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Subtidal habitats

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1. Introduction

The Wadden Sea, as a tidal area, can be divided in intertidal and subtidal zones. The intertidal area is alternately flooded and drained during the tidal cycle while the subtidal area is influenced by the tidal currents but stays submerged during low tide. About 27% of the Wadden sea is subtidal. The benthic species diversity and density in the Wadden Sea is generally higher in the subtidal area compared to the intertidal (Johnson, 1970; Saier, 2002). However, information on habitats in the subtidal of the Wadden Sea is very limited, its enhancement is urgently needed for both scientific demands and ecosystem-based Wadden Sea management.

1.1 Developments in the subtidal area

Changes in the faunal composition of the subtidal were recorded for certain areas in the Wadden Sea (Riesen and Reise, 1982). In the past ages human influences on the existing habitats, organisms and ecosystem processes have increased enormously. Intensive exploitation has resulted in the disappearance of habitat forming species (Wolff, 2000). Since the 20th Century, pollution, eutrophication, invasive species and climate change have also induced changes in the Wadden Sea ecosystem. The relatively high biodiversity in the subtidal, the noted changes and the lack of knowledge in respect to distribution and occurrence of many benthic species and habitats, all contribute to the urgency of research on the subtidal habitats of the Wadden Sea.

1.2 European Directives and trilateral agreements

Knowledge of subtidal habitats is not only required for scientific demands, but also to facilitate

the protection of threatened and rare habitats and to improve spatial and strategic planning of human activities, in particular where there are competing demands like fishing, mariculture, sand extraction, wind energy generation and nature conservation. Marine habitats are one of the key items addressed in European directives. In the European Habitats Directive, three subtidal habitat types are pointed out in the Wadden Sea. As stated in Annex I, sandbanks (habitat 1110), large shallow inlets and bays (habitat 1160) and reefs (habitat 1170) which combines biogenic as well as geogenic structures, belong to marine habitats of community interest and should therefore remain in a favourable status. In accordance with the Marine Strategy Directive (Annex II) evaluation of the status of habitat types, the identification and mapping of habitats of special scientific or biodiversity interest is required, including the occurrence and population dynamics of 'habitat specific' species.

The subtidal area is also one of the items the Wadden Sea Plan aims at where namely Sabellaria reefs and blue mussel beds are important topics with specific targets.

Keywords in the assessment of the status of habitat types stated in the Habitats Directive are the surface and natural distribution of the habitat and 'habitat specific species' and the structure and function of the habitat. Besides knowledge on the distribution and covered area of different habitat types (habitat mapping), it is also important to know the ecological processes that are key to certain habitats and influence population dynamics and distribution of habitat specific species, e.g. *Sabellaria spinulosa*, *Mytilus edulis* or *Crassostrea gigas*.

2. Findings from the QSR 2004

In the past, reflections on subtidal habitats were restricted to *Sabellaria* reefs (QSR 1999, 2004) and blue mussel beds (QSR 2004).

2.1 *Sabellaria spinulosa*

Since the reefs of *Sabellaria spinulosa* are of great importance to biodiversity (Gruet 1971, Gore *et al.* 1978, Mettam, 1992), but show a dramatic decline over the last decades, the intention for their protection as an ecological target exists at different levels in the EU Habitats Directive (Annex I). Although a routine monitoring program on the occurrence and development of *Sabellaria* reefs has been strongly recommended for many years, it has not been adopted so far.

Subtidal blue mussel beds

Subtidal mussel beds differ significantly from intertidal beds in structure, species interactions and associated organisms (Buschbaum and Saier, 2003). Besides their importance as habitat structure, subtidal mussel beds are important feeding grounds for eider ducks (Ens and Kats, 2003), and presumably also for other diving ducks as the greater scaup and the common scoter, all protected in the European Birds Directive. Protection of mussel beds against anthropogenic bottom-disturbance is, however, still predominantly restricted to the intertidal. Although location and biomass is monitored in The Netherlands and Denmark, so far almost no substantial investigation effort is invested in their structure and function.

3. Inventory of habitat mapping activities

Marine habitat mapping combines biological data from discrete observations (direct sampling) with remotely sensed images (remote sensing) to create a visual product, the habitat map (Mapping European Submarine Habitats, www.searchmesh.net). A habitat map makes it possible to visualize the occurrence and distribution of different habitat types on the seabed. The term habitat is used generically in scientific, management, policy and legal circles, resulting in many different definitions and meanings. A specific definition with respect to Wadden Sea conditions is still missing and should be one of the first tasks of a future TMAP working group (see section recommendations). In this chapter we will follow the definition of ICES: '*A particular environment which can be distinguished by its (a)biotic characteristics and associated biological assemblage, operating at particular but dynamic spatial and temporal scales in a recognizable geographic area*' (ICES working group on marine habitat mapping).

In the natural world, sharp boundaries between different habitat types are rarely encountered and therefore clear divisions of the main parameters of a habitat type need to be designed. Habitat classification schemes help to define habitats in a consistent way. Within Europe there is a single pan-European habitat classification scheme, developed by the European Topic Centre on Biological Diversity (see <http://eunis.eea.europa.eu/habitats.jsp>).

Although terrestrial habitat mapping has a long history, seabed mapping is a relatively new procedure. The main reason why information on subtidal habitats was limited so far is the lack of appropriate methods to investigate the seafloor in the deeper parts of the Wadden Sea. The improvement of remote sensing techniques such as multibeam echo sounding and side scan sonar mapping of the subtidal mean that the determination of habitats and biologically relevant structures is now in reach. For a comprehensive overview of available methods, see the website and reports of the MESH project. In this chapter information will be presented on methods, existing activities and first results on habitat mapping in the Wadden Sea which is an obligation under the Habitats Directive.

3.1 Habitat mapping in the Wadden Sea

In preparation for the first trilateral workshop on subtidal habitat mapping in December 2008 a compilation was made, giving an overview of the institutions engaged, methods and sampling gear used (Table 1) and the sites surveyed so far (Figure 1). Several working groups in The Netherlands, Germany and Denmark are investigating the subtidal zone of the Wadden Sea area, but mainly on a small spatial and temporal scale. The methods used range from classic benthos sampling with dredges and corers to remote sensing techniques with echo sounding.



Figure 1:
Survey sites in the Wadden
Sea area where subtidal
habitat mapping has taken
place.

The biomass of the subtidal shellfish populations is monitored every year in spring/summer by a stratified dredge sampling survey. Additionally the entire subtidal area is investigated, taking 30 m² with a hydraulic dredge on a stratified grid. This survey is carried out in September/October. Since 2008 the focus is not only on mussels (*Mytilus edulis*) and cockles (*Cerastoderma edule*), but also on Pacific oysters (*Crassostrea gigas*), razorshell clams (*Ensis directus*) and soft-shelled clams (*Mya arenaria*). In addition several small scale but long term studies on subtidal benthic biodiversity take place in the Dutch Wadden sea, using grab sampling or box-corer (Fey *et al.*, 2008). From 1989-1997 a survey on sediment classification took place in the Dutch Wadden Sea by grab sampling. This survey resulted in a sediment atlas produced by the water management directorate (mentioned by Zwarts, 2004, but published separately by the RIKZ). More recent data on sediment classification consists of local data collected for scientific studies or habitat studies, for example in a reference area near Rottum using the Medusa method (see 3.2.4).

3.2.2 Acoustic remote sensing

For decades, acoustic systems have been successful instruments for marine research (Newton and Stefanon, 1975; Flemming, 1976), because they can 'see' the sea bottom without needing underwater optical visibility. Nowadays sidescan sonar, single beam and multibeam sonar are commonly used for the identification of the seafloor environment. Seabed structures and sediment types are determined by the acoustic response of the bottom, which is a function of the physical properties of the sea bottom (grain size, texture, roughness, slope).

Multibeam Sonar

The multibeam sonar system sends out multiple beams of sound energy and records the time elapsed between the emission of each acoustic pulse from the transducer to the seafloor and back again to the receiver of the system. Transducer and receiver are mounted on the hull of a research vessel, so the ship's positioning can be integrated into the data collection. By means of a differential global positioning (D-GPS) or even real time kinematic (RTK) system and an intertidal motion unit (IMU), the ship's position can be recorded at the time of each pulse and a highly accurate bathymetric record can be produced. Modern shallow-water systems can describe the seabed at spatial resolutions of as little as a few centimetres (Hughes, Clarke *et al.*, 1996). Simultaneously the

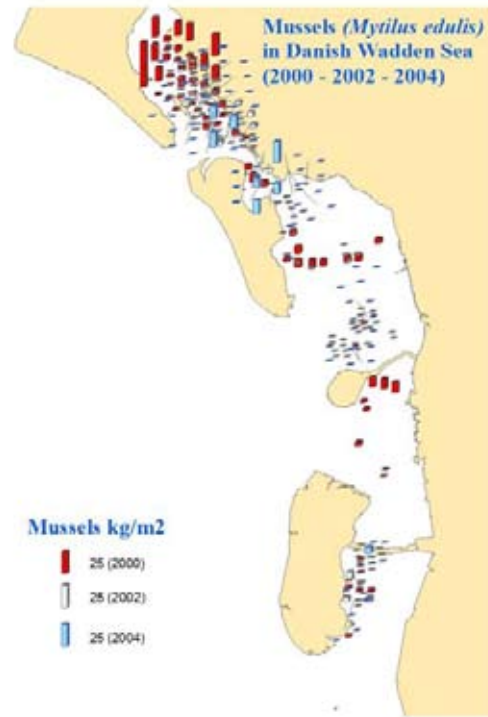


Figure 3: Blue mussel biomass and distribution pattern in the Danish Wadden Sea in 2000, 2002 and 2004 (Kristensen *et al.*, 2007).

'sidescan mode' of the multibeam sonar system records the backscatter intensity of the acoustic return in order to derive seabed characteristics for habitat mapping. By running parallel survey lines, large areas of the seabed can be mapped. Thus, the bathymetric data deliver a precise full-coverage digital elevation model of the studied area and the backscattering data can be used for sediment classification.

In the German Wadden Sea, multibeam sonar was used for a number of research projects conducted by the Research Centre GKSS. The system (here: Simrad EM 3000/3002) is especially adapted for shallow water with a range for application between one and 100 meters water depth. In the Dutch Wadden Sea, single beam echo sounding is used to produce a new bathymetric map for the entire Wadden Sea area every six years. Multibeam sonar is used in individual construction or dredging projects in the Wadden Sea, but not in monitoring programs.

Sidescan Sonar

Sidescan Sonar produces images of the seabed based on sound transmitted and received from a sonar tow fish trailed behind a ship. In contrast to the multibeam system, sidescan sonar measures not the time but the strength of the returning acoustic beam. The signal sent out is a single beam with a wide opening, one on the right and one on the left side of the tow fish. The positioning of the sonar fields creates a blind spot perpendicular

under the sonar fish, visible as a black line in the middle of sidescan sonar images. The scan range achieves nearly 180° and the system is independent of water depth. Thus, the productivity of survey work is especially good in shallow areas. Based on textural patterns and the intensity of the reflected sound, the image can be used to identify discrete seabed structures and to characterize sediment types. Sidescan sonar does not provide data on depth and an exact geographical reference of the tow fish position behind the ship is not available.

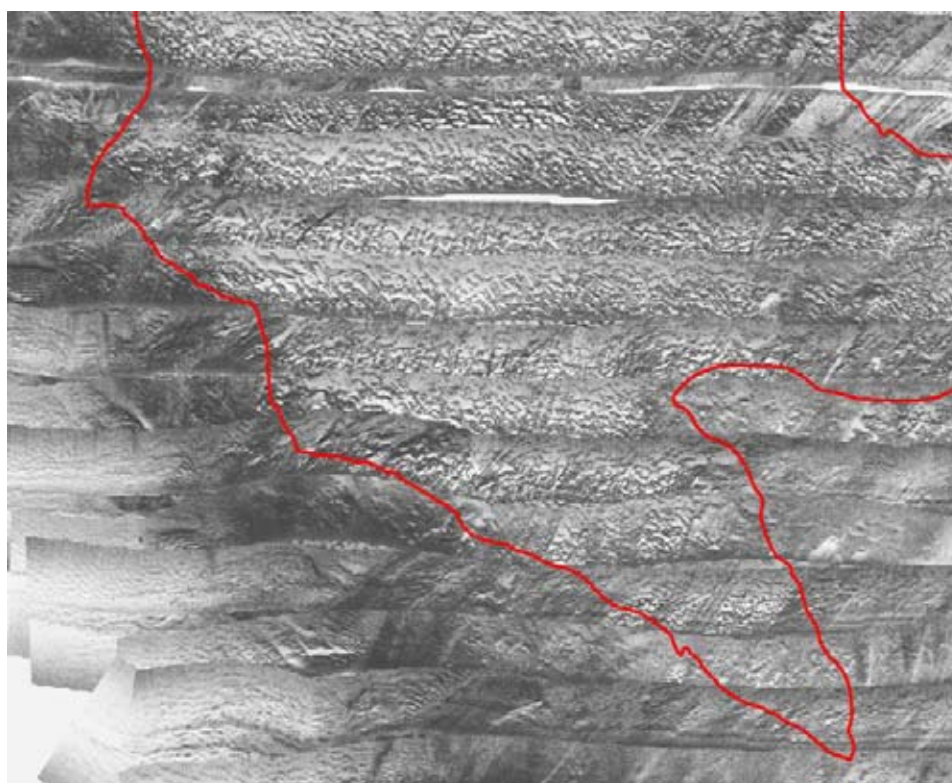
This acoustic technique is used in the Dutch Wadden Sea to map the contours and patterns of shellfish beds (mainly blue mussel and Pacific oyster). In a study on the effects of mussel seed fisheries (PRODUS) sidescan sonar gave an impression of the distribution and development of mussel patterns on the research plots (Fey *et al.*, 2008). Sidescan sonar was also used in a study on the development of individual subtidal mussel beds, describing the contours and patterns (Figure 4). Sidescan sonar images are sometimes used to identify the location of oyster or mussel structures which thereafter are sampled by grab sampling for quantitative data on biomass (Kater *et al.*, 2002). As the sidescan sonar images are not yet resulting directly in quantified data, they are used in a descriptive way and are always combined with dredge or grab sampling for ground truthing.

Underwater Video

Underwater videoing is a well established method for investigating the marine environment from the intertidal up to the deep sea (Holme, 1984). Frequently, underwater video is used as ground-truth procedure in combination with acoustic seabed mapping (Vorberg, 1998; Rooper and Zimmermann, 2007). The camera can be mounted on a towed sledge or remotely operated vehicle (ROV). In both cases the camera is connected to the vessel by a bidirectional umbilical for data transfer. An underwater light is attached to the video system to illuminate the seabed in case of insufficient light conditions. The underwater video is viewed in real time on board and recorded for further analysis. The time stamp of the video is linked to the temporal information of the global positioning system.

Strong tidal currents and high turbidity in the Wadden Sea often yield unfavourable conditions for visual surveys and applicability was therefore limited in this area. Best results for underwater videoing in the Wadden Sea were obtained one hour before and after high water when current speed is low and the clear water from the open North Sea has entered the system. Under good conditions the video recordings enable a detailed analysis of the sediment type and biotic and abiotic

Figure 4: Sidescan sonar image of a subtidal mussel bed in the Dutch Wadden Sea. The red line indicates the contours of the mussel structure. On the image the parallel survey lines are clearly identifiable as separate horizontal bars on the picture. Within the red contour lines the structures or "patches" of the mussel bed are visualised by dark spots, which are not present on the bare sand outside the mussel bed.





structures on the sea bottom can be determined, as well as macrobenthic species (Figure 5).

In the Dutch Wadden Sea, the technique is used on specific research plots, mainly for measurements on blue mussel densities, but also on other macrobenthos like crab and starfish. The camera is combined with a water-filled, pyramid-shaped lens and the system is lowered from a boat.

Thus, underwater videoing is on one hand a suitable method for seabed mapping and can on the other hand as ground truth procedure to verify the findings of acoustic surveys.

3.2.4 Other methods

The multi-element detector for underwater sediment activity (MEDUSA) uses a combination of a detector for natural gamma radiation and a detector for friction sounds when the instrument is dragged over the sea floor. The method measures the coarseness and composition of the top layer of the sediment. In The Netherlands this method is used in individual small research or construction projects (e.g. Dankers *et al*, 2006).

Figure 5: Screenshots from underwater video recordings of different sediment types (A: pure sand with ripples; B: sand covered by mussel shells; C: *Cancer pagurus* and *Pholis gunnellus*)

4. Subtidal Wadden Sea habitats

Habitat types in the subtidal of the Wadden Sea can be based on specific abiotic characteristics, resulting from relief, sediment type or seabed structures like gravel, shells, stones or peat. These physical characteristics can, however, also result from habitat-forming species or biogenic structures, which influence physical conditions in such a way that they form a habitat.

4.1 Seabed or sediment classes

In the subtidal Wadden Sea region, sandy sediments prevail. Natural rock formations do not occur, although pebbles and boulders are scattered locally. In some locations, patches of peat occur on the seabed surface, with a thin cover of tidal sediments. The Wadden Sea sand is of fluvial and glacial origin, the fine clay fraction in the sediments is thought to be primarily derived from recent riverine sources. Most subtidal sediment consists of fine sand. The coarsest sediment can be found near the coastal zones and the sea entries. From the Wadden islands towards the east the sand particles become smaller. The fine clay fraction increases towards the mainland. Each seabed or sediment type accommodates specific biological assemblages, which is of course also influenced by other environmental factors such as salinity and water movement. Only little information exists on seabed type or sediment distribution in the Wadden Sea. In the Dutch Wadden Sea the most recent survey on sediment classification took place in 1989-1997. Some recent data

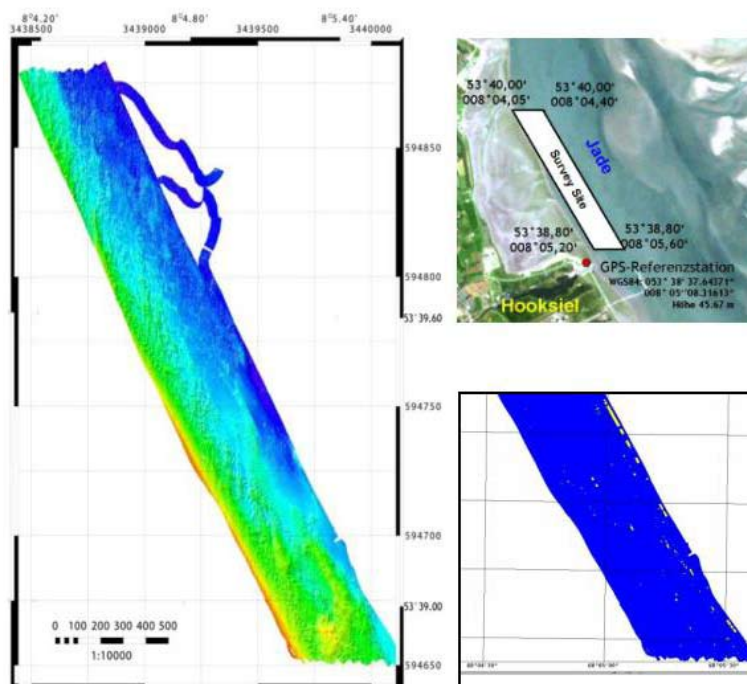
on sediment classification consists of local data collected for scientific studies, but no information exists on changes of sediment composition in recent decades.

4.2 Biogenic structures

4.2.1 Sabellaria reefs

Polychaetes of the species *Sabellaria spinulosa* produce reef like structures in the subtidal of the Wadden Sea. It is a common and widespread polychaete species in the North Sea. Although single individuals of this species can be found throughout the entire Wadden Sea, reef-like structures occur only in a few locations. It is believed that only under certain conditions reefs are built but there is a serious lack of knowledge of the primary conditions for the genesis and further development of those reefs. In the Jade River near Hooksiel, harbour reef structures were known for many decades. Investigations in the 1990s confirmed the existence of extended reefs (Vorberg, 1997; Grotjahn, 2000). At this site an acoustic survey by means of multibeam echosounding was conducted in 2005. By using this acoustic method only little reef fragments could be found. The digital elevation model of the studied area shows a uniformly shaped sandy sea bottom with no noticeable structures occurring and only the analysis of the backscatter data gave hints of the existence of bottom structures with hard texture (Figure 6). Underwater video records could confirm little

Figure 6: Mapping of *Sabellaria* reef structures in the Jade river near Hooksiel: location of the survey site (right above), digital elevation model (left) and sediment composition analysed by backscatter data (right down).



Sabellaria reef-clumps mainly along the slope in 9-12 meter water depths. Reef structures as known from the past were no more present in this area. Sabellaria reefs are not known in the Dutch or Danish Wadden Sea, although, at least in the Dutch Wadden Sea, individuals of these species are sporadically found (Dekker, *pers. comm.*).

4.2.2 Lanice fields

The polychaete *Lanice conchilega* constructs small tubes of fine sand particles or shell fragments. Lanice can occur in dense fields of a few hundred to several thousands of individuals per square meter. Extended beds were found in the course of a seabed mapping survey in the Osterems area between the East Frisian islands of Borkum and Memmert (Figure 7). Some small stretches of subtidal *Lanice* fields were found the Dutch Wadden Sea near Texel in a study on acoustic (sidescan sonar) type signatures of different macrobenthic species (Overmeeren, 2009). They were visible on sidescan sonar images and found in grab samples taken on the spot. No monitoring programs exist which can give insight into the development and distribution of this habitat forming species.

4.2.3 Subtidal blue mussel beds

Blue mussel beds come into existence after annual spatfall events and can survive at a specific location for many years. The current status of subtidal mussel beds is broadly discussed in the QSR 2009 (Nehls *et al.*, 2009). Although the importance of

blue mussel beds for associated species is broadly recognised, there is limited information on the fauna associated with subtidal mussel beds in the Wadden Sea area. Some work has been done on associated fauna and species interactions differed between intertidal and subtidal mussel beds and between wild subtidal beds and culture plots (Buschbaum and Saier, 2001; Saier, 2003). Besides their importance as habitat structures, subtidal mussel beds, including associated species, form important feeding grounds for diving ducks. In the Dutch Wadden Sea, a research program named PRODUS studies the effects of seed fisheries on the biodiversity of subtidal mussel beds. In this research project a comparison between natural beds and culture lots is included. The project will be finalized in 2012.

Occurrences and distribution of intertidal mussel beds is monitored regularly throughout the entire Wadden Sea. Monitoring programs on subtidal blue mussel beds do not exist, except in the Dutch Wadden Sea, where subtidal beds are roughly mapped in spring and autumn for fishing purposes.

4.2.4 Subtidal Pacific oyster beds

The current status of Pacific oyster development is discussed in detail in the QSR 2009 (Nehls *et al.*, 2009). Although the Pacific oyster (*Crassostrea gigas*) population in the subtidal has remained small compared to the intertidal, recent expo-

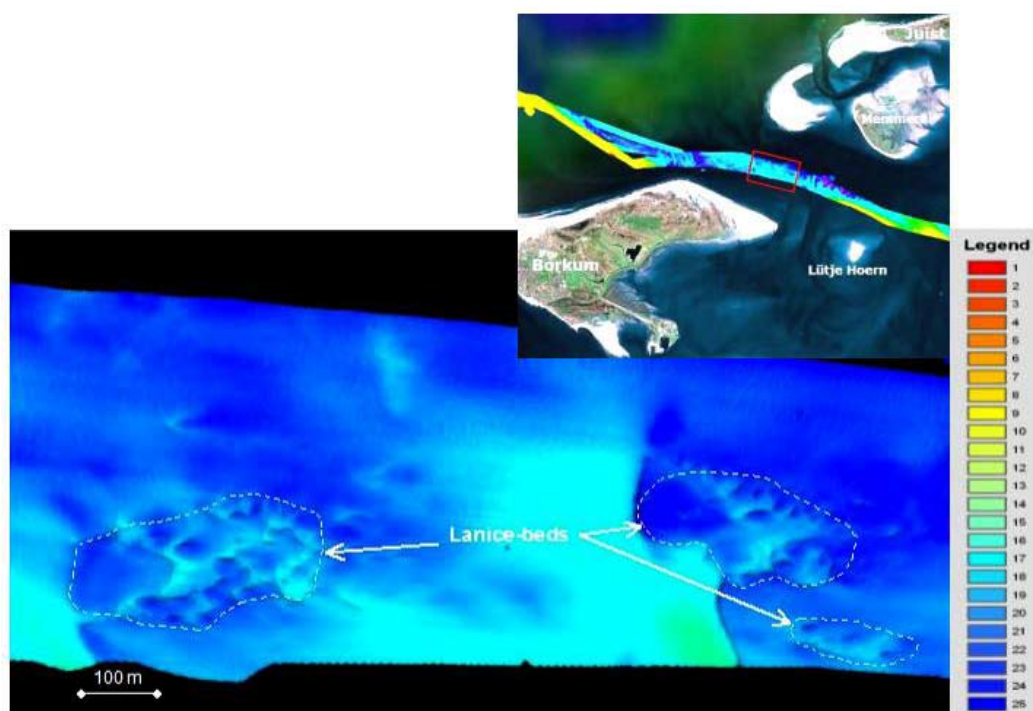


Figure 7: Extended Lanice fields in the Osterems could be detected by the digital elevation model obtained from the multibeam sonar data (Legend: water depth [m]).

mental growth of the subtidal population was observed in Dutch waters. While subtidal oysters mainly occur scattered, associated with blue mussels, reefs are formed at some localities, with multiple oyster generations accumulating. It is not known if and to what extent subtidal oyster reefs differ in biodiversity from intertidal oyster reefs or subtidal mussel beds. In a study on differences between intertidal blue mussel beds and oyster reefs in the German Wadden Sea (Markert, 2006), it was found that oyster reefs are characterized by a higher availability of hard substrate, a more complex habitat matrix and an increased biodeposition. These habitat features affected the living community and the composition of the associated macrofauna. Pacific oyster reefs showed a higher biodiversity than sites predominantly occupied by blue mussels.

Occurrence and distribution of subtidal Pacific oyster beds has been monitored in The Netherlands since 2008. Regular investigations in Germany and Denmark are restricted to the intertidal, but pilot and research projects in Germany are carried out to enlighten the situation in the subtidal.

4.2.5 Subtidal seagrass and macroalgae

The surface of subtidal *Zostera marina* in the Dutch western Wadden Sea was estimated to occupy a total area of 6,500-15,000 ha (Wolff, 1983). Since the extermination of this form by the wasting disease in 1932, only individual intertidal stands occur. The development of seagrass and macroalgae in the intertidal is further discussed in the QSR 2009 (van der Graaf *et al.*, 2009). There is no monitoring program on subtidal seagrass and macroalgae in the Wadden Sea.

5. Discussion and conclusion

5.1 Target evaluation

The following ecological targets for tidal areas (Trilateral Wadden Sea Plan) are valid for the subtidal:

- a natural dynamic situation in the tidal area;
- an increased area of geomorphologically and biologically undisturbed tidal flats and subtidal areas;
- an increased area of, and a more natural distribution and development of, natural mussel beds and *Sabellaria* reefs and *Zostera fields*,

In addition, targets for marine mammals and birds have been formulated.

Three habitats types are relevant in the Wadden Sea concerning Annex I of the EU Habitats Directive. In The Netherlands, the subtidal habitat is classified as habitat 1110 (sandbanks which are slightly covered by sea water all the time). In Germany and Denmark an additional habitat type (1170, reefs) is recognized. The Dutch government does not consider subtidal reefs as a separate habitat type and includes reefs in the habitat 1110 description. Habitat 1110 extends over about 120,000 ha in the Dutch Wadden Sea, of which 0.1% is closed for all commercial activities and thereby about 120 ha are valid as undisturbed subtidal area. In total, the status of conservation of the Dutch habitat type 1110 is evaluated in 2007 as moderately unfavourable. In Germany, the entire Wadden Sea national parks of both Schleswig-Holstein (452,000 ha) and Lower Saxony (278,000 ha) were reported as habitats to the European Commission. Due to the limited knowledge of the subtidal, the conservation status of habitat types 1110 (submerged sandbanks) and 1160 (large shallow inlets and bays) is unknown and despite an unknown situation, reefs (habitat type 1170) were evaluated as moderately unfavourable.

5.1.1 Mussel beds and *Sabellaria* reefs

Mussel beds fulfil an important role in the subtidal ecosystem. They form, together with Pacific oyster reefs, the only remaining biogenic structures forming hard substrate in the Wadden Sea, but little is known about the occurrence and distribution of subtidal mussel beds

All subtidal blue mussel beds are exploited by mussel (seed) fisheries, except for a part of the Hörnum Deep (Schleswig-Holstein), which is a zero use area since 1997. Recent agreements between mussel growers and nature conservation

organisations in The Netherlands have resulted in plans to close parts of the subtidal mussel beds for fisheries. A growing surface area of older mussel beds in this part of the Wadden Sea should be promoted.

Information concerning *Sabellaria* reefs is unsatisfactory and based on surveys several years ago. Latest results indicate a further decrease of one of the last existing reefs in the Jade near Hooksiel and the occurrence of other reef sites is unknown. Suitable methods for searching and monitoring are available, but due to lacking monitoring work a target evaluation for *Sabellaria* reefs is not possible.

5.2 Appropriate methods for habitat mapping

For a complete detection and assessment of all Wadden Sea habitats, a variety of different methods is required. Assessment of habitat types is based on the occurrence and distribution of habitat types, reflected in the morphology of the seabed, the sediment type and biogenic structures, and the function and structure of the habitat in combination with the occurrence and development of habitat specific species.

Acoustic remote sensing methods allow large-scale registration of the seabed, resulting in detailed three-dimensional pictures of the morphology, information of the sediment types and occurrence and distribution of biogenic structures. Direct sampling generates validation of remote sensing techniques and information on structure and function and the status of specific species. Full-coverage mapping of the entire Wadden Sea by means of remote acoustic methods is the first step towards an ecosystem-based management and should be supported by traditional sampling techniques (dredging, grab sampling) in order to get information on biodiversity, species variation and abundance on different habitat types.

5.2.1 Remote sensing

Pictures derived from multibeam echosounding or sidescan sonar give information of the seafloor comparable to aerial photos from ashore. In contrast to that, dredge and grab sampling and close-up photography yield very detailed but very small-scale information. The large-scale approach of acoustic methods in combination with direct measurement validation fits the trilateral policy and management demands as well as the requirements of the EU Habitats Directive. Full-coverage mapping of the subtidal of the Wadden Sea enables the detection of *Sabellaria* reefs, blue mussel

and oyster beds as well as the habitat types sand-banks (habitat type 1110), large shallow inlets and bays (habitat type 1160) and reefs (habitat type 1170), which are relevant in the sense of the EU Habitats Directive. In addition to the detection of subtidal habitats, long-term investigations of the extent, distribution, structure and development of habitats yield valuable information concerning the assessment and evaluation of management measures.

Which sonar system to use for a specific task depends on a number of factors, including the seabed properties to be measured (e.g. bathymetry, surface texture, sediment type), the area of seabed to be surveyed, and whether complete coverage of the seabed is required. The special challenge surveyors are faced with in the subtidal of the Wadden Sea is the water depth, which is in wide parts very low and permanently changing due to the tidal regime. Because sidescan sonar works independent of water depth, the system is suitable for the Wadden Sea. The attractiveness of multibeam echo sounding lies in the exact three-dimensional positioning of the backscattered data. Moreover, the high reproducibility of multibeam sonar surveys is advantageous for monitoring purposes.

A promising way in hydro-acoustic surveys of shallow tidal areas can be the integration of both, multibeam and sidescan sonar. Shono *et al.* (2004) suggest a combination of the techniques and could demonstrate an economic and effective way for mapping seagrass beds.

5.2.2 Direct sampling

Besides as validation of remote sensing techniques, direct sampling is essential to evaluate the occurrence and natural distribution of 'habitat specific or typical species' and the structure and function of the habitat. Remote sensing techniques are very strong in delivering full coverage information on structural characteristics, but do not provide information on population dynamics or occurrences of infauna species, missing out the majority of the biological/ecological information. While a stratified sampling survey by means of dredging may assess a mussel or oyster stock with an accuracy (95%) of approximately $\pm 25\%$ (Jansen *et al.* 2008), translation of sonar images via ground-truth analysis will add a considerable error to such a biomass estimate.

5.3 Future perspectives

To be able to give a valid and complete assessment of subtidal habitats, there is an urgent need for information on the surface and natural distribution as well as on the structure and function of these habitats.

5.3.1 Practical work

Full-coverage mapping of the subtidal of the Wadden Sea can be achieved if a trilaterally integrated survey work program can be installed. Closest attention should be paid to remote acoustic methods since sidescan and multibeam sonar are the most effective techniques to map the seabed, sediment and surface of biogenic structures of the entire subtidal of about 5,000 km² in an appropriate period of time, although direct sampling on regular intervals will remain necessary. Given that multibeam sonar maps about 3 km² per day and sidescan sonar reaches twice as much, we can assume, that a fleet of 5 research vessels can carry out the survey work for the entire Wadden Sea area within 1 – 2 years. This calculation ignores already existing results, as well as methodological difficulties and the time needed for ground truthing work. The availability of research vessels, appropriate equipment and manpower is a matter of organisational work, which could be done in the framework of a coming trilateral working group on habitat mapping. Main tasks of this working group must be the integration and harmonization of existing activities just like the equilibration and further development of the methods.

5.3.2 Theoretical work

An important task for the working group is to elaborate the theoretical basis for habitat mapping in the subtidal of the Wadden Sea. A special working group should come up with proposals of which habitats should be mapped. Wadden Sea specific habitats have to be worked out on the basis of classification schemes set up by the EU Habitats Directive or by ICES and EUNIS. The theoretical background about the framework and how to use the classification for habitat mapping purposes is given by Connor *et al.* (2004).

6. Recommendations

The following recommendations for subtidal habitat monitoring and assessment can be given:

- Installation of a trilateral working group on subtidal habitat mapping.
- Full-coverage approach should be the main objective for subtidal habitat mapping.
- Development of an integrated hydro-acoustic survey combining multibeam and sidescan sonar technology for full-coverage mapping and underwater video for ground truthing.
- Harmonization of the trilateral survey work.
- Equilibration of methods applied for habitat mapping.
- Regular workshops for joint analyses of the data and trilaterally tuned results.

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