DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/15

Broad scale habitat mapping of the Natura 2000 site 168: Læsø Trindel and Tønneberg Banke, Kattegat, Denmark

Based on acoustic methods and ground truthing

Jørgen O. Leth & Zyad Al-Hamdani

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A research and development project between
Skov- og Naturstyrelsen, Orbicon A/S
and GEUS, 2005

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GEUS

Contents

1. Introduction

The present report published in 2012 includes a comprehensive presentation of the results and assessments of the habitat mapping techniques used for broad scale habitat mapping. The acoustical field survey has been reported in the cruise report Leth et al. 2006. A summary of the scientific results has previously been published as part of the BALANCE Interim Report No. 27 (Dinesen (ed.), 2008).

A survey has been conducted in the area of Læsø Trindel situated in the northern part of Kattegat, Denmark conducted by GEUS in co-operation with Orbicon A/S. The aim of the field survey was to assess new tools for broad scale mapping and classification of marine habitats by combining acoustic methods with diver activities. The Natura 2000 site 168, Læsø Trindel and Tønneberg Banke was chosen as testing site due to the known presence of various Habitats Directive Annex 1 habitats (1110 Sandbanks, 1170 Reefs and 1180 Submarine structures made by leaking gases).

During the project, the applicability of the combined use of multibeam sonar and sidescan sonar systems has been tested as a tool for mapping of marine habitats. The project aims at providing evidence on the intercalibration of newly acquired acoustic data with other geological and biological information acquired from a dive survey within the Natura 2000 site. Initially the study area for acoustic surveying was delimited and the project partners fixed the order of priority. The acoustic survey was performed September 2005.

Based on a preliminary interpretation of the acoustic data, features and sites for the subsequent ground truthing by diving were decided. Orbicon A/S performed diving in October 2005. Dependent on the type of acoustic features and the state of the substrate GEUS suggested either paravane diving or point diving to be performed. I.e. objects or other pronounced local features was inspected by point diving, while larger areas of specific types and change of substrate were inspected by paravane diving. The results of the ground truthing were subsequently integrated with the acoustic data set and the initial interpretation of the substratum was adjusted and extrapolated within the project area.

During the survey period, the study area was split into two sub-areas to ensure an acceptable set of acoustic data to be acquired in the available survey period in defiance of downtime due to bad weather or technical breakdowns. These sub-areas consist of a southwestern part, which has been affected by dredging, and a central part including the Læsø Trindel proper. Due to bad weather in two days the two sub-areas unfortunately were not connected by the survey. The present study has been concentrated on the central part of the Læsø Trindel.

The study was conducted partly to fulfil the obligations to the research and development contract 2005 between The Geological Survey of Denmark and Greenland (GEUS) and the Danish Forest and Nature Agency and partly to fulfil the Danish obligations to the EU BSR INTERREG IIIB project BALANCE (www.Balance-eu.org)
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2. General description of the area

The Nature 2000 site 168, Læsø Trindel and Tønneberg Banke is located about 12 km northeast of the island Læsø in the Kattegat (figure 1).

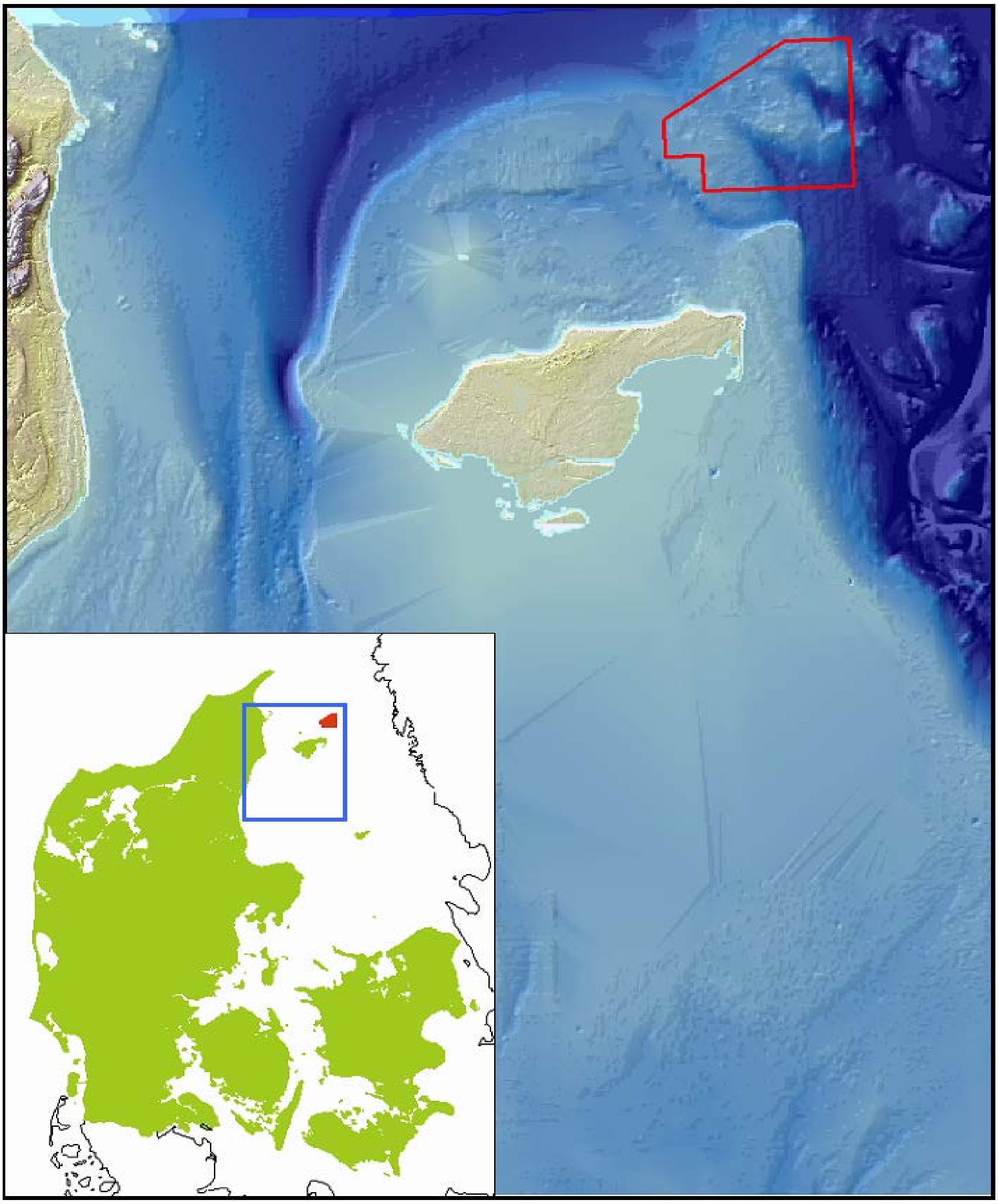


Figure 1. Bathymetric map showing the location of the Natura-2000 habitat area 168, Læsø Trindel and Tønneberg Banke (red box) northeast of the island Læsø in the northern Kattegat. The study area is located inside the shown habitat area. The modelled bathymetry is based on data from The Royal Danish Administration of Navigation and Hydrography.

2.1 Bathymetry

The bathymetry of northern Kattegat around the island of Læsø is very irregular with depths reaching 123m only 12 km east of Læsø, whereas flat areas and reefs with more shallow water depths less than 10 m extend in north-easterly and north-westerly direction. The top of the Læsø Trindel plateau is at only 3.8m depth of water. This plateau has an extension of approximately 2x2 km where the water depth varies between 3.8 m and 10 m. The sediment on the plateau consists mainly of gravel and minor stones with patches of larger boulders in between though there are no cavernous elements left.

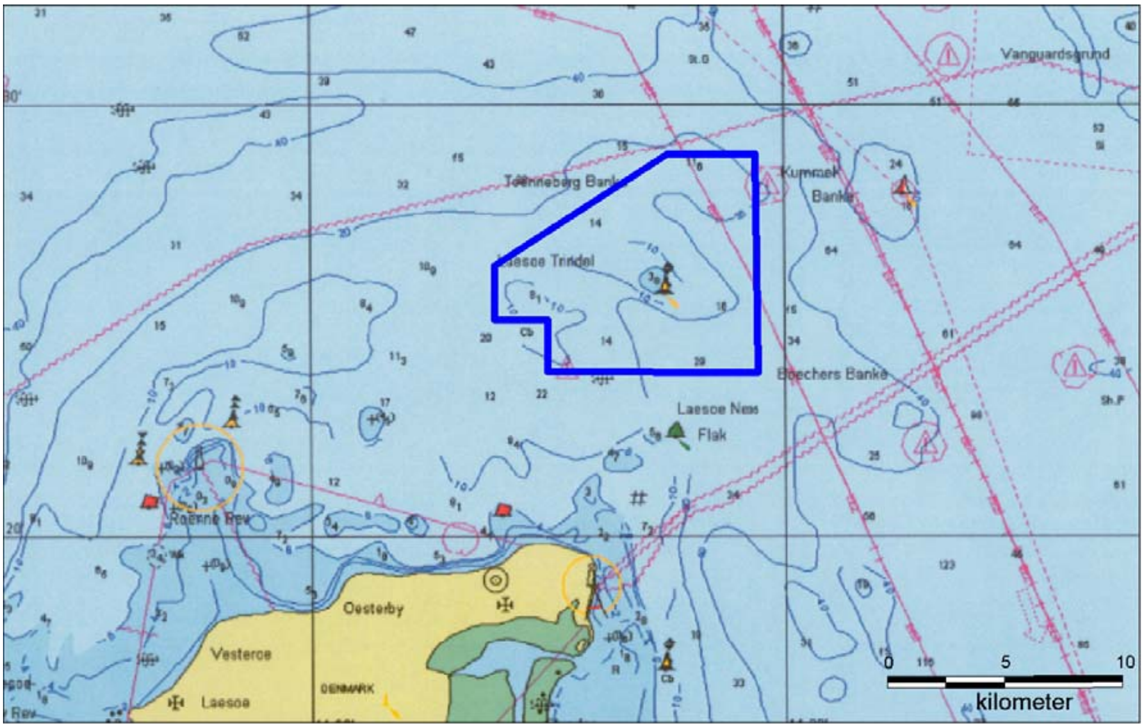


Figure 2. The location of the study area, Læsø Trindel and Tønneberg Banke, shown by the blue polygon on the most recent navigation chart.

The central part of Kattegat east of Læsø has recently been mapped by The Royal Danish Administration of Navigation and Hydrography by means of multibeam sonar and sidescan sonar. These data will be available for future assessments of habitat distribution in Kattegat in relation to other activities of the BSR INTERREG IIIB Balance project.

2.2 Hydrography

The northern Kattegat is characterised by a transition area between the inflowing saline water of Skagerrak and the brackish outflowing water of the Baltic Sea. The mixing of these water masses is prominent north of Læsø in the so-called Kattegat – Skagerrak front. Despite the mixing process there is a permanent layering of the water column is present in the northern and the central part of Kattegat where saline dense water is found deeper than 12-15 m.

The prevailing directions of the currents are north and north-west. From modelling results the maximum current speed has been established to be in the order of 1.0 m/s. The maximum tidal induced current has been found to be in the order of 0.5 m/s. The maximum tidal amplitudes in the area are about 0.3 m. From modelling results (2 years hindcast) is has been established that the water level varies between +0.8 m and -0.6 m. With the prevailing wind directions from the north, north-west and south-east the impact on the area from wave action, however, is limited due to wave breaking at the edges i.e. the maximum wave height is found to be in the order of 4.5 m by modelling with a hindcast of 2 years (modelled data from DHI Water and Environment).

3. The seabed sediments

The mapping of seabed structures and sediment types in the Northern Kattegat is mainly based on the marine geological surveys performed by GEUS, Danish Forest and Nature Agency and the Swedish Geological Survey (SGU). Thus, the published seabed sediment map (figure 3) of Hermansen and Jensen (2000) is based on the interpretation and extrapolation of seismic and acoustic data combined with seabed sediment samples and borings.

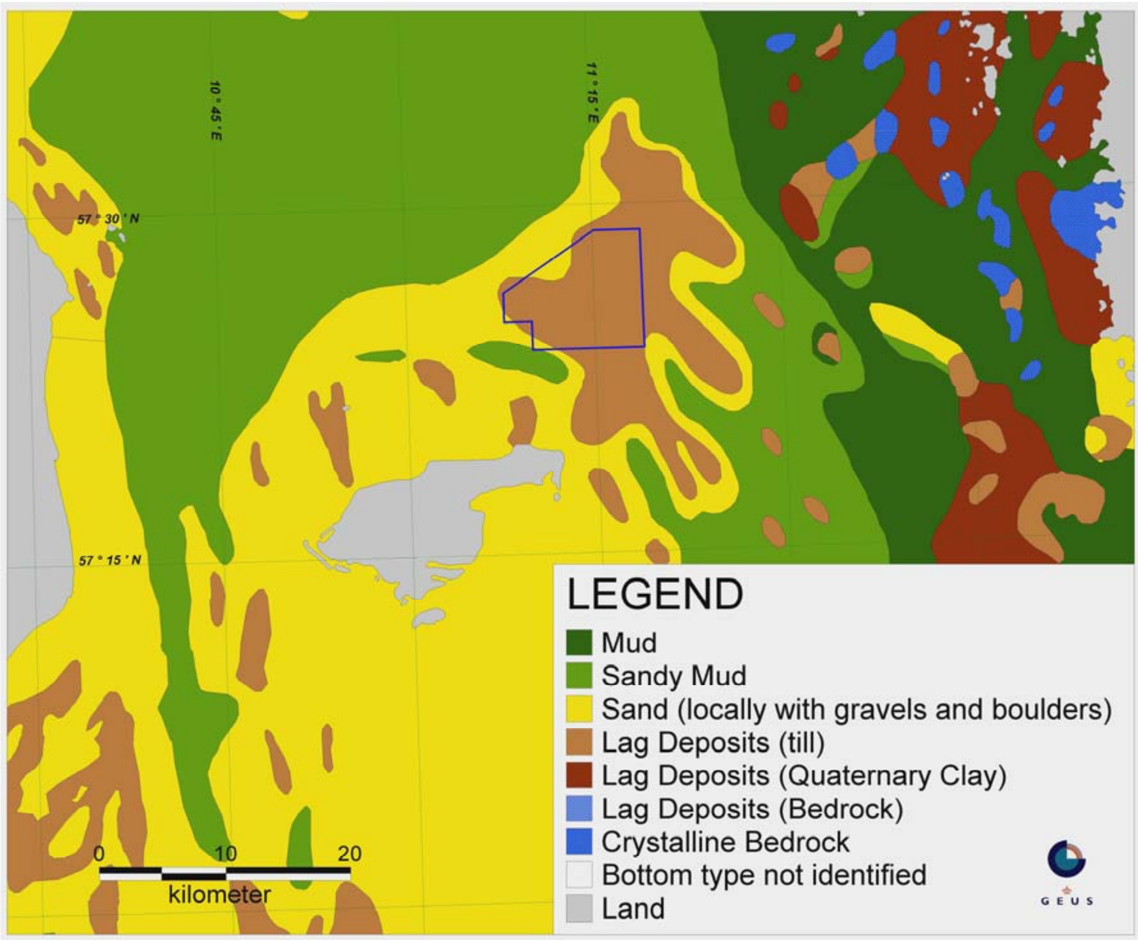


Figure 3. Seabed sediment map of the Northern Kattegat showing the general distribution of sediments in the study area northeast of Læsø. The Nature 2000 site 168 is indicated by the blue polygon. From Hermansen and Jensen, 2000.

Parts of the Læsø Trindel have been mapped in some detail by GEUS (GEUS Report 1996/106) in relation to the evaluation of the aggregate potential in the area. Specifically, this study has focused on mapping the density of boulders at the seabed evaluated based on side scan sonar data. The dense grid of survey line with a distance of 100 m supported by a number of grab samples increased the level of confidence of the sediment distribution considerably compared with that of adjacent area. Furthermore, the same study has presented a map of the vegetation coverage based on an evaluation of chirp sonar data.

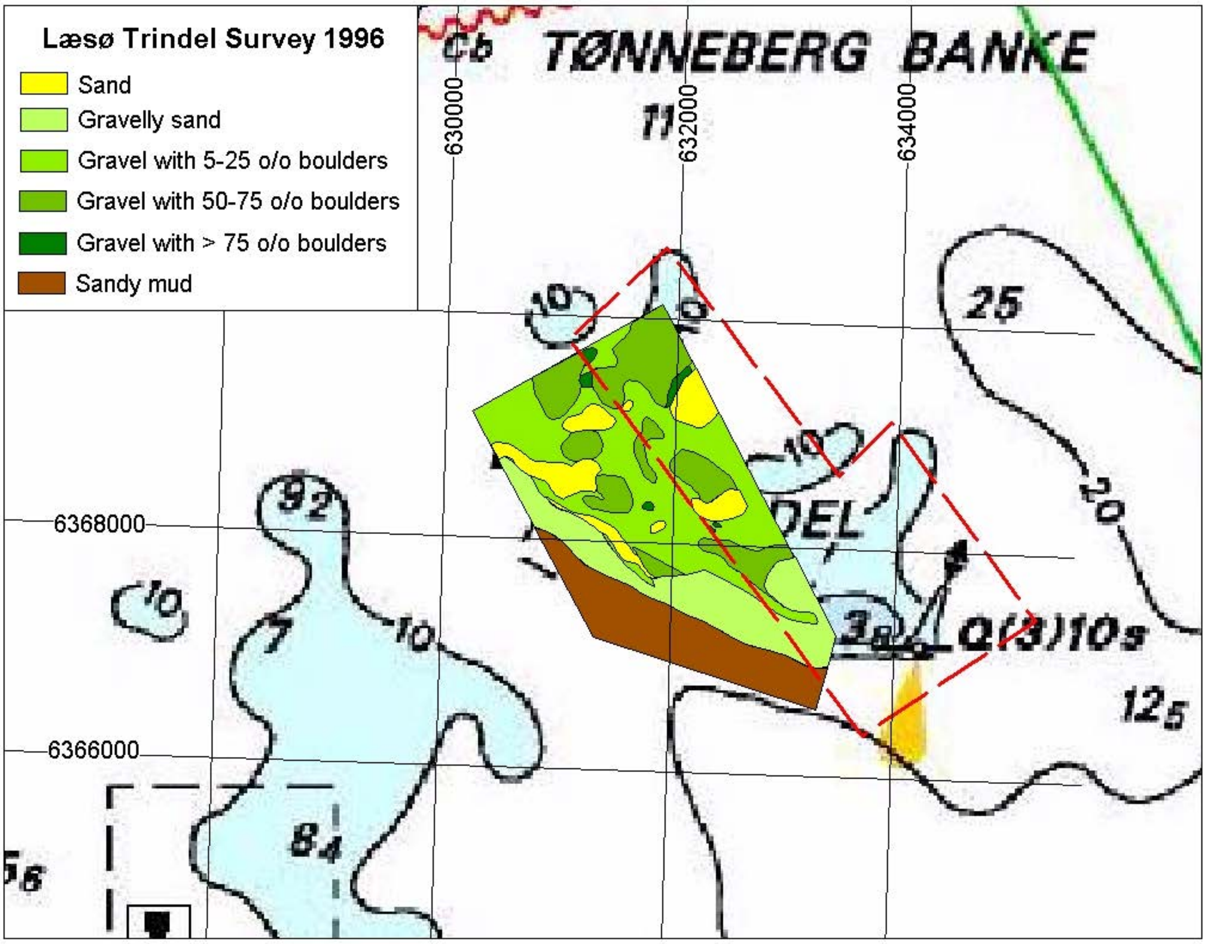


Figure 4. The sediment distribution and boulder coverage mapped on the basis of side scan sonar and chirp data acquired by GEUS in 1996. The red box indicates the present study area.

4. The marine habitats at Læsø Trindel

4.1 Marine habitats of the EU Habitats Directive

The Habitats Directive 92/43/EEC Annex 1 have listed 8 marine habitats of which 3 are present within Natura 2000 site 168, Læsø Trindel and Tønneberg Banke. These are "*Sandbanks which are slightly covered by sea water all the time (1110)*", *"Reefs (1170)"* and *"Submarine structures made by leaking gases (1180)"*. These marine habitats have all been defined in the "Interpretation Manual of European Union Habitats (EUR 15/2)", which was adopted by the Habitats Committee in 1999. As more knowledge has become available on especially the marine habitats present in European waters some of the definitions have in recent years been under discussion by the experts of the Habitats Committee.

As the aim of this pilot project has partly been to investigate if the marine Annex 1 habitats can be identified by acoustic surveys the definitions of the "Interpretation Manual of European Union Habitats (EUR 15/2)", has been applied. However, in recognising the general terms of which the habitats has been defined this report will subdivide the individual habitats where the methodology enables further distinction. The following subchapters contain a description of the general geological origin of the habitats, the definitions of the "Interpretation Manual of European Union Habitats (EUR 15/2)", and the definitions applied by this survey.

4.2 The boulder reefs (Natura 2000 code 1170 Reefs)

The presence of the boulder reefs at Læsø Trindel and its variability is closely linked to the geological development of the area. The geology of the Læsø Trindel area is described as a vast accumulation of glaciogenic deposits. The type and distribution of the coarse grained sediments giving rise to the stone reef indicates deposition and deformation in the ice marginal zone during the last glacial period. Based on the interpretation of seismic data deformation by thrusting and folding has caused complex layering of the sediments. Furthermore, the morphology of the glacial surface is quite undulating with a relief of up to 10 m throughout the entire area.

At the Læsø Trindel proper, the supposed glaciogenic formations outcrop with a high frequency of cobbles and boulder in the surface layers. In general, thin layers of reworked residual sandy and gravely sediments and marine postglacial sand cover the glacigenic deposits (Larsen, 1996). The detailed mapping of the morphology and the seabed sediment distribution, however, indicates a considerable variation of the stone coverage throughout the area. This expresses different depositional processes in the glacial or late glacial period, e.g. intense erosion, sub-glacial processes or deposition in front of the glacier during the late glacial period. More of these processes could explain the presence of cave-forming layers of cobbles and boulder. Moraine deposits have never been recognised in the area, neither onshore nor offshore (Fredericia, 1987). The sub-surface of Læsø Trindel has recently been penetrated in boreholes (Skov- og Naturstyrelsen, 2006) indicating that late glacial clay - the so-called Yoldia Clay – is widespread in the area.

Aggregate extraction from the reef, especially by the removal of boulders by man, had a provable negative influence of the amount of stones present. In the surroundings to the Læsø Trindel the glacial surface submerge and the sediments there become dominated by late glacial marine clay and mud accumulated in the basins to the south and east of the Læsø Trindel.

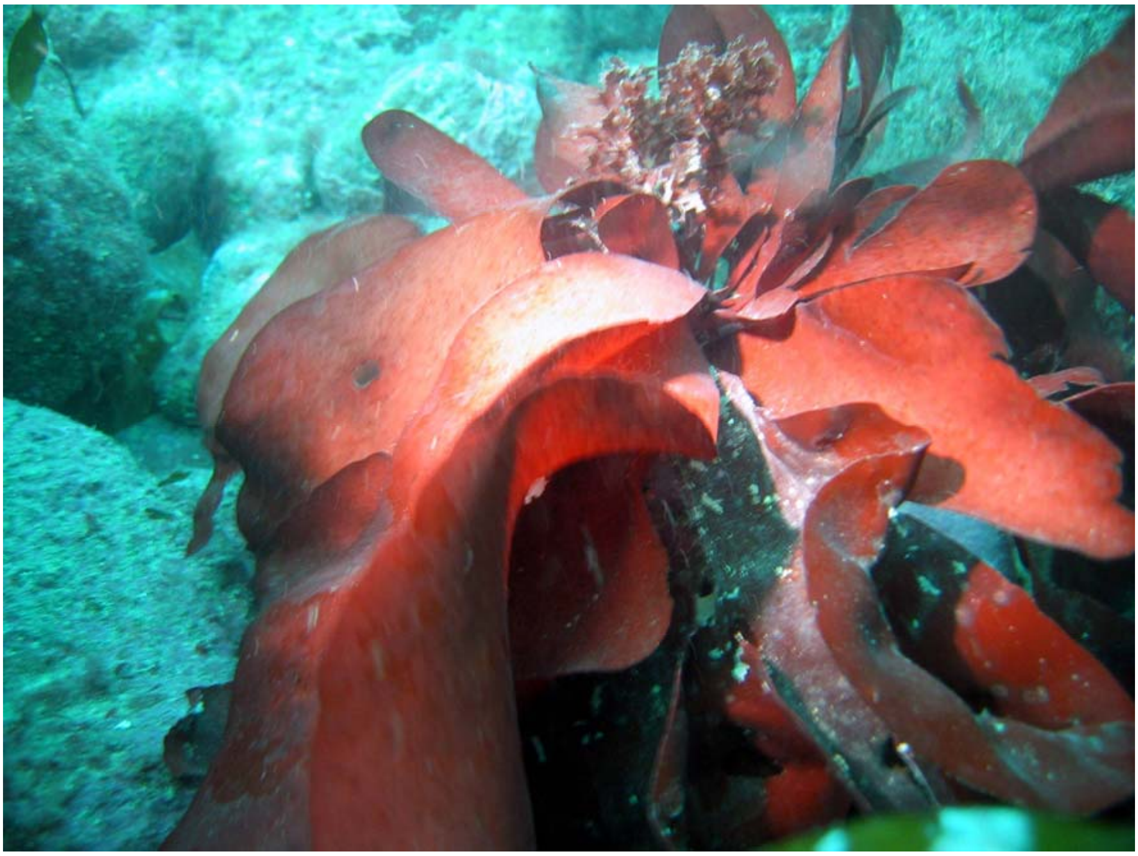


Figure 5. Photo showing a dense cover of boulders forming a boulder reef covered by a variety of algae species e.g. Laminaria hyberboria in the picture. (Photo: Jan Nicolaisen).

4.2.1 The definition of a boulder reef

The definition of a boulder reef has been a matter of discussion amongst biologists and geologists for years. The "Interpretation Manual of European Union Habitats (EUR 15/2)" defines Reefs (code 1170) as:

"*Submarine, or exposed at low tide, rocky substrates and biogenic concretions, which arise from the sea floor in the sublittoral zone but may extend into the littoral zone where there is an uninterrupted zonation of plant and animal communities. These reefs generally support a zonation of benthic communities of algae and animal species including concretions, encrustations and corallogenic concretions.*

In the northern Baltic areas, the upper shallow water filamentous algae-zone with great annual succession is normally well-developed on gently sloping shores. Fucus vesioculosus is submerged at depth of 0.5-6 m in the sublittoral zone. A red algae zone occurs below the Fucus zone at depths of 5 to 10 m".

For the Danish territorial waters Dahl *et al*. (2003) has made a comprehensive study of hard substrate habitats present in Danish waters. A Danish boulder reef is in a geomorphological sense "*an elongated area or bank rising from the surrounding seabed*". However, a further characterisation of the reef is important in order to recognise the variation in reef morphology. This includes recognising i.e. the amount and density of the hard substrate. Therefore, Dahl *et al.* (2003) suggests the following definition in 2003. Figure 7 illustrates the different kind of reefs.

"A reef is an area rising from the surrounding sea floor. The hard substrate made by pebbles, cobbles, stones, boulders, bedrock or biogenic concretions has to cover at least 5% of the sea floor within an area of at least 10 m^2. If the reef is subdivide into smaller banks, i.e. composed of separate aggregations of hard substrate, the border of the reef is defined by delineating individual aggregations fulfilling the criteria for size of minimum 10 m^2 and 5% cover of hard substrate. If the reef is sharply or gradually changing into a sandy or gravel dominated seafloor, the border of the reef is defined by the cover of 5% hard substrate".

Furthermore, Dahl *et al*. (2003) defines hard substrate as:

"*Geological or biogenic material on the seafloor with more than 10% of the surface covered by characteristic hard bottom fauna and/or flora at least once a year*".

The definitions by Dahl *et al*. (2003) have been introduced in acknowledgement of the complexity of the Danish boulder reefs. For the present study at Læsø Trindel we have adapted and elaborated the proposed subdivision to make it applicable for the characterisation of the boulder reef habitat on the basis of the acoustic data combined with ground truth data. The classification details are presented as part of the results in chapter 7. The three classes are as follows:

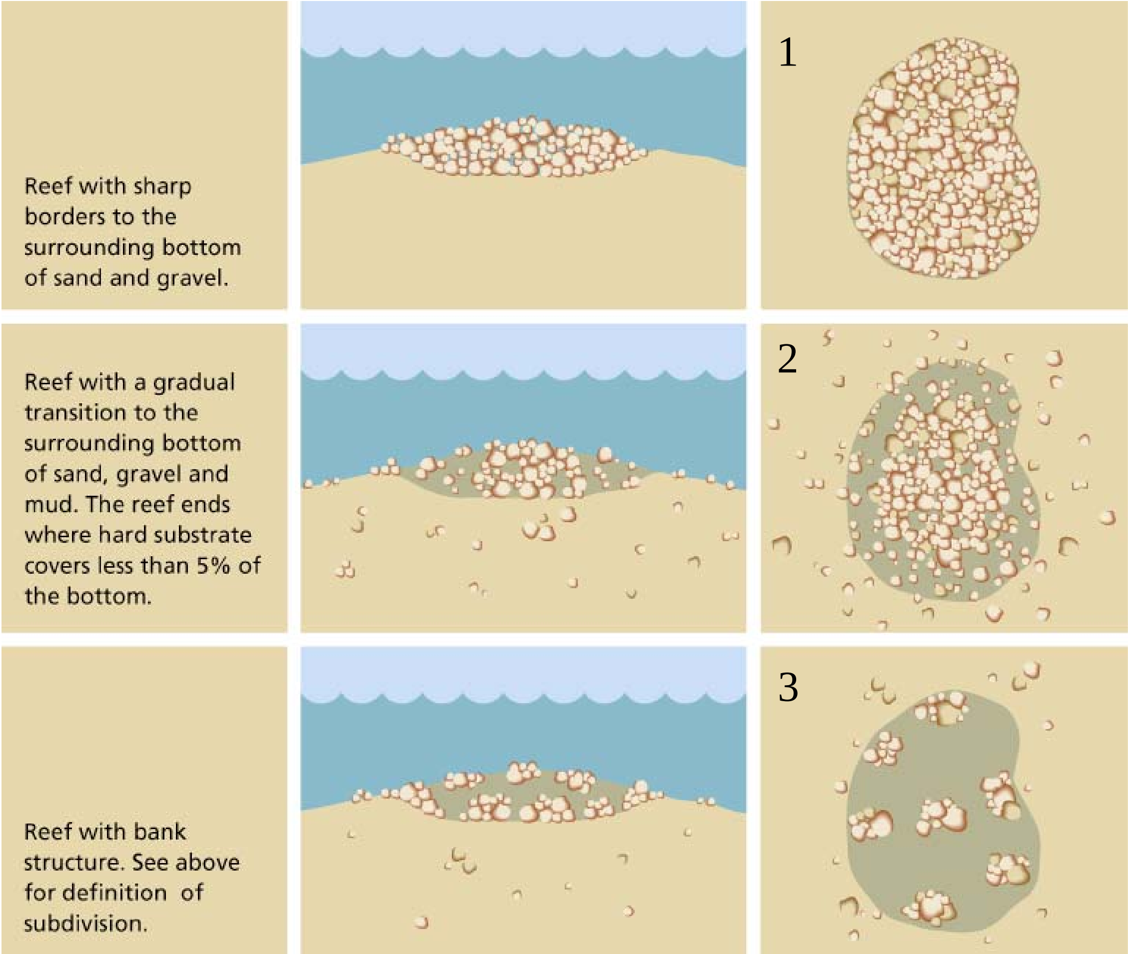


Figure 6. Definition of hard substrate reefs with a schematic presentation of three different reef types and their delineation to other types of seabed habitats. The middle column shows a vertical cut and the right column shows the reef seen from above. The sub-division into type 1, 2, and 3 has been adapted to the classification of boulder reefs in the present study. The figure is modified after Dahl et al. 2003.

Reef 1: Coherent formation of stones with high cover (75 – 100%) of hard substrate. When surrounded by sandy and/or gravely seabed the boundary is sharp.

Reef 2: Scattered formation with high to medium cover (25 – 75%) of hard substrate. When surrounded by sandy and/or gravely seabed the boundary is gradual.

Reef 3: Smaller individual banks of stones each at least 10 m^2 forming a low cover (5-25%) of hard substrate. When surrounded by sandy and/or gravely seabed the boundary is gradual.

In the classification of the Læsø Trindel it is found that these three types of reefs frequently borders to each other rather than to sandy seabed types according to Dahl et al.

Experiences from the analysis of the sidescan sonar data has demonstrated that a minimum diameter of particles in the order of 25 cm can be detected under optimum conditions, i.e. no vegetation cover to blur the shape of individual objects. In the geological sense the acoustical detection limit in the magnitude of 25 cm is in agreement with the definition of 'boulders' as particles of a diameter above 256 mm (Wentworth, 1922).

The above definitions do not define a minimum sediment diameter, because the minimum diameter relevant for macroalgae vegetation or epiphyte community depends on the long-term stability of the substrate. The long-term stability of e.g. smaller stones depends on the energy level (wave exposure and/or current strength) on the individual site.

The above definitions do not take the photic depth of the feature into account though differences in biomass can be expected between similar features depending on the depth of the photic zone. Where relevant photic depth as determined by the lower distribution limit of perennial macroalgae should be used to delineate and distinguish between various reef areas. No reefs below photic depth were identified during this field survey.

At Læsø Trindel, in general, a kelp forest characterised by *Laminaria hyberboria and Laminaria digitata* where the boulder reef forms well-developed cave-forming structures (Reef type 1). Underneath the brown algae canopy foliose red algae such as *Phycodrys rubens, Membranoptera alata, Dilsea carnosa* and filamentous tufts such as *Ceramium rubrum* and *Coralina officinalis* typically is present as well as the foliose brown algae *Desmarestia aculeata.* Where the reef area is characterised by scattered large boulders and smaller stones (Reef type 2 and Reef type 3) with pebbles and gravel dominating the seafloor between the boulders, the large boulders are covered with large the kelp *Laminaria hyberboria,* while the smaller boulders and stone are dominated by the kelp *Laminaria saccharina,* filamentous brown algae such as *Desmarestia viridis* or foliose red algae such *Dilsea carnosa*. The pebbles have no cover of large algae though various encrusting species might be present.

4.3 The sandy seabed (Natura 2000 code 1110 Sandbanks which are slightly covered by seawater).

The sandy seabed is the most common substrate in the Danish waters. The sand is defined as loose sediment with grain size diameters between 0.2 mm and 2.0 mm. Due to repeated reworking of the upper decimetres of the seabed the sand normally is well-sorted with only a small content of fine grained material (clay and silt) or organic matter. The sandy seabed originates from a suite of different depositional environments such as late glacial meltwater deposits and fossil postglacial coastal deposits. The current and wave induced transport is responsible for the transportation and deposition of marine sand including sandbanks. However, a considerable part of the sandy seabed in areas of non-deposition or erosive conditions is composed of relict formations. Sandy seabed types are often found as transition areas between the shallow reef areas and the deeper parts of the seabed dominated by mud or sandy mud.

Figure 7. Photo showing a sandy seabed with scattered debris of shells and algae. Note the presence of ripples, which indicate active sediment transport. (Photo: Gorm Larsen)

4.3.1 The definition of sandy seabed types

The Interpretation Manual of European Union Habitats (EUR 15/2) defines sandbanks which are slightly covered by sea water (1110) as:

"Sublittoral sandbanks, permanently submerged. Water depth is seldom more than 20 m below Chart Datum. Non-vegetated sandbanks or sandbanks with vegetation belonging to the Zosteretum marinae and Cymodoceion nodosae."

This definition is very difficult to handle in the field and has in the recent years caused some discussion among the members of the Habitats Committee. In May 2005 the Habitats Committee made some amendments to the Marine Guideline with the purpose to include the offshore part:

"Sandbanks are elevated, elongated, rounded or irregular topographic features, permanently submerged and predominantly surrounded by deeper water. They consists mainly of sandy sediments, but larger grain sizes, including boulders and cobbles, or smaller grain sizes including the mud may also be present at the sandbank. Banks where sandy sediments occur in a layer over hard substrata are classed as sandbanks if the associated biota is dependent on the sand rather than on the underlying substrata."

Clarification:

“Slightly covered by sea all the time” means that above a sandbank the water depth is seldom more than 20 m below chart datum. However, sandbanks can extend beneath 20 m below the chart datum and it is appropriate to include in designations such areas where they are part of a feature. Such features may have trans-frontier dimension.

We find that a further characterisation of the sandy seabed is important in order to recognise the variation and possible conservation value of individual sandy habitats. The most controversial part of the existing sandbank definition is how to define and delimit sandbanks as topographic features rising from the surrounding seabed. From our experience such delimitation only can be performed on the assumption that a high quality and density of bathymetric data is available. Navigation charts, which are the immediate available open bathymetric data source, will normally not provide such sufficient set of data. This implies that other depth data sources should be included - if available - as background data for evaluating if the sandy seabed actually forms a sandbank with a certain slope to the surrounding seabed or it forms a flat seabed with a negligible slope. In any case a specification value of slope angle is recommended in future amendments of the guidelines.

The present project has emphasised the need for supplementary sandy habitat types to be added to the existing sandbank definition. Hence, we have proposed and applied an extension to the Interpretation Manual of the European Union’s definition of sandbanks.

The proposed definition build upon the experiences of the mapping and the recognition of the sandy seabed by use of the in-hand tools i.e. acoustics and ground truthing by samples/video/diving. The definition build upon the recognition of the topography, composition of grain sizes, the spatial extend of the feature, the presence of current-induced bedforms such as ripples and the relation to the surrounding seabed. It also defines the relative coverage of the seabed type within a specific defined area.
By using the proposed classification system distinctions can be made between sandbanks and flat sandy seabed. Furthermore, a transitional seabed type composed of sandy and gravely sediments between the reef and the latter sandy seabed habitat types named ‘gravely seabed’ is introduced as this seabed type most likely represents a specific type of habitat.

All the defined seabed types are applicable at water depths beneath and above 20 m.

4.3.2 A new extended definition of sandy seabed types

A new extended definition of sandy seabed types is proposed here, building on the Interpretation Manual of European Union Habitats, the amendments from the Habitats Committee and the experiences from the present project.

The definition of sandbanks

The sandbanks are elevated, elongated, rounded or irregular topographic features, permanently submerged and predominantly surrounded by deeper water. They consist mainly of sandy sediments with grain size diameters between 0.2 mm and 2.0 mm. The sandy sediments cover at least 95% of the sea floor within a square of at least 50 x 50 m. Coarser grain sizes including boulders and cobbles or finer grain sizes including mud may be present at the sandbank, but cover less than 5% of the square. If the seafloor is covered with several sandbanks a distinctive slope delineates the border of the individual sandbank. Coarser grain sizes will usually be present between the individual sandbanks banks where sandy sediments occur as a layer over hard substrata but are classified as sandbanks if the associated biota is dependent on the sand rather than on the underlying substrata.".

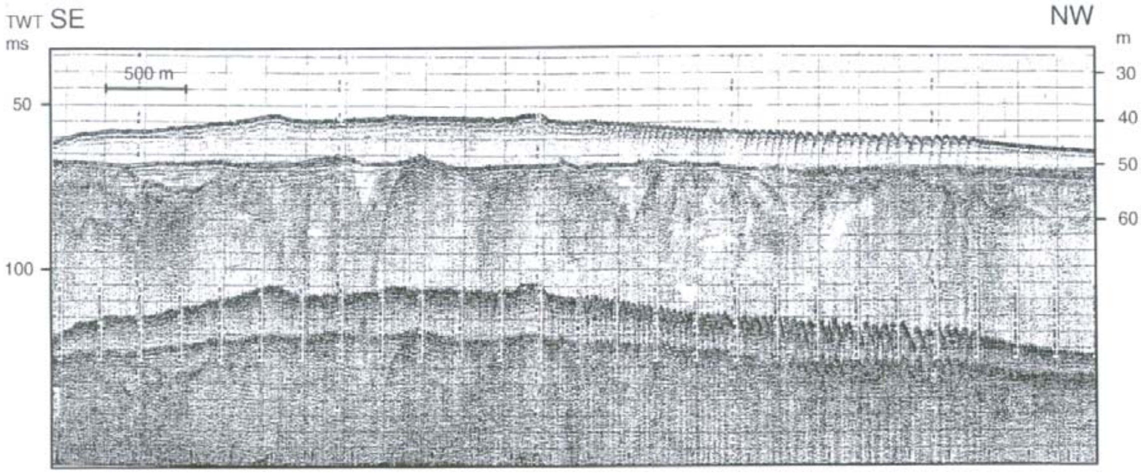


Figure 8. An example of a perfect developed sandbank illustrated in a seismic cross section from the North Sea. The sand layer is the semi-transparent top unit between 38 and 50m water depth with a slope against the SE and the NW. Active sediment transport is documented by the presence of megaripples in the right part of the section. From Leth (1998).

Definition of the flat seabed

***The flat sandy seabed** is a coherent seabed covered by sand with little or no measurable slope and no distinctive elevated or irregular topographic features except for small-scale ripples. It consists mainly of sandy sediments with grain size diameters between 0.2 mm and 2.0 mm. The sandy sediments cover at least 95% of the sea floor within a square of 50 x 50 m. Coarser grain sizes including boulders and cobbles or finer grain sizes including mud may also be present, but cover less than 5% within a square of 50 x 50 m. When sandy sediments occur in a layer over hard substrata, the seabed is classified as flat sandy seabed if the associated biota is dependent on the sand rather than on the underlying substrata.*

Definition of the gravely seabed

The gravely seabed is a seabed type surrounding the reef (code 1170) and usually transitional to the sandy seabed types. The gravely seabed habitat consists mainly of sand and gravel (grain sizes between 2.0 and 20 mm). The seabed is featureless but can be recognised by relatively high reflectance on the backscatter and sidescan sonar signal. The gravely seabed covers at least 95% of the sea floor within a square of 50 x 50 m. The gravely seabed typically originates as lag deposits accumulated on top of the underlying moraine. The gravely seabed type has, in general, no cover of algae except from different types of encrusted algae species. However, at some stations annual species such as *Desmarestia viridis* and different types of red bushes have been observed.

The habitat definitions do not take the photic depth of the features into account though differences in biological content can be expected between similar features depending on the depth of the photic zone. At Læsø Trindel no sea grasses has been observed due to the high degree of exposure and level of energy.

4.4 Submarine structures made by leaking gases (1180)

The distribution of the submarine structures made by leaking gases in the northern Kattegat area is directly linked to methane seeps in shallow waters. They form spectacular submarine landscapes due to carbonate-cemented sandstone structures, which are colonised by brightly coloured animals and plants (figure 10). In the Northern Kattegat evidences indicate that these formations cover up to 500 m^2 of the seabed and consist of pavements, complex formations of overlying slab-type layers mushroom like or vertical pillars up to a height of 5 m high above the surrounding seabed.

The carbonate cement consisting of high-magnesium calcite, dolomite or aragonite indicates that it originated from a microbial methane oxidation (Laier et al., 1992, 1996). The methane most likely originated from the microbial decomposition of plant material deposited during the Eemian and Early Weichselian periods 100.000 to 125.000 years before present. It is believed that the cementation occurred in the subsurface and that the rocks were exposed by subsequent erosion of the surrounding unconsolidated sediment. The formations are interspersed with gas vents that intermittently release gas, primarily methane. Many animals live within these formations in holes bored by sponges (example of typical species), polychaetes (example of typical species) and bivalves (example of typical species). Within the sediments surrounding the seeps there is a poor metazoan fauna, in terms of abundance, diversity and biomass. This may be a result of toxicity due to hydrogen sulphide input from the gas.

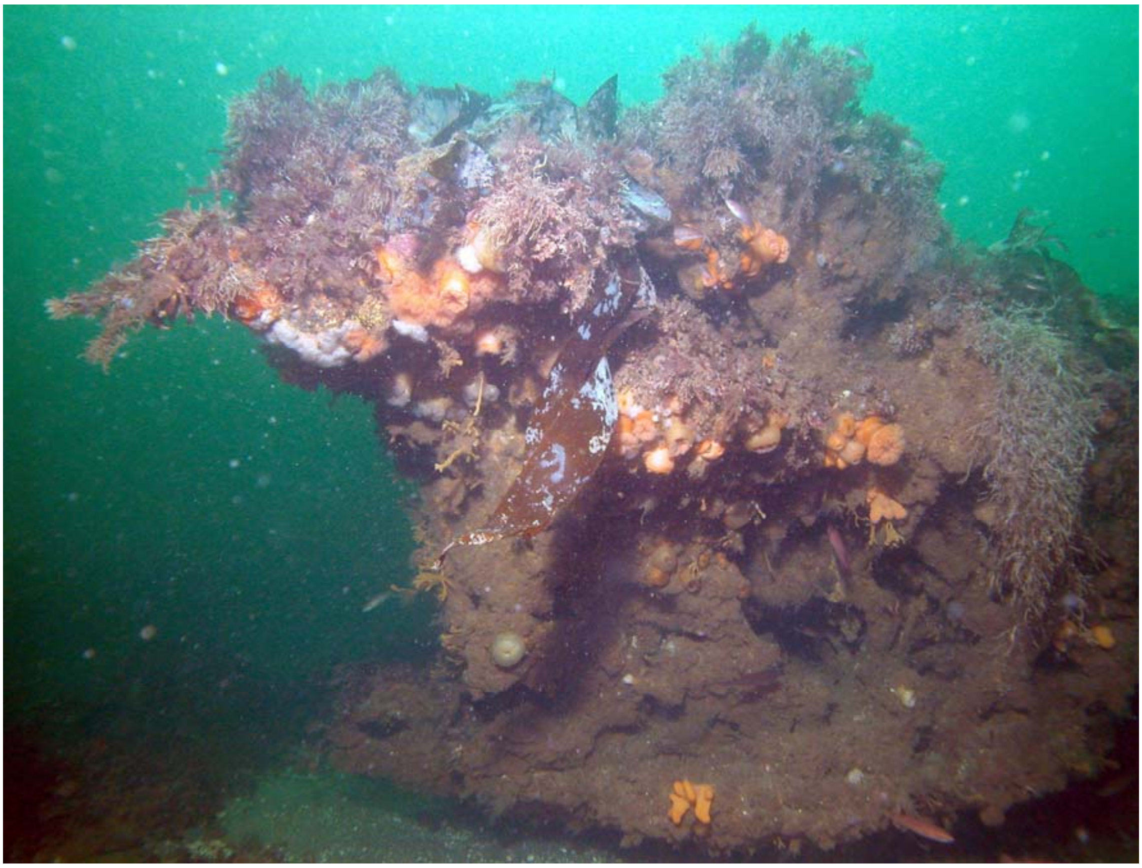


Figure 9. Photo from The Læsø Trindel showing the sub-marine structure of cemented sandstone made by leaking gases with a high diversity of species present. (Photo: Jan Nicolaisen).

The interpretation of the acquired data and the delineation of submarine structures made by leaking gases in the present study primary build upon the analysis of sidescan sonar data. The area of the characteristic reflection pattern (see figure 11) was then chosen for the diver's inspection. Like this, the acoustic method has been demonstrated as a useful tool for recognising and delineating the sub-marine complex structures from leaking gas. However, the verification of the structures by diver is needed due to the limited information from the sidescan picture. I.e. the sidescan picture will provide information on the presence of the structures - as long as these are emerging above the seabed - but will only display the complexity of the structure to a limited extend. In case the structures are present are formed by pavements partly covered by loose sand they will not be reflected by the sidescan sonar method.

4.4.1 The definition of submarine structures made by leaking gases

"Interpretation Manual of European Union Habitats (EUR 15/2)" defines submarine structures made by leaking gases (1180) as:

"Spectacular submarine complex structures, consisting of rocks, pavements and pillars up to 4 m high. These formations are due to the aggregation of sandstone by carbonate cement resulting from microbial oxidation of gas emissions, mainly methane. The methane

most likely originated from the microbial decomposition of fossil plant materials. The formations are interspersed with gas vents that intermittently release gas. These formations shelter a highly diversified ecosystem with brightly coloured species".

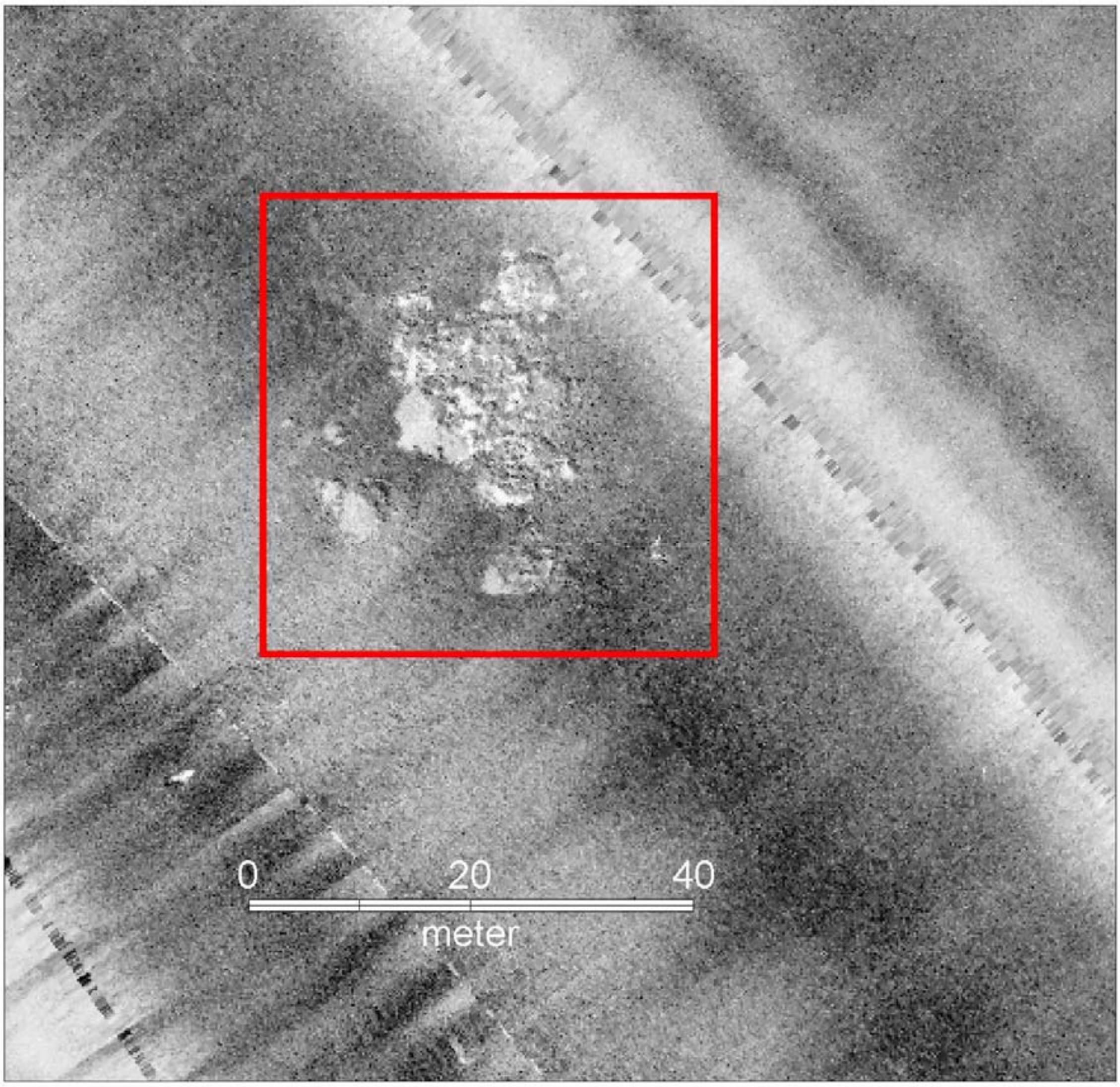


Figure 10. Section from the sidescan sonar mosaic at Læsø Trindel showing the carbonate cemented sandstone structures rising from the surrounding sandy seabed. The example represents the diving station 14 described later in the text. The size of the red box is 40 x 40 meter.

5. Survey methods

The methods used have been chosen to fulfil the aim of the project, an assessment of the combined use of marine acoustics and ground truthing by diving to classify and map marine habitats.

Two remote sensing instruments were deployed in this survey, namely: the multibeam sonar system (MBS) and the sidescan sonar system (SSS). Auxiliary systems like the navigation and positioning systems as well as the sound velocity profiler were also used in this survey.

5.1 The multibeam sonar system (MBS)

The used system is a high resolution EM3002 dual head seabed mapping system. Each head delivers a 1.5° beam for transmission and reception, where the swath coverage of the dual head system can reach up to 10 times the water depth. In the high-density mode of operation, each head acquires up to 254 soundings per ping. The operating frequencies are 293 and 307 kHz to avoid interference between the two heads. The operation range of the system is from 1m to 150m, which is also a function of salinity and temperature. The depth resolution is very high (~1cm), the across track measurement accuracy is a function of depth and the distance from nadir position, a nominal range resolution of 5cm is reported.

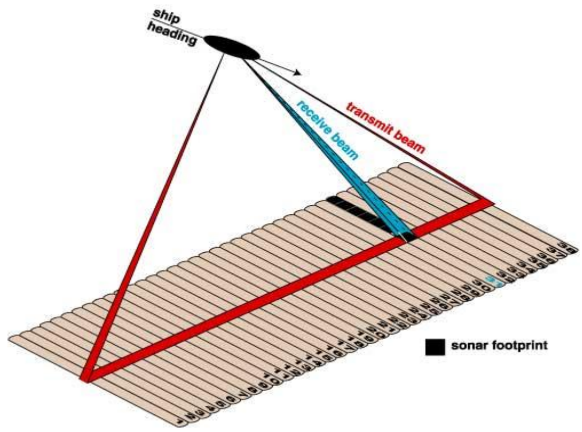


Figure 11. Schematic diagram of Multibeam system operation.

The EM3002D was mobilised to the bow of the survey boat M/S “Line” and the Kongsberg’s company engineers performed calibration in Copenhagen harbour. The boat then transferred to Læsø with the MBS lifted out of the water for safety reasons. The MBS transmit across track fan shaped beam, which can be electronically stabilized for pitch, and the received beams are electronically stabilized for roll. The pitch, roll, heave, heading and the applied stabilization are all taken into account when calculating the sounding depths and positions. Further details of the cruise is published in the cruise report (Leth et al. 2006)

5.2 The sidescan sonar (SSS)

The used equipment was the EdgeTech DF-1000 dual frequency digital sidescan sonar. The sidescan fish was towed behind the survey boat at a safe distance. The system operates at two frequencies; 100 and 500 kHz corresponding to a standard and high-resolution operation respectively. The system generates a fan shape beam in the cross track direction with 50m°beam width. In the along-track direction the beam width is 1.2° for the 100 kHz operation and 0.5° when the 500 kHz option is used. A nominal operating range of 200-300m is reported and that depends on the type of the benthic sediments, and to a minor extent on temperature and salinity. A 12 knots maximum surveying speed is given in the manual, but a survey cruise of 6 knots was found to be adequate for the survey in hand. The resulting sidescan picture is of high resolution and considered being very useful for seabed habitat mapping.

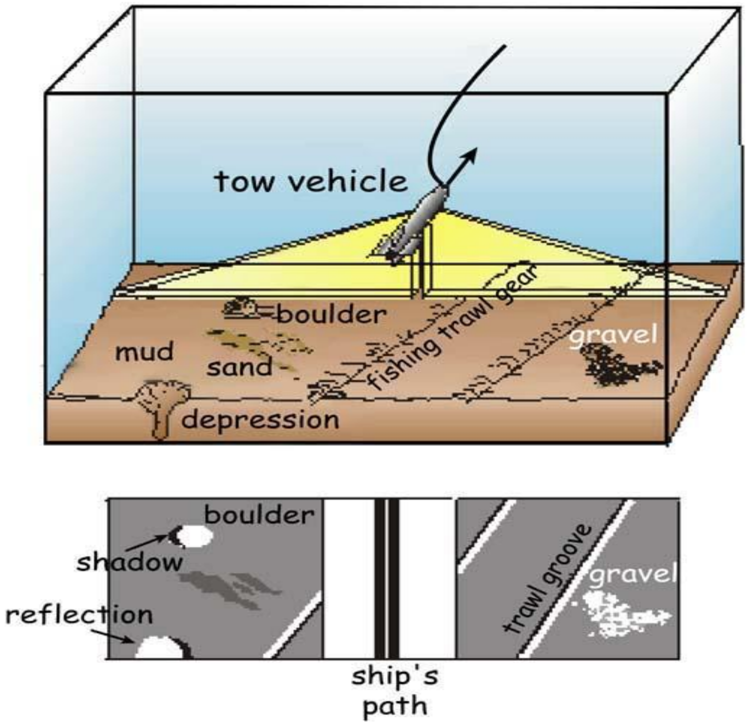


Figure 12. Sketch showing the sidescan sonar in operation. The yellow colour illustrates the swath width of the sidescan beams and the coverage of the seabed.

5.3 Navigation and positioning systems

5.3.1 Navigation system

The EIVA NaviPac integrated navigation and data acquisition software was used for navigation purposes. The software enables the time synchronising, survey planning of survey lines, navigation display as well as Helmsman display for survey boat navigation. The positioning devices and the motion sensors can be interfaced to the software.

5.3.2 The positioning systems and motion sensors

The positioning system is Sagitta GPS a product of Thales Navigation. It consists of an antenna and a receiving unit with its corresponding software. This system provides a positioning accuracy of centimetres (depending on the operation mode). Kongsberg provides the motion sensors as part of the purchasing deal of the Multibeam system. It is the Seatext Motion Reference Unit MRU-5 for high accuracy measurements of pitch, roll, heave and yaw of the survey ship. It provides roll and pitch accuracy of 0.02° accuracy at $\pm 5^{\circ}$ amplitude. For heading accuracy the Seatex Seapath 20 GPS compass is used to achieve a heading accuracy of $\sim 0.4^{\circ}$ RMS.

5.4 The sound velocity profiler

This plays an important role in the accuracy of the depth measurement. The instrument measures Time-on-flight sound velocity with 0.03 m/s accuracy. The profiler is lowered down at the beginning and the end of the survey day. The SV Plus from Applied Microsystems was used in the survey and the acquired data was fed directly to the acquisition system for calibration. Also the Sound Velocity Smart Sensor was used to provide continuous sound velocity measurements at the vicinity of the sonar heads.

5.5 Data acquisition and processing

The data used in the project originates from the newly acquired acoustic data from the sidescan and the multibeam sonar systems and divers observations. The acoustic survey was performed by GEUS in the period from the 30th of August to the 7th of September 2005. Within the surveyed area two areas of designated Natura 2000 reef structures are present. Furthermore, in the surveyed area to the southwest a sandbank area is found. The surveying of the Læsø Trindel area has been continued in the eastern direction with the purpose of covering the depth interval from about 3 to 35 m.

The subsequent diving including photo documentation performed by Orbicon A/S in October took place at a series of positions decided by GEUS based on the preliminary interpretations of the acoustic data.

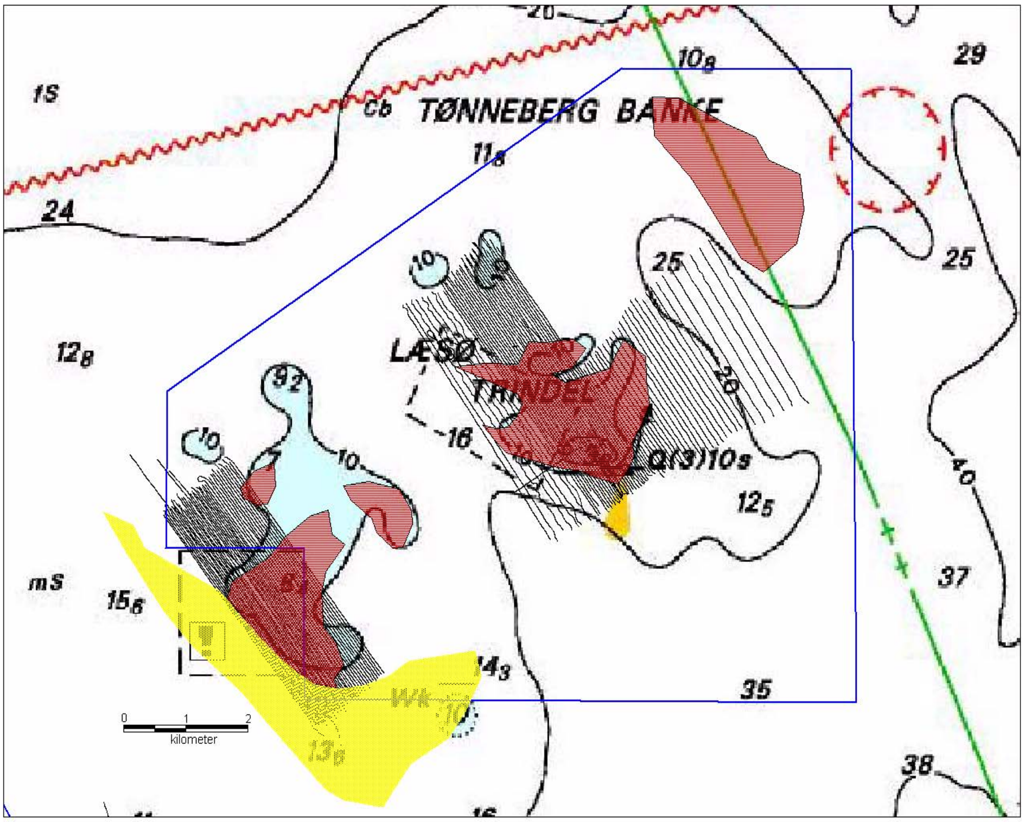


Figure 13. The project area, Habitat area 168 Læsø Trindel and Tønneberg Banke (blue box). The designated Natura 2000 Annex-1 stone reef areas are shown (red colour) and sandbanks (yellow colour). The 2005-survey lines are shown as dark lines.

5.6 The multibeam sonar system

Data was collected and stored using the Kongsberg SIS software. Return signal depth and amplitude was recorded for further processing as *.all files. All other information concerning the installation, calibration and navigation data were also stored in as well as the sound velocity profile taken during the survey. The raw data was then processed by software from Kongsberg called Neptune, where all raw data converted to survey data, which then can be processed for depth and backscattering data files. The data can be grid and displayed in different format one can choose from the menu. The final processed and cleaned from outliers data can be exported into different format that suits many presentation programs.

5.7 The side scan sonar system

The Triton Elics ISIS Sonar software was used for collecting side scan data. The data was recorded digitally in *.XTF format, also a hard copy was produced continuously during data acquisition. Important targets were noticed online and delineated for further inspection. The processing software is also the ISIS Suite where data was corrected for range and grey tone to enhance its quality for interpretation. The processed data was then build into a mosaic by the same software and displayed by another software, DelphMap, also from Triton Elics where it could be configured and merged and exported in different format acceptable by the current GIS software for presentation.

5.8 Ground truthing

It is a rather important procedure to be conducted during or shortly after the execution of an acoustic survey or any other remote sensing survey. Ground truthing has to be planned according to the results obtained from the geophysical survey. The geologists will study carefully the resulting map of the seabed after the primary processing and corrections and look for the important features and anomalies that are relevant to the aims of the survey, or they could be key features in the overall interpretation of the surveyed area.

Ground truthing can have different aspects, it could be through diver's observations, video camera, still photos, and grab samples and cores. All depends on the purpose of the survey and the available time and budget. There also exists a trade off between different ground truthing methods, grab samples can give detail analysis of the sediment size and composition but it only covers a very small part of the surveyed area, while video footage and divers observations can cover much larger area but its highly subjective. The type of the geology of the area also plays an important role in deciding the ground truth operation. Dealing with a flat area with little or no change in sediment type and morphology, few grab samples are adequate for truthing. Contrarily, if the area is complex then video and divers are the recommended ground truthing procedure.

It is worth mentioning the importance of conducting a dialogue with the diver's team *prior* to the ground truth survey identifying the potential important features delineated from the acoustic survey.

5.8.1 Ground truthing by diving

In this survey some transects that are relevant to the aim of the survey and crossing areas of interest was chosen for diving. The ground truth survey was conducted shortly after the acoustic survey. Video and still camera were used as well as the observations of the experienced divers.

Based on the acoustic interpretations a series positions were chosen by the geologist and put in the order of priority for the ground truthing by diving. The listed positions were subdivided into point dive positions and paravane dive positions.

The diving was conducted by two professional divers assisted by one diving assistant in agreement with the direction of the "Safety diving" handbook. Whenever the diver was submerged, he communicated with the ship via an underwater communication system ensuring the diver and the assistant on-board unlimited communication (the duplex system).

By the point diving procedure the ship was anchored within a distance of a few metres from the chosen position. The primary task of point diving was to recognise the objects or substrate features pointed out by the geologist on the acoustic data, and to confirm if the interpretation was correct. Finally, the diver should document the substrate features by still photos and / or underwater digital video recordings.

By the paravane diving procedure the ship was anchored in an appropriate distance to the start position of the paravane track. After preparing himself, the diver submerged to the bottom waiting for the starting signal there.

The paravane diving was conducted along pre-defined survey lines using the GPS system to ensure the exact position of the diver. The uncertainty was estimated to a few metres off the line. The survey speed of the paravane diver (2 – 4 km/t) was appropriate for the diver to register the overall substrate and biological features. Every paravane track was extended in both ends to ensure the total coverage of the suggested survey line. The diver communicated his observations directly to the onboard assistant who registered all information and data from the diver directly on a laptop. The software “Paravane” was used linking the divers observation to a contemporary calculated actual position of the diver. The parameters registered by the diver are type of substrate (sediment type), degree of coverage (%) and the type of vegetation.

6. Results

6.1 The acoustic methods

6.1.1 Multibeam sonar calibration

The multibeam system was mobilised on the survey vessel “Line”. The position of the sonar head and other measuring devices were carefully measured and referenced to a common datum, documented as part of the system integration, and SAT. Then a calibration procedure was followed to calibrate the two sonar heads for roll and pitch. The calibrating values were then stored in the instillation parameters file to be used later on in processing. A few problems were encountered during calibration but they were solved later on. An error was discovered with the water level parameter and was corrected after the survey and during the processing period.

6.1.2 Bathymetri map production

After performing the required processing on the Multibeam data, the data for Læsø Trindel were pooled and gridded together. The resulting sun illumination map was printed and it reveals a highly detailed manifestation of the seabed in the survey area. The depth of the seabed varies between 3.5m down to 42m approximately. The structures are well pronounced in the map and places of stone reefs and flat sediment areas can be readily distinguished (Figure 14). When zooming in, one can notice a “ripple shape” feature along the outer beams of the survey lines; they have a depth difference of about 12-16 cm from the surrounding area depth. This was reported to Kongsberg and we have recently received a corrected version of the SIS software, which Kongsberg claims they have remade the mentioned problem. This is yet to be tested during the next survey.

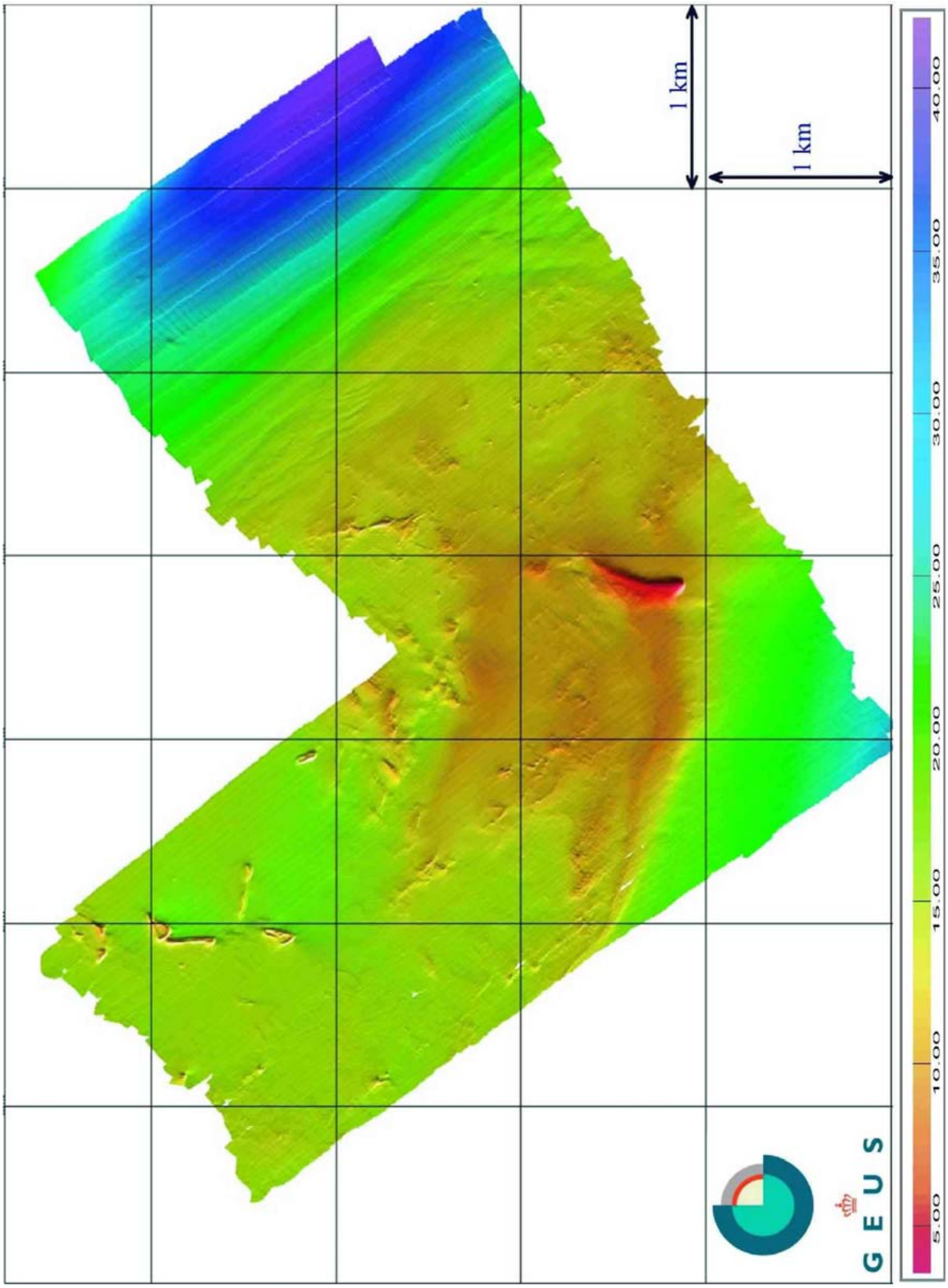


Figure 14. Bathymetric map of the Læsø Trindel obtained from multibeam sonar system.

The scattered signal recorded by the Multibeam system could also be used after mosaicing for seabed sediment discrimination. Due to the nature of the multibeam system beam pattern, the resulting scatter map will have a poorer resolution in comparison to the Side Scan sonar results. This is very understandable, but in broad scale resolution, the two results are very similar as one can notice in Figure 15.

6.1.3 The backscatter results of the side scan sonar

The processed XTF files were merged into a mosaic using the DelphMap software so it can be geo-referenced and exported to MapInfo GIS software. The scattering map of the area was interpreted first according to the intensity of the scattered signal and its relation to the type of sediment (Figure 16). Seabed areas were segmented accordingly.

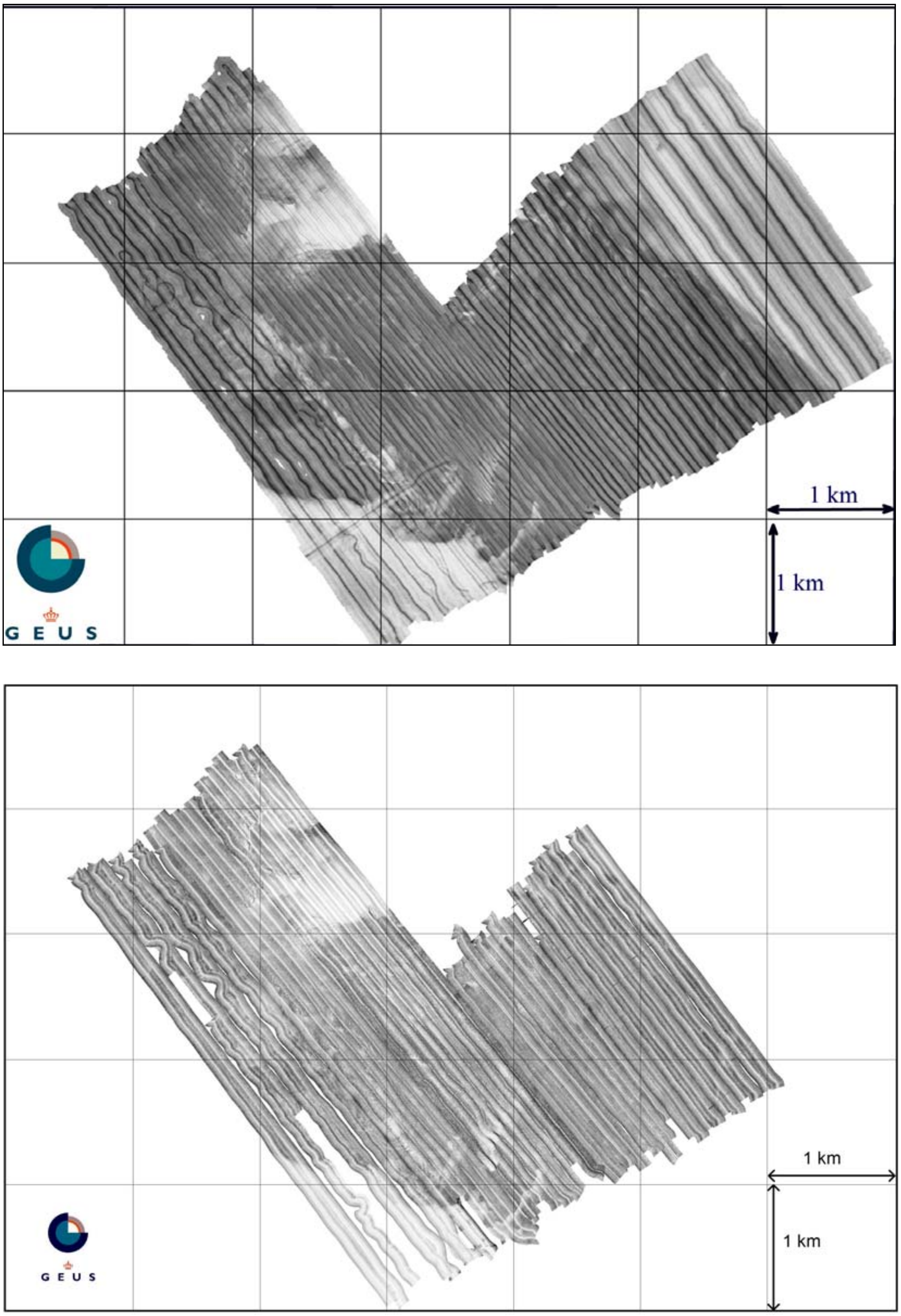
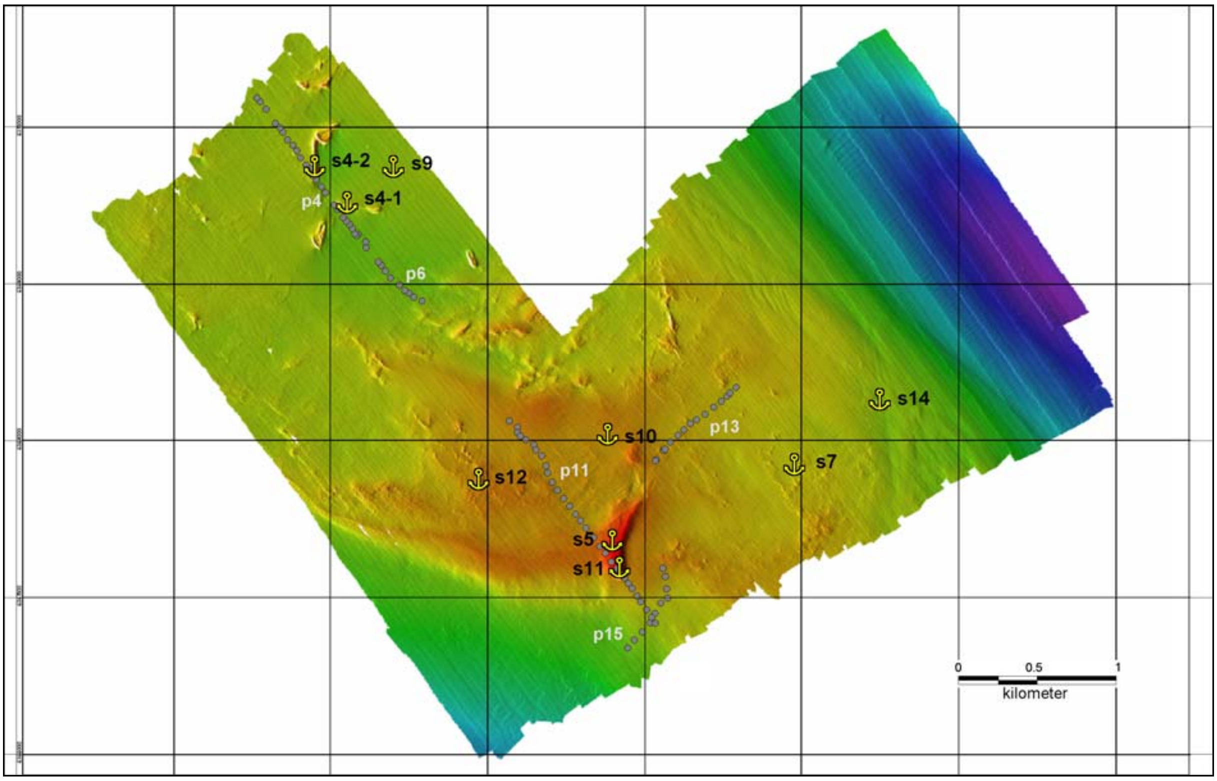


Figure 15. Mosaics of the scattered signal recorded by the multibeam system (upper part) and the sidescan sonar (lower part). Due to the nature of the multibeam system beam pattern the scatter map from this equipment will have a lower resolution in comparison to the sidescan sonar.



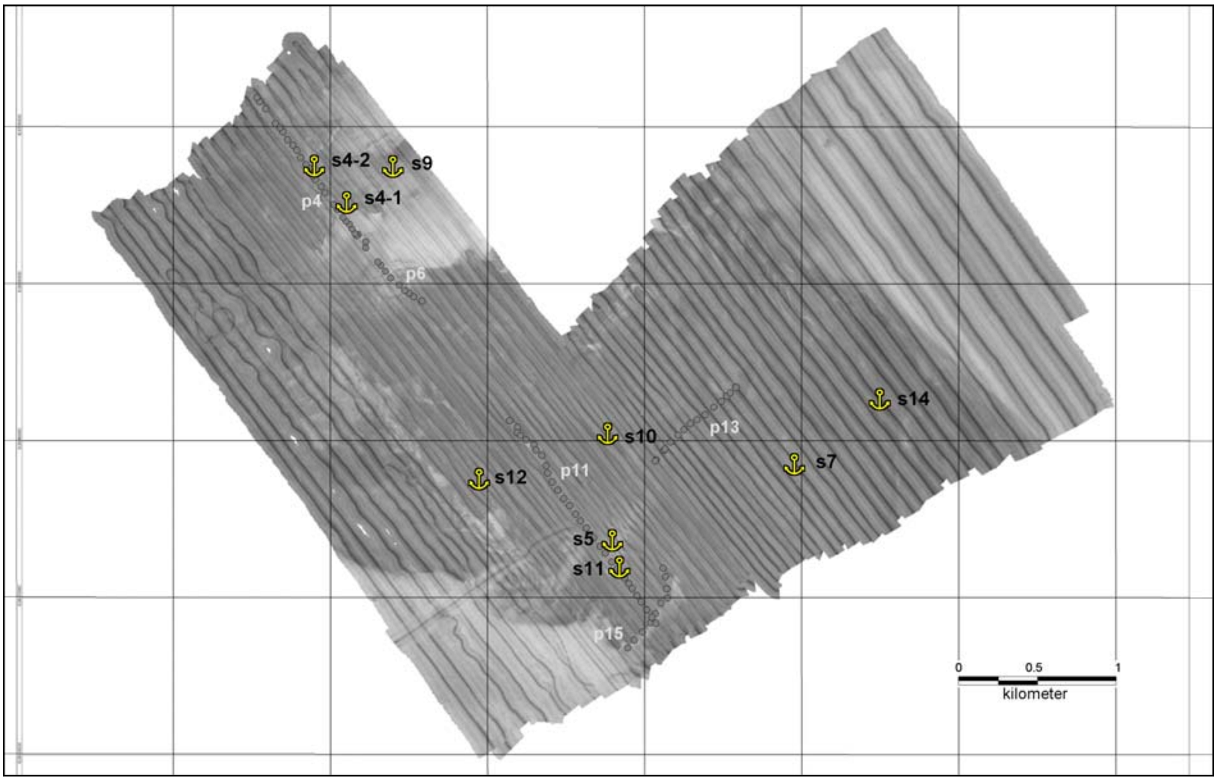


Figure 16. Multibeam bathymetric map (upper) and backscatter sidescan mosaic (lower) of the surveyed area with ground truth station indicated. Dots = paravane tracks with track numbers in white; Anchors = point dive stations with station numbers in black.

6.1.4 Ground truth calibration

The ground truthing by diving was conducted in the Læsø Trindel to verify the bathymetric results of the multibeam system as well as the backscatter results of the side scan sonar system. The divers used a high precession depth-meter for measuring the exact depth from sea level. The position of the diver was estimated from the position of the survey boat and the length of the towing cable. The positions of the ground truth reporting were plotted on top of the bathymetric map and a comparison was made between the reported depth and the multibeam calculated depth (figure 11). The results were very encouraging at some places, whereas a noticeable difference is reported in other areas. But an acceptable overall agreement is found between the two measurements with an average difference in depth of ~30cm.

The sediment ground truth results considerably agree with the scattering map interpretation, except in few rather important areas. A thorough investigation was carried out to find the reason for discrepancy.

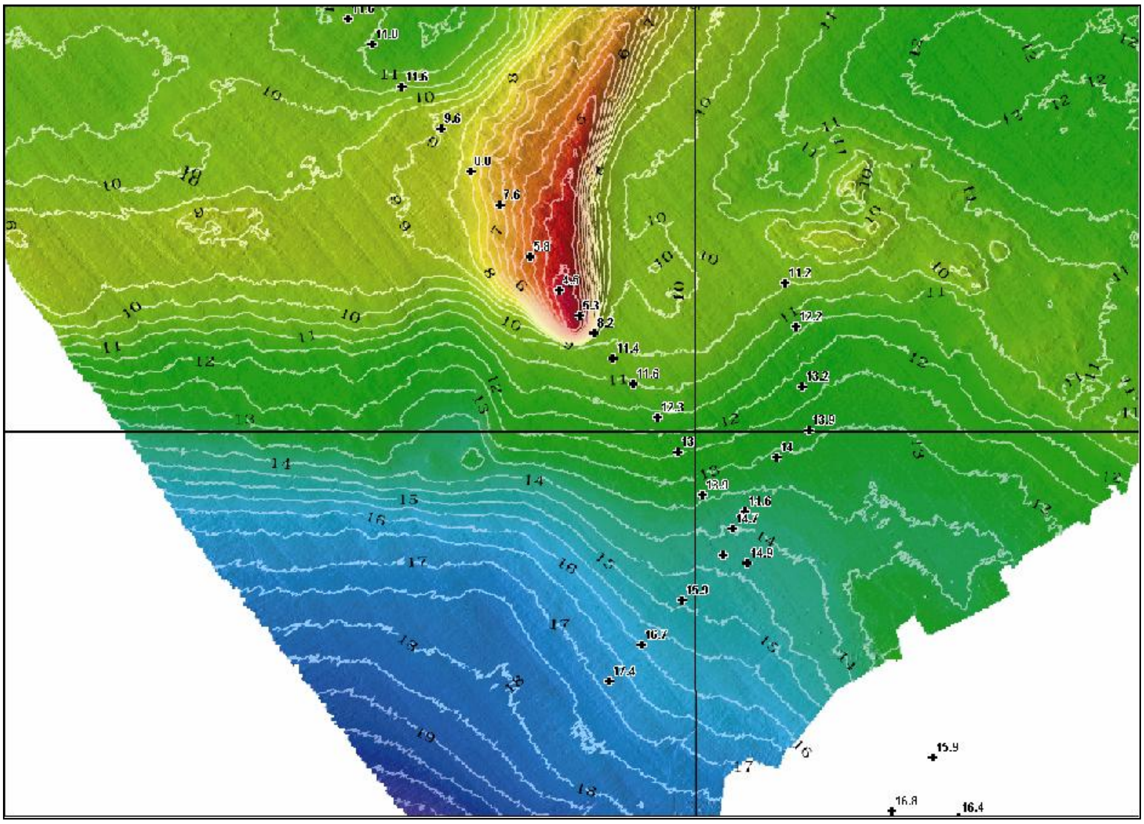


Figure 18. Contour line map of the southern Læsø area, also shown diver positions with depth measurements.

6.1.5 Error observed and sources of error

The ground truth depth measurements, when accurately executed, can be considered as a robust calibrator to the multibeam bathymetric results. A number of observed discrepancies were noticed during interpretation, these are:

1. Depth discrepancies: The relatively large difference in depth registered at few points was discussed with the diving team and they clarify the sources of error. It appears that when the diver climbs a large and high stone, he sometimes do not wait for the depth measuring system to settle down before taking the reading, so error can appear here. Also sometimes the drift is high so the reporting position is not precisely accurate and can cause an error especially if the area under consideration is full of large stones causing a hummocky sea floor.

2. Substrate discrepancies: In the following we zoom in on the bathymetric map figure 12 and look at the three arbitrary chosen areas, namely area 1, 2 and 3, which all are cut by the ground truth paravane 4+6. The individual ground truth positions of this paravane are here referred to as numbers between 4 and 25. We will notice that **area (1)** looks very flat with gradual depth increase towards the west and southwest. If we look at the sidescan map of the same area (1) in figure 13, we can say that it is composed of soft sediments with some scattered stones.
Area (2) in the figures 12 and 13 shows rugged elevations from the sea floor which it is also manifested by a high backscatter in the sidescan map. The divers that reports from the paravane 4+6 in both areas confirm the above-mentioned interpretation, with almost 100% of sand reported at diving stations 7 to 19. While at the stations 20, 23, 24 and 25 a complete coverage of stones of all sizes was reported by the diver the stations 21 and 22 are mixed sediments but mostly sand.

1. **Area (3)** also shows some controversial results. On the bathymetric map the area looks rough with some stones, on the backscatter map it variable with intermittent hard and soft patches which could reflect scattered stones on soft bottom and the stones are covered with vegetation. The diver reports from the stations 4, 5, 6 and 7 reports that the area is covered by about 80% of sand with some minor quantities of stones. We are inclined towards the remote sensing results interpretation hence these are the result of the interpretation of a larger area than the diver actually can observe.

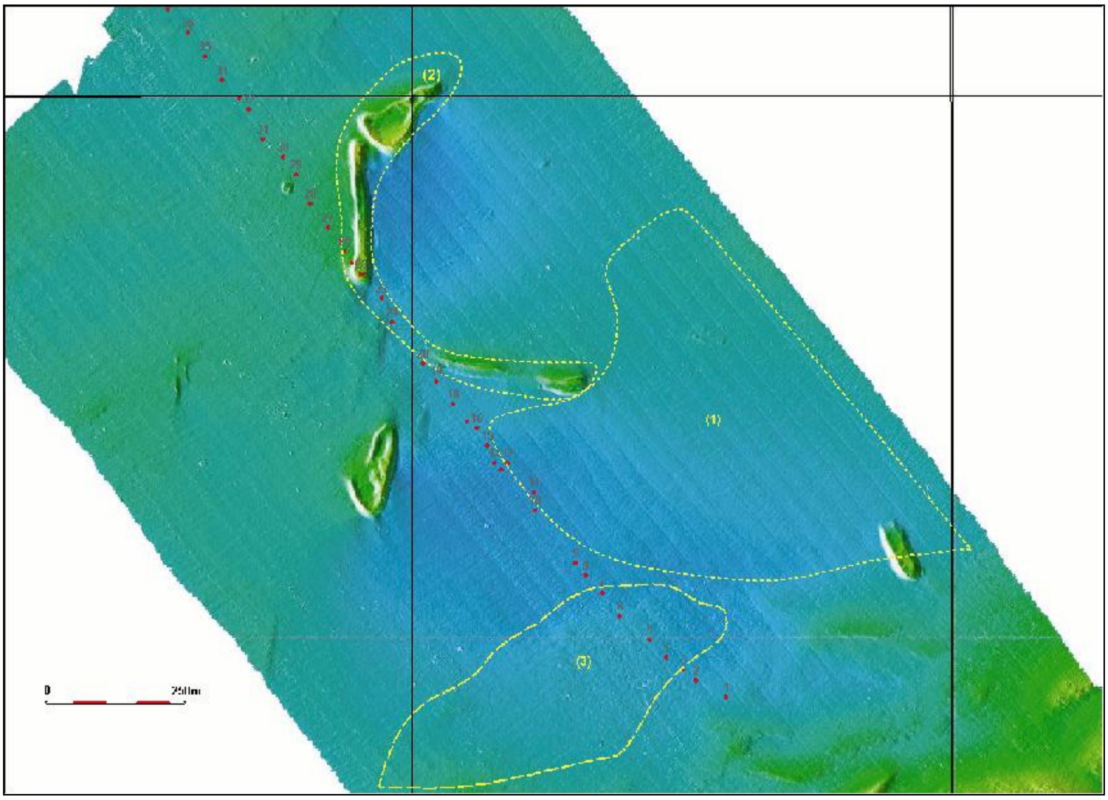


Figure 19. Zoom in bathymetric map of the northern part of the survey area. Dots with numbers are the ground truth positions. For the delineated areas (1, 2, 3) please see text.

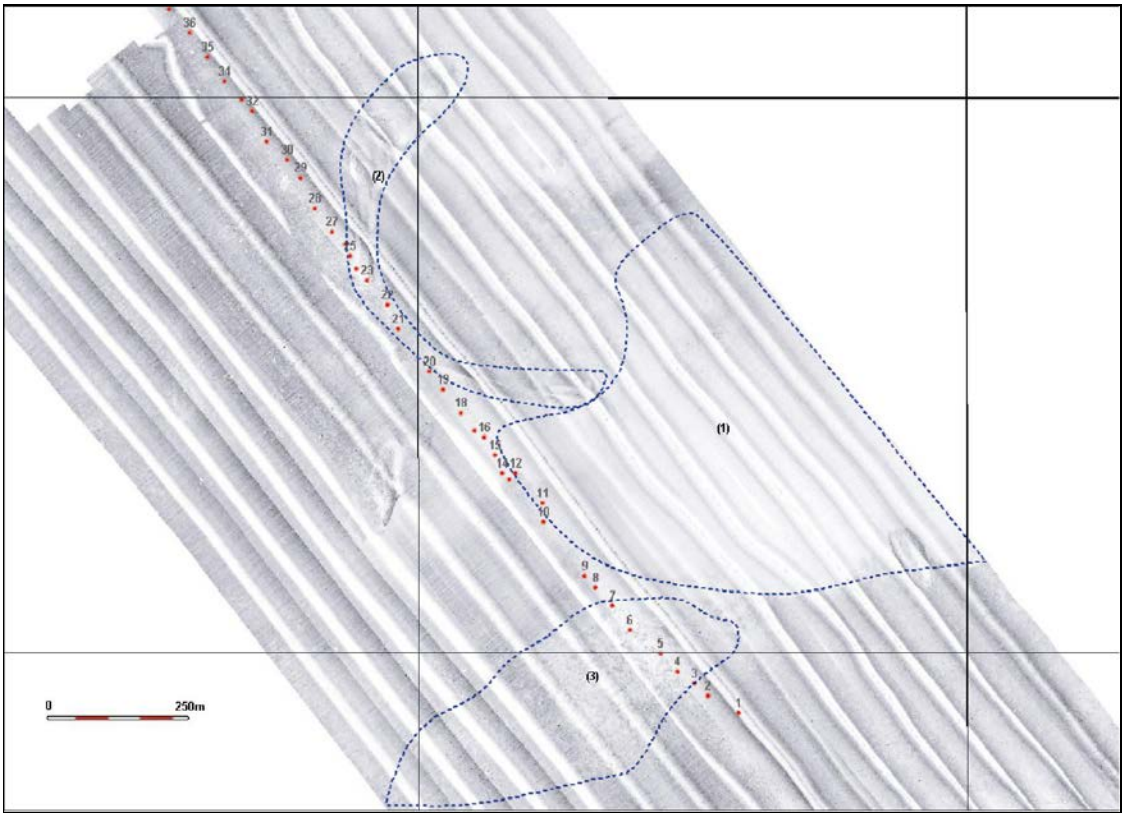


Figure 20. Zoom of the sidescan map of the northern part of the survey area. Dots with numbers are the ground truth positions on paravane transect 4+6. For the delineated areas 1, 2, and 3 see text.

3. Complex discrepancies: In the southern part of the survey area, there is another interesting observation. In the area that exhibits a shallow geological feature, **area (6)** in figure 14 there exist a discrepancy between the divers reported seabed type from the diving paravane 11 and 15 and the seabed types measured using side scan sonar .One can explain that as follows: When one study the bathymetric map of the area an elevated accumulation of large stones that comprise an elevated rough seabed (a boulder reef) is noticed. The scattering map reveals a low backscattering value which is much less than the expected for a hard bottom. Inspecting the ground truth results, one can clearly notice that this particular area is stony but 100% covered with vegetation. The low backscattered signal in this area is presumably due to the presence of this thick vegetation cover that obviously obscures the stones. The reported vegetation cover was found in stations 58 to 63. Station 68 and 69 are reported as sand with 35 and 5% cover of stones and 15 to 5% vegetation coverage respectively.

Area (4), (5) and (7) show a reasonable coherency between the bathymetric and the scattering map. Reported ground truth stations 88 till 93 in area (7) reveal that this area is composed of over 90% sand with minor percentages of stones with partial vegetation coverage.

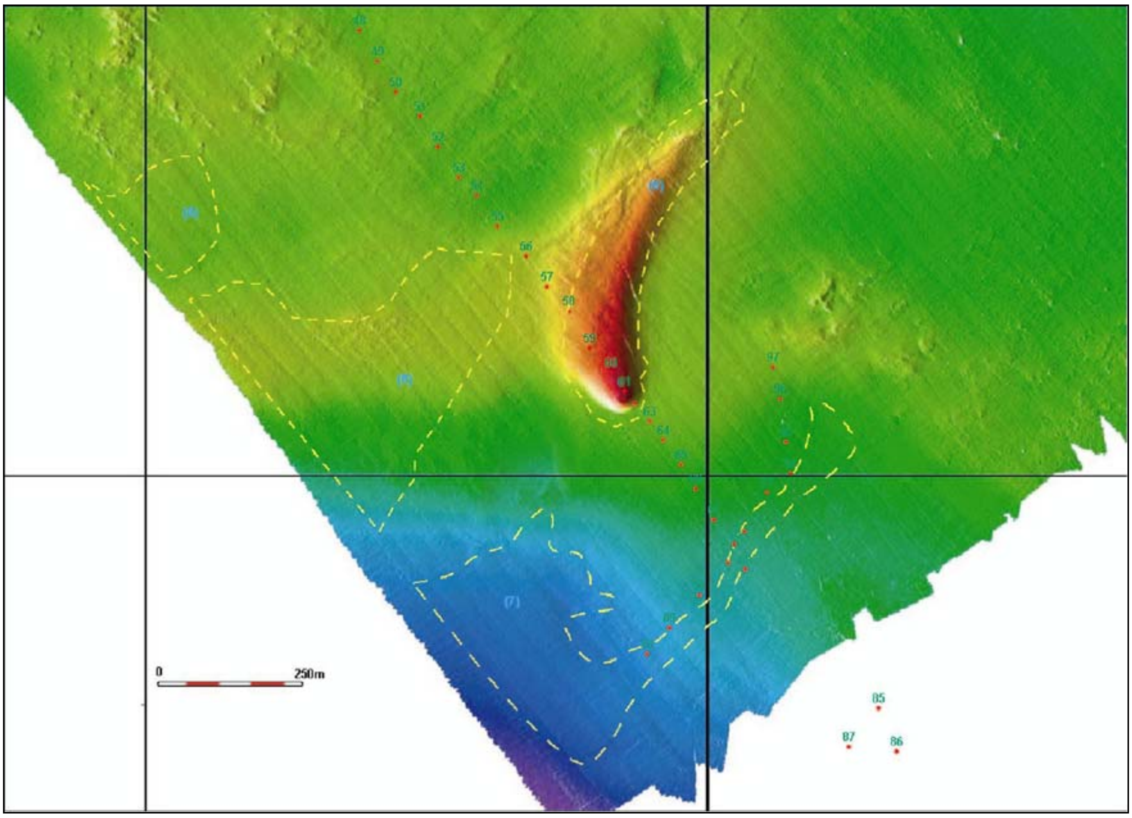


Figure 21. Zoom of the bathymetric map in the southern part of Læsø Trindel. Dots with numbers are the ground truth positions on paravane transect 11 and 15. For delineated areas 4, 5, 6 and 7 see text.

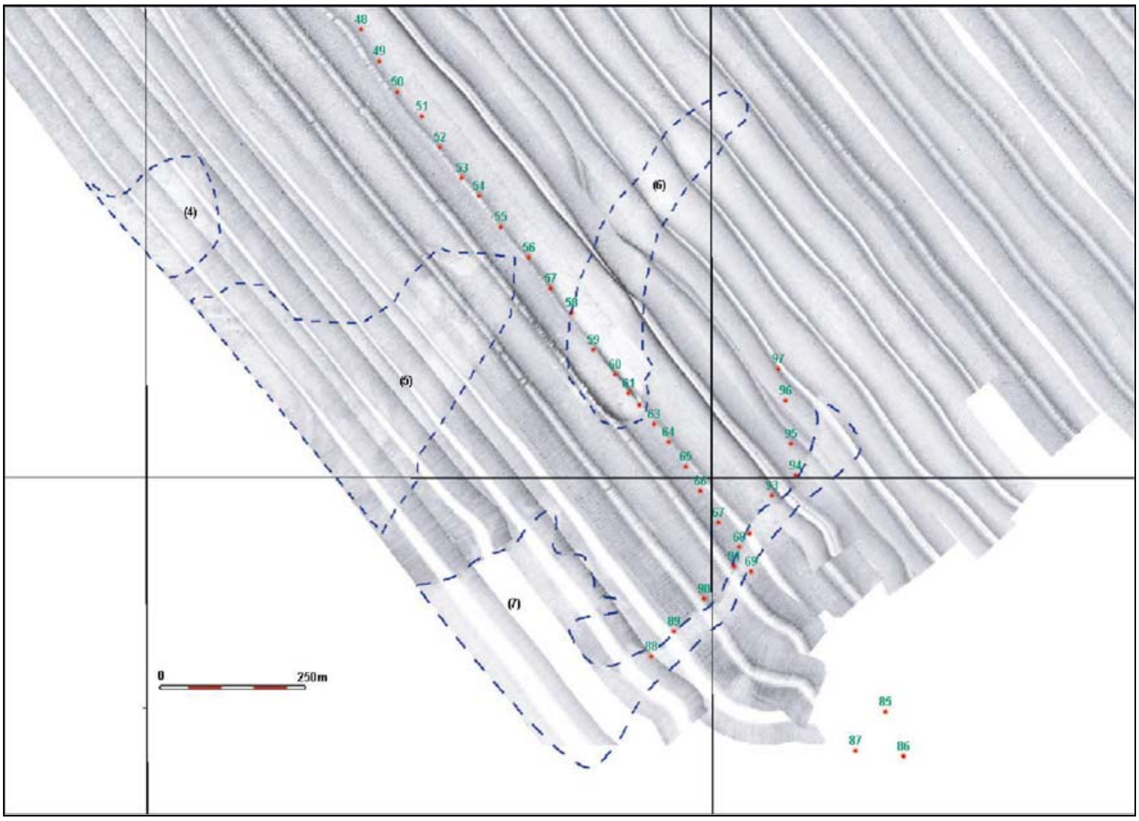


Figure 22. Zoom of the side scan map of the southern area of Læsø Trindel. Dots with numbers are the ground truth positions on paravane transect 11 and 15. For delineated areas 4, 5, 6 and 7 (see text).

7. Habitats at Læsø Trindel

7.1 Seabed classification

For the present study at Læsø Trindel we have adapted and elaborated subdivision of reefs proposed by Dahl et al. (2003) to make it applicable for the characterisation of the boulder reefs habitat on the basis of the acoustic data combined with ground truth data. The three classes are as follows:

Reef-1: Coherent formation of stones with high cover (75 – 100%) of hard substrate. When surrounded by sandy and/or gravely seabed the boundary is sharp.

Reef 2: Scattered formation with high to medium cover (25 – 75%) of hard substrate. When surrounded by sandy and/or gravely seabed the boundary is gradual.

Reef 3: Smaller individual banks of stones each at least 10 m^2 forming a low cover (5-25%) of hard substrate. When surrounded by sandy and/or gravely seabed the boundary is gradual.

Despite the resolution of individual objects is as high as 25 cm using acoustical methods, a more general evaluation of the reef substrate is needed due to the size of the study area of about 12 km^2. For that purpose the sidescan mosaic and the high-resolution bathymetry map has been analysed for the classification of the entire mapped seabed following the above definitions. During the analysing process the acoustic data have been calibrated with the available ground truth information from the diving inspection.

It has been found that reefs areas of 10 m^2, as defined by Dahl et al. (2003) "*hard substrate covering at least 5% of the sea floor within an area of 10 m^2*", is difficult to recognise from the general acoustic classification. However, we acknowledge their method is has been developed on the basis of divers investigations. An area of 10 m^2 is beyond the limit of resolution of the sidescan mosaic and much too detailed in relation to the idea of using the acoustic method for the characterisation of larger seabed areas. Boxes of different sizes have been tested (side length of 10 m, 30 m, 50 m and 100 m) to evaluate the relationship between the resolution of individual objects versus the characterisation of the defined reef types (see figure 23). **We concluded that for the purpose of the seabed classification into the three defined reef types a box/cell size of 50 x 50 m is the optimum size within which the hard substrate coverage has been evaluated.**

At the same time the chosen cell size has to be considered as a pragmatic way to classify the seabed systematically and to delineate the present habitat types on a harmonised set of data.

The on-line interpretation and classification was done using the MapInfo GIS software. Working with the sidescan mosaic on-screen map scale was chosen like 1 cm equals 6 m of the seabed.

The resulting seabed habitat classification maps based on the integrated analysis of acoustic and ground truth data are presented in the figures 24 and 25. Comparing the designated Natura 2000 boulder reef area Læsø Trindel/Tønneberg Banke (shown by the dashed line in fig. 25) with the mapped reef area it is obvious that it only partly includes the 'real' reef area. Hence, the actual size of the Natura 2000 area is in the magnitude of double size of the previous designated area. This demonstrates clearly the usefulness of the mapping effort using the integrated approach of acoustic methods and ground truthing.

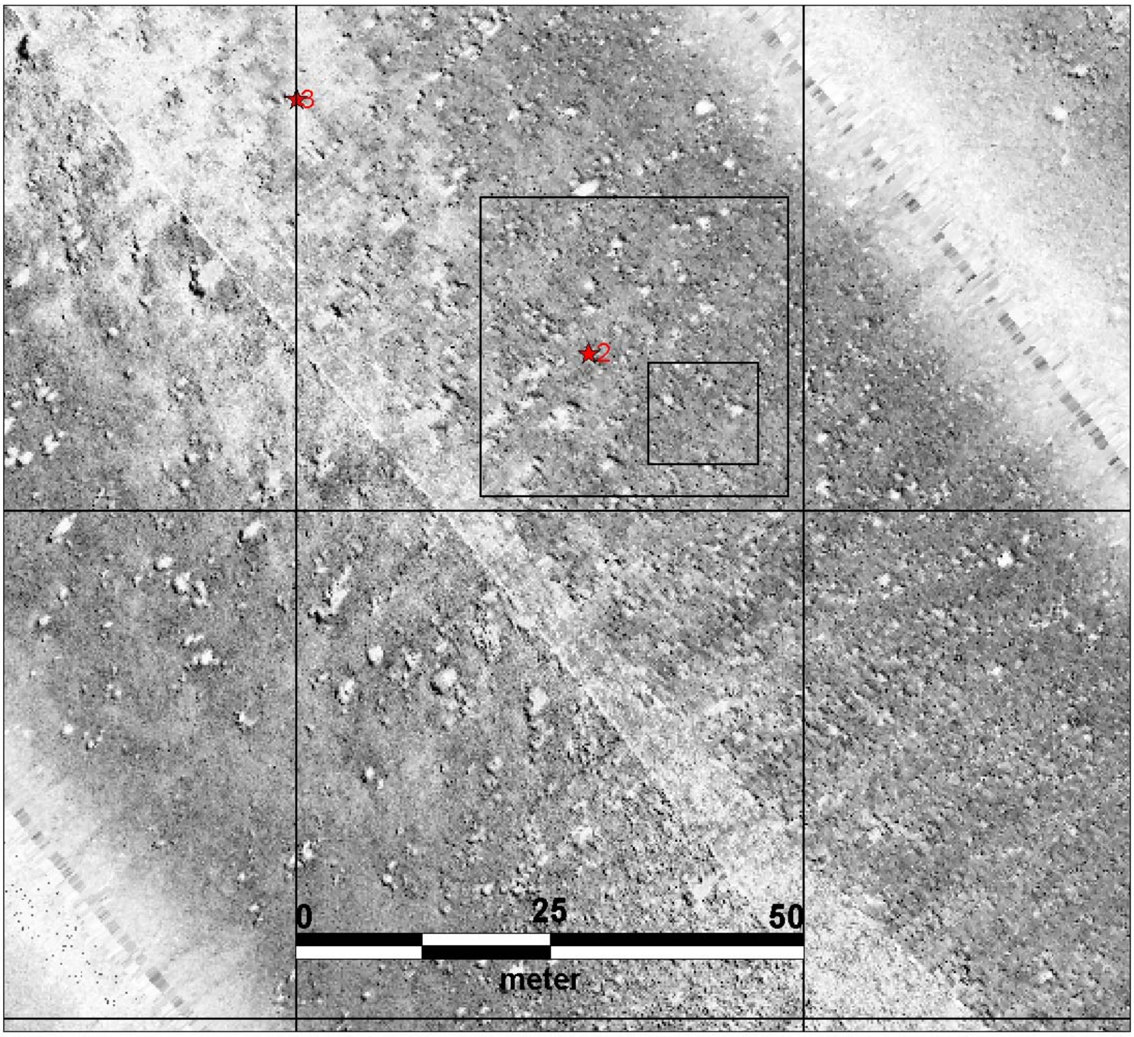


Figure 23. A section of the sidescan mosaic showing different cell sizes used for the evaluation: 10 m, 30 m and 50 m. The 50 m cell size has been applied to the present classification of the seabed into three reef types. The red stars indicate ground truth positions.

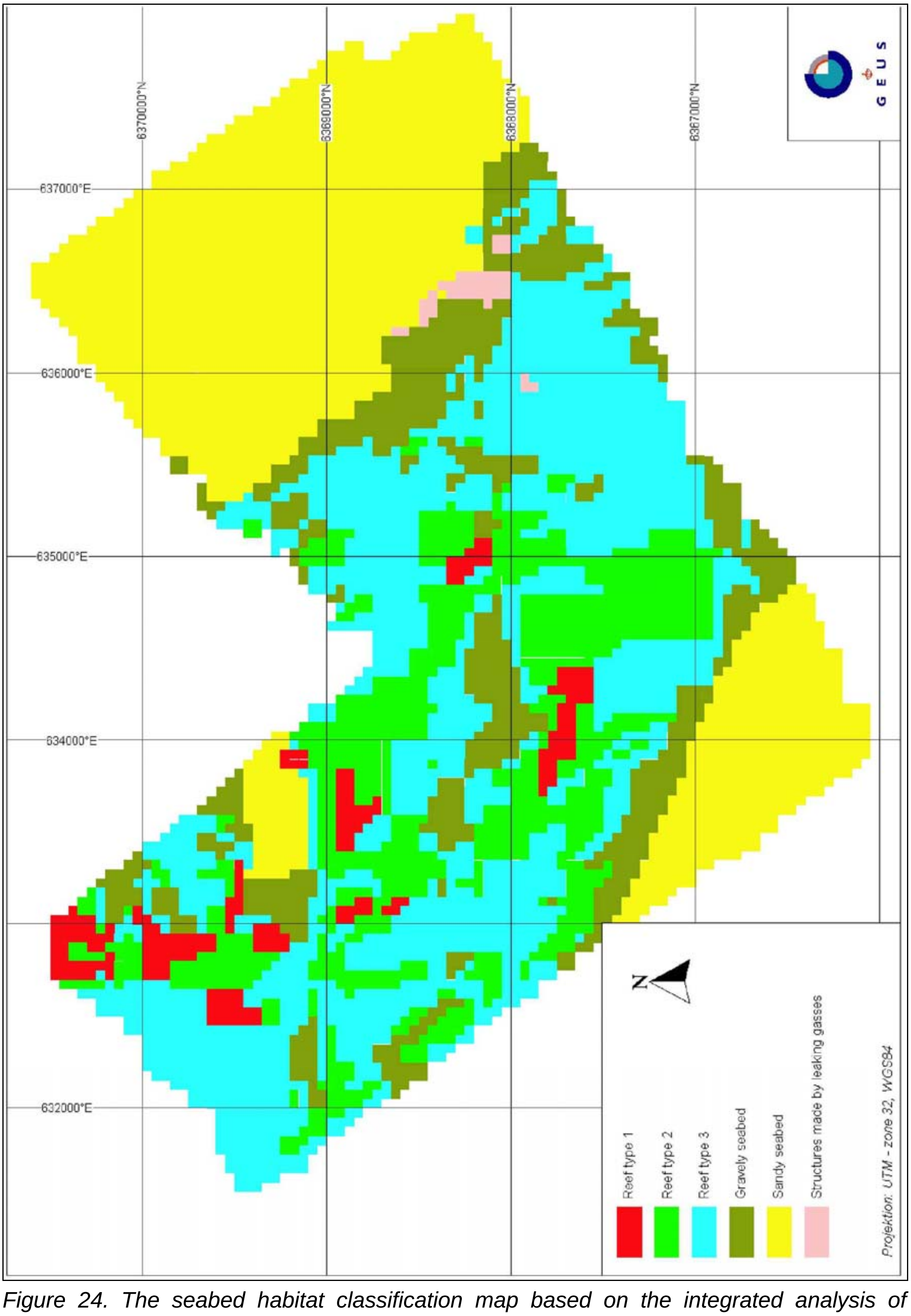
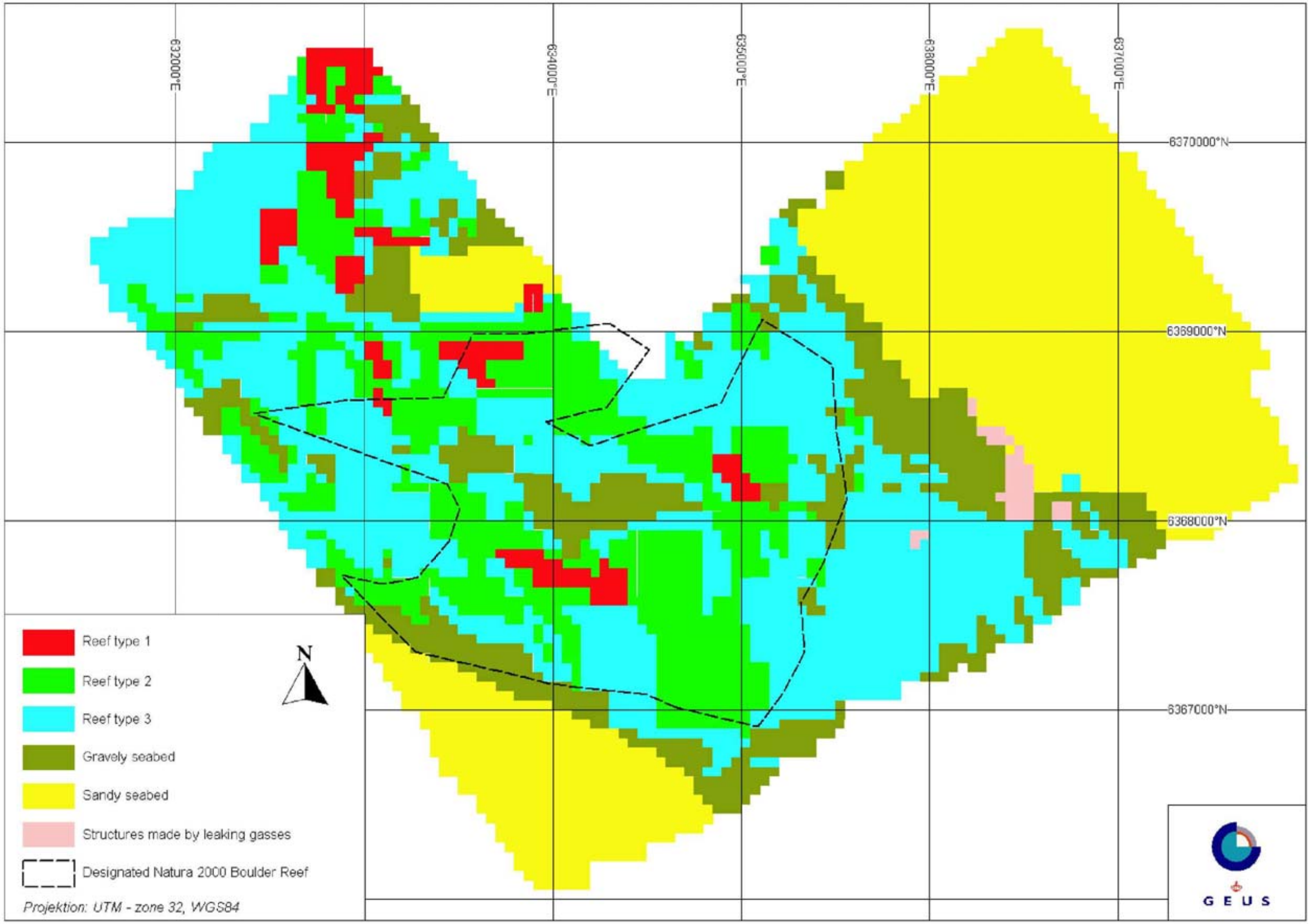


Figure 24. The seabed habitat classification map based on the integrated analysis of acoustic and ground truth data. The present designated Natura 2000 boulder reef area (shown by the dashed line in fig. 25) covers only partly the mapped reef area.

Figure 25.


632000°E
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N
Reef type 1
Reef type 2
Reef type 3
Gravely seabed
Sandy seabed
Structures made by leaking gasses
Designated Natura 2000 Boulder Reef
Projektion: UTM - zone 32, WGS84
G E U S

8. Discussion

The differences between the various available remote acoustic sensing techniques, irrespectively of the post-processing being used, often make it difficult to judge, which sonar device is most suitable to the actual need. In the context of habitat mapping the geophysical characteristics of the seabed area essential, hence it allows the wide-scale geology and the modern-day sedimentary processes to be understood. Based on the understanding of the sediment dynamics and geological structure the marine scientists produce maps of the seabed, which help managers of the marine environment to predict the impacts on those habitats which may be of high nature conservation and ecological value.

The techniques applied in this study have demonstrated the usefulness of combining acoustic methods with ground truthing to produce maps revealing the physical characteristics of the seabed. The multibeam swath bathymetric and the sidescan sonar devices used in the Læsø Trindel study are the most highly developed and versatile available systems. They offer great data control and supporting real-time visualisation of sonar data as true geo-corrected mosaic seabed maps. Sidescan sonar provides information on sediment texture, topography, bedforms and other discrete objects at the seabed (e.g. boulders). The multibeam data system provides depths of centimetre resolution. Multibeam data processing enhances subtle aspects of relief elements through shading techniques for an understanding of erosive and depositional processes. The maps produced and interpreted such as seabed geology, relief and processes provide the foundation for assessment and mapping of seabed habitats.

There are many technologies capable of mapping the seafloor including acoustic systems and ground truth devices and methods. The choice of system will depend on survey objectives and scale of the area to be mapped. For inshore areas < 50m water depth where identification of small (< 10m) habitat features may be required, a combination of multibeam echosounder and sidescan sonar ensures that both quantitative high resolution bathymetric data (1-10cm scale) and qualitative, high-resolution habitat relief data (decimetre resolution) is obtained (Kenny et al. 2003).

A number of conclusions may be put forward in relation to the advantages and disadvantages of the various devices for habitat mapping. But based on numerous experiences from biotope and habitat mapping reported the recent years there are no doubts that the combination of acoustic systems and ground truth verification is recommended. Swath systems offer the availability to discriminate small habitat features (0.3 – 1m) together with providing information on sediment dynamics and geological development make them most suited for detailed biotope mapping. By contrast, single beam echosounder systems are most useful for detecting gross differences in substrate type i.e. between rock, sand and mud, but often require intensive ground truthing limiting their utility as a tool for broad-scale biotope mapping.

For broad-scale mapping of habitats (>1 km^2) the sidescan sonar combined with the multibeam echosounder is considered to be the most cost-effective means of discriminating sediment types and dynamic processes (Kenny et al. 2003).

For small-scale habitat classification (>1 km^2), high-resolution sidescan sonar, underwater cameras/videos and grab-sampling methods are considered to be the most appropriate mapping tool (Kenny et al. 2003).

The interpretation of the sidescan mosaic and multibeam data from Læsø Trindel has demonstrated that the sandy and hard seabed unambiguously can be distinguished. However, the acoustic maps (e.g. the sidescan sonar mosaic) reflecting the variable acoustic properties of the seabed has to be 'ground truthed' by seabed sediment samples for calibrating the acoustic classes into sediment types and biological samples to characterise the flora and fauna present. Dependent on the complexity and distribution of the acoustic classes a relevant sampling programme will ensure the optimum amount of samples to verify the present seabed types.

Broad scale marine habitat mapping based on acoustic techniques combined with ground truth verification can be customised to fit many purposes. For implementing the EC Habitats Directive at least three purposes can be identified. These include:

a) Broad scale scanning of large areas of seafloor for which little information exist in order to establish a baseline habitat map for designating sites

b) More detailed surveys within individual Natura 2000 sites for delineating the area of individual habitats

c) Identifying locations and area of habitats with a limited distribution, such as "*Submarine structures made by leaking gases (1180)*"

System	**Coverage**	**Resolution (horizontal)**							**Remarks**
	km²/h	km	100m	10m	m	dm	cm	mm	
Remote Sensing, Satellite	> 100	**x**	**x**	**x**					Restricted to satellite operation coverage and to shallow areas (not more than 6 m water depth)
Remote Sensing, Aircraft	> 10	**x**	**x**	**x**	**x**				Only for shallow areas (not more than 6 m water depth)
Multi Beam	3 - 6	**x**	**x**	**x**	**x**	**x**			Allows the use of backscattering data for analysing bottom substrate
Single Beam	1 - 2	**x**	**x**	**x**	**x**	**x**			Narrow surface coverage
Side Scan	1 - 8		**x**	**x**	**x**	**x**			Size of surface coverage (swath) depends on the frequency used

Synthetic Aperture Sonar	1 - 10					**x**	**x**		Optimal operation at 50 - 100 kHz
Subbottom Profiler	0.5 - 1	**x**	**x**	**x**	**x**	**x**			Narrow sub-surface coverage
Video Camera	0.1 - 0.2				**x**	**x**	**x**		Allows epibenthos identification and provides ground truth for acoustic survey mapping technology.
Sediment Profile Camera	< 0.001						**x**	**x**	Only site inspections
X-ray photography	< 0.001						**x**	**x**	Only site inspections, allows more detailed analysing than the profile camera (water content, density, etc.)
Macro Grab/Corer Sampling	< 0.003					**x**	**x**	**x**	Quantitative data on the macro- and meio-fauna requires additional analysis in a laboratory

Table 1. Overview of seabed mapping tools. The table provides an overview of the area covered (mapped) and the resolution which can be achieved under optimal conditions. Modified after ICES, 2000.

Water depth (m)	**EM1000 multibeam 12 knots**			**MS992 330 kHz Sidescan 4 knots**		
	Horizontal width (m)	Maximum footprint (m)	Coverage (km^2 per day)	Horizontal width (m)	Maximum Footprint (m)	Coverage (km^2 per day)
10	70	2.4	40	400	1.0	67
50	350	12	195	400	1.0	67
100	700	24	390	400	1.0	67
200	1400	48	780	400	1.0	67

Table 2. Coverage comparison between survey systems. From ICES, 2000.

Table 2 compares the resolution of each system and the unit area covered (km^2/day) under a range of different depths. It is clear that the multibeam bathymetric systems are greatly influenced by water depth. For example, as the water depth increases and the area covered increases the resolution decreases. The side-scan sonar is not affected by water depth, but the innate instability of the sonar fish, gives rise to qualitative data compared to the multibeam bathymetric system.

A number of conclusions may be made in relation to the technical advantages and disadvantages of the various devices for biotope mapping. The swath systems are most likely to provide the best high resolution maps of sea-bed, particularly over a wide area (swath widths that vary between 30 to 500 metres). They provide information on sea-bed sediment texture and bedform structure which allow dynamic process (eg. sediment transport) to be defined. The disadvantages associated with swath systems are their high costs and the need to have skilled interpretation. In addition, the output often requires considerable post-processing time and expense to derive the best images. On the other hand single beam systems cost much less and are generally simple to operate. The disadvantage of single beam sounders is they require intensive calibration (ground truthing) when being used to discriminate sea-bed biotopes. The 'echo' beam often has a large acoustic footprint (typically $4m^2$) which results in low resolution of sea-bed features. The lack of swath coverage of the bed results in the need to undertake extensive spatial interpolation in order to provide full-coverage maps of the sea-bed.

The value of one system *versus* any other will depend on the objectives of the survey, but as a general guide the high resolution capability of side-scan sonar systems and their ability to discriminate small scale habitat features (0.3 m – 1 m) together with providing information on habitat stability makes them most suitable for most detailed biotope mapping applications.

The single beam sediment discrimination systems (e.g. RoxAnn) are useful for detecting gross differences in substrate. Whilst they can discriminate much more subtle differences in habitat the repeatability and level of discrimination is difficult to define often resulting in unexplained variability between surveys

The interpretation and mapping of the Læsø Trindel seabed has made the basis for the designation of 3 different seabed habitat types. The mapping approach carried out put forward robust procedure defining reefs and sandy seabed types to the Danish Forest and Nature Agency, still in agreement with the definition applied by the *"Interpretation Manual of European Union Habitats (EUR 15/2)"*.

Acoustic techniques could probably also be used to identify biogenic reef areas such as *Sabellaria spinolosa* reefs present upon sandy sediments or *Modiolus modiolus* beds present within soft sediments. Both reef types are protected as biogenic reefs under the Habitats Directive though often present within habitats, which are not listed within Annex 2. No such biogenic reefs were identified in the present survey and as such will not be further discussed in this report.

The following sections will discuss the various mapping set-up in relation to the identification of habitats at different scales.

9. Conclusion and perspectives

The differences between the various available remote acoustic sensing techniques, irrespectively of the post-processing being used, often make it difficult to judge, which sonar device is most suitable to the actual need. In the context of habitat mapping the geophysical characteristics of the seabed area is essential; hence it allows the wide-scale geology and the modern-day sedimentary processes to be understood. Based on the understanding of the sediment dynamics and geological structure the marine scientist produce maps of the seabed, which help managers of the marine environment to predict the impacts on those habitats which may be of high nature conservation and ecological value. The techniques applied in this study have demonstrated the usefulness of combining acoustic methods with ground truthing to produce maps revealing the physical characteristics of the seabed. The multibeam swath bathymetric and the sidescan sonar devices used in the Læsø Trindel study are the most highly developed and versatile available systems. They offer great data control and supporting real-time visualisation of sonar data as true geo-corrected mosaic seabed maps. Sidescan sonar provides information on sediment texture, topography, bedforms, and other discrete objects at the seabed (e.g. boulders). The multibeam data system provides depths of centimetre resolution. Multi-beam data processing enhances subtle aspects of relief elements through shading techniques for an understanding of erosive and depositional processes. The maps produced and interpreted such as seabed geology, relief and processes provide the foundation for assessment and mapping of seabed habitats.

There is a wide range of technologies capable of mapping the seafloor including acoustic systems and ground truth devices and methods. The choice of system will depend on survey objectives and scale of the area to be mapped. For inshore areas <50 m water depth where identification of small (<10 m) habitat features may be required, a combination of multibeam echo sounder and sidescan sonar ensures that both quantitative high resolution bathymetric data (1-10 cm scale) and qualitative, high-resolution habitat relief data (decimetre resolution) is obtained (Kenny et al. 2003). A number of conclusions may be put forward in relation to the advantages and disadvantages of the various devices for habitat mapping. Nevertheless, based on numerous experiences from biotope and habitat mapping reported the recent years there no doubts that the combination of acoustic systems and ground truth verification is recommended. Swath systems offer the availability to discriminate small habitat features (0.3 – 1 m) together with providing information on sediment dynamics and geological development make them most suited for detailed biotope mapping. By contrast, single beam echo-sounder systems are most useful for detecting gross differences in substrate type i.e. between rock, sand and mud, but often requires intensive ground truthing limiting their utility as a tool for broad-scale biotope mapping.

For broad-scale mapping of habitats (>1 km^2) the sidescan sonar combined with the multibeam echo sounder is considered to be the most cost-effective means of discriminating sediment types and dynamic processes. For small-scale habitat classification (> 1 km^2), high-resolution sidescan sonar, underwater cameras or videos, and grab-sampling methods are considered to be the most appropriate mapping tool. The interpretation of the sidescan mosaic and multibeam data from Læsø Trindel has demonstrated that the sandy and hard seabed unambiguously can be distinguished. However, the acoustic maps (e.g. the sidescan sonar mosaic) reflecting the variable acoustic properties of the seabed has to be ground truthed by seabed sediment samples for calibrating the acoustic classes into sediment types and biological samples to characterise the flora and fauna present. Dependent on the complexity and distribution of the acoustic classes a relevant sampling programme will ensure the optimum amount of samples to verify the present seabed types.

10. References

Dahl, K., Lundsteen, S. & Helmig, S., 2003: Stenrev – havets oaser. Miljøbiblioteket. Gads Forlag. ISBN 87-12-04019-3.

Dinesen, G. E. (ed.), 2008: Mapping and modelling of marine habitats in the Baltic Sea region. The Danish Forest and Nature Agency. BALANCE Interim Report no. 27 (draft). www.balance-eu.org

Fredericia, J., 1987: Geological Map of Denmark 1:50:000. Map sheet 1417 Læsø. Geological Survey of Denmark. Map Series no.3.

Kenny, A. J., Cato, I., Desprez, M., Fader, G., Schüttenhelm, R. T. E., and Side, J., 2003: An overview of seabed mapping technologies in the context of marine habitat classification. ICES Journal of Marine Science, 60: 411–418.

Larsen, B., 1996: Sand, grus og sten. Ressource undersøgelse Læsø Trindel-område 574. Marin-geofysisk undersøgelse. Detailopmåling for SNS, Maj 1996. Danmarks og Grønlands Geologiske Undersøgelse, Rapport 1996/106.

Hermansen, B. and Jensen, J.B., 2000: Digitalt kort over havbundssedimenter omkring Danmark 1:500.000. Danmarks og Grønlands Geologiske Undersøgelse, Rapport 2000/68.

Laier, T., Jørgensen, N.O., Buchardt, B., Cederberg, T. & Kuijpers, A., 1992: Accumulation and seepage of biogenic gas in northern Denmark. Cont. Shelf Research, Vol.12, p. 1173-1186.

Laier, T., Kuijpers, A., Dennegård, B. & Heier Nielsen, S., 1996: Origin of shallow gas in Skagerrak and Kattegat – Evidences from stable isotopic analysis and radiocarbon dating. NGU Bulletin, Vol. 430, p. 119-125.

Leth, J.O., 1998: Late Quaternary geology and recent sedimentary processes of the Jutland Bank region, NE North Sea. Ph.D. Thesis: Aarhus Universitet.

Leth, J.O. & Alhamdani, Z., 2007: Multibeam and sidescan sonar survey in Kattegat. Cruise Report. Habitat mapping of the Natura 2000 site 168: Læsø Trindel and Tønneberg Banke, Kattegat, Denmark. Danmarks og Grønlands Geologiske Undersøgelse, Rapport 2007/1.

Skov- og Naturstyrelsen, 2006: Læsø Trindel – Blue Reef. Jordbundsundersøgelser i relation til naturgenopretningsprojekt. Jysk Geoteknik datarapport.

Wentworth, C.R., 1922. A scale of grade and class terms for clastic sediments. Jour. Geology, 30: 377-392.

Appendix

The ground truth procedure

After the analysis of the sidescan/backscatter data a number of ground truth positions have been selected for ground truthing. The stations were carefully selected to represent a variety of substrate types and seabed features typical for the Læsø Trindel area. The resolution sidescan pictures (decimetre scale) allowed the geologists to describe and interpret the physical properties such as sediment type, size and type of objects. At some stations the type and amount of epifauna also has been evaluated. All the selected stations were listed in order of priority and forwarded to the diver for the ground truth operation.

The following presents the background data description of the individual stations, firstly the description of the sidescan picture and secondly the divers observation and descriptions. Each station is illustrated with a sidescan picture showing the characteristic features to be verified by the diver. Furthermore, selected photos of the infauna taken by the diver are presented for each station. Each station has a reference numbers, which can be found in figure 17.

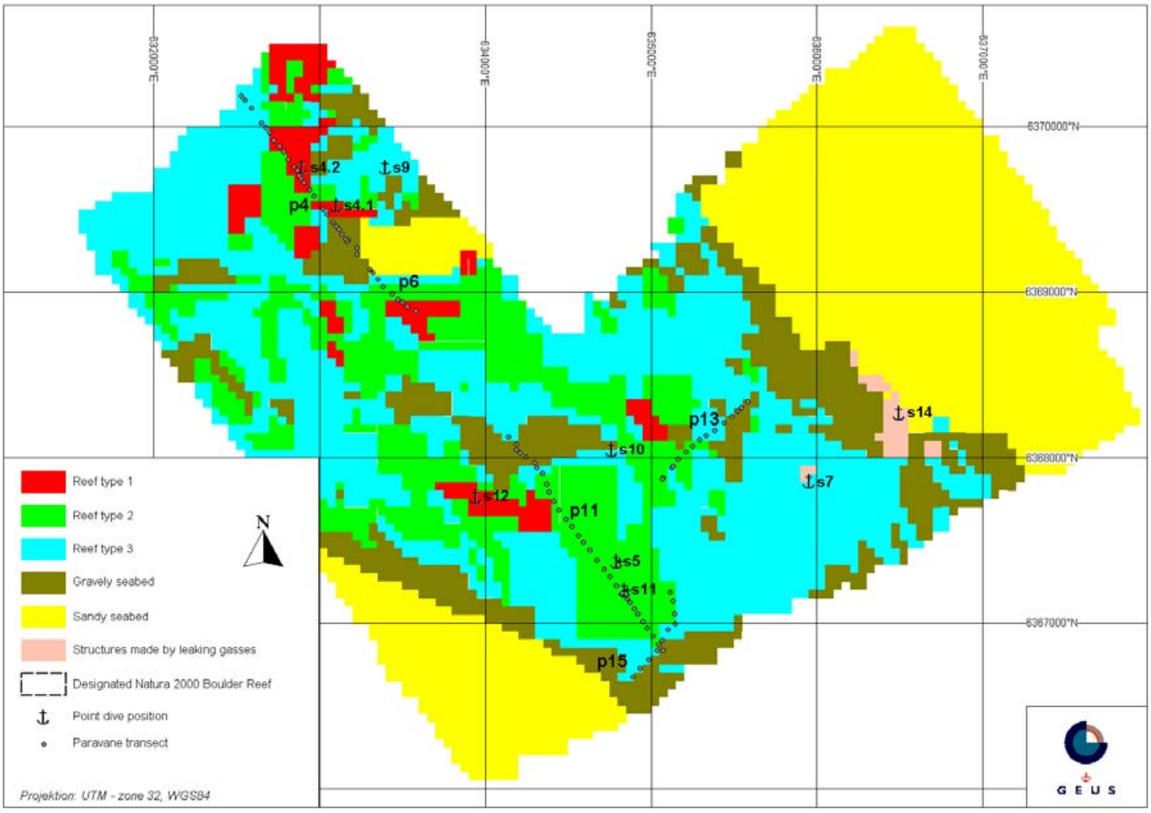
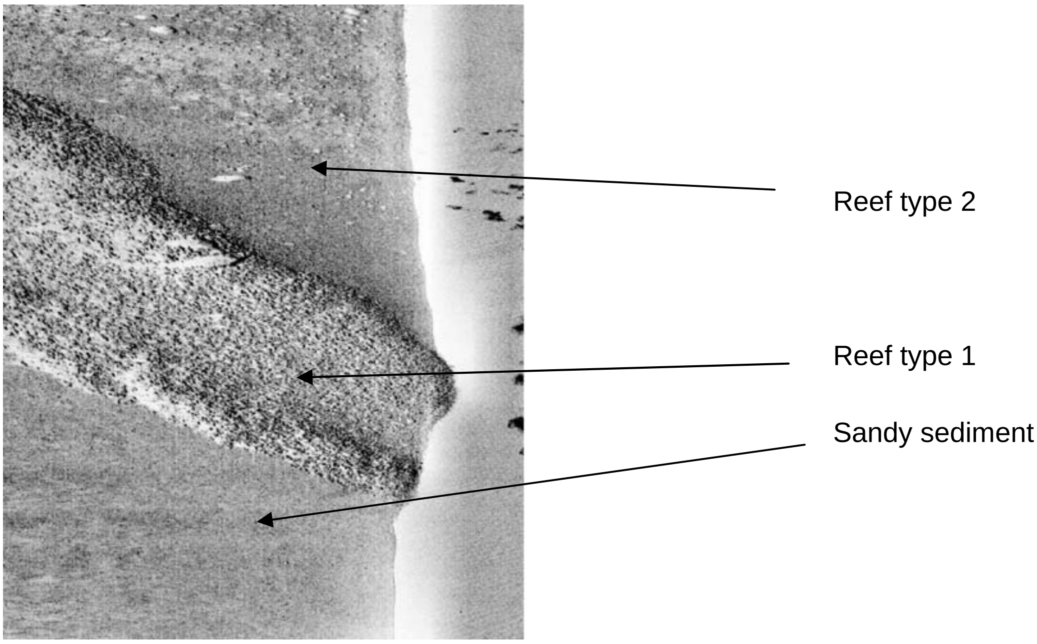


Figure 17. Overview of the seabed types within the study area with ground truth locations indicated.

Station s4.1 and s4.2.



Approximate dimension of the section: height 150 m and width 50 m.

Sidescan description

The station marks the transition from a level featureless sandy seabed to a remarkable morphological bank-like structure. The interpretation suggested the presence of elongated gravel and stone banks. The features are remarkable as they rise from the surrounding seabed with heights of 2 – 3 m and sharp boundaries to the nearby seabed. The latter structures selected for diving and described here are two individual and separated features. On top of the bank individual boulders are found with a height of at least 3 m. The structure marks the transition from the sandy seabed (lower part of the picture) to a mixed seabed with high density of boulders (upper part of the picture). The structure, which can be traced several hundred metres into the nearby area, is a striking feature on the sidescan picture as well as on the multibeam picture. More similar structures are seen throughout the northern part of the mapped Læsø Trindel area.

Diver description: Station s4.1

Habitat description Station s4.1 – Reef type 2

The reef is classified as a Reef type 2 based on the 100% coverage of pebbles and stones with a diameter of 2 - 10 cm. The reef is at 14 m of depth. The neighbouring habitat to the south is classified as Reef type 1.

The reef is characterised by the presence of well-sorted pebbles and stones with a sparse cover of vegetation. Foliose brown algae such as *Laminaria saccharina* and *Desmarestia aculeata* as well as the red algae *Odontalia dentata* where attached to the largest stones.

Habitat description Station s4.1 – Reef type 1

The bank-structure described as a gravel bank on the sidescan picture showed up to be a bank of 100% stones with diameters of 10 - 60 cm rising 2.5 m above the surrounding gravel bed. The stones and boulders were arranged in a distinctive bank-like feature with well-developed cave-forming structures. Individual boulders on the top of the reef reach 3 m in height. The surfaces of these boulders were covered by *dødningehånd koral og sønelliker.* A kelp forest characterised by *Laminaria hyberboria* cover the entire reef area. Underneath the brown algae canopy foliose red algae such as *Phycodrys rubens, Membranoptera alata, Dilsea carnosa* and filamentous tufts such as Ceramium rubrum and *Coralina officinalis*. A plateau was found at the water depth of 11.7 m characterised by the presence of scattered boulders of up to 1 – 2 m in diameter. The plateau was as a whole covered by a forest of *Laminaria hyberboria* with a sparse undercover *Phycodrys rubens, Delesseria sanguinea and Dilsia carnosa.*

The reef is classified as a Reef type 1 with 100% coverage of stones with a diameter of 10-60 cm with individual boulder reaching 3 m in height. The reef is rising 2.5 m above the surrounding seafloor at 14-16 m water depth striking in the east-western direction. Vegetation cover is 100%. To the north the habitat is bordered by a Reef type 2 and to the south bordered by a flat sandy seabed type.

Habitat description station s4.1 – Flat sandy seabed

The divers transect continued to the south across the plateau reaching another steep slope. At the foothill the water depth was more than 16.1 m. The seabed at the southern side of the slope was sandy. The flat sandy seabed is characterised by sandy, structureless sediment clearly delineated to the north by the bank-like structure.

Ground truth evaluation

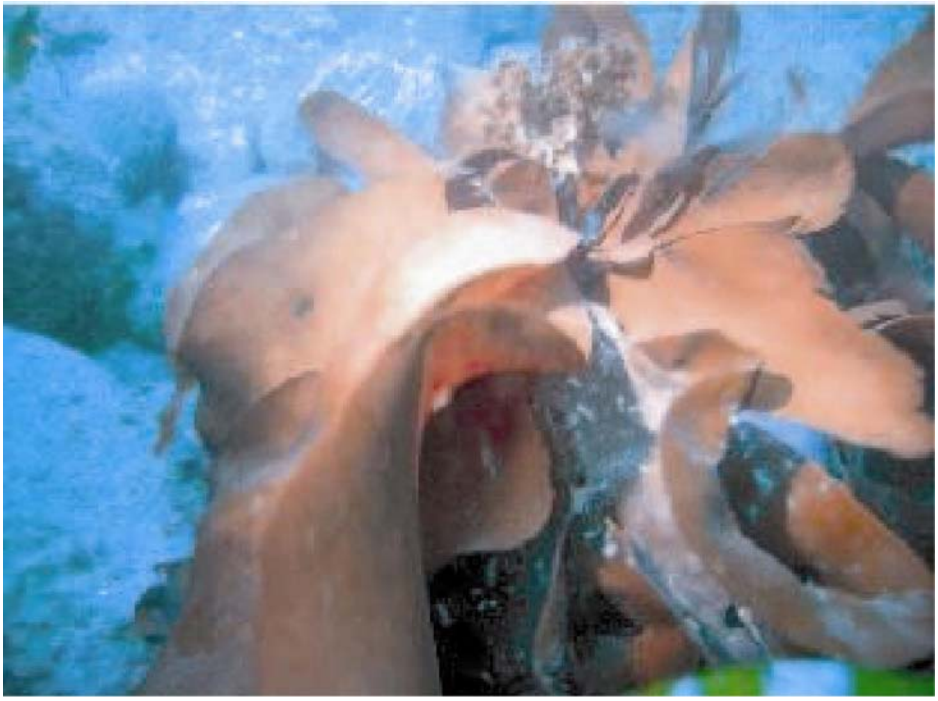
The diving confirmed the presence of the bank structure as suggested from the sidescan interpretation. The assessment of the seabed type on the sidescan picture, however, underestimated the degree of coverage of stones because of the 100% vegetation coverage mainly of *Laminaria hyberboria* blurring the sidescan picture.

Diver description: Station s4.2

Habitat description Station s4.2 – Reef type 1

The station is situated on the north-western part of the Læsø Trindel, ca. 300 m northwest of station s4.1.

The starting point for the diver was at the plateau of the structure. The level part of the structure with a water depth of 10.7 m was 100% covered by stones of 10 – 60 cm in diameter with a few scattered boulders. In between the boulders smaller decimetre size stones with carbonate encrusted red algae covered up to 10 – 20 % of the seabed. At the plateau the larger stones primary were covered by a variety of red algae of which the dominating species were *Phycodrys rubens, Coccothylus truncatus, Delesseria sanguinae* and *Ceramuim rubrum.*



Station s4.1. Reef type 1 with *Dilsia carnosa.*

Station s4.1. Reef type 1 with *Laminaria hyberboria.* (Photos: Jan Nicolaisen).

The large species of *Laminaria* only covered about 10 – 20 %. At the slopes south of the bank structure the types of algae changed into *Laminaria hyberboria* covering up to 100% of the boulders, with a sparse undercover of a variety of red algae.

Habitat description station s4.2 – Flat sandy seabed

At the southern part of the structure the slope terminated. At the foothill the seabed became sandy with no structures at the water depth of 17.2 m.

Habitat description station s4.2 – Reef type 3

At the northern side the slope terminated at a water depth of 13.9 m with a seabed of sand with scattered boulders. Further down this slope at 13.0 m the *Laminaria hyberboria* gradually disappeared, and at 17 m water depth at the southern side only a few red algae species as *Phycodrys rubens and Dilsia carnosa* were still present. It is obvious that the decreasing algae coverage is due to the decrease of light at this depth.

Ground truth evaluation

As for station s4.1 the sidescan interpretation has predicted the substrate type, however, the amount of stone coverage predicted was limited due to the vegetation coverage. The diver description of station s4.2 showed that the structure is a well-developed cave-forming Reef type 1 similar to the one described at station 4.1. However, the variety of algae actually was different at the two stations. At station 4.1 the plateau was dominated by *Laminaria hyberboria.* At station s4.2 it was dominated by red algae species with scattered *Laminaria*, while the slopes were totally dominated by *Laminaria hyberboria.*

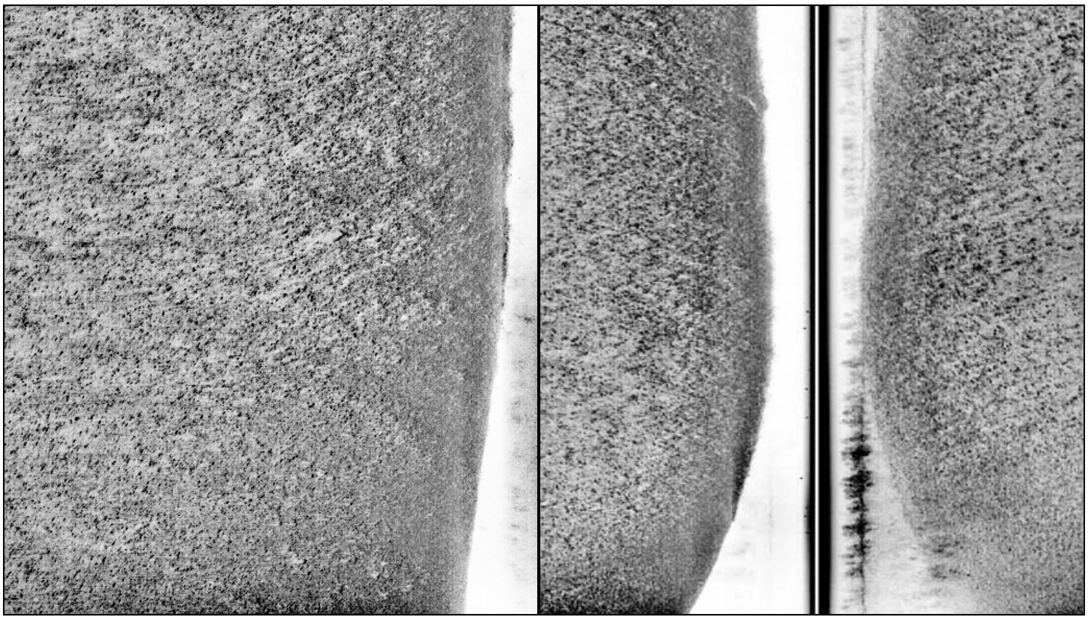
In addition to the point dive at station s4.1 and s4.2 the paravane 6 dive has been performed along a transect passing station s4.1 and s4.2 (see figure 16). The positions of the paravane track were based on the sidescan pictures predicting a cross section from a sandy seabed type into a mixed seabed with a dense cover of stones (reef type 2). The sidescan pictures below illustrate the background data for the paravane track.

Sidescan picture of paravane 6. The picture shows the paravane start position with a transition from a sandy seabed type at the top via a sharp boundary to a gravely seabed with a moderate coverage of boulders (reef type 3). The boulders at the bottom of the picture are partly covered by vegetation (dark grey colours). Approximate dimension of the section: Height 150 m and width 50 m.

Station s5 and s11

Sidescan description

The stations were selected based on the sidescan data. Both are located at the shallowest part of the Læsø Trindel.



Station s5 (left) and s11 (right). Sidescan pictures of the top of Læsø Trindel. Acoustically the seabed type is characterised as a rough inhomogeneous seabed type. No individual boulders or other larger objects have been identified possibly due to the fact that are missing or that a dense cover of vegetation blurs them. Approximate dimension of the sections: Height 150 m and width 50 m.

The diver description: station s5

Habitat description Station s5: Reef type 1

The diving position is located at the northern part of the Læsø Trindel proper at water depths of 6 – 6.5 m. The seabed was covered 30 – 40% by boulders with diameters of 20 – 60 cm. Smaller stones with diameters of 2 – 20 cm cover the remaining part of the seabed. In general, the station has a stone reef like character with up to 100% macroalgae coverage on stones larger than 10 cm. The dominating species on the boulders larger than 30 cm is *Laminaria digitata,* while the stones smaller than 10 – 30 cm was covered by a variety of red algae species primary *Ceramium rubrum*. Beside the algae some *Flustra foliacea (bladmosdyr)* and a few *Ctenolabrus rupestris (havkarusse)* and *Pholis gunellus (tangspræl)* were observed. Due to the stones covering the seabed in one level only this part of the Læsø Trindel doesn’t give rise to cave forming reef structures.

The diver description: station s11

Habitat description Station s11: Reef type 1

The point dive was carried out in the vicinity of the position defined by the sidescan interpretation within a diving radius of about 25 m from the anchoring point, primary in the area south and west to the anchoring point. The water depth registered in the diving area was 4.8 to 5.5 m. The water depth at the actual position was 4.8 m with a substrate consisting of 25 – 35 % boulders ranging from 20 – 50 cm in diameter. The surrounding 65 – 75 % of the seabed consisted of gravel and pebbles. The boulders present were covered by a variety of red algae dominated by *Ceramium rubrum.* Apart from that, many encrusted red and brown algae were present. The most common algae covering the smallest boulders with diameters of 10 – 20 cm were *Corda filum* and *Chordaria flagelliformis*. Only a few animals such as starfish and *Carcinus maenas (strandkrabbe)* were present. The lower part of the Læsø Trindel is clearly marked by its exposed position, which also is reflected by its community of macro algae. At deeper water (ca. 5.5 m) boulders with diameters of 20 – 60 cm covered about 50% of the seabed. Smaller stones, 10 – 20 cm in diameter, covered the remaining part of the seabed. In addition, a few scattered larger boulders up to 1 m in diameter were registered. The deepest part of this station was registered about 50 m south-southwest to the anchoring position.

The minor differences of water depth compared with the presence of more and larger boulders were clearly reflected in the community of macro algae species. The larger stones primary was covered by *Laminaria saccharina*. *Ceramium rubrum* and *Corda filum* as seen in the other parts of this station covered the other stones primary. Furthermore, a single *Ctenolabrus rupestris (toplettet havkarusse)* was observed here.

In a stone reef context the top of the Læsø Trindel is represented with only a few species. The stone formation does not give rise to cave forming reef structures i.e. with no beneficiaries for animals. Furthermore, the exposed location of the reef makes it frequently influenced by winter storms and unstable for flora and fauna due to the frequent erosion and relocation of especially the smaller stones.

Station s7

Sidescan description

From the sidescan mosaic a large object has been registered. It was anticipated that the object could be a structure made by leaking gasses. The height of the object has been measured from the sidescan data to be in the order of 4 – 5 m. The surrounding seabed is mainly gravely with scattered stones with diameters between 0.5 and 1.0 m.

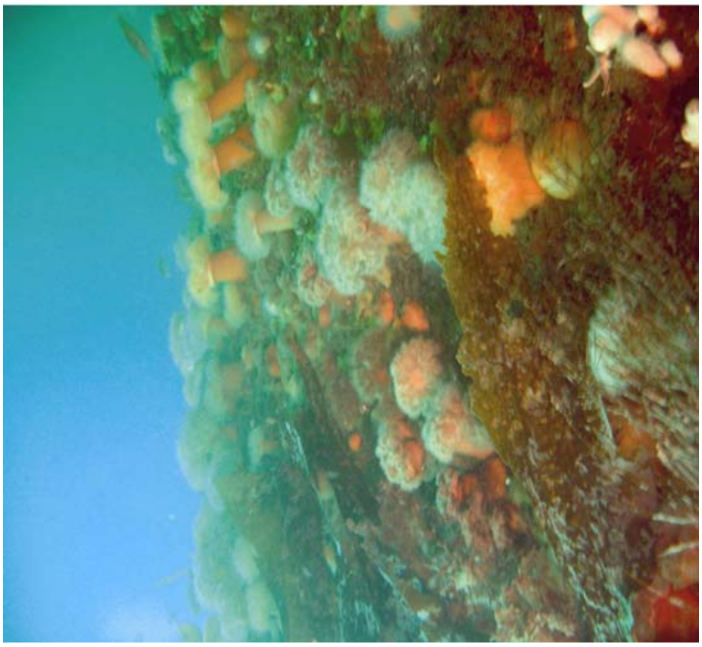
Station s7. Single, very large object lying on a gravely to stony seabed. The height of the stone is measured to 3 – 4 m in height. The blurred outline of the surrounding seabed is most likely due to vegetation. Approximate dimension of the sections: Height 150 m and width 50 m.

Station 7. Wall of stones with *Tealia sp.* (*sønelliker).*
(Photo: Jan Nicolaisen).

Diver description: Station s7

Habitat description of Station s7 – reef type 3.

The depth of the area varies between 13.3 and 13.8 m. In the northern area of the diving station the seabed was sandy with scattered stones and boulders less than 1 m in diameter. The stones covered between 2 and 25 % of the seabed, which made a perfect substrate for the macroalgae. The dominating species were *Laminaria hyberboria*, *Desmarestia aculeata* and a diversity of red bushes, but also some *Halidrys siliquosa* was observed. The large object seen at the sidescan sonar was found and identified. It was a huge single block with the dimension of 4 – 5 m length, 2 – 3 width and 2.3 – 2.7 m height surrounded by a pure sandy seabed. *Laminaria hyperboria* and *Laminaria digitata* as well as a variety of different red algae species covered the topmost part of the block. The sides of the block were dominated by *Alcyonium digitatum (Dødningehånd)* and large sea urchins.



Station 7. Wall of the large block with *Metridium senile.*
(Photo: Jan Nicolaisen).

Habitat description of Station s7 – Structures made by leaking gasses

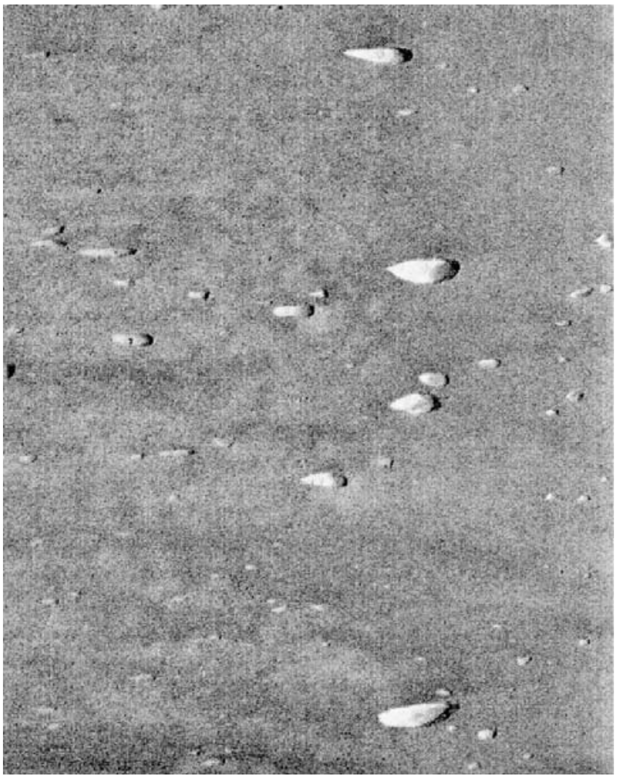
In the area north and northwest of the station 3 – 4 positions a series of cemented plate-formed sandstone was observed. These are most likely structures made by leaking gasses as those described at station s14, but here they seem to be inactive. They emerge slightly (<0.5 m) above the surrounding sandy seabed. The area covered an area in total about 75 – 150 m² with a very dense cover of algae dominated by *Laminaria hyberboria*.

The difference from these structure made by leaking gasses and those described at station s14 most likely is that the sand, in which they are formed, still is present and surrounding the structures at station 7. Contrarily, the sand has been eroded and transported at station s14 i.e. the structures there are seen protruding the seabed.

Station s9

Sidescan description

The station is located east of station s4.1 and s4.2. The seabed is characterised of predominantly gravely sand with scattered occurrence of boulders. The height of the boulders in the picture has been measured to 3-4 m above the seabed. Some vegetation might blur the presence and shape of smaller stones.



Station 9: Sidescan picture showing the scattered occurrence of boulders on a flat and predominantly gravely seabed. The height of the boulders in the picture has been measured to 3-4 m above the seabed. Approximate dimension of the sections: Height 150 m and width 50 m.

The diver description: station 9

Habitat description Station s9 – Reef type 3

The area was quite level with a water depth around 15.8 m. The seabed was sandy with a few solitary boulders covering the total seabed with less than 2%. The size of the boulders ranges from 30 cm to 2.5 m in diameter. The largest boulder raises 1.5 m above the seabed. The topmost part of the boulders was typically covered by *Laminaria digitata* and *Laminaria hyberboria* and with a sperse undercover of single *Dilsia carnosa, Coccothylus* *truncatus* and some *Coralina officinalis.* The total coverage of algae was less than 50%. Apart from the algae described also a few other species such as sea anemones, star fish and sea squirts were observed covering the stones.

Furthermore, a few very large *Laminaria saccharina* up to a length of 3 m were observed sitting on decimetre size stones. Due to the large surface of these algae leaves these stones are drifting with the currents dragged by the leaves.

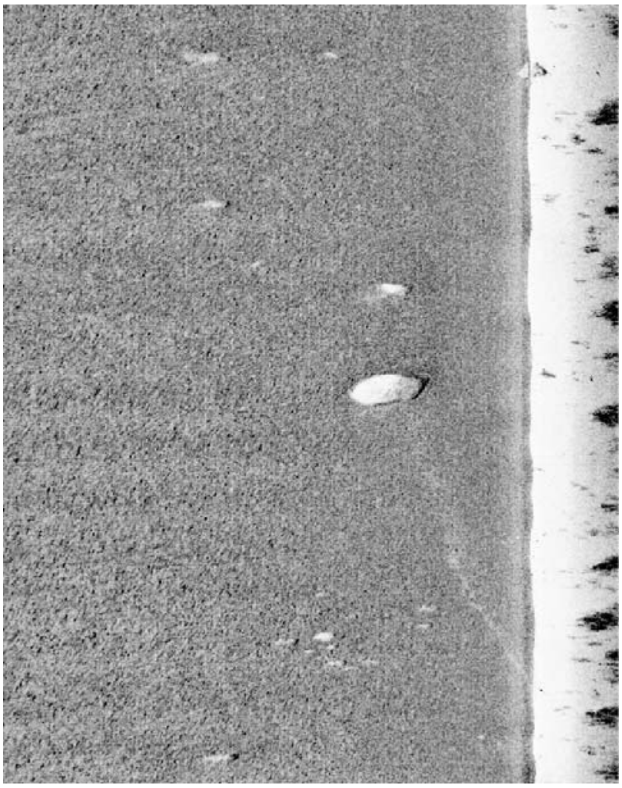
Ground truth evaluation

Despite the diver has evaluated the stone coverage in the range of a few percentages the habitat at Station s9 has been classified as reef type 3 based on the sidescan analysis. The advantage of the acoustic method is the large area coverage, specifically useful for the habitat classification.

Station s10

Sidescan description

The sidescan picture of this station shows the presence of an object interpreted as a boulder and a remarkable scar in the seabed to be traced over a long distance away from the object. The diver should evaluate if the scar could originate from “a rolling object” i.e. from a stone covered by algae drifting across the seabed by the current leaving a scar at the seabed behind. Such process has previously been described in the area. The surrounding seabed is characterised as reef type 3, i.e. sandy and gravely seabed with scattered stones and a few boulders.



Station s10. Sidescan picture showing a gravely seabed with scattered stones (reef type 3) and specifically one very large boulder with a height of approximately 4 m. The light and indeterminable track can be traced from this stone to the bottom of the picture. Approximate dimension of the sections: Height 150 m and width 50 m.

The diver description: station 10

Habitat description Station s10 – Reef type 3

The dive covered the water depth interval from 11.0 to 11.4 m surrounding a single boulder pointed out from the sidescan picture reached 4m above the seafloor. Vegetation cover is 100% on the boulders.

The seabed is characterised by pebbles and gravel but with larger boulders of a diameter up to 1 m and stones covering 10 – 20 % of the seabed. The large boulders were covered with large the kelp *Laminaria hyberboria,* while the smaller boulder and stone were dominated by the kelp *Laminaria saccharina,* filamentous brown algae such as *Desmarestia viridis* or foliose red algae such *Dilsea carnosa*. The dominating gravely substrate had, in general, no cover of algae except from different types of encrusted algae species.

The diver found no traces of the rolling object. Based on the general composition of the substrate at the station the diver concluded that the scars seen on the sidescan picture does not originate from a rolling stone at the seabed. If any large boulder should start drifting it would stop immediately because of collision with another nearby boulder. Furthermore, the almost plane seabed at the station does not support any rolling mechanism either.

The reef is classified as a reef type 3 with approximately 20% coverage of boulders and stones with pebbles and gravel in between. No cave forming structures.

Ground truth evaluation

The diver has verified the seabed type and the presence of the large boulders as observed from the sidescan picture. The coverage of stones and boulders of a larger area has been the basis for the classification of the habitat type. The diver has confirmed this general coverage less than 20% and, by that, classified the habitat into reef type 3.

Station s12

Sidescan description

The interpretation of the sidescan picture characterised the seabed as gravely with the presence of scattered boulders of an average diameter of 1.0 m. The coverage of stones is estimated to be in excess of 50%. But most likely this number is underestimated due to a dense coverage of algae.

Station s12. Sidescan picture showing a seabed with a dense cover of boulders with average heights of less than 1.0 m. A few scattered large stones of 2-3 m height have been registered. The blurred outline of the boulders most likely is due to vegetation.
Approximate dimension of the sections: Height 150 m and width 50 m.

The diver description: station 12

Habitat description Station s12 – Reef type 1

The diving was performed in a cross section from north to south passing the suggested position at the top. The shallowest water depth of this structure was 9.5 m increasing to the surroundings to about 11 m.

At the top the seabed characterised by 75% coverage of boulders of maximum 1 m in diameter. Diameter scale stones covered the remaining 25% of the seabed. The reef area is characterised by a dense coverage of large boulders with well-developed cave-forming structures. A kelp forest characterised by *Laminaria hyberboria and Laminaria digitata* cover the entire reef area. Underneath the brown algae canopy foliose red algae such as *Phycodrys rubens, Membranoptera alata, Dilsea carnosa* and filamentous tufts such as *Ceramium rubrum* and *Coralina officinalis*. The foliose brown algae *Desmarestia aculeata* was also present. Vegetation cover is 100%.

Habitat description Station s12 – Reef type 3

Beneath the top point the degree of stone coverage decreased gradually i.e. at 10.5 – 11.0 m water depth the coverage was only about 15 %. The reef area is characterised by a few scattered boulders and smaller stones with a gradual transition to a more pebbly and gravely seafloor. Annual species such as filamentous brown algae *Desmarestia viridis* or filamentous read algae tufts such as *Ceramium rubrum* dominated this reef area. Kelp such as *Laminaria hyberboria* and *Laminaria digitata* were present at the larger boulders. Vegetation cover is 100% on the boulders.

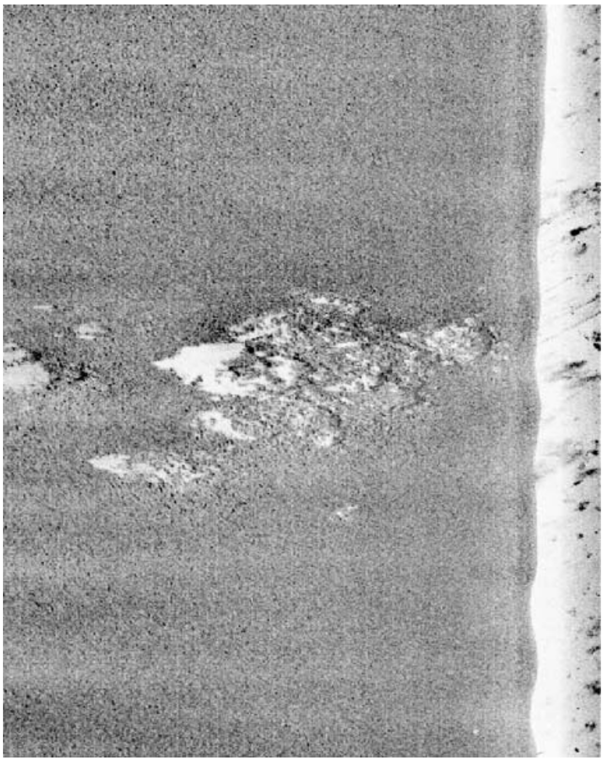
Ground truth evaluation

The diving has confirmed the sidescan interpretation suggesting the blurred picture was due to the presence of boulders covered by macro algae.

Station s14

Sidescan description

About 1800 m east of the Læsø Trindel top an area of characteristic unknown features has been designated on the basis of the side scan sonar data. A detailed analysis of the sidescan picture suggested that the features could represent a hitherto unknown location of the habitat type – structures made by leaking gasses. The depth of the area was about 16 m. A position located in the middle of the area was pointed out for the ground truthing.



Station s14: Sidescan picture showing the structure of high reflectivity anticipated as a 'bubbling reef' surrounded by a level sandy seabed. The transition is sharp. Some topography within the feature is recognised by the shadows indicating a rough surface. These features are found scattered within an area of 600 m x 200 m.
Approximate dimension of the section: Height 150 m and width 50 m.

The diver description: station s14

Habitat description Station s14 – Structures made by leaking gasses

The diver immediately realised the presence of bubbling reefs at the location. The structure was rising up to 2.5 m above the seabed as more or less coherent reef structures. The area distribution of the reef was difficult to define by point diving due to the limited visibility and the limited diving range. The delineation of the reef structure like this, therefore, will depend on the determination from the side scan picture.

In the following the submarine structures made by leaking gases is referred to as 'the bubbling reef habitat type'.

The amazing bubbling reef habitat type here markedly illustrates how suitable a structure like this is as a substrate for flora as well as fauna. The present structure resembles an eroded pyramid with shelves, niches and caves extending several metres into the bubbling reef itself. Individual structures reached 2,5 m above the surrounding seafloor. A limited amount of leaking gas bubbles leaking into the water column was registered in two places of the structure.

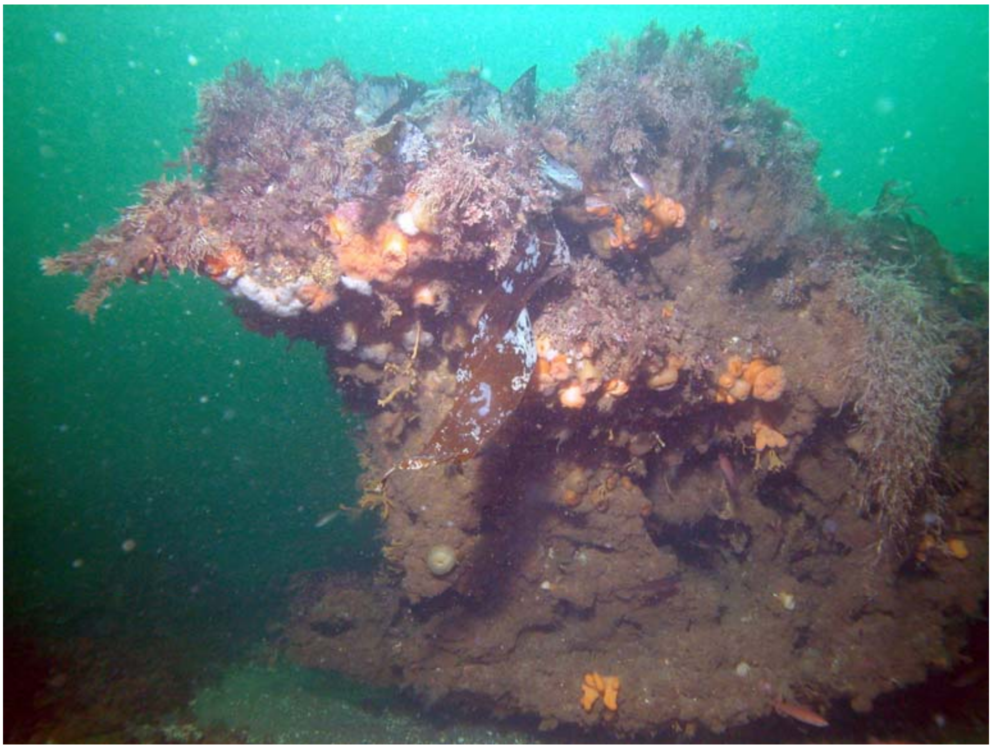
Vegetation cover is 100% on the topside of the structure, primary represented by *Laminaria hyberboria* with sparse undergrowth of different species of red algae primary of *Phycodrys rubens* and *Dilsia carnosa* and different crust shaped red algae, primary carbonate encrusted species. In the caves and cracks of the bubbling reef a series of different fauna species have been registered, all connected to the hard substrate such as sea anemones *Tealia sp.* (*sønellike), Alcyonium digitatum (dødningehåndkoral)*. Furthermore, more mobile species such as *Cancer pagurus (sand- and taskekrabber), Echinus esculentus (søpindsvin), Marthasterias glacialis (pigget søstjerne) and star fish* are connected to the reef. Specifically, a number of large *Labrus bergylta (berggylt)* up to the size of 35 – 40 cm has been registered. In one of the larger caves two cods of at least 4-5 kilo also was observed. Apart from the big cods the bubbling reef is the domicile of hundreds of *Ctenolabrus rupestris (toplettet havkarusse).*

Habitat description Station s14 – Sandy and gravely seabed types

Gravel, pebbles and sand dominated the seabed surrounding the bubbling reef. Within a zone of 10 – 20 m of the bubbling reef the seabed was dominated by a gravely seabed type of gravel and stones (< 10 cm), at further distance the changing into a sandy seabed type of sand with pebbles. The pebbles apparently made up a specific substrate for *Laminaria saccharina*. The *Laminaria saccharina* attached to stones often has gained a size to allow transportation of stones up to a diameter of 10 cm by means of the bottom current. By that, the current catches the algae and carries the stones by drifting until the bubbling reef of other larger stones surrounding the reef catches the drifting stones.

Station s14. Gas bubbles ascending from the bubbling reef.

Station s14. Cave forming structure of the bubbling reef.
(Photos: Jan Nicolaisen).



Station s14. The bubbling reef. Cemented sandstone covered by algae. (Photo: Jan Nicolaisen).

Ground truth evaluation

The analysis of the sidescan and multibeam data has discovered a hitherto unknown occurrence of structures made by leaking gasses. From the sidescan mosaic the area has been delimited from the surrounding seabed dominated by sand and gravel. The subsequent ground truthing has confirmed the existence of the structures and furthermore characterised the detailed structure of the feature including a description and assessment of the biota. It can be concluded that the acoustic method is very suitable for discovering new areas of structures made by leaking gasses. Once the acoustic characteristics of this type of structures were recognised is allows the geologist easily to register and delimit similar areas. The existing knowledge of the performance of structures made by leaking gasses indicates that they may occur as either reef-like structures or as cemented sandy plates within or at the seabed. So far the acoustic method has demonstrated itself as a promising method for mapping structures made by leaking gasses emerging from the seabed. We still need to demonstrate its efficiency to mapping the plate-like structures.

Finding more structures by diving alone has a long perspective due to the low coverage and limited visibility by this method.