stability judged, when possible, by the actual presents or absence of epiflora and epifauna. General descriptions and differences in biota elements were analysed based on this seabed classification.

B. Classification based on core samples analysis:

Out of 310 attempts to sediment sampling along the five transect lines in case study area a total of 112 samples were successfully taken and selected for grain size analysis at the GEUS sediment laboratory. The grain size classification used in the laboratory is the defined in the Larsen et al.(1995):

- Silt and clay (< 0.063mm)
- Sand, fine (0.063mm – 0.200mm)
- Sand, medium (0.2mm – 0.6mm)
- Sand, coarse (0.6mm – 2 mm)
- Gravel (> 2mm)

The grain size scale used ends at gravel as none of the core samples collected composed coarser fractions than gravel due to the sampling method.

Subsequently, the sediment information from the diving/video inspection as well as from the sediment laboratory analysis were gathered and re-classified into four new classes characterising the sediment types of the area under investigation. The new classes are:

- silt and clay
- sand (fine – coarse)
- mixed gravely sediments with < 10% stones
- complex seabed with >10% stones

The sidescan data obtained from fieldwork in the designated sub-area named “Den Kinesiske Mur” within study area (a) have been processed, geo-referenced and combined into a mosaic. These data allows a resolution in decimetre scale. The classification of the sidescan picture has been performed by analysing squares of 50 x 50m. This method has previously been developed and applied in the habitat mapping project at Læsø Trindel in the northern part of the Kattegat, Denmark (Leth et al. 2007). Subsequently, the seabed of the area was classified into the newly defined 4 sediment classes extrapolating the sidescan picture and ground truth information (sediment samples, diver and video) throughout the area. However, only 3 classes have been found, as no silt and clay is present.

2.3.3 Multivariate analysis of biota and surface sediments

The statistic analyses of algal communities were performed using the PRIMER software programme (Carr, 1997 and Clarke & Gorley, 2001). PRIMER is a non-parametric multivariate statistical programme designed for analysis of species communities, requiring no specific distribution patterns of individual species. Comparisons between groups of samples are based on the Bray-Curtis similarity index (Bray & Curtis, 1957), where levels of significances are calculated with the ANOSIM (Analysis of similarity) procedure, a parallel to a common analysis of variance (ANOVAR). The ANOSIM procedure also calculates a Global R-value, which indicates similarities between groups of samples. Global R ranges between 0 (equal) to 1 (all replicates within site are more similar to each other than any replicates from different sites) but Global R can in principle also be –1, if each replicates from one site is more similar to a replicate at another sites.

Similarities between individual samples are visualized in **M**ultidimentional **S**caling **P**lots (MDS-plots) where calculated stress values indicate how well the data are presented in two dimensions. Stress values between 0.10 and 0.20 indicate that the plot gives a reasonable presentation of the similarities. Values between 0.10 and 0.05 give a good presentation and values below 0.05 express that the visualization is excellent.

2.3.4 Empirical models describing macroalgal cover

Background statistically analysis has been done to establish cause-relationships between the response in macroalgae vegetation on hard substrate and

- water quality elements like water concentrations of DIN, DIP,TN, TP and Secchi depth, nutrient load of nitrogen and phosphorous,
- biological factors like drifting algal mats and presence of sea-urchine (grassing) and
- climatic factors like radiation and physical stress induced by wind.

Based on these analyses which will be reported in Jacobsen & Dahl (in prep), two habitat models have been developed, both dealing with vegetation cover on hard stable substrate. In both cases, empirical relationships are identified between the development of benthic macroalgae vegetation and a number of important factors controlling this vegetation. Large variations in pressure and response both in space and time registered in the period 1993-

2006 have facilitated the development of the models. Both models are based on General Linear Models framework with an appropriate transformation of data.

The first model describes total vegetation cover of erect macroalgae vegetation as a function of location, water depth, nutrient load (from January to July) diver and cover of sea urchins. This model is a further development of a previous work by Dahl et al. (2005) including important biotic elements such as sea-urchin grassing drifting algal mats in the analysis. This model is presumed to be the most robust as total cover is relatively easy to collect. However, the model has the disadvantage that it is restricted to reef areas with water depth deeper than 12-14m where total erect macroalgal covers is less than 100%.

The second model describes the cumulated cover of all reported erect macroalgal species. This model was first investigated with a similar model as for total vegetation cover assuming a maximum attainable cover of 300%. However, cumulated vegetation cover does not show the same tendency to reduced variation around 300% as total cover does close to 100%. Therefore, the cumulated vegetation cover is described using a linear model.

Cumulated vegetation cover was first investigated with a similar model as for total vegetation cover assuming a maximum attainable cover of 300%. However, cumulated vegetation cover does not show the same tendency to reduced variation around 300% as total cover does close to 100%.

Therefore, cumulated vegetation cover is described using a linear model. The second model describes the cumulative erect macroalgal cover as function of the same variables as the first model. The data for this model is presumably more variable due to the more difficult task describing multi-layered vegetation. On the other hand, the advantage of the cumulative model is that it also works on shallow water until wave exposure becomes an important factor. A necessary assumption for the model estimation was a 6m water depth limit above which physical exposure was assumed to decrease the cumulative cover.

2.3.5 Key species groups and benthic communities

Spatial distribution of key benthic species or algal assemblages' described from the video transects and whole communities described by divers and subsequent species identification in the laboratory is analyzed according to location and depth within the two case study areas. The analysis is done using the multivariate statistical software package PRIMER (Clarke & Gorley (2001).

2.4 Seabed classification using remote sensing

The results achieved in the backscatter analysis are presented in two parts. Firstly, the results from "*Den Kinesiske Mur*" using combined data obtained from sidescan sonar survey, acquired multibeam data and ground truthing data (annex 2), and secondly the analysis of the entire case study area (a) where backscatter data from multibeam survey and ground truthing data were used for sea bottom sediment segmentation (figure 2).

The area was partly known beforehand from previous diving as hosting spectacular reef areas. Analysis of the two acoustic data sets has been performed independently to demonstrate the strength and limits of each method with respect to the characterization of the seabed.

During the multibeam mapping campaign performed by The Royal Danish Administration Navigation and Hydrography the backscatter part of the acquired data have been recorded. Seabed classification based on sidescan data.

The resulting classification of the seabed sediments from the sidescan data presented in figure 8 indicates that complex seabed types dominate the area. According to the newly defined sediment classes we distinguish between two classes of complex seabed according to the stone density. A spectacular structure – *"Den Kinesiske Mur"* - having a dense coverage of stones is crossing the area from the southwest to the northeast. More similar but less dominating structures are seen scattered in the centre of the area. In the central part the seabed is mostly covered by coarse sand. The surrounding seabed is mostly sandy.

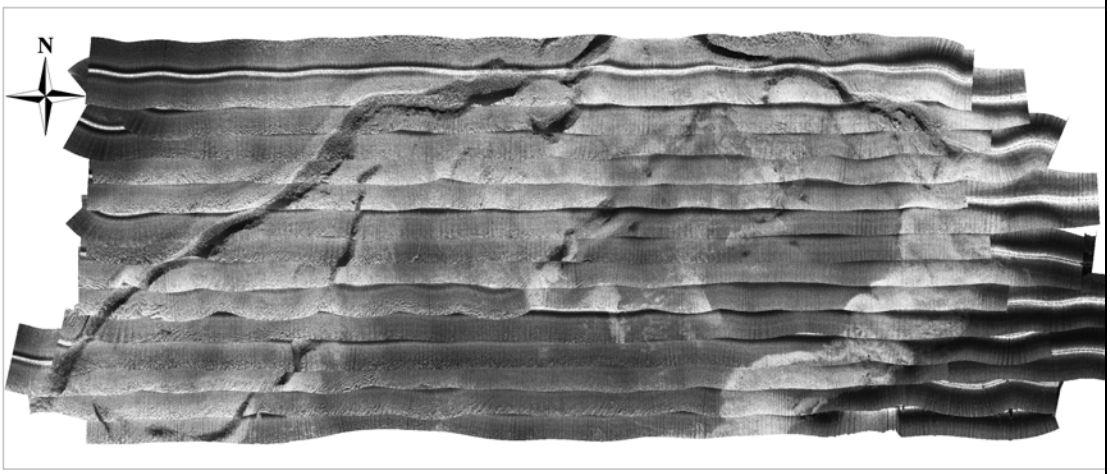


Figure 8. The sidescan data acquired by GEUS merged into a mosaic. Box dimension approximately 1 x 3 km.

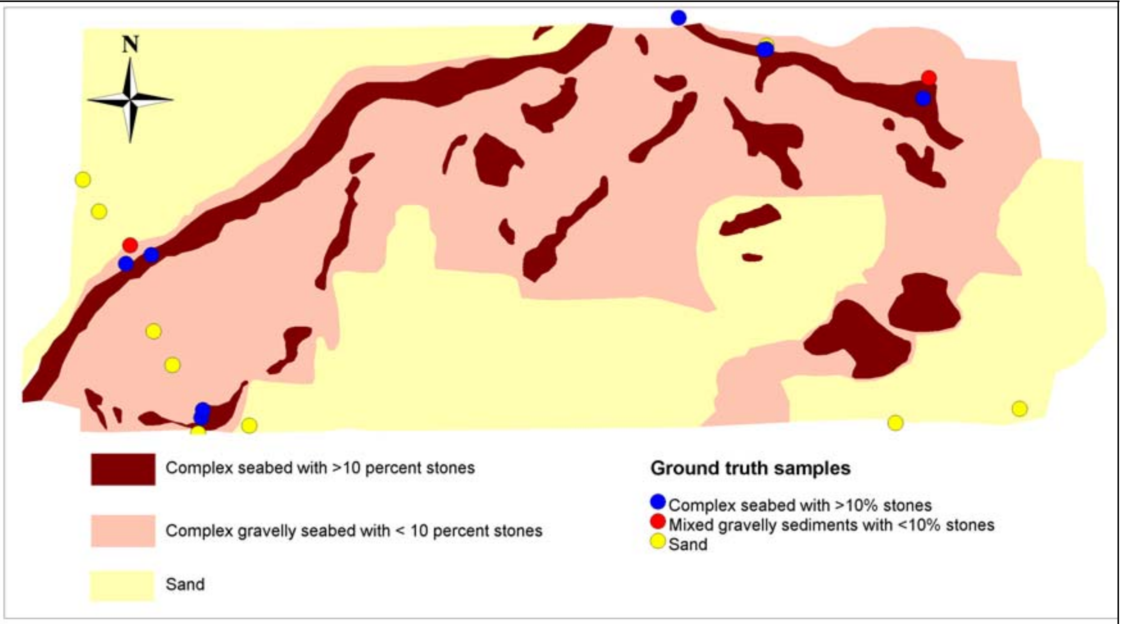


Figure 9. Seabed sediment map classified according to the defined seabed types (left colour boxes). No silt and clay have been found in the area. All available ground truth samples plotted on top of the sediment map.

Based on the high-resolution multibeam bathymetry data of the study area (figure 9) the morphology of the seabed has been analysed in details to add essential information on the complexity of the sea floor. By use of the Fledermaus® software, which allows a 3D-display of the bathymetry, a manual classification of the morphology was performed defining 6 classes. Their spatial distribution is presented in figure 10.

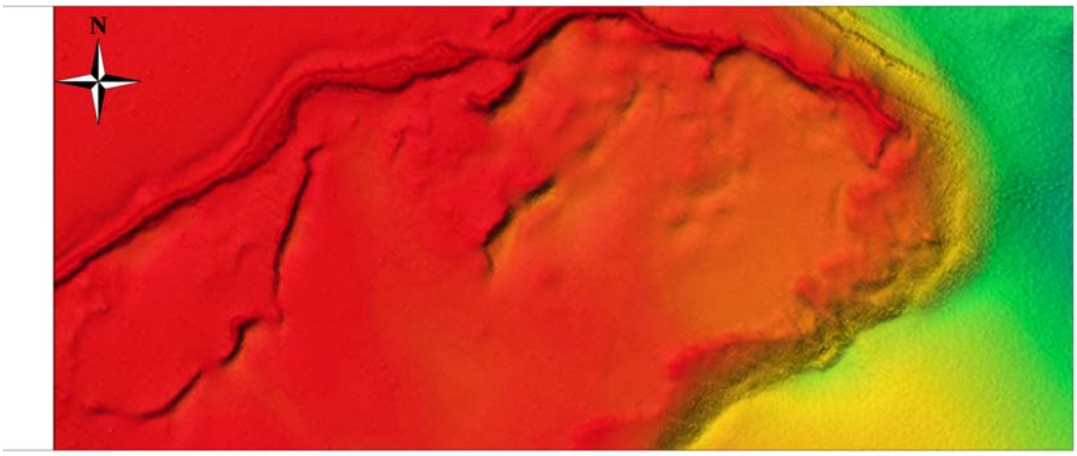


Figure 10. Multibeam sonar bathymetry data. The depth of the area is ranging from approximately 12 to 80m. By courtesy of The Royal Danish Administration Navigation and Hydrography. Box dimension approximately 1 x 3km.

The resulting seabed map produced by overlaying the sediment map with the morphology map is a high resolution seabed map with detailed information on the physical state of the seabed which is very useful in the prediction of the benthic habitats which is closely linked to latter parameters (figure 10). The two complex seabed types where stones are present are the most significant in relation to reef habitats. It appears from figure 10 that the ridges with steep slopes for the most parts are overlapping the complex seabed with high content of stones, however, a continuation into the sloping seabed is recognised. The distribution of the complex seabed with a low and scattered content of stones appears together with a wide range of different morphologies from the even seabed type in the shallow central part to even seabed type at deeper water including the sloping seabed. The hummocky seabed type is seen to overlap a frequent appearance of the complex seabed types.

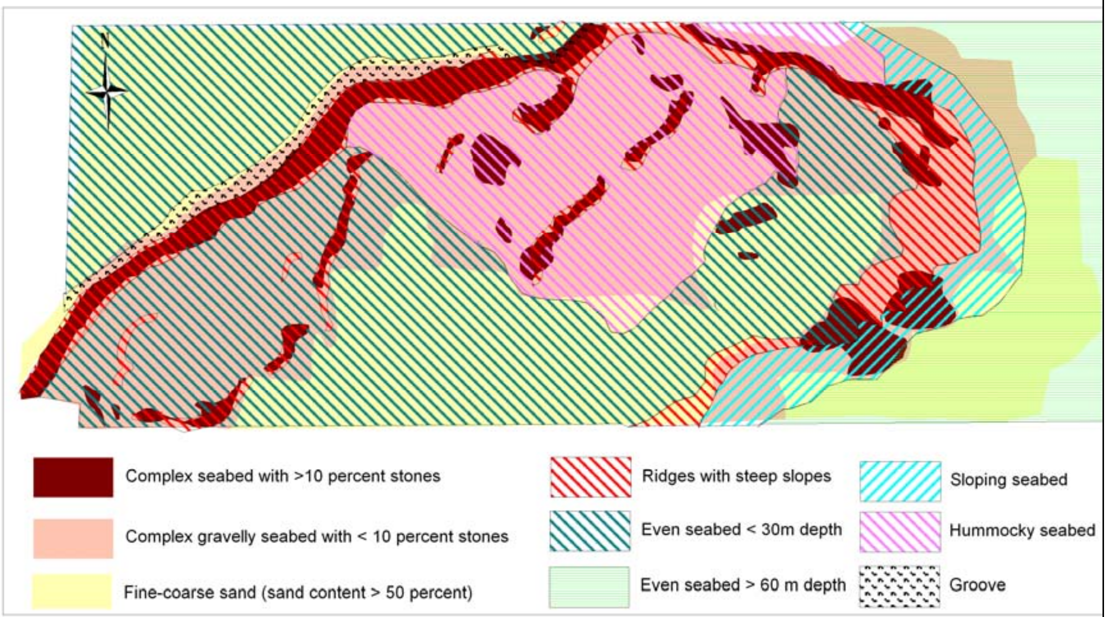


Figure 11. The resulting map overlaying the seabed sediment map with the morphology. Box dimension approximately 1 x 3 km.

The two sets of seabed classification are both build upon acoustic remote sensing techniques. It is evident, that the latter systems are supplementary to each other in the description and characterization of the physical properties at the seabed. When calibrated with ground truth information the aim of preparing habitat maps can be fulfilled. It can be concluded that the combined approach is a useful tool providing information in relation to delineate areas of Natura 2000 reef habitats.

2.4.1 Seabed classification based on multibeam backscatter data

The multibeam echosounder is a device used not only for mapping the depth of the seabed but it can also provide information on the reflectivity of the same seabed which we call the backscatter dataset. The backscatter dataset is very similar in nature to that obtained from a sidescan sonar system; the only difference is in the resolution. As it was mentioned earlier, the very narrow horizontal beam angle of the sidescan sonar and its low aspect angle with respect to the seabed results in a high resolution backscattered seabed image (figure 4). On the other hand the relatively wider beam angle of individual beams generated by the multibeam echosounder causes the resulting seabed image to be of lower resolution than that obtained from the sidescan system.

Multibeam data sets were provided by The Royal Danish Administration Navigation and Hydrography. They represent two sets of data; the first is the detailed bathymetry of area (a) under consideration (fig. 2), and the second is the backscatter data obtained from the same multibeam survey (fig. 12).

The bathymetry map shows a distinctive canyon-like structure going from north to south and has several branches. It is very deep at some locations reaching up to 127m. The figure also reviles area of variable topography that is very shallow at some locations to about 14m depth near Kims Top (see fig. 2 and Annex 3).

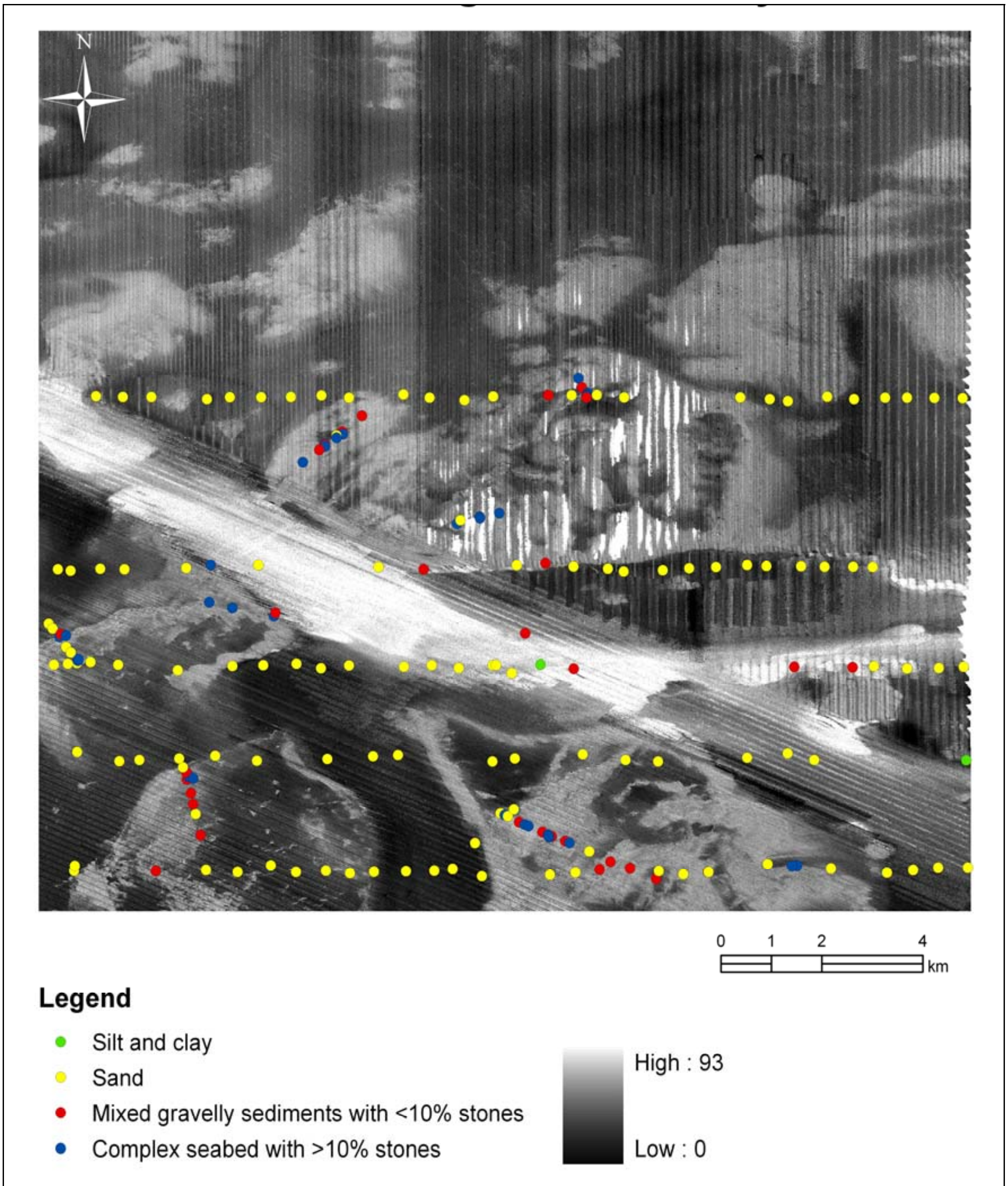


Figure 12. Backscatter image of the study area (a) including the ground truth positions. The location of the section is shown in figure 1.

The backscatter image of the same area shows regions of hard and soft substrates as well as some mixed sediment regions. The image resolution is not very high but still the differences in sediment reflectivity are obvious and can be used to zone areas of different sediment types.

The ground truthing with video and diving confirmed in all cases the preliminary expert judgement of the presence of reef areas, solely based on pronounced bathymetric elevations from the surrounding seabed (figure 2) on the multibeam bathymetry. It can be concluded that a substantial numbers of small and large reefs are present within the three bank areas, *Groves Flak* in the northern part of study area (a) (Annex 3), *"Den Kinesiske Mur"* and the area south of this huge feature and the area around Kim's Top.

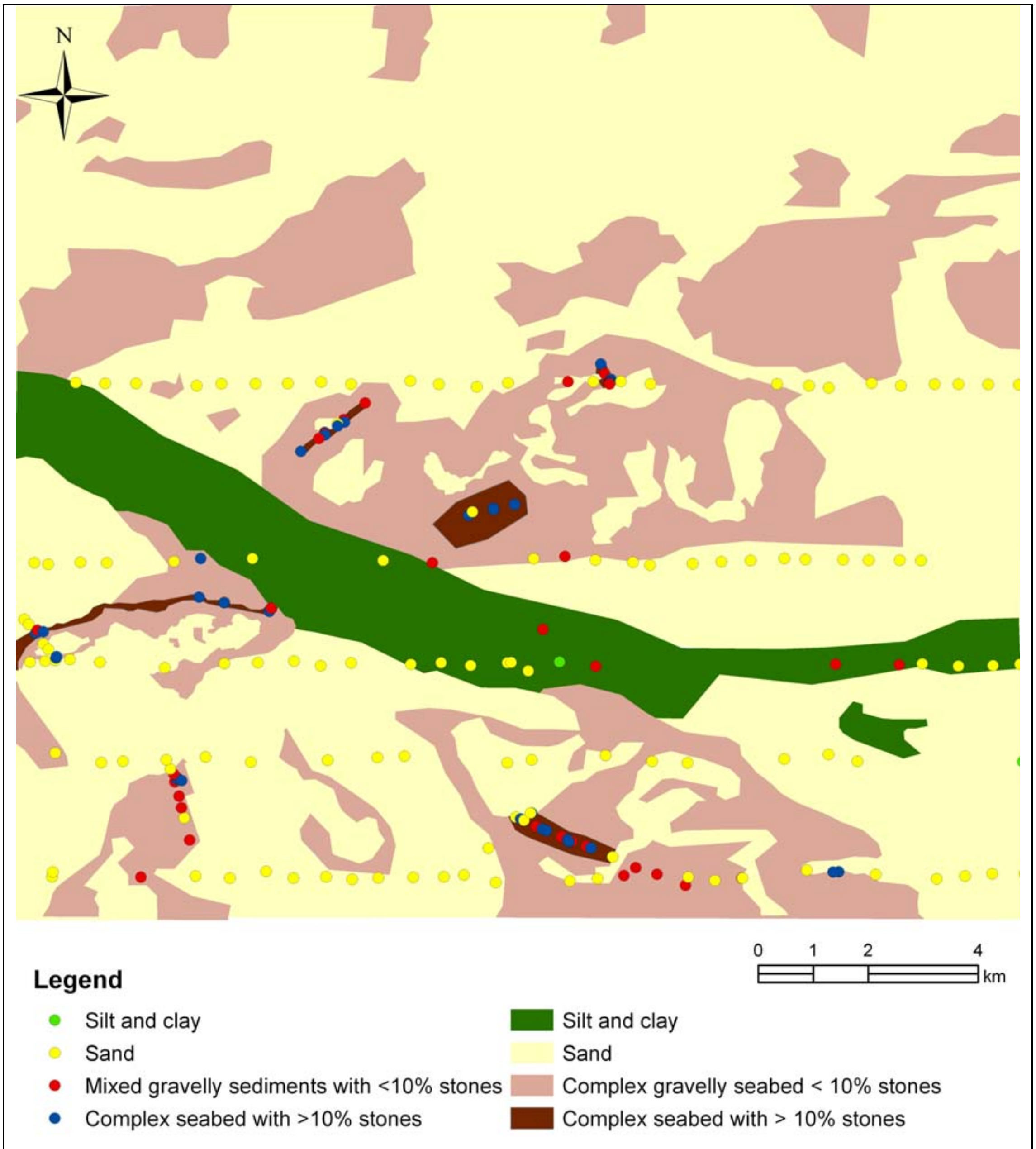


Figure 13. Seabed classification based on the interpretation of the backscatter image

The ground truth samples locations were also drawn on the backscatter image. These samples are either grab samples or divers and video description. The ground truth information as well as the bathymetry and seabed topography are all used to aid the classification and interpretation of the backscatter image. The resulting classified seabed is shown in figure 13.

2.4.2 Sediment characterisation from ground truthing

Based on the classification system used for the visual observations of the seabed three different types of reefs was found in 39 cases, gravel beds was observed in 6 cases, sand and coarse sand in 20 cases, mixed mud with few stones in 3 cases and sand and coarse sand mixed with few stones in 32 cases.

A multivariate analysis of the seabed types was performed using an ANOSIM test in the PRIMER statistical package (Clarke & Gorley, 2001). At all types they are significantly different (P<5%), except the three groups: “coarse sand” / “coarse sand with few stones”, “coarse sand” / “reef with coarse sand” and “sand-coarse sand” / “sand with few stones”.

The relative difference between each of the described seabed types expressed by Bray-Curtis similarities (Bray and Curtis, 1957) are shown in the MDS plot in figure 14.

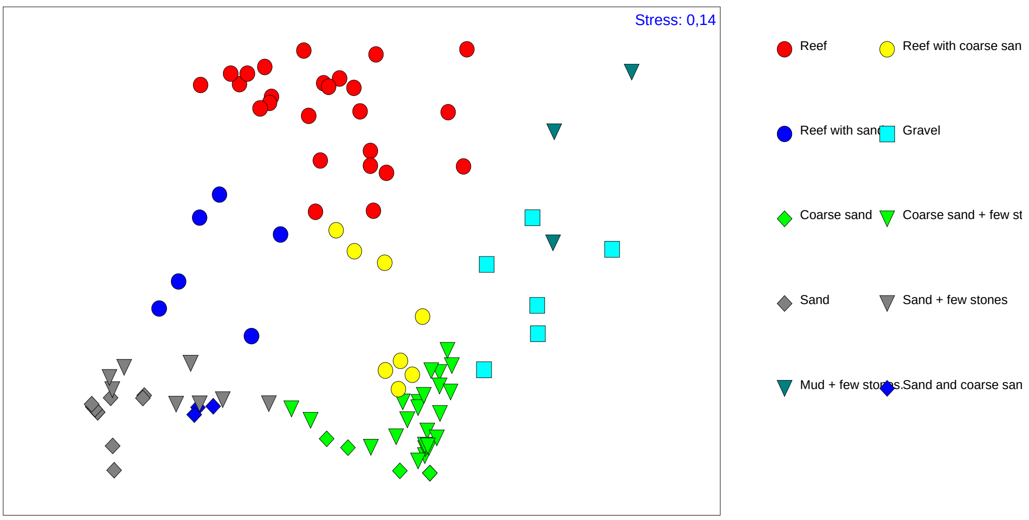


Figure 14. MDS plot of seabed types characterized by Bray-Curtis similarities of the percentage surface sediment composition.

Stone reef areas were identified in all cases where they were expected solely based on a visual interpretation on the bathymetric map. Beside those reefs clearly rising from the surrounding seabed a few deepwater locations with a surprising high surface cover of stones were localized in both the Danish and Swedish area.

Stone reef areas were identified in all cases where they were expected solely based on a visual interpretation on the bathymetric map. Beside those reefs clearly rising from the surrounding seabed a few deepwater locations with a surprising high surface cover of stones were localized in both the Danish and Swedish area.

2.5 Classification and identification of biota elements for habitat modelling

Based on the video inspection it is possible to make a very rough characterization of major epibentic biota elements along the transects, sub-transects and part of sub-transects.

2.5.1 Hard bottom

It was not possible to distinguish between the recognisable epibentic biota elements sitting on hard substrate described for the three different reef types "reef", "reef with coarse sand" and "reef with sand" using an 2-way crossed ANOSIM test (Significance level >40% in both global as well as pair wise tests).

Table 1. 2-way ANOSIM test for difference between reef types and depth groups.

		Global R	Significance level (%)
Reef type	**Global test**	0,005	45,1
	Pair wise test		
	Reef / reef with sand	0,019	40,9
	Reef / Reef with coarse sand	0,003	43,2
	Reef with sand / Reef with coarse sand	-1,55	66,7
		Global R	Significance level (%)
Depth group	**Global test**	0,292	0,2
	Pair wise test		
	Groups	R Statistics	Significance level (%)
	10-15m / 15-20m	0,209	1,0
	10-15m / 20-25m	0,665	0,3
	10-15m / 25-50m	-	*
	15-20m / 20-25m	0,019	37,7
	15-20m / 25-50m	0,458	20 **
	20-25m / 25-50m	0,556	10 **

However, there was a significant effect of depth on the overall dataset (Significance level 0.2%) and between some of the dataset separated in 5m depth intervals (table 1). As a result of this analysis data from all three types of hardbottom sea bed types were aggregated before further analysis. The effect of depth on the recognizable biota elements on the joint dataset of reef types is visualized in a MDS plot in figure 15.

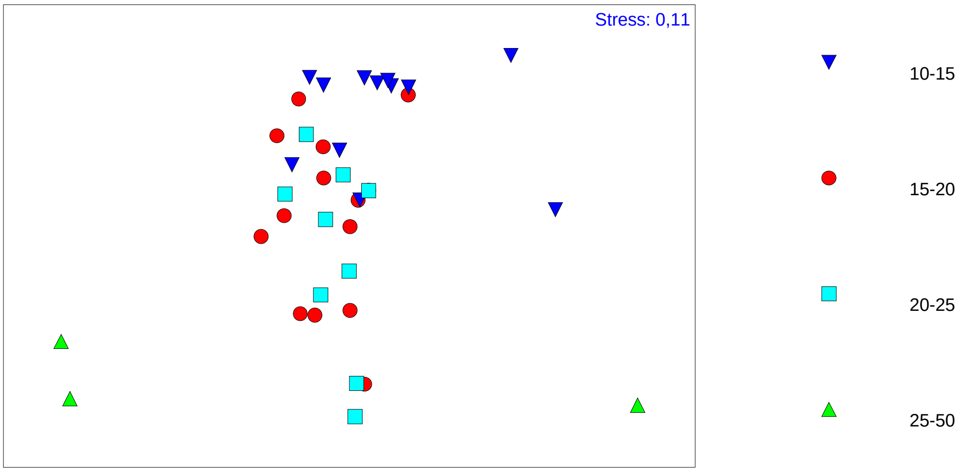


Figure 15. MDS plot of major epibentic biota elements from different depth intervals in case study area (a) and (b) in pilot area 1 in Kattegat

Biota on hard stable substrate was dominated by macroalgal vegetation at the most shallow stations investigated. Erect macroalgal vegetation covers the stable hard substrate completely down to approximately 15m water depth in 2006 (figure 16 A). Below this water depth the vegetation cover gets thinner. Erect algal species cease to grow between 23 and 27m.

Algae belonging to the groups brown and red algae are both common at 10-15 water depth but the red algal group dominate at deeper water (figure 16 B and C). Variation in brown and red algal cover between locations having the same water depth within the case study area is very huge.

Large brown algal species predominantly the kelp *Laminaria digitata* is most often the dominating species with a cover exceeding 40% from the shallowest investigated station at 10m water depth down to 15-16m depth. The soft coral *Alcyonium digitatum* is most common between 18 and 25m depth (figure 16 D) but the variation is also huge for this species.

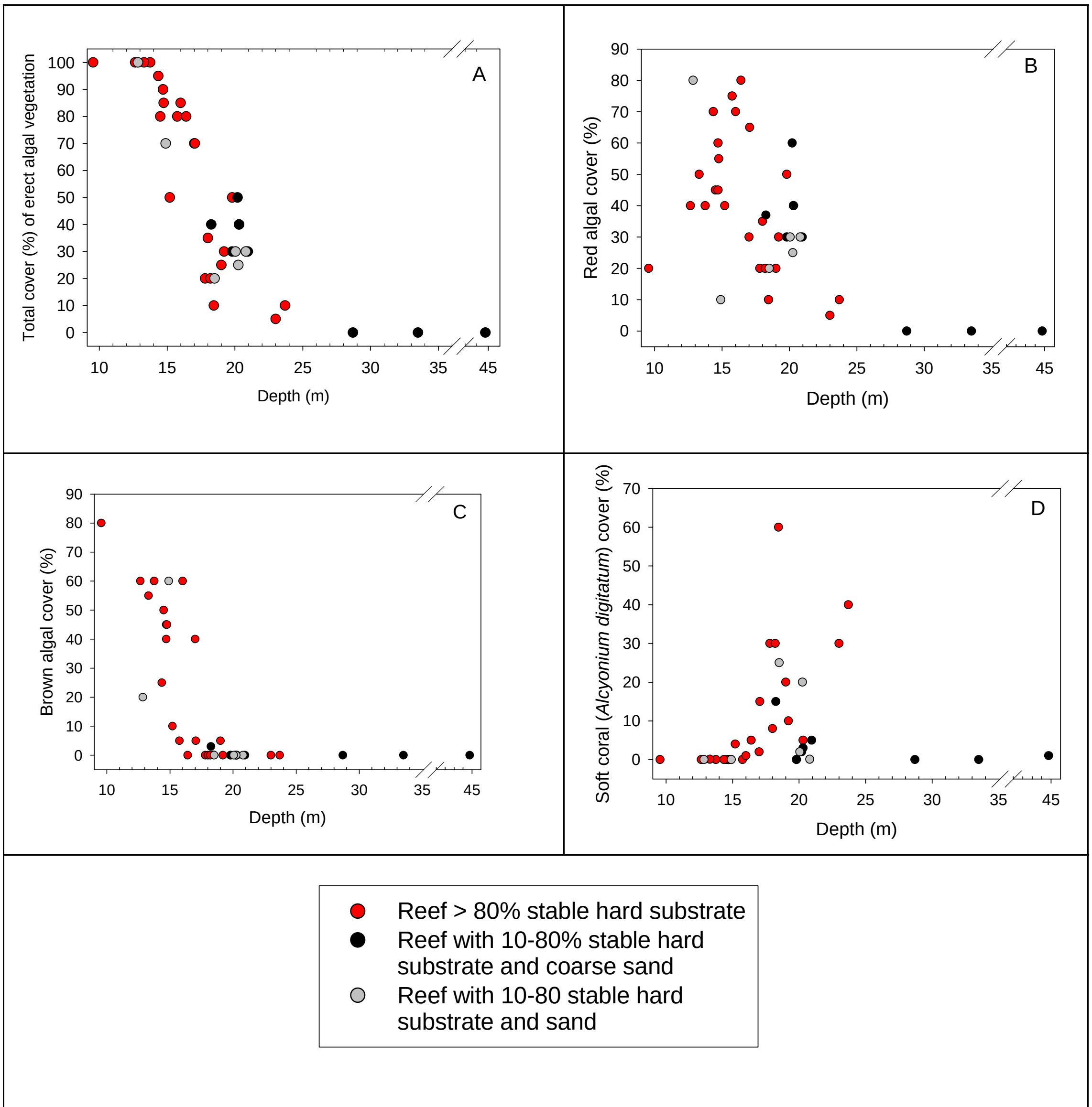


Figure 16. Cover of total erect macroalgal vegetation (A) total erect red (B) and brown (C) algal vegetation as well as total cover of the soft coral Alcyonium digitatum (D) on stable hard substrate at 3 different types of reefs described by used of submerged television camera.

2.5.2 Biota on other sea bed types

Visible biota on top of sand and coarse sand sediments is extremely scarce. Species of starfish, *Asterias rubens*, *Marthasterias glaciale* and *Astropecten irregularis,* were the most common species and in a few cases next to reef areas huge amounts of the brittlestar *Ophiocomina nigra* were present.

Unstable substrate like gravel beds and sandy sediments were dominated by hydroids and smaller red algal species. Occasionally large laminaria species also occurred but the algae and its small anchor stone were in all cases judged to be newly transported to the place due to the unusual position of the stone laying on the top and not somewhat within the seabed.

2.6 Community studies of habitat forming species within the case study areas

Covers on benthic flora and fauna species given by divers on reefs available from the Balance project and the National Monitoring programme is given in annex 3.
Focus in this analysis is the spatial distribution of erect fauna and flora elements from two depth intervals as they contribute to the physical habitat complexity and for this reason can be considered habitat forming species. Erect flora and fauna elements also to some extent contribute to acoustic backscatter signal. Crusts forming species and mobile fauna have been left out of this analysis as well as small and very rare species only identified in the laboratory. Informations on the biodiversity on the reefs in the case study areas are presented in Lundsteen et al, 2007.

2.6.1 Spatial variation in community forming species

Only one biological data set describing cover of epibenthos and macroalgal vegetation are available from a relative shallow reef area (10-13m) at Lille Middelgrund within case study area (b) This dataset has been compared with data from reefs of similar depth in the northern and southern Kattegat (Annex 3) using multivariate statistics from the PRIMER package.

Overall the similarity expressed by Bray-Curtis similarity index is rather low (18 – 45%) between the benthic communities at Lille Middelgrund and the other reef stations at 10 – 13m of depth. Ebbeløkke in the south-western Kattegat and Per Nilen north of Læsø are the two locations being most similar to Lille Middelgrund as expressed in the MDS plot in figure 17.

The most important differences in habitatforming species between Lille Middelgrund and the northern reefs is a much higher cover of *Halichondria panicea*, *Delesseria sanguinea*, *Laminaria saccharina*, the group of filamentous red algal species and a lower cover of *Laminaria digitata / hyperborea*

Halidrys siliquosa is scarce at Lille Middelgrund but cover 20% in average in the southern reef stations. *Halichondria panicea*, *Deleseria sanguinea* and *Laminaria saccharina* on the other hand had a higher cover at Lille Middelgrund than at Store Middelgrund and Ebbeløkke Rev in the south.

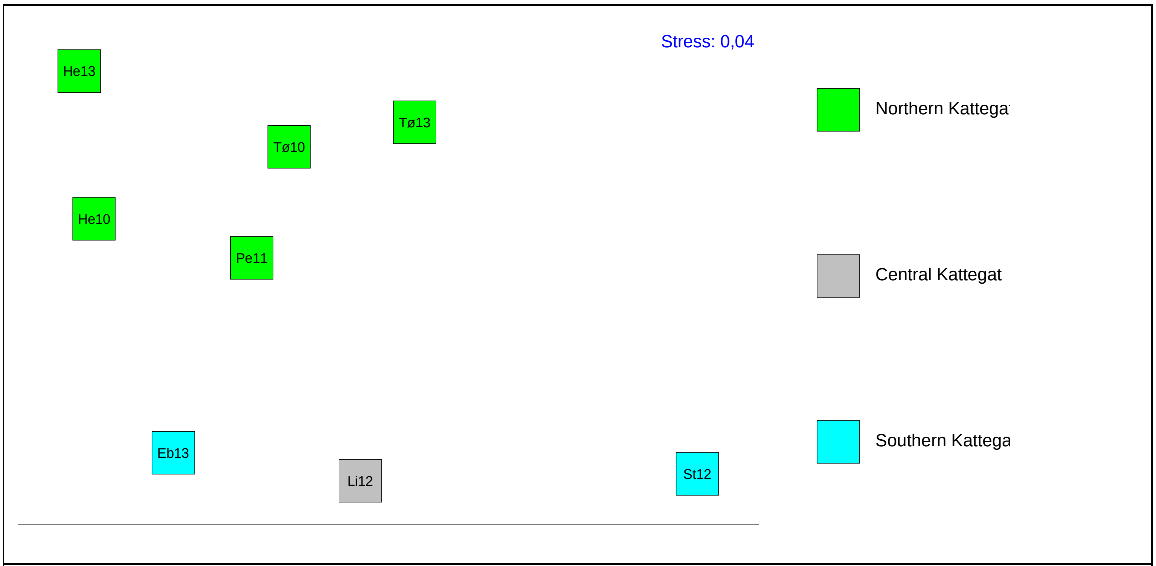


Figure 17. MDS plot showing the similarities in cover of erect habitat forming species at 9-13m depth stations in Kattegat. Each point represents one stations community and distance between the points reflects the relative difference in similarities expressed by the Bray-Curtis similarity index. Full station names, in geographical order, are: Herthas Flak 10m and 13m (He), Tønnerberg Banke 10m and 13m (Tø), Per Nilen 11m (Pe), Lille Middelgrund 12m (Li), Store Middelgrund 12m (St), Ebbeløkke 13m (Eb).For locations see Annex 3.

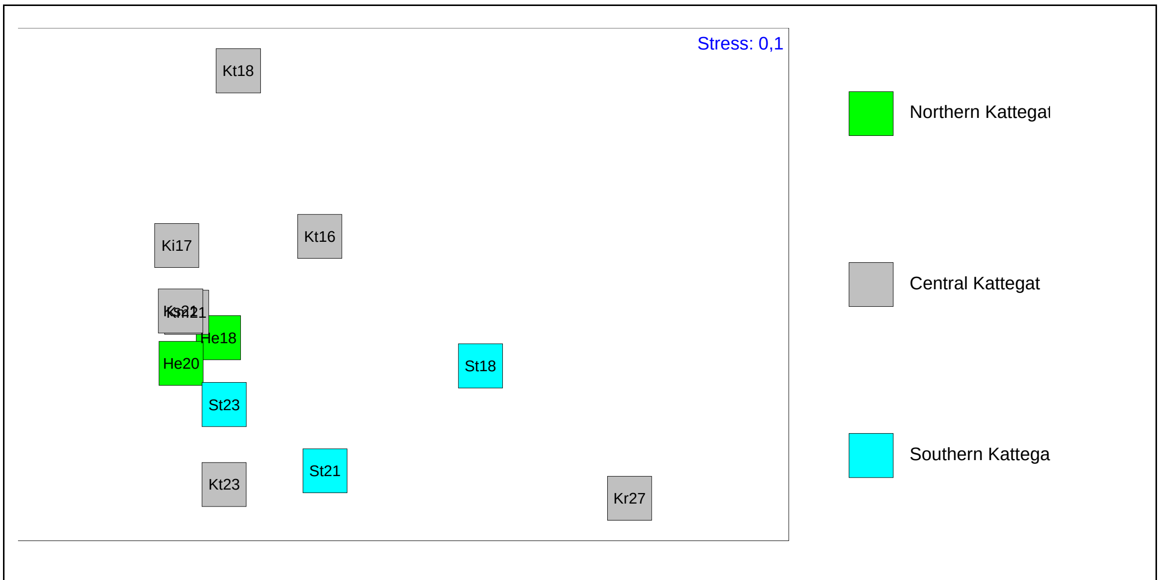


Figure 18 MDS plot showing the similarities in cover of erect habitat forming species at 16-27m depth stations in Kattegat. Each point represents one stations community and distance between points reflects the relative difference in similarities expressed by the Bray-Curtis similarity index. Full station names are: Herthas Flak 18 m and 20m (He), Krateret 27m (Kr),Den Kinesiske Mur midt 21m (Km),Den Kinesiske Mur syd 21m (Ks), Kims Top 16m, 18m and 23m (Kt), Kilbladet 17m (Ki), Store Middelgrund 18m, 21m and 23m (St).

The community structure at the deep reef locations in case study area "a" in the central Kattegat show a very high degree of variation, taking into consideration that they are located very near to each other and keeping in mind the differences in sampling depth from 16 to 27m (figure 18). Notably the two stations at Kim's top sampled at 16 and 18 m have a very low similarity with other reef areas within case study area "A" (Bray-Curtis similarity index between 0.4-14%). On the other hand the two samples taken at *"Kinesiske Mur*" are much more similar (Bray-Curtis similarity index = 63%).

The most important differences in habitat forming species sampled at Kim's Top 16 and 18m depth is less cover of *Alcyonium digitatum* compared to most other stations investigated in the whole Kattegat. On the other hand the species group *Laminaria digitata / hyperborea* covering 20 and 5% at these stations are not found elsewhere this year below 16m water depth. Cover of important habitat forming species from the same two stations at Kim's top also differ substantially from each other although they were only separated by 20m distance. *Phyllophora pseudoceranoides* and *Derbesia marina* had high covers at 18m depth not noticed elsewhere. A similar single observation of high cover of *Odonthalia dentata* was done at 16m.

Other major differences in presents of habitat forming species within the Kattegat area are presents of *Flustra foliacea* only registered at the deepest station at the northern Herthas Flak and a general lower cover of erect biota elements at Store Middelgrund in the southern Kattegat compared to stations in the central and northern reefs.

2.7 Modelling benthic macroalgal vegetation

2.7.1 Identification and quantification of variables controlling algal vegetation

The models describing total and cumulative cover of erect macroalgal vegetation were both significant ($p<0,001$) for the overall dataset including reefs from Skagerrak, Kattegat, The Belt sea area and the western Baltic explaining more than 80 % of the variation ($r^2 = 0.835$ and 0.801 respectively). Reef site, depth of seabed, global radiation, load of nutrient, presents of sea urchins and the diver carrying out the investigation all contributed significantly ($p<5\%$) to describe both total and cumulative erect algal cover. The effect of depth was site specific on each locality and the effect of nutrient was site specific on both locality and depth. Parameter estimates and levels of significance for the two models are given in table 2 and 3.

In both models there is an overall site specific effect on the development of the vegetation and this effect is significant for most reef sites, including the reef areas Kim's top, Herthas Flak, Tønneberg Banke and Per Nilen in the BALANCE pilot area 1.

Vegetation decreases overall with depth but in a different manner from reef to reef. The effect was significant at site level in most cases including reef areas like Kim's Top, Tønneberg Banke and Herthas Flak in pilot area 1.

Table 2. Parameter estimates and levels of significance on factors describing the total cover of erect macro-algal vegetation. Nitrogen load (TN) is given in tons for January–June, depth in m, sea urchins in percent cover of suitable hard substrate and solar radiation as Wm^{-2} for the period January-June.

Parameter estimates

Variable	Reef locality	Estimates	Significans level
Solar radiation		**0.0093**	**0.0177**
Sea urchins (log)		**-0.9769**	**< 0.0001**
Locality	**All together:**		**< 0.0001**
	For each locality:		
	- Briseis Flak	*1.0387*	*0.5419*
	- Broen	*9.7540*	*0.0097*
	- Herthas Flak	*6.8224*	*<0,0001*
	- Kim's Top	*6.3550*	*<0,0001*
	- Kirkegrund	*-1.2406*	*0.6189*
	- Knudegrund	*-4.0980*	*0.1419*
	- Lysegrund	*-1.3489*	*0.5799*
150	*- Læsø Trindel*	*-0.5586*	*0.8342*
	- Lønstrup Rødgrund	*3.8175*	*0.2621*
	- Munkegrunde	*3.6629*	*0.2744*
	- Møn's Klint	*-4.3572*	*0.0409*
	- Per Nilen	*4.3038*	*0.0065*
	- Røsnæs	*8.8327*	*0.3104*
	- Schultz's Grund	*5.6482*	*<0.0001*
	- Store Middelgrund	*3.1667*	*0.0015*
	- Tønneberg Banke	*3.4725*	*0.0328*
	- Vejrø	*5.2835*	*<0.0001*
Depth*Locality	**All together:**		**<0.0001**
	For each locality:		
	- Briseis Flak	*0.1245*	*0.5409*
	- Broen	*-1.1404*	*0.0047*
	- Herthas Flak	*-0.6123*	*<0.0001*
	- Kim's Top	*-0.3967*	*<0.0001*
	- Kirkegrund	*2.7971*	*0.6479*
	- Knudegrund	*-1.5351*	*0.0477*
	- Lysegrund	*0.3755*	*0.2264*
	- Læsø Trindel	*-0.1208*	*0.4165*
	- Lønstrup Rødgrund	*-0.4085*	*0.2533*
	- Munkegrunde	*-0.4273*	*0.2365*
	- Møn's Klint	*-0.7180*	*0.8492*
	- Per Nilen	*-0.3948*	*0.0610*
	- Røsnæs	*-1.0966*	*0.1804*
	- Schultz's Grund	*-0.5956*	*<0.0001*
	- Store Middelgrund	*-0.2732*	*<0.0001*
	- Tønneberg Banke	*-0.2332*	*0.0453*
	- Vejrø	*-0.5050*	*<0.0001*
TN * Depth* Locality	**All together:**		**0.0008**
	For each locality:		
	- Briseis Flak	*-0.000005871*	*0.0016*
	- Broen	*0.000005115*	*0.1496*
	- Herthas Flak	*-0.000001107*	*0.0524*
	- Kim's Top	*-0.000002984*	*<0.0001*
	- Kirkegrund	*-0.000064314*	*0.6744*
	- Knudegrund	*0.000030695*	*0.1276*
	- Lysegrund	*-0.000004875*	*0.4280*
	- Læsø Trindel	*-0.000001901*	*0.0705*
	- Lønstrup Rødgrund	*-0.000006871*	*0.0847*
	- Munkegrunde	*0.000000309*	*0.9078*
	- Møn's Klint	*0.000022077*	*0.8142*
	- Per Nilen	*-0.000001792*	*0.5707*
	- Røsnæs	*0.000003710*	*0.3425*
	- Schultz's Grund	*-0.000001031*	*0.2233*
	- Store Middelgrund	*-0.000001892*	*0.0034*
	- Tønneberg Banke	*-0.000002253*	*0.0204*
	- Vejrø	*-0.000001456*	*0.0036*
Diver	**All together:**		**0.0234**
	For each diver:		
	-Diver 1	*-2.2021*	*0.1210*
	-Diver 2	*-0.2954*	*0.6952*
	-Diver 3	*-0.3799*	*0.0691*
	-Diver 4	*-0.4397*	*0.0019*
	-Diver 5	*0.1036*	*0.8061*
	-Diver 6	*0*	-

Table 3. Parameter estimates and levels of significance on factors describing the cumulative cover of erect macroalgal vegetation. Nitrogen load (TN) is given in tons for January–June, depth in m sea urchins in per-cent cover of suitable hard substrate and solar radiation as Wm^{-2} for the period January-June.

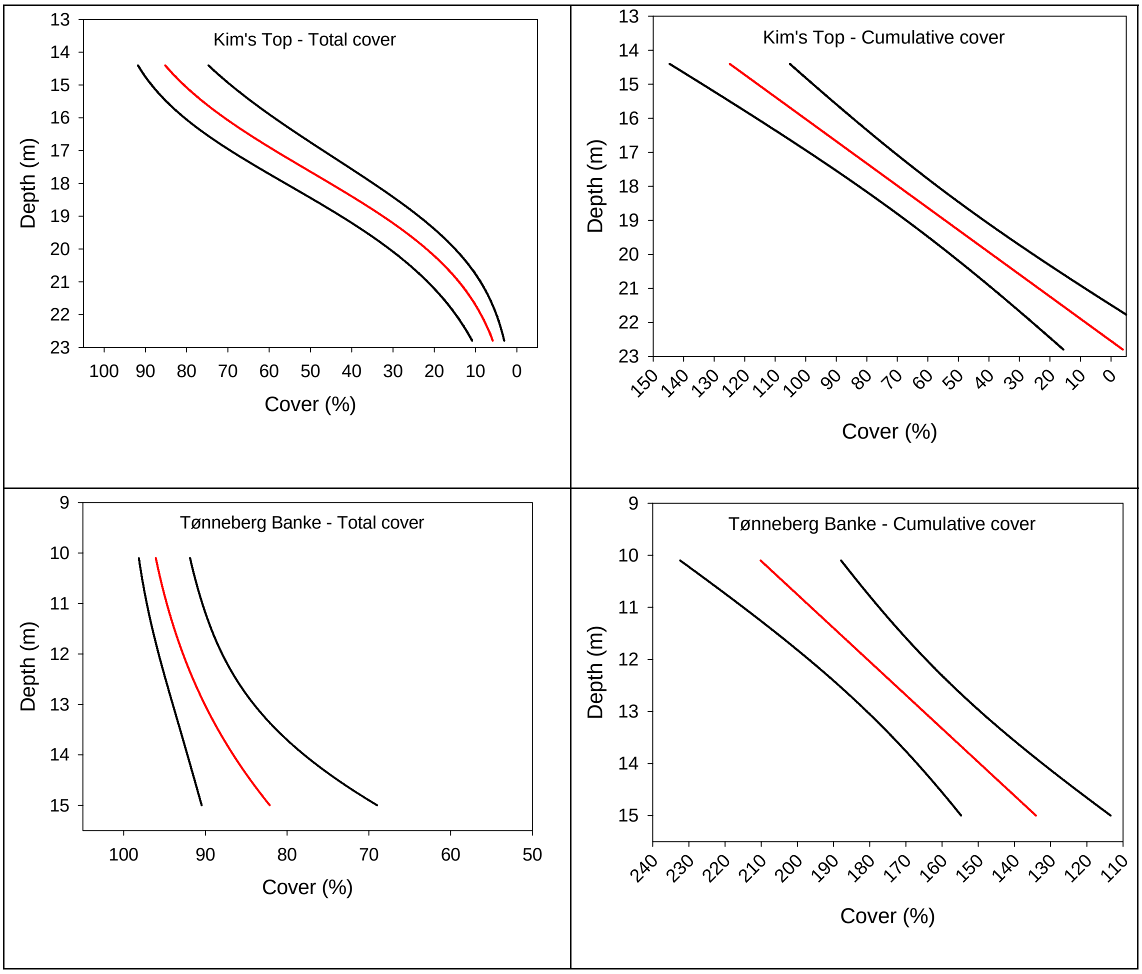
Parameter estimates			
Variable	Reef locality	Estimates	Significans
Solar radiation		**0.2263**	**< 0.0363**
Sea urchins (log)		**-14.7670**	**< 0.0001**
Locality	**All together:**		**< 0.0001**
	For each locality:		
	- Briseis Flak	*176.25*	*0.0002*
	- Broen	*323.64*	*0.0017*
	- Herthas Flak	*269.89*	*<0.0001*
	- Kim's Top	*279.52*	*<0.0001*
	- Kirkegrund	*57.22*	*0.4024*
	- Lysegrund	*19.84*	*0.7647*
	- Læsø Trindel	*152.56*	*0,0417*
	- Munkegrunde	*367.47*	*<0.0001*
	- Møn's Klint	*-20.67*	*0,7238*
	- Per Nilen	*165.61*	*0,0001*
	- Røsnæs	*732.28*	*0.0020*
	- Schultz's Grund	*166.85*	*<0.0001*
	- Store Middelgrund	*212.97*	*<0.0001*
	- Tønneberg Banke	*300.81*	*<0.0001*
	- Vejrø	*244.42*	*<0.0001*
Depth*Locality	**All together:**		**<0.001**
	For each locality:		
	- Briseis Flak	*-3.17*	*0.5657*
	- Broen	*-27.47*	*0.0127*
	- Herthas Flak	*-16.48*	*<0.0001*
	- Kim's Top	*-12.53*	*<0.0001*
	- Kirkegrund	*311.33*	*0.0620*
	- Lysegrund	*17.40*	*0.0391*
	- Læsø Trindel	*-8.19*	*0.0469*
	- Munkegrunde	*-25.60*	*0.0092*
	- Møn's Klint	*154.36*	*0.1749*
	- Per Nilen	*-2.36*	*0.6792*
	- Røsnæs	*-63.75*	*0.0042*
	- Schultz's Grund	*-9.96*	*<0.0001*
	- Store Middelgrund	*-8.85*	*<0.0001*
	- Tønneberg Banke	*-12.35*	*0.0002*
	- Vejrø	*-13.02*	*<0.0001*
TN * Depth* Locality	**All together:**		**0,0008**
	For each locality:		
	- Briseis Flak	*-0.0000903*	*0.0726*
	- Broen	*0.0001276*	*0.1861*
	- Herthas Flak	*-0.0000121*	*0.4967*
	- Kim's Top	*-0.0000585*	*0.0013*
	- Kirkegrund	*-0.0076923*	*0.0651*
	- Lysegrund	*-0.0000693*	*0.6783*
	- Læsø Trindel	*-0.0000480*	*0.1052*
	- Munkegrunde	*-0.0000245*	*0.7357*
	- Møn's Klint	*-0.0037479*	*0.1867*
	- Per Nilen	*-0.0000821*	*0.3388*
	- Røsnæs	*0.0001356*	*0.2015*
	- Schultz's Grund	*-0.0000247*	*0.3017*
	- Store Middelgrund	*-0.0000534*	*0.0024*
	- Tønneberg Banke	*-0.0000664*	*0.0137*
	- Vejrø	*-0.0000297*	*0.0325*
Diver	**All together:**		**0.0131**
	For each diver:		
	-Diver 1	*-16.12*	*0.4555*
	-Diver 2	*-5.76*	*0.3494*
	-Diver 3	*-5.86*	*0.1455*
	-Diver 4	*-40.53*	*0.0008*
	-Diver 5	*0*	-

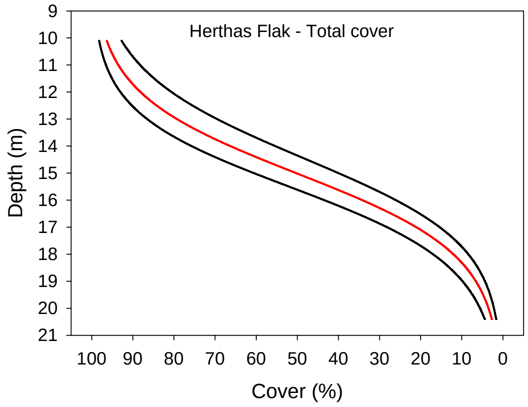
Although there was a good overall effect of nitrogen load on both total and cummulative erect algal vegetation cover the effect was statistically significant (p<5%) on only four reefs

of each of the models and a few more if 10% confides level is accepted. (Kim's Top in the case study area (a), p<0.1% for both models, Tønneberg Banke within the pilot area, p<2% for both models. Herthas Flak within the pilot area P=5.2 for "Total cover" model only).

2.7.2 Vegetation scenarios for selected reefs in pilot area 1

The results of the vegetation models are presented in selected scenarios for Kim's Top in the case study area (a) and for Tønneberg Banke and Herthas Flak located within the pilot area 1 (figure 19).





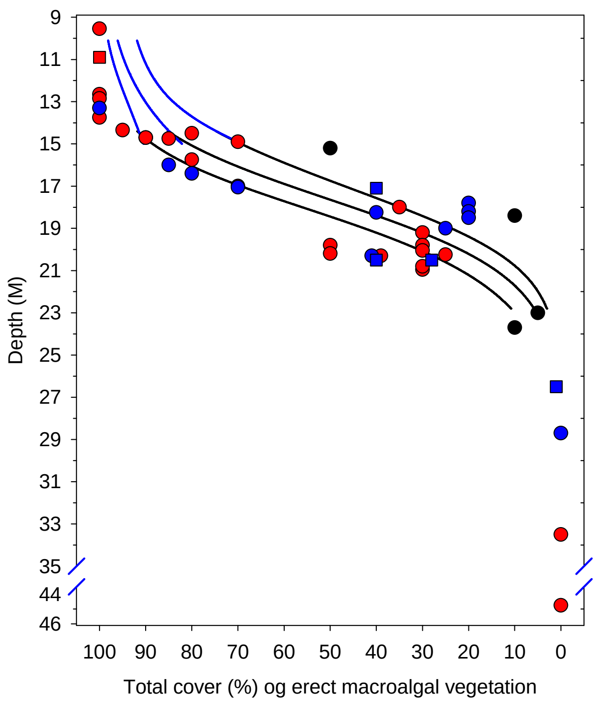
No significant model estimates

Figure 19 Estimated total erect vegetation cover and cumulative species cover of erect macroalgel vegetation at different depth at Kim's Top, Tønneberg Banke and Herthas Flak. The chosen scenarios are based on a nitrogen load on 48.000 tons from January to June and solar from May-July both average values for the period 213.3 W m^{-2} and presence of 0,1 cover of sea-urchins.

The scenarios describe the depth dependent development of each vegetation parameter at an average load of nutrient to Kattegat in the first half calendar year (January-June) for the period 1993-2005, an average solar radiation level on 213.3 Wm^{-2}, an “average” diver and with a sea urchin cover of 0,1%.

2.7.3 Model validation

The estimated total vegetation cover for reef areas in the open Kattegat is validated on data collected in the BALANCE project on several reefs in the central part of Kattegat at and in the neighbourhood of Kim's Top. The modelled vegetation cover use a scenario with an average nitrogen load from 1993-2006 an “average” diver and solar radiation as well as presents of 0.1% sea-urchin cover. The data has been collected by a submerging a video camera and not by divers and the depth accuracy on this data set is not perfect. Anyway the observations done in the BALANCE project fits reasonably well with the model from Kim's Top and not quite as well with the model from the northern reef area, Tønneberg Banke.

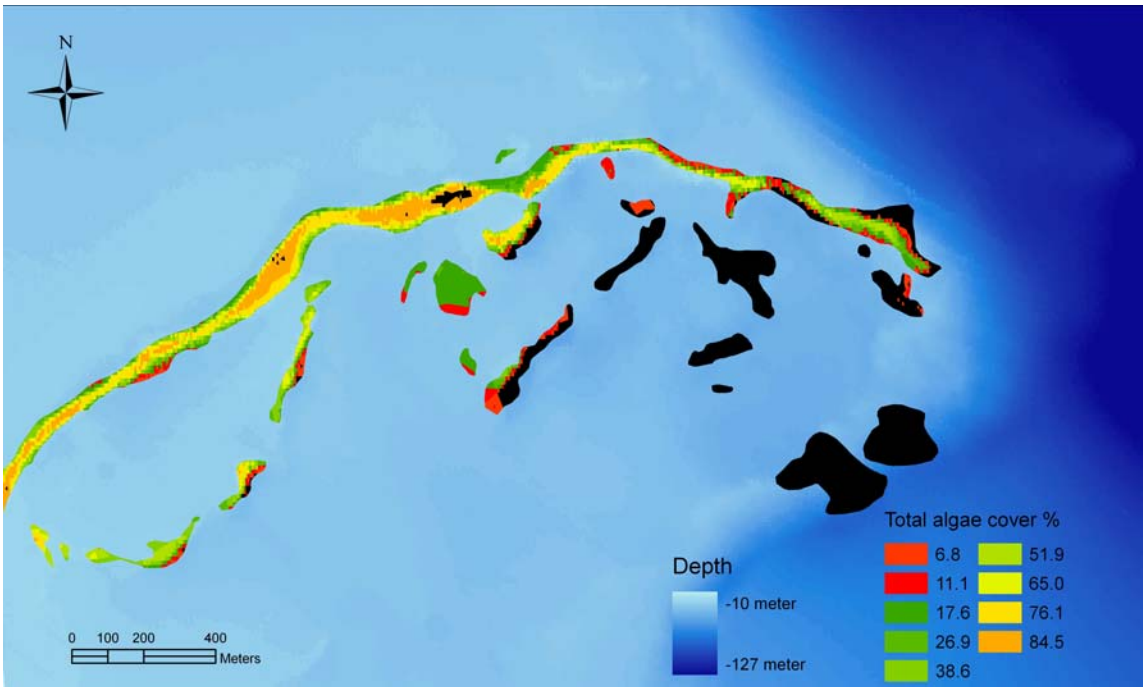
Figure 20. Estimated total cover of erect macro algal vegetation at Kim's Top (black line from 14-23m) and Tønneberg Banke (blue line from 10-15m) and actual observations using a submerged television camera. Red circle: data from videotransect and no sea urchins. Blue circle: data from videotransect and <0,1% sea urchins. black circle: data from videotransect and 1-2% sea urchins. Red square: Data from diver and no Sea urchins. Blue square: Data from diver and <0,1% sea urchins.	

2.7.4 Modelling of seaweed habitats

The model describing total and cumulative vegetation cover from Kim's Top at a specific depth and average nitrogen load and a sea-urchin cover of 0,1% has been used to model the average covers at the neighbouring reef *"Den Kinesiske Mur*". From the sediment mapping that was performed by combining acoustic and groundtruth information the area of complex seabed with >10% stones have been delineated. As this seabed type can be considered as a reef habitat the model output has been projected onto these areas. The projection is done using the bathymetry of the reef areas segregated in 1m depth intervals within the depth interval of the vegetation model (14,5-23m). By that it has been possible to represent the predicted total and cumulated algae cover of *"Den Kinesiske Mur*" reef area (figure 21). The overall reef area in each depth interval is summarized in table 4.

Depth,,meter	Area, km^2
<14	0,003153
4 -15	0,033999
15 -16	0,033479
16 – 17	0,022822
17 – 18	0,028162
18 – 19	0,028579
19 – 20	0,022625
20 – 21	0,035860
21 – 22	0,018254
22 – 23	0,014649
>23	0,126700
Total area with reef	0,368282

Table 4. Depth depended area estimate (1m interval) at the reef "Kinesiske Mur" and surrounding areas.



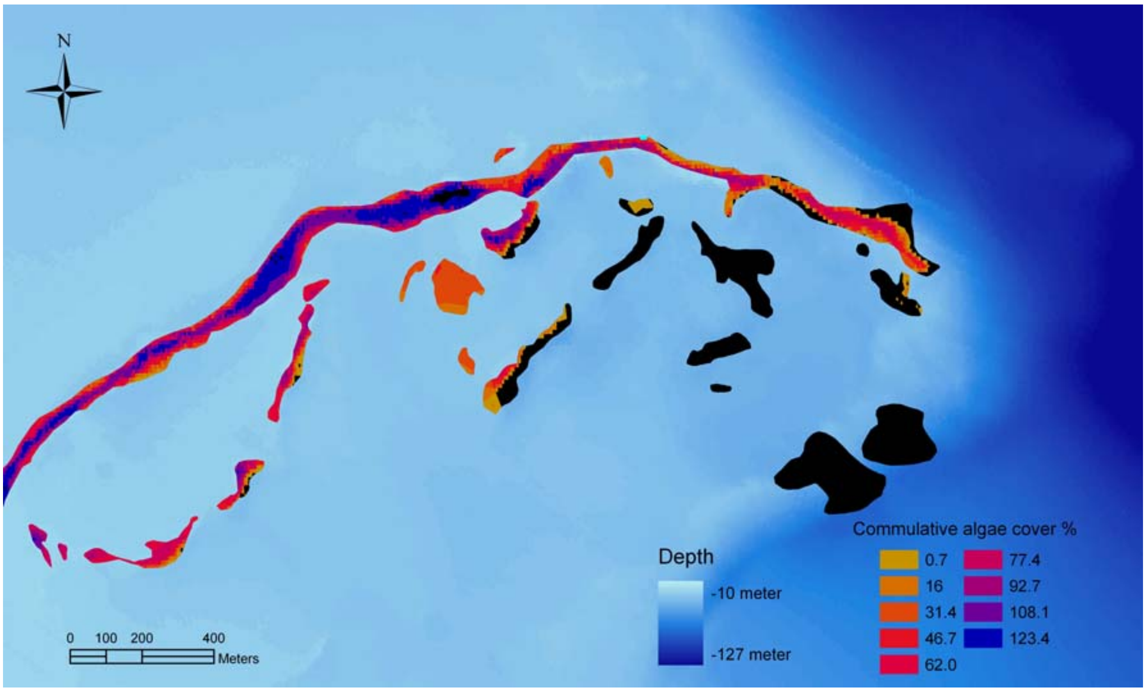


Figure 21. Modelled values of total cover of erect macroalgae in % (upper figure) and Modelled values of cumulative cover of erect algae in % (lower figure) as a function of water depth over hard substrate at Kinesiske Mur in the case study area in the Kattegat region. Black colour represents no-data regions above and below the modelled depth intervals.

3. Discussion

3.1 Seabed classification

The different sets of seabed classification building upon acoustic remote sensing techniques (sidescan sonar and multibeam bathymetry and backscatter) has demonstrated to be a very useful tools to provide information in relation to the mapping of Natura 2000 habitats. The different tools are supplementary to each other in describing and characterising the physical properties of the seabed. However, the use of multibeam backscatter data to delineate reefs seems to be limited in the present study due to the low degree of resolution in the data. On the other hand the multibeam bathymetry picture provides very high details on morphology from which reef structures easily can be delineated from the surrounding seabed. However, ground truthing is needed to verify such delineations. The high survey speed using the multibeam system which reduces considerably the ship time, as well as the bathymetry map it produces makes the multibeam system a very attractive and useful instrument to be used for multiple seabed mapping task. The importance of the seabed bathymetry in enhancing seabed sediment classification is well demonstrated in figure 9 and 11. The resulting seabed map produced by overlaying the sediment map over the morphology map contains valuable information on the physical state of the seabed, which is essential in the prediction of the benthic habitats. Two complex seabed types where stones are present are easily mapped and provide specifically good information in relation to delineating reef habitats in Nature-2000 areas. The presence of ground truth samples is an important parameter in defining the seabed types despite the local nature of these samples.

3.2 Description of biological elements

Description of major biological elements based on the submerged television camera is not very detailed and precise. Basically the depth measurements can not be considered very accurate due to several reasons. 1) The variable angle between the boat's navigation equipment over the seabed and the actual position of the camera equipment. This angle depends both on drifting speed, depth depended current speeds and water depth. 2) The actual depth registrations were based on the ships echo sounder and not by continuously measurements by a censor on the video-rig overlaid the video signals. On steep slopes this might result in a mismatch between the averaged rough community description and depth registration for the chosen distance.

There is also a risk of systematic judgement of higher degrees of cover using the submerged camera on the frame compared to diver estimates. The frame has a tendency to catch larger *Laminaria* leaves and stretch them out under the frame. This might explain the 5-10% higher cover of algal observed from 10-15m water depth were *Laminaria* is most frequent compared with the model results based on diver observations.

The more detailed biological description of hard bottom biota within the case study area is in this context very restricted to only five dives. However a comparison with other datasets collected from reef locations in Kattegat indicates that the biological variation between reefs is rather huge. Petersen et al. (2006) have analysis macro algal communities from reef areas in Kattegat at two water depths (8-10m and 18-20m). In this study they show that the communities from each reef could be differentiated significantly despite a pronounced year to year difference in the communities.

3.3 Quality and validation of vegetation model

The chosen scenarios shows the two modelled vegetation parameters as well as the 95% confidence limits for an average TN input of 48.000 tonnes N, an average radiation of 213.3 Wm^{-2} for the different locations included in the study that had a significant and decreasing relationship with depth.

There is an acceptable accordance between the model estimate of total erect vegetation cover and the actual observed values. Some of the observed differences might be attributed methodological problems caused by the use of a drifting frame and the less accurate depth measurements as described above. Other reason for differences between the model estimates of total cover of erect algal vegetation or cumulative cover of erect algal species and the observed values might be a different nutrient load in 2006 compared to the 48000 tons used in the model. A different load will result in a systematic different vegetation cover. At present the 2006 load is not known.

Observations of sea urchins, mainly *Echinus esculentus* varied from 0 to 2 % cover whereas the model assumes an average cover of 0.1%.

3.4 Evaluation of reef habitats in pilot area 1

This study confirms that the reefs Kim’s Top, Den Kinesiske Mur, Groves Flak and surrounding areas all form outstanding geological formations. The presence of coherent reef structures from 14 to 33m depth form features on the seabed, which is not registered anywhere else in inner Danish waters. The reefs are to a very large extent made up by huge boulders piled up on top of each other, forming caves between and beneath the stones.

The Lille Middelgrund located in Swedish waters close to the Danish reefs forms an area including both sandy seabed and reefs but the largest part is much shallower that the Danish reefs.

The reefs in the central part of Kattegat are located where the water quality is less affected by eutrophication compared to more coastal areas. The resulting better living conditions for algae in the open-water reef areas are reflected in deep penetration of macroalgal vegetation and improved algal cover on these open-water shallow areas compared to more coastal reefs.

The reef areas in the pilot area 1 also host a very high biodiversity as documented in Lundsteen et al. (2008). New species for Danish waters and larger distribution ranges for others are documented on these open water reefs. It is expected that more intensive studies will document even higher biodiversity.

Another study in Pilot area 1 has also documented that reefs in this central part of Kattegat can play an important role as donor area of fauna larvae and algal propagules to large part of the Kattegat and the Belt sea area (Bendtsen et al., 2007).

4. Conclusion and perspectives

This investigation show that key biological elements like cover of total erect macro algal vegetation and cumulative erect macro algal vegetation can be modelled and extrapolated successfully to other areas on a local scale. It is important however to keep in mind that the actual values depends on depth, changing levels of eutrophication and grazing by sea urchins. The variation in community structure expressed by Bray-Curtis similarities indicates that variations between even nearby sites are very high making predictive benthic community modelling questionable.

The utilisation of acoustic data is a strong tool for the broadscale characterisation of benthic habitats. The technology of remote sensing is developing fast and systems with high resolution is being developed, also software for data cleaning and interpretation is getting very advanced and complex. The need for groundtruth information is however important for the verification of the seabed classification. It is strongly recommended that ground truthing is governed by the acoustic interpretation to optimize the field work and costs.

Overall this study confirms that the reefs Kim's Top, Den Kinesiske Mur, Groves Flak and surrounding areas all form outstanding coherent reef structures in inner Danish waters. The presence of piled up cave forming boulders from 14 to 33m depth are very unique.

The Lille Middelgrund in the Swedish part of Kattegat is appointed as Nature-2000 area in accordance with the EEC Habitats Directive. In Denmark only minor parts of those outstanding reef areas are included in the Natura-2000 network as the present protected area cover 23.8 km^2 just around Kim's Top.

Based on the present findings of new spectacular reef features, the presence of very high biodiversity and unique species composition and the potentially very important donor area in the central Kattegat it is recommended to enlarge the Danish Nature-2000 area around Kim's Top to include the surrounding reefs to secure a future proper management of this outstanding area.

5. Acknowledgement

We would like to thank: The Royal Danish Administration Navigation and Hydrography for setting the multibeam data at the disposal for the project. This has been of great value for developing the acoustic approach. The Geological Survey of Sweden (SGU) for setting the seabed sediment information from Lilla Middelgrund at the disposal for the project and the Swedish Agricultural University, Sund & Bælt Holding A/S), Dept. of Wind Energy, Risø National Laboratory as well as HC Ørsted Institute, Copenhagen University for other relevant data.

6. References

Bendtsen, J., Söderkvist, J., Dahl, K., Hansen, J.L.S. & Reker, J. 2007: Model simulations of blue corridors in the Baltic Sea. BALANCE, The Danish Forest and Nature Agency. - BALANCE Interim Report 9: 25 pp. Available at : http://balance-eu.org/xpdf/balance-interim-report-no-9.pdf

Bergsten, H. & Nordberg, K. (1992): Late Weichselian marine stratigraphy of the southern Kattegat, Scandinavia; evidence for drainage of the Baltic Ice Lake between 12,7000 and 10,300 years BP. *Boreas 21*, 223-252.

Bray, J. R. & Curtis, J. T (1957): An ordination of upland forest communities of southern Wisconsin. *Ecological Monographs 27*: 325-349.

Carr, M. R. (1997): PRIMER User Manual. Plymouth Marine Laboratory.

Christiansen, C., Conradsen, K., Emelyanov, E. Trimonis, E., Heinemeier, J. & Rud, N. (1993): Hydrographic changes in the southern Kattegat (Scandinavia) during the early Holocene transgression. *Boreas 22,* 349-356.

Clarke, K. R. & R. N. Gorley (2001). PRIMER v5: User Manual/Tutorial. *PRIMER-E: Plymouth:* 1-91.

Dahl, K.(red.), Andersen, J.H.(red.), Riemann, B.(red.), Carstensen, J., Christiansen, T., Krause-Jensen, D., Josefson, A.B., Larsen, M.M., Petersen, J.K., Rasmussen, M.B. & Strand, J. (2005): *Redskaber til vurdering af miljø- og naturkvalitet i de danske farvande. Typeinddeling, udvalgte indikatorer og eksempler på klassifikation. Danmarks Miljøundersøgelser.* - Faglig rapport fra DMU 535: 158 s. (elektronisk). Available at: http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR535.PDF

Dahl, K., Hansen, J., Helmig, S., Nielsen, R. & Larsen, H.S. (2001): Naturkvalitet på stenrev. Hvilke indikatorer kan vi bruge? Danmarks Miljøundersøgelser. - Faglig rapport fra DMU 352: 130 s. Available at : http://www.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR352.pdf

Dahl, K., Hansen, J.L.S. & Leth, J.O. (2006): The BALANCE Cruise Report: The Kattegat, 1st of April - 23rd of November 2006. BALANCE, The Danish Forest and Nature Agency. - BALANCE Interim Report No. 7: 18 pp. Available at: http://www.balance-eu.org/xpdf/balance-interim-report-no-7.pdf

Gregersen, S, Leth, J., Lind, G. & Lykke-Andersen, H. (1996): Earthquake activity and its relationship with geologically recent motion in Denmark. *Tectonophysics 257,* 265-273.

Kaas, H. & Markager S.S. (1999): Tekniske anvisninger for marin overvågning. National Environmental Research Institute, Denmark. Available at: http://www2.dmu.dk/1_Om_DMU/2_tvaerfunk/3_fdc_mar/programgrundlag/tekanv/tekniskanv.asp)

Krause-Jensen, D., O. Mancher, J. S. Laursen, A. L. Middelboe & M. Stjernholm (2004). 3.1 Bundvegetation m. v. *NOVANA. Tekniske anvisninger for marin overvågning. Red. Andersen, Markager & Ærtebjerg:* 1-47.

Larsen, G., Frederiksen, J, Villumsen, A., Fredericia, J., Gravesen, P., Foged, N., Knudsen, B. & Baumann, J. (1995). A guide to engineering geological soil description. *DGF-Bulletin 1.* Danish Geotechnical Society.

Leth, J. O. & Al-Hamdani, Z. (2007): Mapping of NATURA 2000 habitats at Læsø Trindel. Cruise report*. GEUS Report 2007/1*.

Liboriussen, J., Ashton, P. & Tygesen, T. (1987): The tectonic evolution in the Fennoscandian Border Zone in Denmark. *Tectonophysics 137,* 21-29.

Lundsteen, S., K. Dahl & O. Mancher (2004). 4.2 Hårdbundsfauna. *NOVANA. Tekniske anvisninger for marin overvågning. Red. Andersen, Markager & Ærtebjerg:* 1-8.

Lagerlund, E. & Houmark-Nielsen, M. (1993): Timing and pattern of the last deglaciation in the Kattegat region, southwest Scandinavia. *Boreas*, Vol. 22, 337-347.

Lykke-Andersen, H. (1987): Thickness of Quaternary deposits and their relation to the Pre-Quaternary in the Fennoscandian Border Zone in Denmark. *Boreas*, Vol. 16, 369-371.

Nielsen, R., Kristiansen, A., Mathiesen, L., & Mathiesen, H. (1995): Distributional index of the benthic macroalgae of the Baltic Sea area. *Acta botanica fennica, The Baltic Marine Biologists Publication No. 18* vol. 155: 1-51.

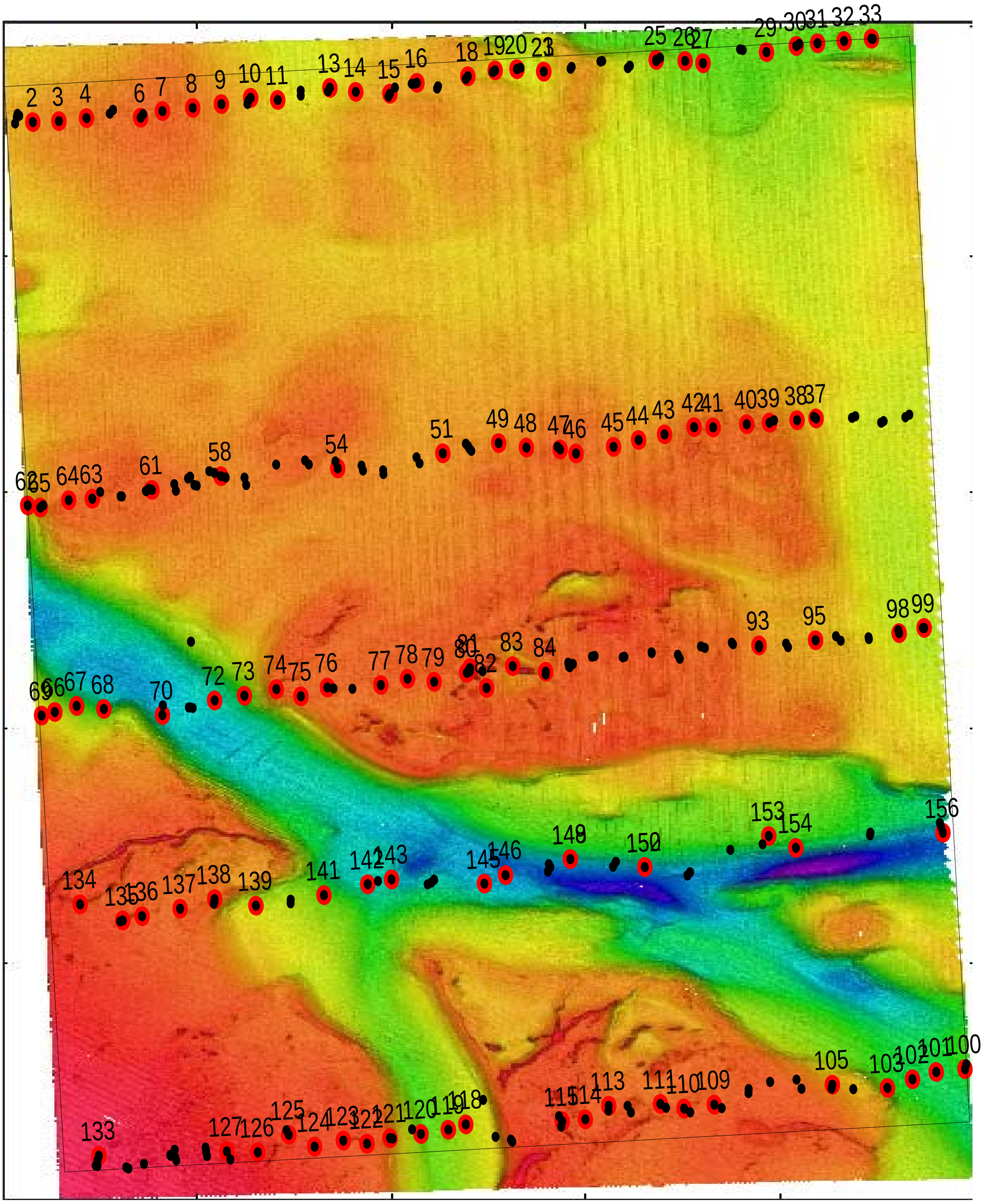
Novak, B. & Pedersen, G.K. (2000): Sedimentology, seismic facies and stratigraphy of a Holocene spit-platform complex interpreted from high-resolution shallow seismics, Lysegrund, southern Kattegat, Denmark. *Marine Geology 162, p 317-335.*

Petersen, J.K., Andersen, J.H., Dahl, K., Hansen, O.S., Josefson, A.B., Karlsson, J., Loo, L.-O., Magnusson, J., Moy, F. & Nilsson, P. (2006): *Reference conditions and EQOs for aquatic vegetation and macrozoobenthos*. Copenhagen: Nordic Council of Ministers. - TemaNord 2006: 510: 138 pp. Available at: http://www.nmr.dk/pub/miljo/miljo/uk/TN2006510.pdf

7. Annexes

7.1 Annex 1

Haps sampling stations within case study area (a). Red circles indicate a successful sampling, black circle indicate that the sampler was empty.



7.2 Annex 2

Seabed classification at different stations, transects and part of transects as well as information on position of start and end of the transect, depth and sediment covers. Data are given for both video transects and diver observation.

Bottom type	Transect	Sub-transect	Part	Depth		Start position		End position		Mud	Shells	Sand		Stone size in cm				
				Start	End	Longitude	Latitude	Longitude	Latitude			Fine	Coarse	<5	5-10	10-30	30-60	>60
VIDEO transects																		
Coarse sand with few stones	DMU	109		20,7		1137,108	5700,413	1137,178	5700,386		5	0	60	30	2	2	0	1
Reef	DMU	J106		20,8	17,2	1138,048	5700,480	1138,139	5700,444				10	0	28	60	2	
Sand with few stones	DMU	J129		14,9		1131,198	5700,420	1131,298	5700,400		5	70	20	3	1			
Sand	DMU	J133		12,3		1130,319	5700,420	1130,429	5700,405		1	99						
Sand and coarse sand	DMU	J18		21,4	21,4	1135,484	5705,282	1135,391	5705,264		5	80	15	0,1				
Coarse sand with few stones	DMU	J53		47	43,4	1134,073	5703,491	1134,139	5703,503				84	15	1	0,1	0,1	
Reef with coarse sand	DMU	J60		37	52,5	1131,816	5703,515	1131,851	5703,560				55	10	30	5		
Coarse sand with few stones	G1	1		21,2	18,7	1133,448	5705,077	1133,447	5705,054				99	1			0,1	
Coarse sand with few stones	G1	2	a	20,7	16,2	1133,234	5704,914	1133,243	5704,891				98		1	1		
Reef	G1	2	b	16,2	17,1	1133,243	5704,891	1133,243	5704,865				2	1	1	35	60	1
Sand	G1	3	a	20,9	16,4	1133,174	5704,875	1133,176	5704,846		35	65						
Reef	G1	3	b	16,4	19,2	1133,176	5704,846	1133,177	5704,831				20			5	50	25
Reef	G1	4	a	19,2	19,6	1133,051	5704,783	1133,051	5704,771				3			40	40	17
Coarse sand with few stones	G1	4	b	19,6	20,1	1133,051	5704,771	1133,052	5704,760				95	3				2
Reef with sand	G1	4	c	20,1	20,4	1133,052	5704,760	1133,053	5704,744			30			10	40	20	
Coarse sand with few stones	G1	5		20,7	20,3	1132,993	5704,729	1132,994	5704,705		10		80	6	2		2	
Reef with coarse sand	G1	6		20,7	21,2	1132,815	5704,606	1132,819	5704,573		5		80	5		5	3	2
Reef with coarse sand	G2	1		20,3	20,3	1134,361	5703,971	1134,565	5703,949		20		65		5	5		5
Coarse sand	G2	2		20,7	20,5	1134,497	5704,010	1134,502	5703,982		20		80	0,1				
Gravel	G2	3	a	18,7	18,0	1134,702	5704,041	1134,707	5704,023				4	80	15	1		
Reef	G2	3	b	18	18,0	1134,707	5704,023	1134,708	5704,015					10	20	50	20	1
Reef with sand	G2	4		19,8	20,3	1134,906	5704,076	1134,920	5704,065			40			10	50	1	
Reef with sand	G3	1		20,9	20,7	1135,769	5705,468	1135,752	5705,428			20	10	10	10	20	30	0,1
Sand with few stones	G3	2		20,7	20,3	1135,811	5705,383	1135,781	5705,325			98	2					0,1
Reef with coarse sand	G3	3	a	19,5	17,0	1135,872	5705,318	1135,849	5705,276				70	1	1	1	10	20
Reef	G3	3	b	21	25,0	1135,849	5705,276	1135,848	5705,270			2				10	50	40
Reef with coarse sand	G3	3	c	28,7		1135,848	5705,270	1135,847	5705,267				25			10	65	

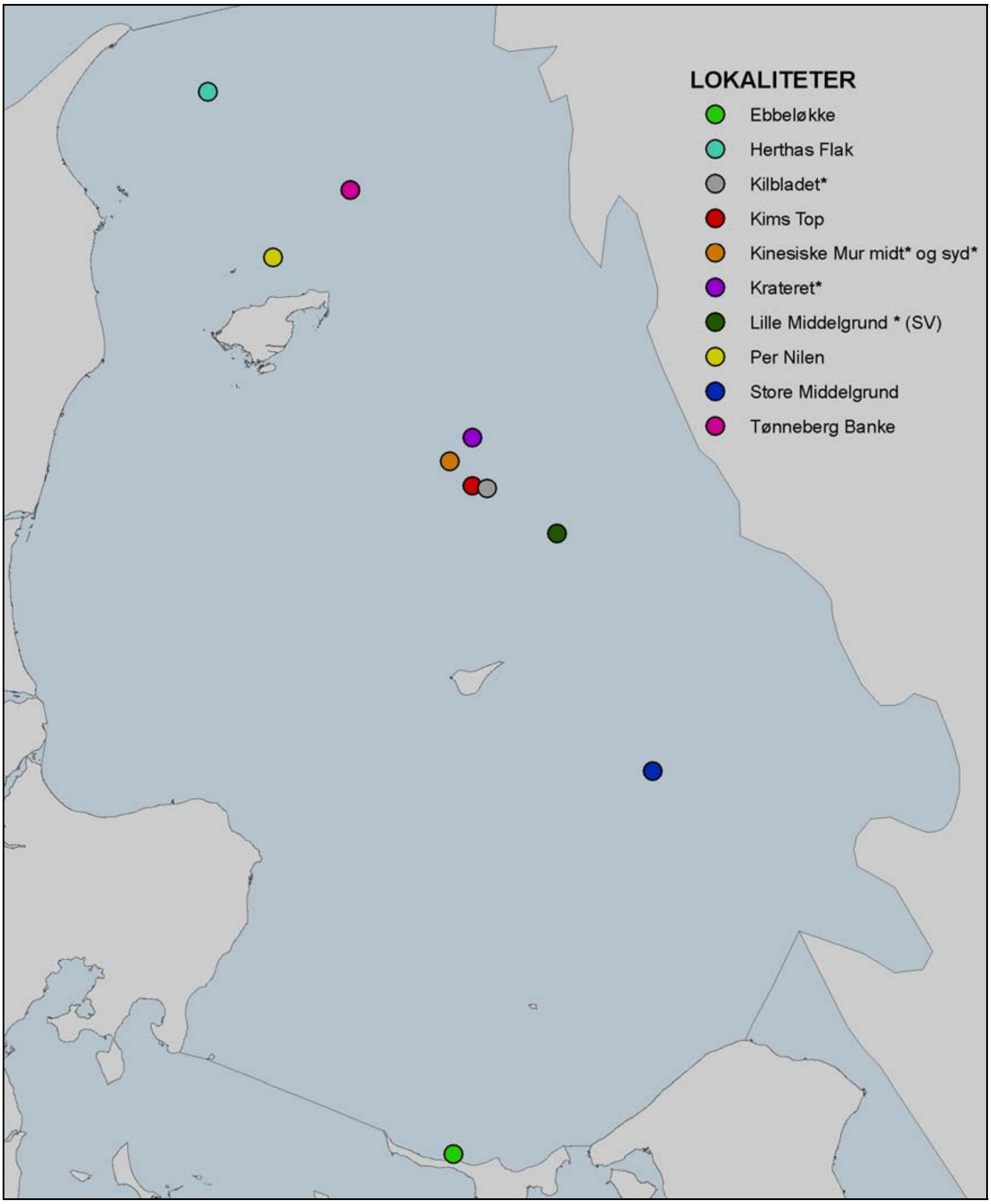
Bottom type	Transect	Sub-transect	Part	Depth		Start position		End position		Mud	Shells	Sand		Stone size in cm				
				Start	End	Longitude	Latitude	Longitude	Latitude			Fine	Coarse	<5	5-10	10-30	30-60	>60
VIDEO transects																		
Reef with coarse sand	G3	3	d	33,5		1135,847	5705,267	1135,846	5705,259				45		10	45		
Sand and coarse sand	G3	3	e	33,6	32,9	1135,846	5705,259	1135,846	5705,245			78	20	2				
Sand	G4	1		19,3	19,7	1130,112	5702,931	1130,092	5702,949		1	99						
Sand	G4	2		18,6	18,8	1130,149	5702,880	1130,139	5702,899		3	92	5	0,1				
Coarse sand with few stones	G4	3		19,3		1130,197	5702,816	1140,187	5702,863		5		95		0,1			
Reef	G4	4	a	14,3		1130,206	5702,787	1130,226	5702,826							75	20	5
Coarse sand with few stones	G4	4	b	19,8	20,7	1130,226	5702,826	1130,234	5702,844		5		55	35	5			
Sand	G4	5		19,7	18,2	1130,281	5702,682	1130,294	5702,718		5	90	4	1				
Sand	G4	6		19,1	19,5	1130,327	5702,628	1130,349	5702,665		3	97						
Sand	G4	7	a	20		1130,396	5702,520	1130,412	5702,557		1	99						
Reef with sand	G4	7	b	17		1130,412	5702,557	1130,417	5702,569		5	75			5	10	5	0,1
Reef	G4	7	c	17,9	18,5	1130,417	5702,569	1130,422	5702,580				10	5	10	75	1	
Sand	G6	1	a	24,5		1134,899	5701,008	1134,954	5700,987		20	80	0	0	0			
Reef	G6	1	b	15,2		1134,954	5700,987	1134,992	5700,972						19	60	20	1
Coarse sand	G6	1	c	20,9		1134,992	5700,972	1135,019	5700,262			20	80	0	0		0	0
Coarse sand with few stones	G6	2	a	20,2		1135,077	5700,926	1135,176	5700,087				74	20	5	1		
Reef	G6	2	b	19,8		1135,176	5700,087	1135,198	5700,878				20	10	5	60	5	0
Reef with coarse sand	G6	2	c	19,8		1135,198	5700,878	1135,252	5700,858			5	70	15	10	0	0	0
Coarse sand with few stones	G6	3	a	19,1		1135,339	5700,821	1135,409	5700,791				94	5	1			
Reef	G6	3	b	14,9	19,1	1135,409	5700,791	1135,463	5700,767				3	1	10	45	40	
Coarse sand with few stones	G6	3	c	19,1	19,1	1135,463	5700,767	1135,489	5700,757				90	10				
Coarse sand with few stones	G6	4	a	19,2		1135,587	5700,727	1135,651	5700,701				97			2		1
Reef with coarse sand	G6	4	b	20,2		1135,651	5700,701	1135,677	5700,691				40			20	30	10
Coarse sand	G6	5		22		1135,843	5700,617	1135,908	5700,601				100			0	0	0
Coarse sand with few stones	G6	6		20,2		1136,083	5700,507	1136,120	5700,497				98	1	1	0,1		
Coarse sand with few stones	G6	7		21,3	22,0	1136,285	5700,444	1136,337	5700,428				88	3	5	2	2	
Coarse sand with few stones	G6	8		22,0	a	1136,549	5700,343	1136,629	5700,316			37	60	2	1		0,1	

Bottom type	Transect	Sub-transect	Part	Depth		Start position		End position		Mud	Shells	Sand		Stone size in cm				
				Start	End	Longitude	Latitude	Longitude	Latitude			Fine	Coarse	<5	5-10	10-30	30-60	>60
VIDEO transects																		
Sand with few stones	G7	1		17,1	17,1	1131,715	5700,757	1131,735	5700,793		7	90				3		0,1
Sand	G7	2				1131,663	5700,980	1131,681	5701,001		3	97						
Sand and coarse sand	G7	3		17,8	18,0	1131,629	5701,075	1131,660	5701,107		10	75	15					
Coarse sand with few stones	G7	4		17,4	17,8	1131,605	5701,186	1131,640	5701,224		5		85	5		5	0,1	
Sand with few stones	G7	5	a	18,1		1131,569	5701,327	1131,589	5701,364		10	80	10				0,1	
Reef	G7	5	b	13,3		1131,589	5701,364	1131,604	5701,380					0,1	1	20	60	20
Reef	G7	5	c	16,4		1131,604	5701,380	1131,611	5701,383				10	10	20	60		
Sand with few stones	G7	5	d	17		1131,611	5701,383	1131,531	5701,451		3	60	35				2	
Sand	G7	6		19	19,4	1131,531	5701,451	1131,542	5701,489		2	98						
Gravel	L1	1		16,7		1153,485	5657,338	1153,569	5657,321				20	80	0,1			
Coarse sand with few stones	L1	2		16,2		1153,509	5657,186	1153,587	5657,173			5	90	2	0,1	1		
Coarse sand with few stones	L1	3		16,1	15,2	1153,519	5657,023	1153,613	5657,010			2	83	10	2	3	0,1	0,1
Reef	L1	4	a	14,2	13,3	1153,533	5656,861	1153,635	5656,847							20	60	20
Coarse sand	L1	4	b	13,3	12,8	1153,635	5656,847	1153,665	5656,843			30	70					
Reef	L1	5	a	14,3		1153,566	5656,698	1153,597	5656,692						20	80		
Reef	L1	5	b	14,7		1153,597	5656,692	1153,642	5656,685						90	10		
Reef	L1	6	a	14,7		1153,571	5656,520	1153,637	5656,510				5	15	70	10		
Gravel	L1	6	b	14,7		1153,637	5656,510	1153,661	5656,507				17	80	2	1		
Reef	L1	7		15,9	15,6	1153,564	5656,364	1153,645	5656,353				2	5	80	15		
Gravel	L1	8	a	15,8		1153,600	5656,212	1153,654	5656,207			0,1	10	90	0	0,1	0	0,1
Reef	L1	8	b		14,5	1153,654	5656,207	1153,684	5656,204						0,1	40	60	
Coarse sand with few stones	L1	9		16,8		1153,622	5656,045	1153,672	5656,038			2	70	20	8	1		
Coarse sand with few stones	L1	10		17,6	17,7	1153,646	5655,883	1153,713	5655,875				70	28	1	1	1	
Coarse sand	L1	11		19,1	19,1	1153,648	5655,721	1153,709	5655,708				100					
Coarse sand	L1	12		20,5	20,7	1153,669	5655,559	1153,728	5655,546		5	10	85					
Sand	L1	13		23,1	23,0	1153,704	5655,366	1153,747	5655,359		2	97	1					
Sand	L2	1		19,1	19,2	1156,439	5658,059	1156,413	5658,059		5	90	5					

Bottom type	Transect	Sub-transect	Part	Depth		Start position		End position		Mud	Shells	Sand		Stone size in cm				
				Start	End	Longitude	Latitude	Longitude	Latitude			Fine	Coarse	<5	5-10	10-30	30-60	>60
VIDEO transects																		
Reef	L2	2		12,7	16,0	1156,455	5657,822	1156,431	5657,818				2		10	80	10	
Sand with few stones	L2	3		14,0	14,4	1156,476	5657,584	1156,444	5657,592			55	40	5	0,1	0,1		
Sand with few stones	L2	4	a	14,7	14,9	1156,524	5657,342	1156,487	5657,340			83	10	2		5		
Reef with sand	L2	4	b	14,9		1156,487	5657,340	1156,468	5657,336			68		2	10	20		
Sand with few stones	L2	5		12,8	12,9	1156,523	5657,096	1156,485	5657,098			60	20	10	5	5		
Gravel	L2	6	a	10,9	10,7	1156,568	5656,862	1156,554	5656,859				50	49		1		
Reef	L2	6	b	10,7	8,4	1156,554	5656,859	1156,521	5656,855				3	0,1	0,1	32	33	32
Gravel	L2	7			11,2	1156,551	5656,594	1156,585	5656,605					95	5			
Reef	L2	8		12,8	12,5	1156,567	5656,430	1156,635	5656,471					1	33	33	33	
Mud with few stones	L3	1	a	43,4		1158,259	5659,024	1158,275	5659,002	99						0,1		
Mud with few stones	L3	1	b		49,5	1158,275	5659,002	1158,280	5658,977	82			10	5	3	1		
Mud with few stones	L3	2		39,1	40,6	1157,923	5659,013	1157,941	5658,981	83				5	10	2	0,1	
Sand	L3	3		33,8		1157,607	5659,017	1157,617	5658,986		0,1	100						
Coarse sand with few stones	L3	4	a	22,0		1157,266	5658,999	1157,279	5658,971			5	70	24	1	0,1		
Reef	L3	4	b		20,0	1157,279	5658,971	1157,283	5658,962			5	5	5	10	60	15	1
Sand with few stones	L3	5		27,3	26,7	1156,929	5658,993	1156,939	5658,959			100				0,1		
Reef	Other	D1	a	18,7	28,4	1132,498	5703,006	1132,515	5703,031					1	20	50	30	
Coarse sand with few stones	Other	D1	b	28,4	43,7	1132,515	5703,031	1132,535	5703,068				50	30	20	1	0,1	
Reef	Other	D10		16,0		1131,628	5701,359	1131,667	5701,357					0,1		25	70	5

7.3 Annex 3

Biological sampling stations this page and species cover (%) data the following four pages. In the data tables Eb = Ebbeløkke rev, He = Herthas Flak, Ki = Kilbladet, Ki = Kim's Top, Km and Ks = Kinesiske Mur, Kr = Krateret at Groves Flak, Li = Lille Middelgrund, Pe = Per Nilen, St = Store Middelgrund and Tø = Tønneberg Banke.



ecies, taxon or form.	He10	He13	He18	He20	Tø10	Tø13	Pe11	Kr27	Li12	Kt16	Kt18	Kt23	Ki17	Km21	Ks21	St12	St18	St21	St23	Eb13
RHODOPHYTA																				
Aglaothamnion indet.						0,1														
Audouinella membranacea														1						
Bonnemaisonia/Spermothamnion	5			7		5					1			10	21	20	0,1		0,1	10
Bonnemaisonia asparagoides											15		10	0,1	2					
Brongniartella byssoides	5				2	5	5			2			5	0,1		5	0,1			80
Callithamnion corymbosum		0,1					1						15							
Callophyllis cristata											0,1									
Ceramium nodulosum		3			10	5	10													10
Chondrus crispus							2			0,1	0,1					1				10
Coccotylus truncatus						2										1				
Corallina officinalis	2						2									10				
Cystoclonium purpureum					10	1														
Delesseria sanguinea	20	15	10	3	10	20	20		40	20	8	0,1	3	5	5	10	0,1	0,1		10
Dilsea carnosa	1	0,1			2	2	1			2	10		0,1				1			
Erythrodermis traillii		0,1	0,1	0,05				0,1			1		0,1	3					0,1	
Furcellaria lumbricalis									0,1											2
Halarachnion ligulatum													0,1							
Heterosiphonia plumosa											0,1									
Lithothamnion glaciale						2	1			1	0,1		0,1				0,1	3		
Lomentaria clavellosa				0,1							0,1		0,1							
Lomentaria orcadensis													0,1	2						
Membranoptera alata	0,1						0,1									1				0,1
Odonthalia dentata		0,1					5			10	0,1			0,1					0,1	
Palmaria palmata					5	0,1	2													0,1
Phycodrys rubens	60	70	10	20	20	10	20	0,1	5	10	1	10	1	3	2	2	1	15	25	30
Phyllophora crispa											0,1	0,1	0,1	0,1						
Phyllophora pseudoceranoides	40	1		0,1	20	5	40		25	2	75		0,1	0,1						50
Polysiphonia elongata											3									
Polysiphonia elongella *										2	3									
Polysiphonia fibrillosa	0,1									2										
Polysiphonia fucoides																1				2
Polysiphonia stricta	0,1	2			2					2	1		5			1				2

Pterothamnion plumula		1									0,1		0,1	5			0,1	0,1		
Ptilota gunneri										0,1	0,1									
Red bush									50											
Red calcified crust	70	80	60	70	50	80	60	95	20	70	80	80	90	80	70	60	65	30	85	20
Red crust	5	8	15	10	5	5	5	5	5	20	0,1	5	3	0,1	1	20	0,1	1	10	5
Rhodochorton purpureum like	2	5	0,1								0,1	30	0,1						2	
Rhodomela confervoides			0,1	0,1							0,1		1							
Rhodophyllis divaricata											5									
Species, taxon or form.	He10	He13	He18	He20	Tø10	Tø13	Pe11	Kr27	Li12	Kt16	Kt18	Kt23	Ki17	Km21	Ks21	St12	St18	St21	St23	Eb13
RHODOPHYTA																				
Brown crust					2	2					0,1	0,1	1			20	35	65		
Desmarestia aculeata	10	2			10	10	2		0,1	2			0,1							
Desmarestia viridis									0,1				1							
Ectocarpus siliculosus		0,1					1													2
Fucus serratus									3											
Halidrys siliquosa							2		5							60				
Laminaria digitata					20				2	20						1				0,1
Laminaria hyperborea	50	75					20				5									
Laminaria indet.					1	10														
Laminaria saccharina	1	2					1		25		0,1					2				5
Sphacelaria cirrosa							0,1		0,1		0,05					20				
CHLOROPHYTA																				
Bryopsis plumosa												0,1	0,1	0,1					0,1	
Chaetomorpha melagonium							0,1									0,1				
Derbesia marina											30			0,1						
Derbesia marina bulb phase											0,1		0,1						0,1	
Epicladia flustrae				0,1																
PORIFERA																				
Halichondria panicea				0,1					50	0,1	5		0,1	0,1						0,05
Halisarca dujardini	0,1																			
Porifera indet.														0,1						
Scypha ciliata											0,1		0,05	0,1						
HYDROZOA																				
Abietinaria abietina			0,1	0,1										0,1						
Clava indet.											0,1									
Clytia indet.		0,1																		
Hydroida indet.				0,1															0,05	

Kirchenpauria pinnata												0,1								
Obelia geniculata	40	0,1			10	5				5	0,1									0,1
Sertularella polyzonias		0,1																		
Sertulariidae aff.		0,1	10	5				0,1				0,1	2	0,1	1			0,1	0,1	
Tubularia indivisa			0,1	0,1										5						
Tubularia larynx		0,1	0,1	0,1										2					0,1	
SCYPHOZOA																				
Scyphistoma		0,1																		

Species, taxon or form.	He10	He13	He18	He20	Tø10	Tø13	Pe11	Kr27	Li12	Kt16	Kt18	Kt23	Ki17	Km21	Ks21	St12	St18	St21	St23	Eb13
ANTHOZOA																				
Alcyonium digitatum		5	20	20				0,1		0,1	1	5	30	20	15		0,1	0,1	15	
Caryophyllia smithii				0,1				0,1				0,1		0,1						
Metridium senile				0,1					0,05										0,1	
Tealia feline	0,1																0,1			
BRYOZOA																				
Alcyonidium diaphanum										2		0,1	0,1	0,1						
Alcyonidium på alger											0,05									
Bryozoa gul på sten	5	0,1	5	1				0,1		0,1			5	0,1			0,1		0,1	
Bryozoa indet.		5												0,1						
Crisiidae indet.		0,1									0,1									
Electra pilosa	60	1			40	20	50		90	3	0,1									2
Flustra foliacea				20																
Flustra securifrons				0,1																
Membranipora membranacea	40	75			10	5	20			10	0,1									
Scrupocellaria indet.											0,1		0,1							
SEDENTARIA																				
Pomatoceros triqueter	0,1	0,1	0,1		2	2	0,1						0,1		0,1		0,1			
Spirorbis indet.																	0,1			5
PROSOBRANCHIA																				
Acmaeidae indet.								0,1												

Buccinum undatum															0,1		0,1		
Gibbula indet.																0,1	0,1		
Littorina littorea									0,05							0,1				1
Polyplacophora indet.																0,1			
OPISTOBRANCHIA																				
Nudibranchiata indet.		0,1									0,1		0,1						0,1	
BIVALVIA																				
Hiatella arctica		0,1																		
Modiolus modiolus									0,05									0,1		
Mya truncate				0,1						0,1		0,1	0,1	0,1			0,1	0,1		
Pecten maximus												0,1								

Species, taxon or form.	He10	He13	He18	He20	Tø10	Tø13	Pe11	Kr27	Li12	Kt16	Kt18	Kt23	Ki17	Km21	Ks21	St12	St18	St21	St23	Eb13
CRUSTACEA																				
Balanus balanus	0,1								0,1										0,1	
Cancer pagurus				0,1		0,1				0,1		0,1	0,1		0,1			0,1	0,1	
Carcinus maenas																				0,1
Eupagurus indet.																0,1				
Galathea indet.			0,1																	
Galathea strigosa											0,1									
Pisidia longicornis							0,1													
ECHINODERMATA																				
Amphiura indet.																	0,1			
Asterias rubens	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	2	0,1		0,1		0,1	0,1	0,1	0,1	0,1	0,1	10
Echinus acutus												0,1								
Echinus esculentus		0,1						0,1				0,1	0,1	0,1	0,1			0,1	0,1	
Henricia sanguinolenta																	0,1	0,1	0,1	
Martasterias glacialis	0,1		0,1	0,1	0,1	0,1	0,1	0,1		0,1	0,1	0,1	0,1	0,1	0,1		0,1	0,1	0,1	
Ophiocomina nigra																	0,1			
Ophiopholis aculeata		0,1																		
Ophiura indet.														0,1						
Strongylocentrotus droebachiensis																	0,1	0,1		
ASCIDIACEA																				
Ascidiacea indet.									0,05		0,1			0,1	0,1		0,1	0,1		
Botryllus schlosseri like		0,1	0,1								0,1									
Clavelina lepadiformis				0,1								0,1		0,1			0,1		0,1	

Dendrodoa grossularia										1							0,1			
OSTEICHTHYES																				
Anguilla anguilla					0,1															
Ctenolabrus rupestris	0,1	0,1	0,1	0,1	0,1		0,1	0,1	0,05	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
Entelurus aequoreus					0,1	0,1														
Gadus morhua									0,05						0,1	0,1				
Gobiusculus flavescens																	0,1			1
Labrus bergylta		0,1							0,05							0,1				0,1
Labrus bimaculatus									0,1											
Microstomus kitt															0,1					
Pleuronectes platessa				0,1																
Pollachius virens								0,1												
Symphodus melops		0,1																		
ugopterus punctataus			0,1																	