Acoustic habitat mapping in the German Wadden Sea – Comparison of hydro-acoustic devices

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ABSTRACT


Since the Wadden Sea area belongs to the World Nature Heritage the public pressure of habitat protection grows distinctly. To assess the recent stage of the different habitats and to monitor their changes in the near future standard mapping and quality tools are requested. To map the sub-tidal part of the Wadden Sea area optical approaches are mostly less successful. To develop standard procedures for sub-aquatic monitoring, three hydro-acoustic devices were tested their resolution, their redundancy and their value of benefit detecting habitats. In order to find out which are the system-specific limitation, foot-print sizes and coverage in different water depth we surveyed several test areas in water depth of 5 to 15 m simultaneously with singlebeam echosounder (200 kHz), multibeam echosounder (455 kHz) and sidescan sonar (380 kHz). Two surveys (in 2007 and 2008) are described here. By means of acoustic seabed classification tools the different characteristics of seafloor roughness were analysed. Four major acoustic classes were distinguished which cover seafloor sediments of sand, broken shells, gravel, less mud and infrequently some peat. All acoustic devices show similar complex spatial pattern with higher variability in 2007. Class 1 and Class 3 are the most redundant classes which are characterized by medium sand and varying amounts of gravel and shell fragments. Stronger differences in the acoustic classes were observed in the singlebeam which is stronger influenced by its lower frequency. The feedback of footprint and sediment matrix is not sufficiently explained nowadays.

ADDITIONAL INDEX WORDS: multibeam, sidescan sonar, seabed classification, sediment, roughness, backscatter

INTRODUCTION

In 2009 the Wadden Sea area along the southern North Sea was awarded status of the World Nature Heritage of the UNESCO (WHC-09/33.COM/8B and WHC-09/33.COM/INF.8B2). In consideration to the combination of the European marine strategy framework directives and the EU water framework directives the evaluation of marine habitat conditions is requested on a half decade period interval. This will become a major task mainly for the national governments of the neighboring states along the southern North Sea coast. To assess the recent stage of the different habitats and to monitor their changes in the near and further future, standard mapping and quality tools as well as procedures are requested. On demand of the EU new technologies have to be developed and to be standardized for the EU community which allows the comparison of the given stage at the individual habitats. In the framework for Mapping European Seabed Habitats (MESH) general work flows on a larger scale in the shelf region and near offshore area of some European regions have been already standardized. But systematical habitat mapping and classification in the Wadden Sea area are still in process. Analog mapping of habitats in former times was mainly carried out in the intertidal areas of the Wadden Sea (e.g. Krause 1954, 1955, Michaelis 1987, Michaelis et al. 1995, Hertweck 1995).

At present, the major focus is still mainly related to the supratidal and intertidal areas (e.g. Dijkema 1991, Sørensen et al. 2006) which are now gathered by optical remote sensing tools such as high resolution air photos and laser scans (e.g. Bartholdy and Folving 1986, Sørensen et al. 2006, Brzank et al. 2008). In contrast to the intertidal area, optical approaches are less successful to cover the subtidal part of the Wadden Sea area. Only little is known about the subtidal areas of the Wadden Sea (e.g. Essink, et al., 2005). High suspension load coupled with less visibility reduce and/or inhibit wide-spread used optical based techniques.

To compensate for this deficit, alternative techniques have to be developed. From the pelagic area the quite well-known hydro-acoustic devices have been adapted to more shallow water operation. During the last two decades acoustic systems, like singlebeam or multibeam echosounders and sidescan sonar, were used for the remote sensing of the seafloor and benthic biotopes (Collins and Galloway 1996, Ellingsen et al. 2002, Kenny et al. 2003, Freitas et al. 2003, Díaz et al. 2004).

As a side effect, the acoustic return signal contains more than the depth information. The characteristic and intensity of the backscatter return signal can be used for the so-called acoustic seabed classification. Several algorithms were developed to process the data for automated seafloor classification (e.g. Hamilton et al. 1999, Hamilton 2005, Hughes-Clarke et al. 1996, Preston, 2001, 2009).

In this case study, supported by a 3-year funding of the German Lower Saxony government, different sonar source were compared
in order to their system resolution, physical settings such as foot print size and swath coverage as well as their acoustic seabed classification and interpretation. To develop standard procedures for sub-aquatic monitoring, several hydro-acoustic devices were tested simultaneously in different habitat and morphological conditions.

STUDY SITE

The present study is focused on the Lower Saxony Wadden Sea located in the northwestern part of Germany, ranging from the Dutch border in the west to the river Elbe in the east (Figure 1).

This part of the National Park covers an area of about 2,777 km². Roughly 44% (ca. 1,220 km²) of this area is located within the subtidal range. Subtidal areas are defined as being covered by sea-water also during low water. Major focus was given on the backbarrier tidal flats along the Eastfrisian coast and on the Jade Bay area, a quasi-closed embayment. The catchment areas of the backbarrier tidal flats are between 70 and 90 km² in size, expanding to the western margin of the Wadden Sea region (Fig. 1). The study site presented in this paper represents a typical tidal channel habitat in the exposed western part of the Wadden Sea area.

METHODS

In order to compare footprint size, physical resolution and system-specific limitations three sonar system have been used for the shallow water survey in the Memmertbalje area. For the supposed simple approach of single ping measurements a Furuno FCV 1000™ singlebeam echosounder with a working-frequency of 200 kHz and a vertically directed beam angle of 7.5° was used. Oblique-angle-based backscatter return signals were collected by means of a sidescan sonar and a shallow water multibeam echosounder of approximately 400 kHz. These systems allowed a swath coverage between 3.5 and 7 times of the given water depth. The sidescan sonar system Benthos SIS 1624 ™ operates with two major frequencies, the processed frequency ranges between 370 and 390 kHz with a beam angle of 0.5 ° along track and 35° across track. To get high resolution bathymetry data coupled with sea-bottom backscatter information a Reson SeaBat 8125™ with a working-frequency of 455 kHz and 240 beams was operated on a swath coverage of up to 3.5 times of the water depth within a beam angle of 120° (0.5° across and 1.0 along track). The multibeam system was linked to a high resolution AQUARIUS 5002™ (THALES/DSNP) dual frequency (L1/L2) Long Range Kinematic (LRKT) Global Positioning System (e.g. Ernstsen et al. 2005). Corrections for ship movements were applied using an Octans™ Surface. This system configuration allows absolute accuracies of less than a decimetre (Ernstsen et al. 2006). The survey area varies in water depth. We surveyed several test areas in water depth ranges between 5 and 15 m simultaneously with singlebeam, QTC™ Multiview for multibeam, QTC™ Sideview for sidescan sonar data). The wave shape analysis was used for the classification of singlebeam data. To classify multibeam and the sidescan sonar data the backscatter information was processed (e.g. Preston, et al. 2009, Preston et al, 2003). In three different approaches acoustic similarities were splitted by automatic clustering with the same number of iterations. The statistical optimum number of classes was determined by the minimum score (Quester Tangent, 2009). Bathymetry data were processed from geo-referenced depth data of the multibeam. It was used for depth correction and bottom peak function in all data sets. With regard to the water depth depending footprint size the following grid sizes were use to process the raw data of the different sources:

- QTC Multiview : 33x17 pixel (0.9m x 3.7m ; 3.3 m²)
- QTC Sideview : 17x9 pixels (0.8m x 2.4m ; 1.92 m²)
- QTC Impact 1 point (15m water depth footprint; 2.98 m²)

RESULTS

The topography of the study site Memmertbalje is subdivided into the deeper tidal channel and the South and into the more shallow tidal flat area in the North (Fig. 2)

In the first step the different habitats of the Memmertbalje were

Figure 1. Study Memmertbalje behind Juist Island in the East Frisian Wadden Sea area along the southern North Sea coast line

Figure 2. Bathymetry of the Memmertbalje study site – view from the south – Depths related to MSL - 40x exaggerated.

Journal of Coastal Research, Special Issue 64, 2011
classified acoustically into four classes which represent the major seabed characteristics of this part of the Wadden Sea area (Fig 3). In general all three acoustic data sets show similar spatial distribution patterns of the different sand fractions, mussel shell fragments, smaller mud deposits as well as the coarser material such as gravels and peat fragments (Fig. 3).

But the area-percentage of the spatial coverage of the individual classes varies in dependence of the specific acoustic approach (Fig. 4). During the first survey 2007 similarities of spatial coverage were found for all acoustic devices in the second and fourth acoustic class. In contrast, the sidescan sonar data do not correspond with the other backscatter data in class one and three (Fig. 4). In 2008 the classification shows generally lower variability in the spatial coverage. Again, only the singlebeam classification ‘over-amplified’ class four. Both surveys show the same ranking in the class composition. Most dominant third class covers approximately 60 % of the entire area followed by class one with nearly 25 % area-percentage. Only less than 10 % are covered by the second and fourth class, in 2008 the fourth class is neglectable. Combining the acoustic information with the ground information, the major component for the acoustic responds is the sea bottom-roughness which is controlled by the high spatial heterogeneity of surface sediments in this area.

The sediment distribution of this area is mainly composed of the coarser sand fractions and shell fragments. Tidal related small mud deposits and occasionally peat pebbles occur. The inventory of the four major acoustic classes can be subdivided into following components:

Class 1: consists of mainly sandy sediments. The total amount of sand (>0,063mm to < 2mm) varies between 43% and 97%. The weight percentage of the medium sand fraction (0,25 mm – 0,50 mm) varies between 65% and 95%. The amount of fine sand (0,063mm – 0,25mm) shows variations between 3,6% and 15,7%. The amount of gravel (>2mm) is generally low (<1%). The mud fraction (< 0,063 mm) varies between ca. 1% and 55%. The amount of shell debris shows variations between 3% and 31%. Although class 3 comprises of a mixture of different sediment types, the samples show macroscopically a much rougher surface than for classes 1 and 2. A high amount of shell debris and less gravel build the surface of these samples. These coarse components are not covered by finer sediments.

Class 2: was only sampled by 3 grabs. One of these samples recovered a block of muddy peat. The other two samples consist mainly of sand (>0,063mm to < 2mm). The total sand content ranges between 86% and 90%. The sand fraction mainly consists of medium sand (0,25 mm – 0,50 mm : 64,1% - 83,1%). The content of mud (< 0,063mm) is low (1% - 7%) except for the muddy peat sample (63% mud). The amount of shell debris varies between 13% and 2%. Sample surfaces are relatively smooth with a minor amount of shell debris.

Class 3: was sampled by the majority of seafloor samples. The sediments are a mixture between sandy mud and coarse sand. The total content of the sand fraction (>0,063mm to < 2mm) varies for class 3 between ca.45% and 92%. A fine sand fraction (>0,063 mm to < 0,25 mm) between 0,6% and 59% was determined. The variations of medium sand (0,25 mm to 0,50 mm) are also high (ca.7% and ca. 90%). The amounts of coarse sand (0,50 mm to 1mm) and very coarse sand (1mm to 2 mm) are in the range between 0% to ca. 68% and 0% to ca.29% respectively. Gravel contents (>2mm) between 0% and 47% were determined, whereas the amount of mud (< 0,063 mm) varies between ca. 2% and 63%. The amount of shell debris shows variations between 3% and 31%. Although class 3 comprises of a mixture of different sediment types, the samples show macroscopically a much rougher surface than for classes 1 and 2. A high amount of shell debris and less gravel build the surface of these samples. These coarse components are not covered by finer sediments.

Class 4: For multibeam echosounder and sidescan sonar
DISCUSSION

The seafloor of shallow water areas in the Wadden Sea were mapped by means of three acoustic devices which differ in resolution depending on frequency and beam geometry. The major distribution pattern of these very heterogeneous sea bottom surfaces were recognized by all three devices. The quality and distribution pattern of these very heterogeneous sea bottom particles, it is important to define the footprint smoothening effect and footprint geometry.

The second reason for this class shift is related to the geometry of the return signals (e.g. Lurton 2002). Both reasons should possibly explain the mapped composition and the corresponding surface roughness of the sediments. In habitats with widespread homogeneous sediments, it is easy to distinguish different roughness. But in the tidal systems of the Wadden Sea seafloor characteristics can change in less than a square meter. However, to figure out the influence of individual sediment components to the mix matrix of seafloor surface we correlated the weight content of the major sediment components (sand, gravel, shells and mud) of the samples with the generated acoustic classes for each acoustic device (Tab. 1).

The backscatter based systems are much more sensitive to changes in surface roughness than of the sediment type itself in the study area. For the sediments in the Wadden Sea this sensitivity starts getting more relevant in dependence of the footprint size, the effect of smoothing decreases in shallower water depth. But the exact magnitude of this proportion can not recently defined in detail. More research is needed to determine whether these differences are caused mainly by differences in the working frequencies of the systems, or by resolution of the environmental conditions.

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procedure for single sand fraction subdivided into one phi-step interval (Tab. 1). Only “shell” matches significantly (P ≤ 0.05) to the acoustic detection of multibeam and sidescan sonar (Tab. 1). The roughness of the sand fits much better to all devices the best fit is given to the coarse sand which was defined as the major component only in three of the 29 sample. Only the singlebeam makes the very fine and fine sand distinguishable (R = .373 P=0.05). The reason for that could be the vertical signal penetration coupled with the lower frequency. Regarding to the generally smoother surface more “microscatter” returns to the source and give a significant peak in the wave shape. Nevertheless, similar large scale distribution pattern of the acoustic roughness in all acoustic devices confirms this approach of mapping (Fig. 3). Operation in very shallow water depth coupled with small scale heterogeneity needs more system-adapted individual sedimentological interpretation of the acoustic signal. To build up individual threshold values with a proportion index of matrix sediment and superimpose mostly coarser particles, it is important to define the footprint smoothing effect depending on the water depth. Comparing our singlebeam data with the oblique angle based system the most critical variability appears in areas which change in topography and surface roughness simultaneously.

CONCLUSION

Acoustic classification techniques can also be used successfully for habitat mapping in the Wadden Sea. Simultaneous surveys with singlebeam echosounder, multibeam echosounder and sidescan sonar lead to a similar distribution pattern of seafloor classes.

Differences between backscatter based classifications (e.g. systems like multibeam echosounders and sidescan sonar) and waveform analyses based classifications (singlebeam echosounder) may be based in differences in working-frequencies and footprint geometry.

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### Table 1: Spearman Rank order correlation between acoustic classes of multibeam (MBES), sidescan sonar (SSS) and singlebeam (SB) and the main sediment components sand, gravel, mud, shell fragments (as percentage of the total sample amount) and grain sizes fraction of sand.

<table>
<thead>
<tr>
<th>Spearman Rank Order Correlation Memmertbalje 2007</th>
<th>MBES class</th>
<th>Sand</th>
<th>Gravel</th>
<th>Mud</th>
<th>Shells</th>
<th>phi 4-3</th>
<th>phi 3-2</th>
<th>phi 2-1</th>
<th>phi 1-0</th>
<th>phi 0 -1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corr. Coeff.</td>
<td>0.106</td>
<td>0.235</td>
<td>-0.215</td>
<td>0.461</td>
<td>0.135</td>
<td>-0.181</td>
<td>-0.427</td>
<td>0.378</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>P Value</td>
<td>0.580</td>
<td>0.180</td>
<td>0.259</td>
<td>0.0122</td>
<td>0.483</td>
<td>0.343</td>
<td>0.0210</td>
<td>0.0432</td>
<td>0.0000002</td>
<td></td>
</tr>
<tr>
<td>SSS class</td>
<td>Sand</td>
<td>0.176</td>
<td>0.310</td>
<td>-0.289</td>
<td>0.527</td>
<td>0.144</td>
<td>-0.267</td>
<td>-0.436</td>
<td>0.452</td>
<td>0.961</td>
</tr>
<tr>
<td>Corr. Coeff.</td>
<td>0.358</td>
<td>0.101</td>
<td>0.127</td>
<td>0.00347</td>
<td>0.453</td>
<td>0.160</td>
<td>0.0182</td>
<td>0.0140</td>
<td>0.0000002</td>
<td></td>
</tr>
<tr>
<td>P Value</td>
<td>0.358</td>
<td>0.101</td>
<td>0.127</td>
<td>0.00347</td>
<td>0.453</td>
<td>0.160</td>
<td>0.0182</td>
<td>0.0140</td>
<td>0.0000002</td>
<td></td>
</tr>
<tr>
<td>SB class</td>
<td>Sand</td>
<td>-0.166</td>
<td>0.148</td>
<td>0.0718</td>
<td>-0.212</td>
<td>0.373</td>
<td>-0.0109</td>
<td>-0.353</td>
<td>-0.0536</td>
<td>0.414</td>
</tr>
<tr>
<td>Corr. Coeff.</td>
<td>0.385</td>
<td>0.441</td>
<td>0.708</td>
<td>0.266</td>
<td>0.0459</td>
<td>0.954</td>
<td>0.0598</td>
<td>0.780</td>
<td>0.0258</td>
<td></td>
</tr>
<tr>
<td>P Value</td>
<td>0.385</td>
<td>0.441</td>
<td>0.708</td>
<td>0.266</td>
<td>0.0459</td>
<td>0.954</td>
<td>0.0598</td>
<td>0.780</td>
<td>0.0258</td>
<td></td>
</tr>
<tr>
<td>Size (µm)</td>
<td>63-125</td>
<td>125-250</td>
<td>250-500</td>
<td>500-1000</td>
<td>1000-2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.of samp.</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
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</tr>
</tbody>
</table>
The amount of gravel (>2mm) is generally low (<1%). The mud (0,063mm – 0,25mm) shows variations between 3,6% and 15,7%. The mud deposits and occasionally pebbles occur. The inventory covered by the second and fourth class, in 2008 the fourth class is one with nearly 25 % area-percentage. Only less than 10 % are same ranking in the class composition. Most dominant third class classification 'over-amplified' class four. Both surveys show the distribution patters of the different sand fractions, mussel shell debris and less gravel build the surface of these samples. These sediment types, the samples show macroscopically a much variety in the mud contents (>2mm) between 0% and 47% were determined, whereas contents (>2mm) between 0% to ca. 68% and 0% to ca.29% respectively. Gravel (ca.7% and ca. 90%). The amounts of coarse sand (0,50 mm to <2mm) between 0% to ca. 65% and 0% to ca.47% and fine sand (0,063mm to <0,50 mm) between 0% to ca.10% and 0% to ca.5%. The total sand content (>0,063mm to < 2mm) varies for sediments are a mixture between sandy mud and coarse sand. The amount of shell debris shows variations between 3% and 20%. The amount of shell debris ranges between 1% and 20%.


