Assessing the ecological status of Blue mussel beds in the North-Frisian Wadden Sea - according to the EU Water Framework Directive and EU Habitat Directive

Heike Büttger
Georg Nehls

In cooperation with **Torsten Berg**
MariLim Gewässeruntersuchung, Kiel

October 2009

On behalf of:
Schleswig-Holstein Agency for Coastal Defence, National Park and Marine conservation
- National Park authority -

Nationalpark Wattenmeer
SCHLESWIG-HOLSTEIN

Contents

1 ABSTRACT

This report presents an approach for the assessment of the good ecological status according to the Water Framework Directive (WFD) and the possibility to transfer this in terms of the Habitat-Directive (HD). The approach refers to the spatial extension and the structure of Blue mussel beds (*Mytilus edulis*) and their associated communities in the Wadden Sea National Park of Schleswig-Holstein. Mussel beds were chosen as model habitat for this approach. They offer unique possibilities for monitoring spatial extension and structure of an intertidal community which are believed to facilitate detection and assessment of anthropogenic impacts against the background of a high natural fluctuation, which is typical for the Wadden Sea.

First, different mussel bed parameters, which are derived from an ongoing monitoring program (according to the TMAP), are evaluated for their suitability for this approach. We recommend using the four parameters ‘mussel bed area’, ‘steadiness of mussel bed sites’, ‘biomass’ (live wet weight) and ‘condition’ (flesh-content) for evaluation. We propose reference values for these parameters in term of an evaluation according to the WFD.

Reference values are derived using data of the years 1958, 1988 to 1994 and the ongoing monitoring program since 1998. For those parameters, for which no data are available before 1998, the period 1998-2001 was chosen for reference values. This approach is based on the finding that no major changes in distribution and spatial extension of mussel could be detected from 1958 until 2001.

Following these conclusions we evaluate the monitoring data for a first period 1998-2003, covering six years according to the required directives report periods. For the first period an EQS of 0,772 is obtained which indicates a good status. As far as the data are available for the second period 2004-2009 the values indicate a worse evaluation reflection decreasing mussel stocks.

The second part deals with the assessment of the associated macrobenthic community of mussel beds with the assessment tool MarBIT. This tool was originally developed by Meyer et al. (2008) for the Baltic Sea and was tested to be adopted in the Wadden Sea. The practicability of this tool for the assessment of intertidal mussel beds of the Wadden Sea is evaluated and further recommendations for usage, modifications and the necessary sampling effort are given.

Basically, the evaluations with the proposed four monitoring parameters and the evaluation of the associated macrobenthic community with MarBIT lead to meaningful results. Further discussions with responsible scientists and stakeholders are necessary and further adoptions might be essential.

2 INTRODUCTION

According to the Water Framework Directive (WFD) all member states have to achieve a good ecological state of their water bodies by 2015. This includes the German coast with the Wadden Sea (Fig. 1). The aim is “the protection of all waters, surface and ground waters in a holistic way” (Marencic et al. 2004). The assessment is based on the “ecological status" which “is an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters, classified in accordance with Annex V” (WFD Art. 2.21). This “ecological status" is evaluated on the basis of biological, chemical, physical-chemical and hydro-morphological parameters. The goal is the “good ecological status” which slightly differs from the undisturbed and natural situation, which is defined as “high ecological status”. The evaluation has to use five quality categories (high, good, moderate, poor, bad) which are transferred to the ecological quality ratio (EQR) ranging between 1 (good) and 0 (bad).

The “characterisation of surface water body types” is given by the WFD (Annex II, Art. 1). For each water body “Type-specific biological reference conditions shall be established, representing the values of the biological quality elements specified in point 1.1 in Annex V for that surface water body type at high ecological status as defined in the relevant table in section 1.2 in Annex V“ (WFD, Annex II, Art. 1.3 (i)).

According to the “characterisation of surface water body types” the Wadden Sea belongs to the coastal waters which are subdivided in exposed/sheltered and euhalin/polyhalin water bodies. For each of these five (N1 – N5) water body types the high ecological status has to be defined based on the composition and abundance of benthic invertebrate fauna under undisturbed conditions

Blue mussels belong to the macrobenthic community. Due to fact that they are habitat builders which offer an important living space and food source in a substrate-poor intertidal turns them to an important and characteristic feature in the Wadden Sea.

Although the evaluation according to the WFD should base on defined biological quality elements, the occurrence, distribution, stock size and further parameters of intertidal Blue mussel beds are considered as important supplements in terms of a broad evaluation. Already the Quality Status report 2004 demands that “The biotope ‘intertidal blue mussel bed at stable sites’ should be considered within the EU Water Framework Directive as a biological quality element for coastal waters” (de Vlas et al. 2005).

Against this background, this report presents an approach for the assessment of Blue mussel beds in terms of this directive. Mussel beds are characteristic structural elements of the Wadden Sea and they are of particular ecological importance. In the Wadden Sea of Schleswig-Holstein, Blue mussel beds are monitored annually since 1998 in order of the Trilateral Monitoring and Assessment Program (TMAP). This includes basic parameters of the mussels themselves as well as the macrobenthic community which is surveyed on certain beds annually. Intertidal Blue mussel beds are centres of high diversity (Asmus 1987, Dittmann 1990, Albrecht & Reise 1994), biomass and species richness are usually much higher than on surrounding tidal flats. Mussel beds are the almost best known habitat in the

tidal flats in comparison to sandflats or mudflats as they can be clearly delimited from the surrounding flats (Buschbaum & Saier 2001).
The assessment of the conservation status within a highly dynamic environment as the Wadden Sea is a challenging task as it requires detecting sometimes subtle changes against the background of a high natural fluctuation. The Wadden Sea is a shallow fringe of the North Sea where fluctuations of the climatic conditions as winter temperatures or storm events exert much stronger impacts than in the North Sea itself. Annual temperature fluctuations are almost two times higher than in the central North Sea and irregular changes of mild winters or extensive ice cover may induce significant variations in the benthic communities (Reise 1985). Likewise storm events, which have shaped the morphology and hydrology of the Wadden Sea throughout its history, structure benthic communities through direct physical forces. The spatial extension and the structure of intertidal benthic communities of the Wadden Sea thus shows much stronger annual fluctuations than open marine waters where such effects are absorbed in a large water body.
The Wadden Sea is different from many other marine waters in a very important aspect: Sheltered areas are sedimentation areas where enrichment with detritus and nutrients is a characteristic process, leading to a natural ‘eutrophication’ which might by assessed negatively by classic approaches to other habitats. Any assessment of the ecological status of benthic communities of the Wadden must thus be based on a solid description of their habitats and their extensions. In this respect, mussel beds offer a marked advantage as their annual and long-term dynamics can be easily and accurately assessed and quantified, because the epibenthic structures of the mussel beds are easily distinguished from other benthic communities.
The continuing mussel monitoring within the National Park of the Wadden Sea Schleswig-Holstein offers a good data basis of more than ten years which is appropriate for an initial assessment in terms of the WFD.

Furthermore the Habitat-Directive (HD) has to be taken into account. Tidal flats are protected areas according to the Annex 1 (LRT 1140 “mudflats and sandflats”) of the Habitat-Directive. For habitats listed in the Annex 1 as well as for species listed in Annex 2, the continuance and favourable conservation status has to be ensured by the member states. Blue mussel beds are considered as characteristic features of this habitat type while their continuance has to be assured.
According to the comparison of rating matrices proposed by M. Stock (Fig. 2) quality states of both directive could be compared and the five quality categories of the WFD could be transferred to the HD-classification. This approach assumes that the favourable conservation status according to the HD is comparable to the good ecological status according to the WFD which would mean that an evaluation of Blue mussel beds basing on structural parameters might be used in term of both directives. We adopt that this definition is not contradictory but rather a meaningful supplement in term of a holistic and broad evaluation of the entire Wadden Sea.

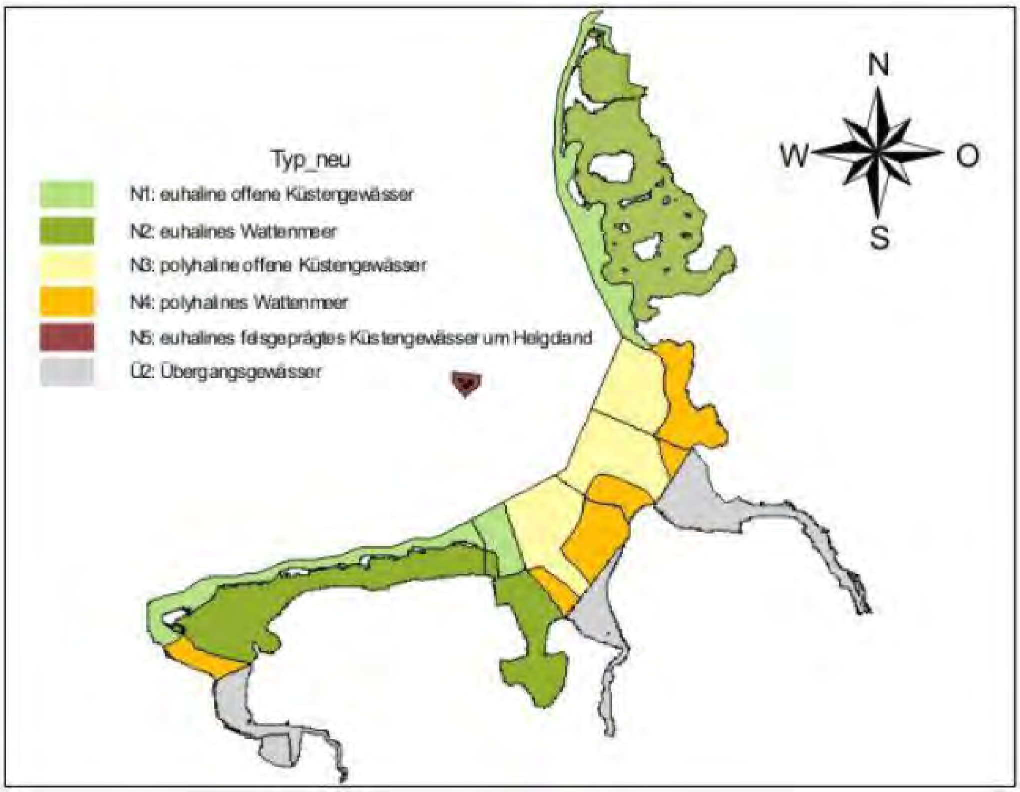

Fig. 1: Proposed typology of water bodies according to the WFD along the German Sea coast (CWSS 2004).

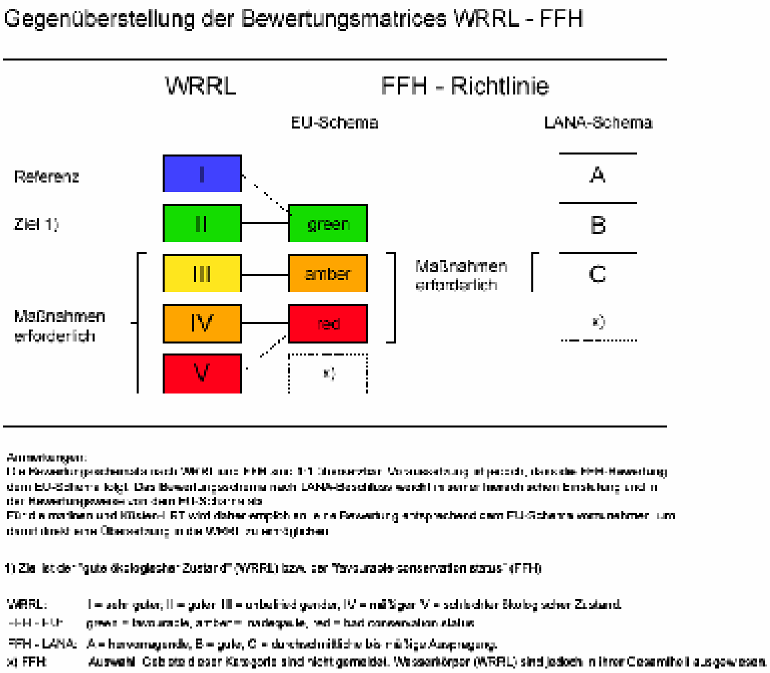

Fig. 2: Comparison of rating matrices according to the WFD and Habitat-Directive (proposal by M. Stock, Schleswig-Holstein Agency for Coastal Defence, National Park and Marine Conservation - National Park authority).

We present a two step approach which incorporates structural parameters and the associated community of mussel beds.

a) Structural parameters

On a first level we evaluate structural parameters (e.g. number of mussel beds, age structure, biomass, stability of mussel beds and others) obtained during the mussel monitoring within TMAP. We will review different monitoring parameters for their applicability and present references for the ecological status and give recommendations how to classify the differing states. We proceed as followed:

1. Analysis of aerial photographs from 1958 and display of the development and spatial distribution of Blue mussel beds in 1958, 1989 and between 1989 and 2007 as a historical baseline.
2. Checking if available monitoring parameters are suitable to assess a good ecological status and a favourable conservation status of Blue mussel beds.
3. Suggestion for reference values to assess the ecological status of blue mussel on basis of 1 and 2.

b) Associated community

The associated community will be examined with the index-tool MarBIT which was developed by MariLim (Kiel) for the Baltic Sea (Meyer et al. 2008). The MarBIT-tool is multi-metric assessment system which uses four criteria (diversity, abundances, sensitive and tolerant taxa). Basing on habitat specific species reference lists, the references for diversity, sensitive and tolerant taxa is determined. The tool evaluates the habitat by comparing a data-set with the reference using these four criterions (see chapter MarBIT). We observed structural changes of mussel beds (e.g. decreasing area or biomass) in the monitoring time (Nehls & Büttger 2006). It will be investigated if these structural changes influence the macrobenthic community of mussel beds and if this will be reflected in the macrobenthic assessment using the MarBIT.

We proceed as followed:

1. Development of a species reference list according to the assessment tool MarBIT in cooperation with Torsten Berg (MariLim; Kiel).
2. Testing the tool with macrozoobenthic data from the mussel monitoring (data from 1999 until 2005)
3. Evaluation of these results and the applicability, including recommendations for sampling effort.

According to the available monitoring data in the Wadden Sea of Schleswig-Holstein the report focuses on intertidal mussel beds in the waterbodies N2 and N4 (Fig. 1). Subtidal mussel beds are surveyed insufficiently for this approach and no data of mussel beds in the exposed water bodies (N1 and N3) exist.

The basic question is if we can define a good reference status for mussel beds and their associated macrobenthic community in terms of the WFD. The Wadden Sea is a comparatively young ecosystem with naturally high fluctuating values of densities and abundances of macrobenthic species. Several main pressures exist: land reclamation (in

Schleswig-Holstein until the mid of the 1980ies), fishery, eutrophication and invasive species (van Hoey et al. 2007).

Besides the MarBIT-tool several other indices have been developed. Our neighbouring countries use different indices to evaluate the quality component “macrozoobenthos” in terms of the WFD.

At present, the M-AMBI is adopted for the assessment of the German Wadden Sea to ensure the European intercalibration process (Scholle & Dau 2007). Originally, the AMBI (AZTI’s Marin Biotic Index) was developed by Borja et al. (2000) for the Spanish Atlantic Coast and proved to be useful especially to assess eutrophication and pollution effects. It bases on the categorization of species in five ecological groups. The relative abundance of these five groups leads to a biotic coefficient (BC). M-AMBi is a multivariate approach of AMBI which includes species richness and diversity (Shannon-index). First evaluations with AMBI and M-AMBI lead to good results for sandy habitats but not for muddy or organic enriched habitats like mussel beds (Heyer 2006, Scholle & Dau 2007). Therefore further evaluations with other indices are required for the Wadden Sea.

Besides AMBI and M-AMBI, the neighbouring country Denmark uses the DKI which incorporates the AMBI and the Shannon-index for diversity, number of species and of individuals (Scholle & Dau 2007).

The Netherlands developed the Benthic Ecosystem Quality Index (BEQI) which includes 3 levels (van Hoy et al. 2007). The ecosystem level evaluates the relation of macrobenthic biomass and system primary production. The second level, the ecotope level compares surface areas of ecotops with a reference situation. At least, the community level evaluates density, biomass, species richness and species composition for each habitat. References are derived from the first 1/3 of data collected in the past 30 years.

As undisturbed conditions are required by the WFD for a high ecological status and evaluation belongs to the high ecological status, the MarBIT-tool was chosen for testing mussel bed communities initially because this tool derives references by using autecological data of species.

3 ECOLOGICAL SIGNIFICANCE OF BLUE MUSSEL BEDS

Mussel beds are long living habitats which occur in the intertidal as well as in the subtidal. Within the North Frisian Wadden Sea mussel beds cover about 1 % of the intertidal area if the population is high. Mussel beds are special and characteristic habitats of the Wadden Sea which can be clearly separated from the surrounding flats. Blue mussels settle upon the surface and are attached to each other with their byssus-threads which lead to a typical physical structure. They harbour many endobenthic as well as epibenthic species which take profit from food, a settling substrate as well as shelter against predators provided by the mussels. Diversity and biomass is higher on mussel beds than on the surrounding tidal flats. Additionally, mussel beds facilitate sedimentation as they accumulate high loads of (pseudo-) faeces and functioning as nutrient buffer. Within the dynamic Wadden Sea mussel beds are stable structures which might persist over decades at the same site. Changes which might affect the macrobenthic community come apparent on such a persistent habitat which could be separated from the surrounding area.

Different factors shape the macrobenthic communities (species composition, abundances and biomass). To mention is the interaction between shelter offered by mussel and algae coverage e.g. for crabs (Dittmann 1987, Nehls & Thiel 1993) against predation (Reise 1985) e.g. by birds. Additionally, community structure is strongly influenced by tidal elevation (Reise 1985).

Mussel beds are often overgrown with the algae *Fucus vesiculosus* which influences the associated community (Albrecht 1991, Albrecht & Reise 1984). *Fucus*-cover facilitates mud accumulation and reduces mussel densities. Additionally, some species occur in lower and some others in higher densities underneath *Fucus*-cover. No effects for endobenthic species are known.

Blue mussel densities and biomass might influence associated species. Although Asmus (1987) did not find a significant correlation between densities of mussels and associated species, other surveys did. Dense mussel layers affect endobenthic densities negatively (Dittmann 1987, compare Saier 2001) or inhibit species which are adapted to the mussel deposition (Commito & Dankers 2001).

Further abiotic factors like weather, storms, ice winters and above average warm winters or cold summers respectively influence the associated community of mussel beds.

At all, it is a complex interaction of different parameters. Although no associated species occur on mussel beds exclusively, mussel beds are centres of diversity (Buschbaum 2002) which offer a substrate for settling. Therefore, mussels are ecosystem engineers (Jones et al. 1994, Buschbaum 2002, Gutiérrez et al. 2003) which modify their living space and provide a habitat for many other species. This and the enormous filtering capability justify their particular importance.

4 EVALUATION OF BLUE MUSSEL BEDS

In this chapter, we evaluate several structural parameters of mussel beds (area, density, biomass and others). This includes an analysis of aerial photographs from 1958 to provide a historical baseline. For the first time the development and spatial distribution of Blue mussel beds in 1958, 1989 and between 1989 and 2007 can be displayed as well as the development since 1989 which can be compared to 50 years old data. This will show us if mussel bed area and distribution changed significantly within this time period or if the recent situation is comparable to former times. Basing on these evaluations we will investigate if other monitoring parameters are suitable to assess the ecological status of Blue mussel beds. Finally we suggest references for these parameters.
The monitoring of mussel beds is part of the Trilateral Monitoring and Assessment Program (TMAP), which is conducted since 1989 in the Wadden Sea of Schleswig-Holstein (Fig. 3). Several parameters (Tab. 1) are assessed each year (Nehls & Büttger 2006). We will recommend an evaluation of the following parameters of Blue mussel beds:

- Mussel bed area, coverage, density, length (maximum length), flesh content and biomass of Blue mussels (live wet weight in g/m²).

The other parameters help to describe the current mussel bed structure but do not provide information about the ecological status.

Tab. 1: Parameters which are recorded during the Blue mussel monitoring in Schleswig-Holstein since 1998.

parameter	**unit**
location, outline	geographic coordinates
area	ha
cover	% (amount of mussel bed area covered with mussels)
algae cover	% (of the heaps)
algae biomass	g/m^2 (covered part of the heaps)
remaining expanse of water	% (of the total mussel bed area)
relief, height	10 cm-units
shell	few-much
barnacle fouling	few-much
sediment	sandy-muddy
density	number of mussels/m^2 (heaps)
length	mm
flesh content	0,01 g
shell weight	0,01 g
biomass (in the heaps)	g/m^2 (live wet weight)
biomass (bed)	t (live wet weight)

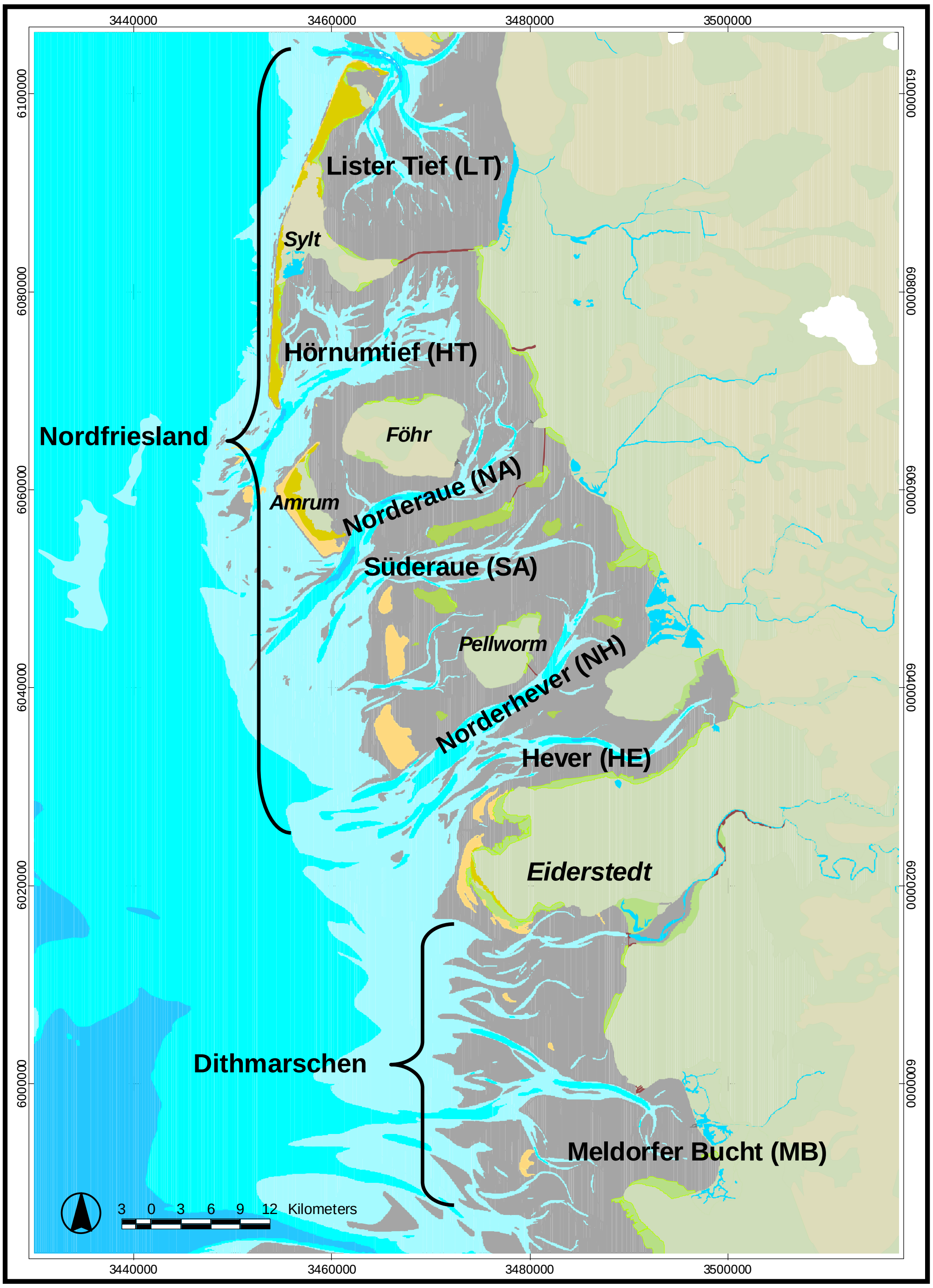

Fig. 3: Overview of the Wadden Sea of Schleswig-Holstein with names of tidal basins (and its abbreviation in brackets) and islands.

4.1 DEVELOPMENT OF MUSSEL BED AREA AND SPATIAL DISTRIBUTION IN 1958 AND BETWEEN 1989 AND 2007

Mussel bed area in 1958

Aerial photographs of the northern Wadden Sea from 1958 were analyzed for mussel beds. A georeferenced ortho-photomosaic (black-and-white) was provided by the Schleswig-Holstein Agency for Coastal Defence, National Park and Marine Conservation (Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum). The scale was 1:20,000. Most pictures were taken between July and September 1958, some in April 1959. All pictures were taken during low tide from a height of approximately 4000-4200 m, covering the entire Wadden Sea National Park of Schleswig-Holstein between the Island of Sylt in the North and the river Elbe in the South.
As ground truth could not be provided for this period, mussel beds were identified from tidal flats due to their colours and structures, which are in most cases much darker and more uneven than other tidal flats. However, not in all cases dark structures indicate mussel beds since also seagrass, green algae, and mud might form almost similar patterns. Moreover, some mussel beds are not recognizable by dark colouring but only by their shape and surficial structures. To provide best possible results, we made this analysis in a combination of 3 procedures:
(1) Optical analysis: Specific patterns, likely to indicate mussel beds, were marked.
(2) Habitat check: We checked by tidal creek characteristics, if marked patterns were situated in locations suitable as mussel bed habitat (distance to creeks or saltmarshes indicated tidal elevation)
(3) Expert knowledge: First results were compared with present mussel bed locations known from ground truth monitoring between 1989 and 2007 and ground truth experience in some areas since the 1960’s (pers comm. Maarten Ruth).
Analyzing aerial pictures without result ground truth from the respective period implies some uncertainties. However, our results from combining optical analysis, habitat check and expert knowledge enables us to estimate at least on large scale and for comparison in mussel bed frequencies and locations between the late 1950’s and present.

Development of mussel bed area in 1989 and between 1998-2007

Stoddard (2003) analyzed aerial photographs (black/white and colour photographs) from 1989. The report contains information about each mussel bed, its location and size. Therefore, these data combined with those from 1958 and 1989-2007 allow detailed examinations of steadiness and area on different spatial level.
Ruth (1994) provides information about total mussel bed area between 1988 and 1994.
Data on mussel bed area from Ruth (1994) were later modified by Stoddard (2003) who assumed to halve the values because of methodical differences between the assessments.

For most years between 1989 and 2007 aerial photograph series are available. Only in 2006 no photographs were taken. The series are black-white with a scale of 1:15.000 and in colour with a scale of 1:25.000. The pictures are taken with a Zeiss RMK Top Camera and a 153 mm Pleogon A3 Objective. The photos overlap to 60% lengthwise and to 30% crosswise to the flight direction. For each picture, served as prints in most years (excepted 2005, in this year they were delivered as georeferenced digital files only), are the central points as geographic coordinates (DGPS-recording) and the flying altitude are given.

The analogous pictures are scanned and georeferenced with the program IMAGINE from Erdas. In 2003, 2005 and 2006 the area of the Lister Deep was processed by the Alfred Wegener Institute for Polar and Marine Research, Wadden Sea Station Sylt. The pictures were scanned and georeferenced accurately on behalf of the AWI and allocated to us for analysis.
In 2004 pictures of the “Landesvermessungsamt” were used for the northern part of the north-Frisian Wadden Sea, which were served digitally and georeferenced accurately, too.

The contours of mussel beds are digitized from the aerial photographs. This analysis provides information about position and area of the beds.
In principle, the analysis of aerial photographs is carried out in the same way as field-surveys. The outline is determined by the same method. Differences occur i.e. with scattered populated areas, which can hardly be identified from aerial photographs, or belong to the colour of the surrounding tidal flats (dark or bright) which make the identification difficult.
The steadiness of field surveys and analysis of aerial photographs was very good in the beginning of the monitoring while mussel beds densely populated. But we have to mention that the first analysis of aerial photographs was conducted with the knowledge from the first field surveys in 1989.

Results

Mussel bed area and distribution in 1958

The analysis of aerial photographs from 1958 identified 126 mussel beds covering an area of about 750 ha which fits to the results of more recent investigations. Most mussel beds were found in similar locations as in the later periods and the analysis allowed the identification of several sites which are apparently populated by mussels over a 50 years period. Some beds in sheltered areas behind the island of Sylt even showed a very similar shape compared to recent surveys.
To compare and integrate data from 1958 with more recent data from 1989 and 1998 until 2007, we summarize some additional information about mussel fishery, weather conditions and mussel stocks in the 1950s to analyse whether 1958 might have been an exceptional year for mussel beds.

Mussel fishery
Due to the infection of Dutch mussels with the parasite *Mytilicola intestinalis*, the German Blue mussel market increased in the beginning of the 1950s (SEIDEL 1999). Although the infection went back in the middle of the 1950s, the demand for mussels was so high that mussel fishery did not drop in Schleswig-Holstein. More and more, Blue mussel fishery turned to mussel breeding and cultivation. The amount of exported mussels from Husum (Husumer Fischereigenossenschaft = fishery cooperative society) in the winter 1959/1960 is documented with 650 t of unsorted and uncleaned mussels (Seidel 1999). Between 1958 and 1960, a fisherman from Husum delivered 53400 kg mussels (Seidel 1999).
Nowadays, modern ships and cultivation of Blue mussels in the subtidal lead to much higher catches. Between 1985 and 1989 about 24.925 t mussels were caught each year. The amount was slightly higher between 1990 and 1994 with 26.109 t and followed with 26.047 t per year until 1997 (RUTH undated).
Additionally, we found just one mussel bed on the pictures of 1958 between the islands of Amrum and Föhr with signs of dredging (Fig. 4).
Comparatively small amounts of mussel landing in the 1950s lead to the assumption that the digitalized mussel beds were not significantly affected by mussel fishery and the area is assumed to be not notably underestimated.

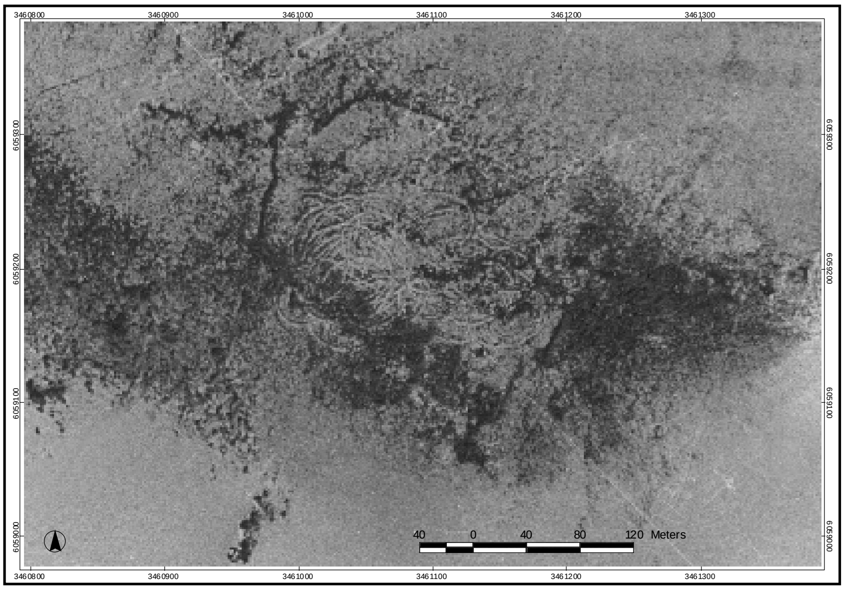

Fig. 4: Mussel bed 1958 between the islands of Amrum and Föhr with anthropogenic traces, probably mussel dredges (= circles).

Historical mussel stocks

Reise et al. (1989) conclude that subtidal as well as intertidal mussel beds in the Wadden Sea of Schleswig-Holstein increased between the 1920s and 1980s. Michaelis (1987) documented increasing mussel coverage (a 2.5 fold increase) in the lower intertidal in the Jadebusen (from the 1930s to the 1970s).

Weather conditions

According to ice winter classification for the German coast (http://www.bsh.de/de/Meeresdaten/Beobachtungen/Eis/FlaeeissummeNord.jsp), the winter 1955/1956 was a strong ice winter (sum of area-related ice volume 4.91 m) in the Wadden Sea of Schleswig-Holstein, followed by two winters (1956/1957 and 1957/1958) with few ice days and little ice-formation (sum of area-related ice volume 0.1 m and 0.2 m; pers comment BSH 2008).

The ice winter might lead to a strong spatfall in 1956 and the following mild winters resulted probably in natural losses but did not induce good spatfalls. According to more recently experiences with the development after strong spatfalls, the digitalized mussel bed area in 1958 is assumed to be within a typical range with natural fluctuations of mussel stocks.

All together, these informations lead to the conclusion that mussel stocks in 1958 have not been affected by apparently strong impacts like fisheries or ice winters. The data can be presumed to reflect an average to a high standing stock of mussel beds. The data thus provide no indication for a substantial change in mussel bed area since the 1950s.

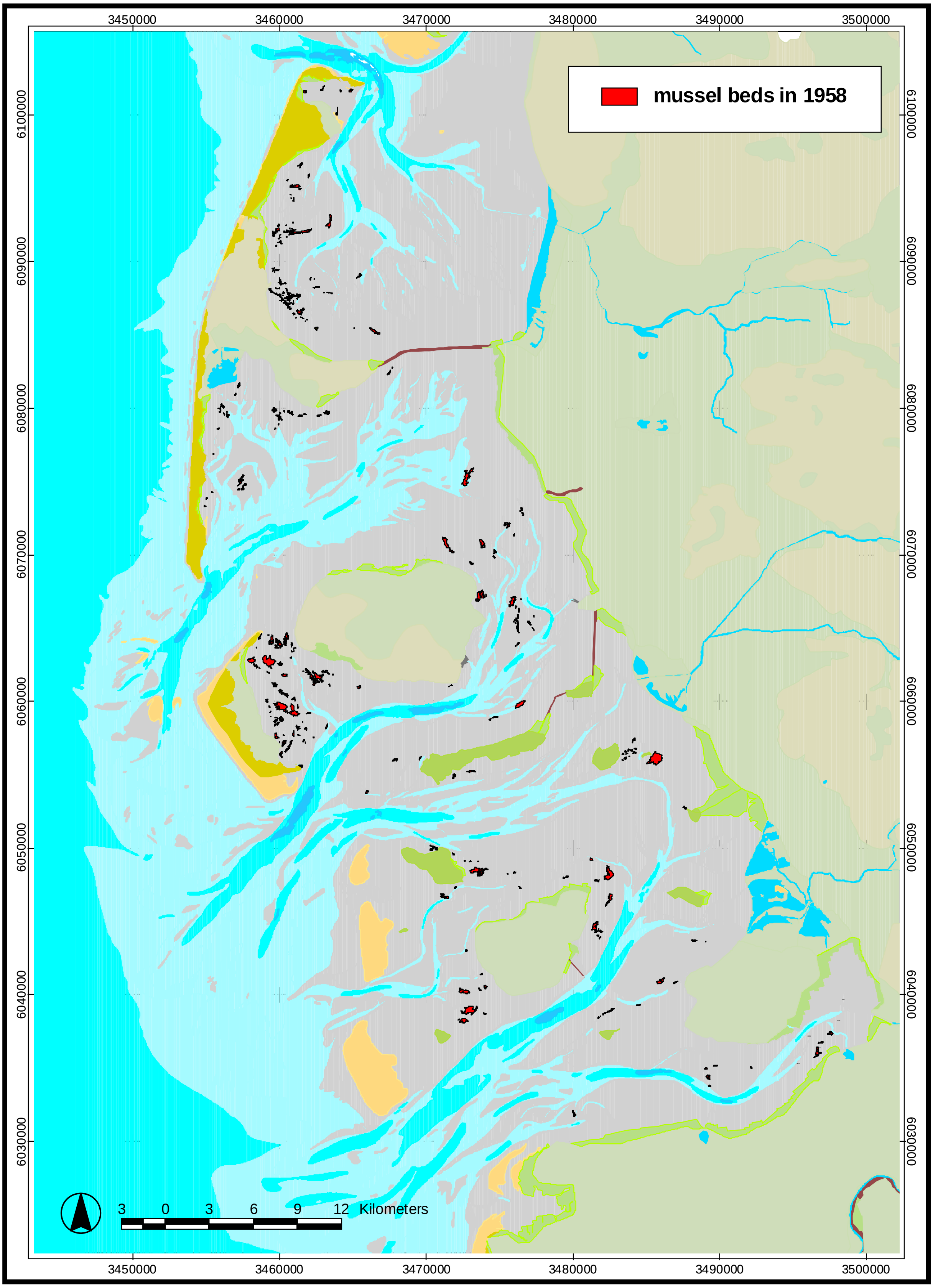

Fig. 5: Mussel beds of the North-Frisian Wadden Sea in 1958. Note: the underlying map shows the topography of 2005.

Development of mussel beds

Considering all data from the Blue mussel monitoring and the analysis of aerial photographs from 1958 and 1989 with information from Ruth (1994) 265 mussel bed sites are identified. Of these 242 sites were occupied at least one year. The total number of sites in each year varied between 53 (2005) and 126 (1989, see Fig. 6). Mussel beds which are digitalized from aerial photographs and which could not be checked in the field (in particular data from 1958) are included independent from size. No threshold for a minimum area was defined but mussel beds smaller than 1 ha are unlikely to be detected.

.

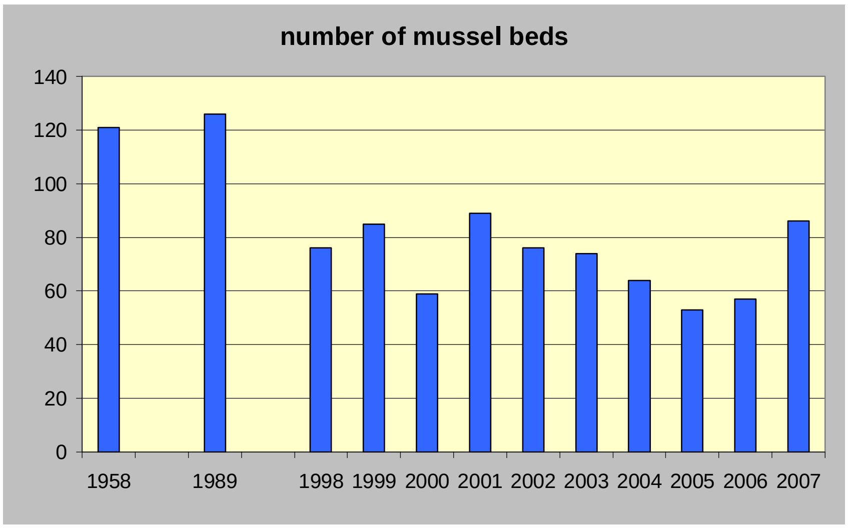

Fig. 6: Number of mussel bed sites populated in the years 1958, 1989 and between 1998 and 2007.

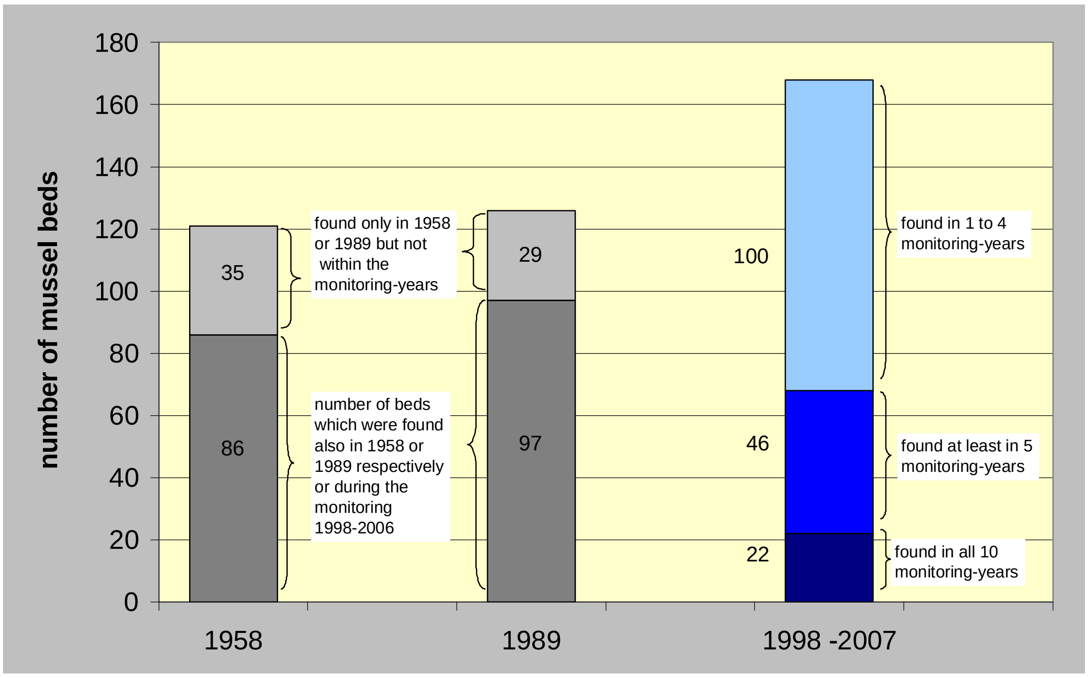

Fig. 7: Number of mussel beds in 1958, 1989 and between 1998 and 2007. Additional information is given about numbers of sites and their steadiness.

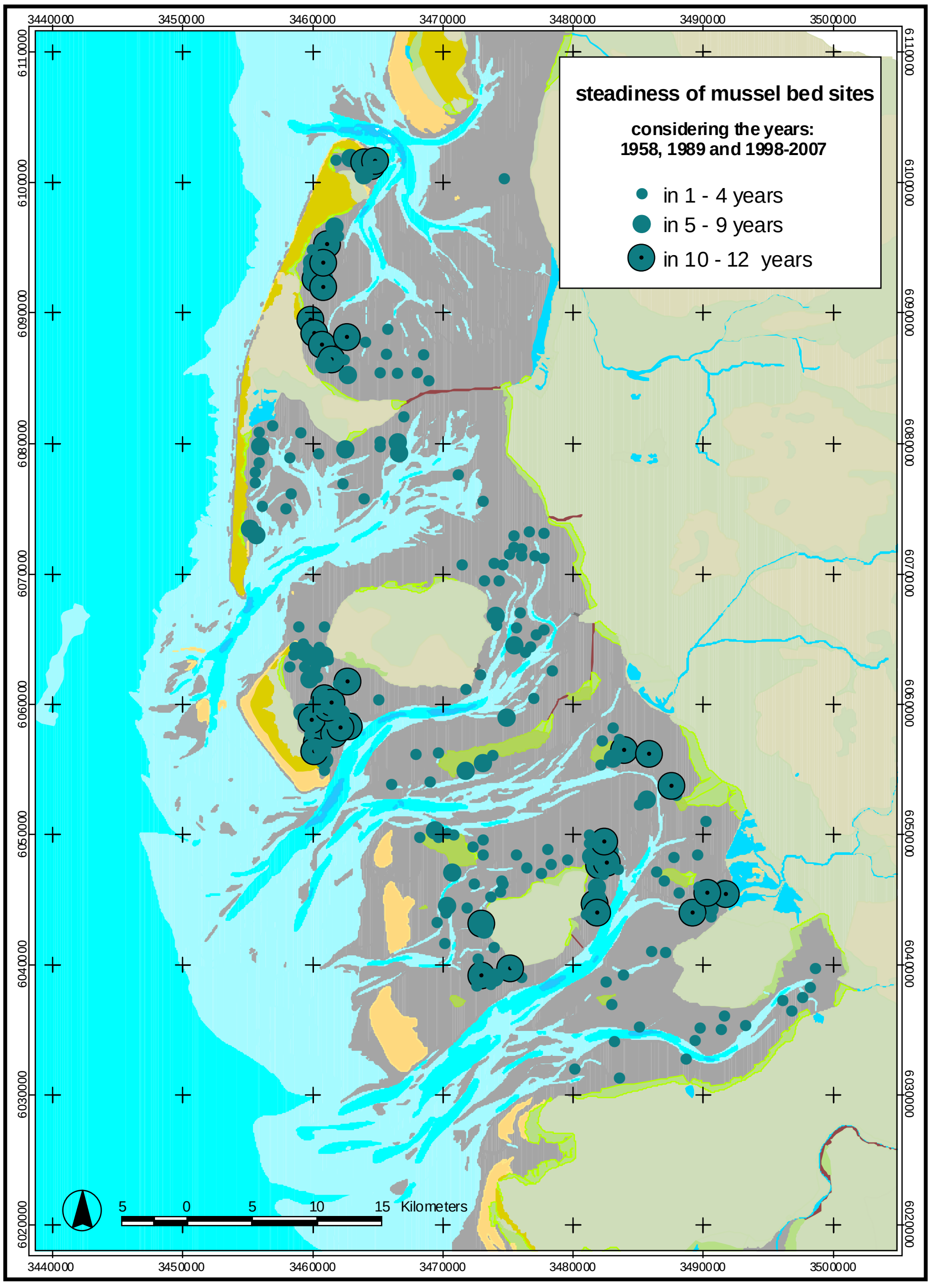

Fig. 8: Steadiness of mussel bed sites in the North-Frisian Wadden Sea (considering the years 1958, 1989 and 1998-2007).

Steadiness

At all, 13 sites existed in all 12 years and 16 sites in 11 years. Between 1998 and 2007, 168 sites of mussel beds could be identified; they were populated at least in one year (Fig. 7). Of these, 22 sites were found in each year between 1998 and 2007, 46 sites at least in five years and the remaining 100 sites in one to four years. From the aerial photographs of 1958 121 sites could be identified of which 35 were only found in this year. In 1989 126 sites were digitalized by Stoddard (2003), 29 sites occurred only in that year and were not found in 1958 or during the monitoring (1998-2007).

The areas „Lister Deep“, „Norderaue“ between the islands of Amrum and Föhr and the tidal flats around the island of Pellworm, close to Hallig Gröde and north of the peninsula Nordstrand harbour many mussel beds which occur with a high steadiness (Fig. 8, Fig. 9). The amount of populated sites is higher within areas where many sites with mussels exist.

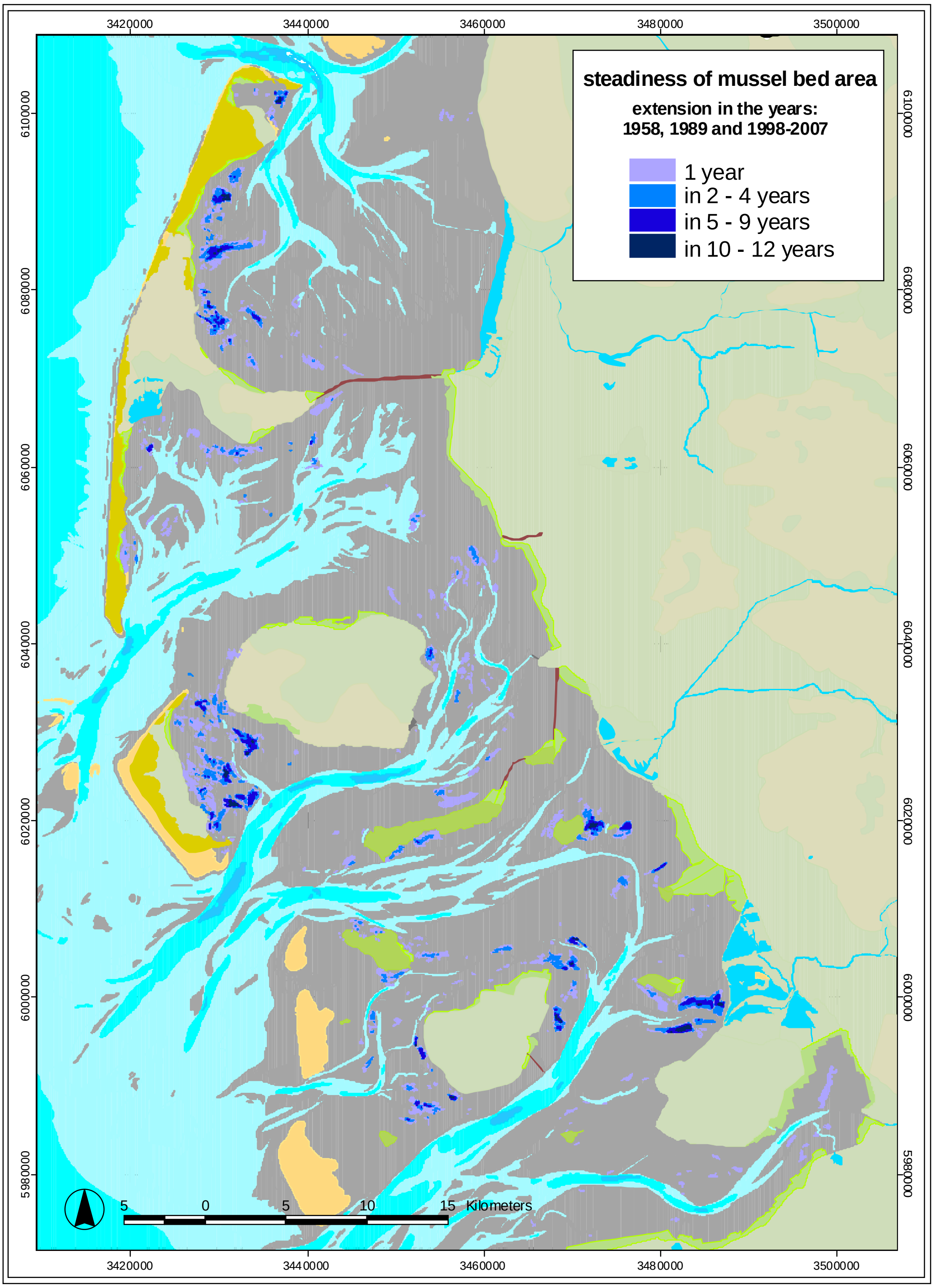

Fig. 9: Steadiness of mussel bed extension in the North-Frisian Wadden Sea (considering the years 1958, 1989 and 1998-2007).

Area

The analysis of aerial photographs from 1958 resulted in about 750 ha of mussel bed area. Highest values in the period after 1988 occurred in 1988 and 1989 (Ruth 1994, Stoddard 2003) with 1500 ha, values between 1990 and 1994 were lower (900 to 100 ha). In the first year of the mussel monitoring (1998) 526 ha of mussel beds were found. But between 1999 and 2001 the area was as high as in the early 1990ties. Since 2002 the mussel bed area decreased and reached the lowest value in 2005 with 353 ha. In the following years the area increased again due to spreading oysters in the Lister Deep and in the area between Amrum and Föhr (Norderaue, Fig. 10).

In the tidal area of Dithmarschen, mussel beds were found in 1958, but no data for 1989 or between 1998 and 2002 exist due to inexistent aerial photographs of this area, however, mussels stocks are reported for this time by Ruth (1994) and occasional surveys in that area. Following a strong spatfall in 2003, a mussel bed re-established at the same site as found in 1958 and persists since then (Tab. 2). Defining a reference value for mussel bed area in Dithmarschen seems to be difficult.

Values of intertidal mussel bed area in the tidal basin of the Hever are mentioned in Tab. 2.

Tab. 2: Development of intertidal mussel bed area within the tidal areas of Dithmarschen and Hever.

tidal basin	intertidal	1958	1989	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Dithmarschen		20							144	100	118	95	80
Hever	110 km^2	23	22	2,4	2,4	(0)							90

Most mussel beds in the Wadden Sea National Park of Schleswig-Holstein are found in the North Frisian part of the Wadden Sea and only few sites are populated in Dithmarschen. So, references values (steadiness, area, biomass or densities) could only be derived for the northern part and are not easy to define for the southern part. The tidal flats between the Eider and the Elbe estuary are not protected by islands against westerly winds and storms and the area is assumed to be less suitable for mussel beds. However, because the Meldorfer Bucht is a comparatively sheltered area and mussel beds were identified already on the aerial photographs from 1958, mussel beds on the tidal flats of this area are adopted as a useful component of an assessment of the ecological status, at least for macrobenthic data (compare chapter 5.2). Because number of sites and area is much smaller than in the Northfrisian part, different references and class limits for structural parameters are difficult to define.

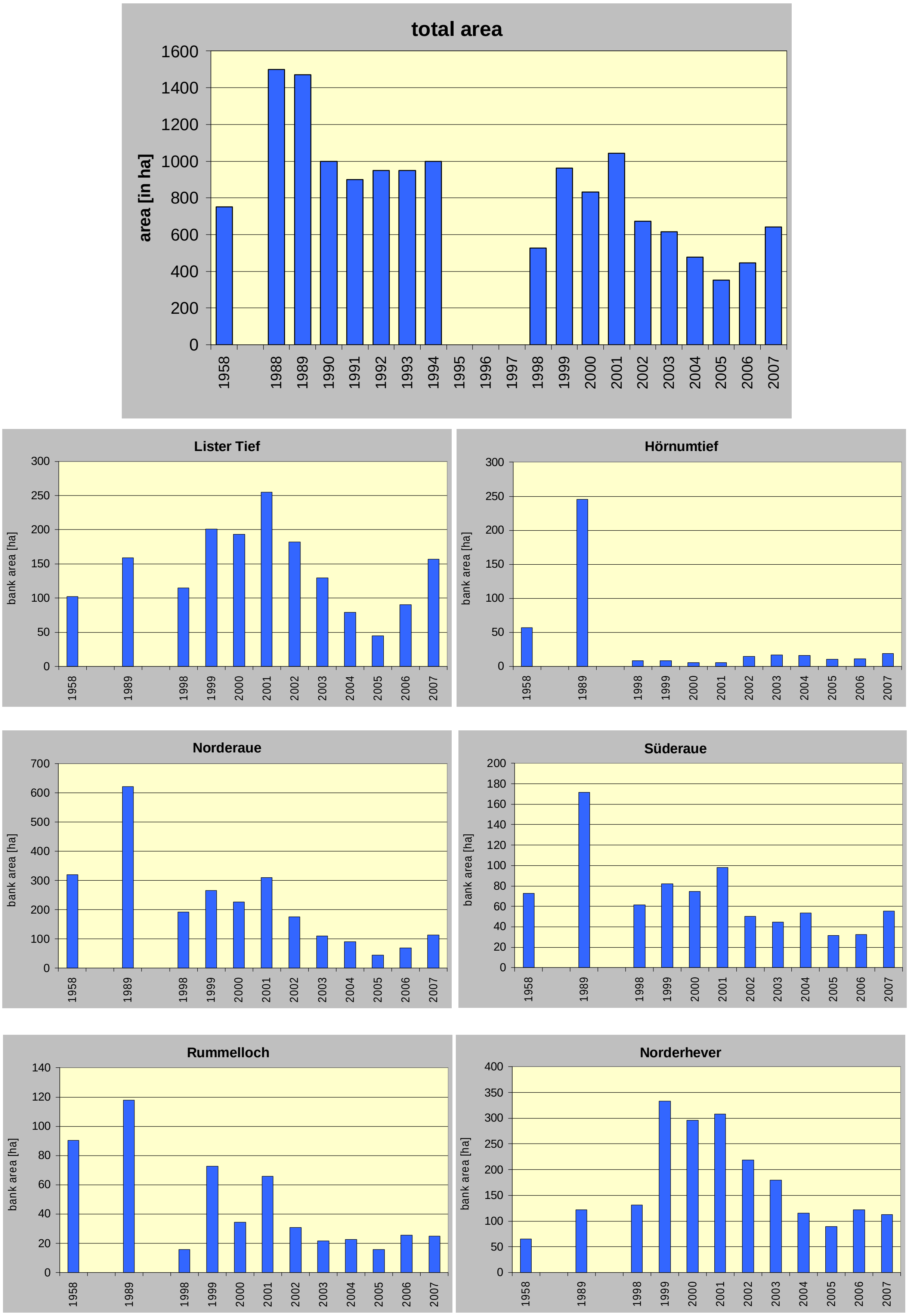

Fig. 10: Development of mussel bed area, shown for the whole Wadden Sea of Schleswig-Holstein and for selected tidal basins.

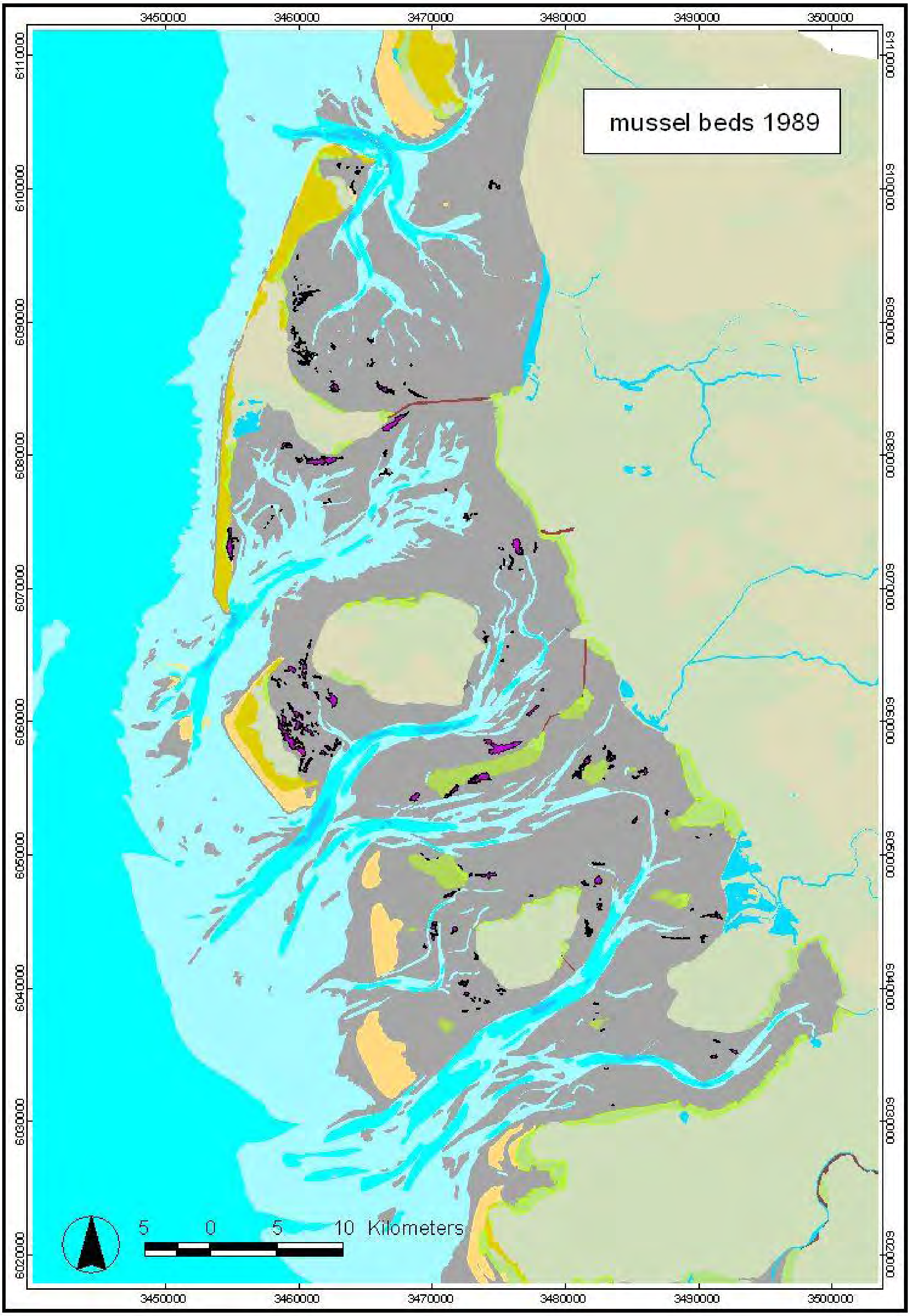

Fig. 11: Mussel beds of the North-Frisian Wadden Sea in 1989 (Stoddard 2003). Note: the underlying map shows the topography of 2005.

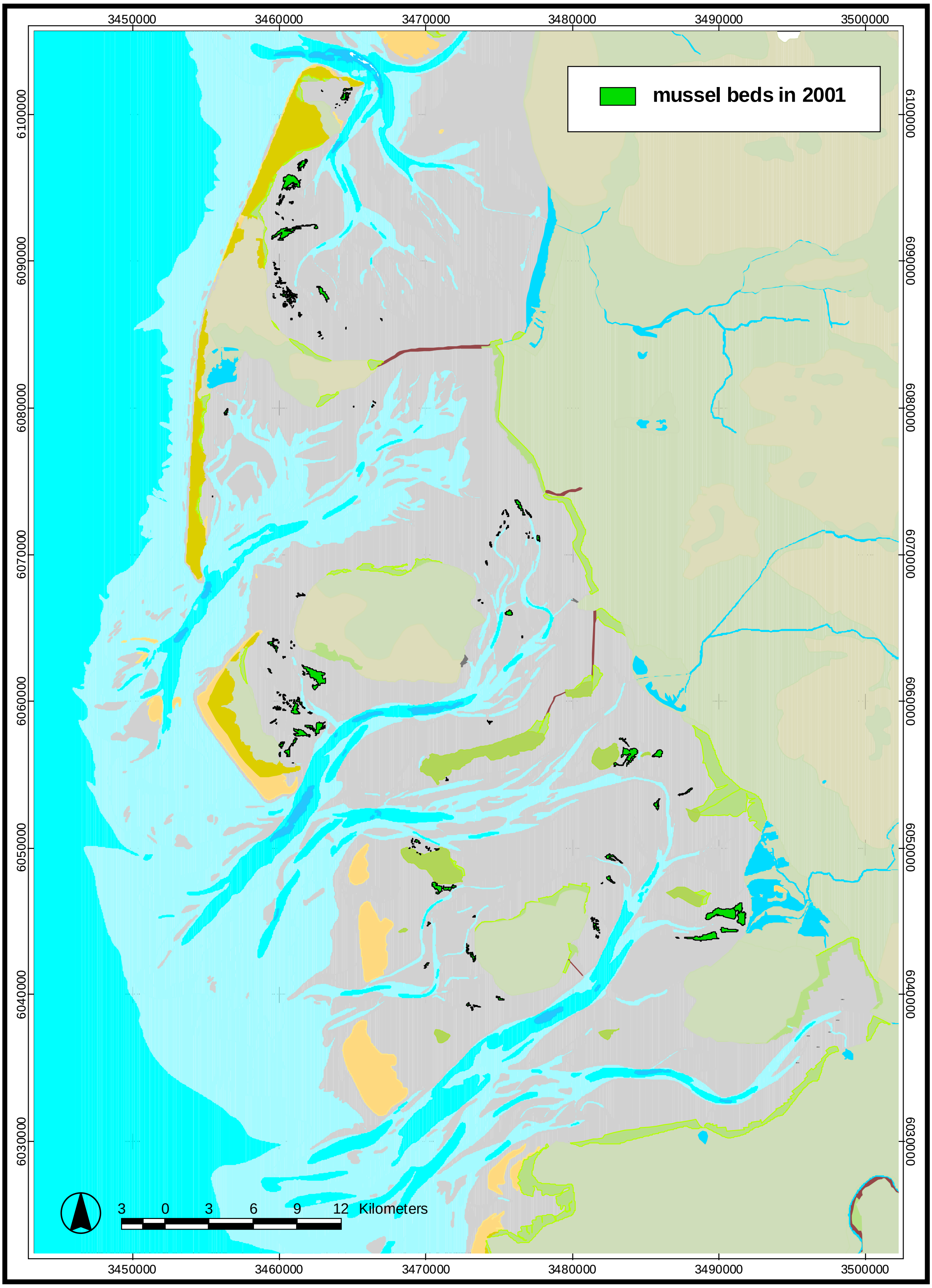

Fig. 12: Mussel beds of the North-Frisian Wadden Sea in 2001. Note: the underlying map shows the topography of 2005.

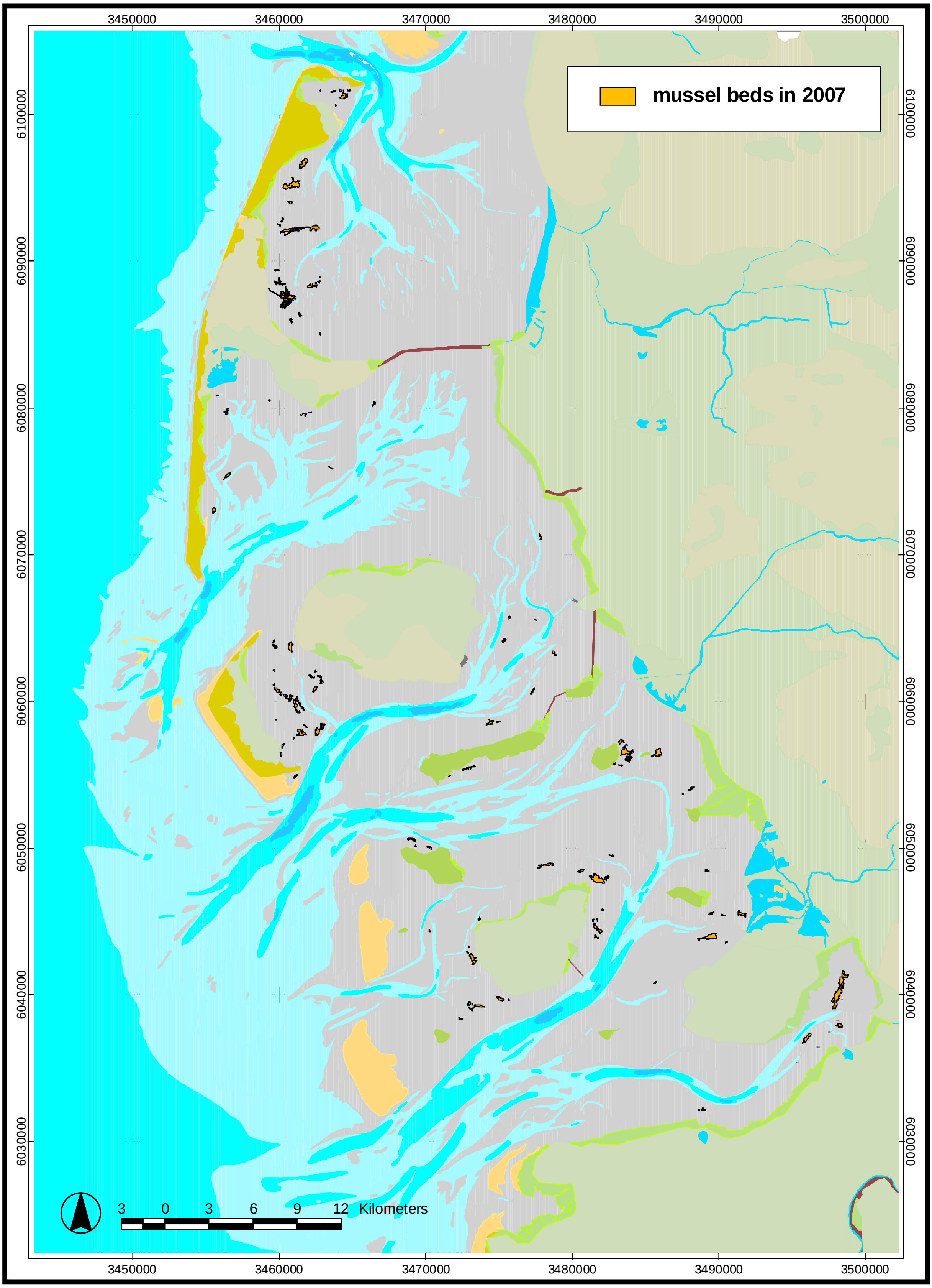

Fig. 13: Mussel beds of the North-Frisian Wadden Sea in 2007. Note: the underlying map shows the topography of 2005.

General remarks on reference values

We have concluded that data from 1958 can be used to determine references of mussel bed area and steadiness of sites, however, apart from area and location of mussel beds, no other parameters can be made available from this time period.

In terms of mussel bed area and further mussel bed parameters, reference values should ideally be based on investigations of several years, which is, however, only possible for mussel bed area. However, as mussel bed area and locations in 1958 are not obviously different from data obtained in 1989 and between 1998 and 2001, it can be assumed mussel beds have a similar ecological status in these years and no marked change of the baseline occurred until 2001. As data for other parameters are available from the mussel monitoring since 1998 we recommend evaluating references basing on frequency distributions of data from these four years (1998-2001, see following chapters) and use the median as lower boundary for the high ecological status. Data since 2002 are expected to be different as mussel bed area and other parameters have been declining in this period. The parameters condition did not change significantly between 1998 and 2006 while these years are used to derive the references. Concerning the steadiness of sites all available data (1958, 1989, 1998-2007) were considered.

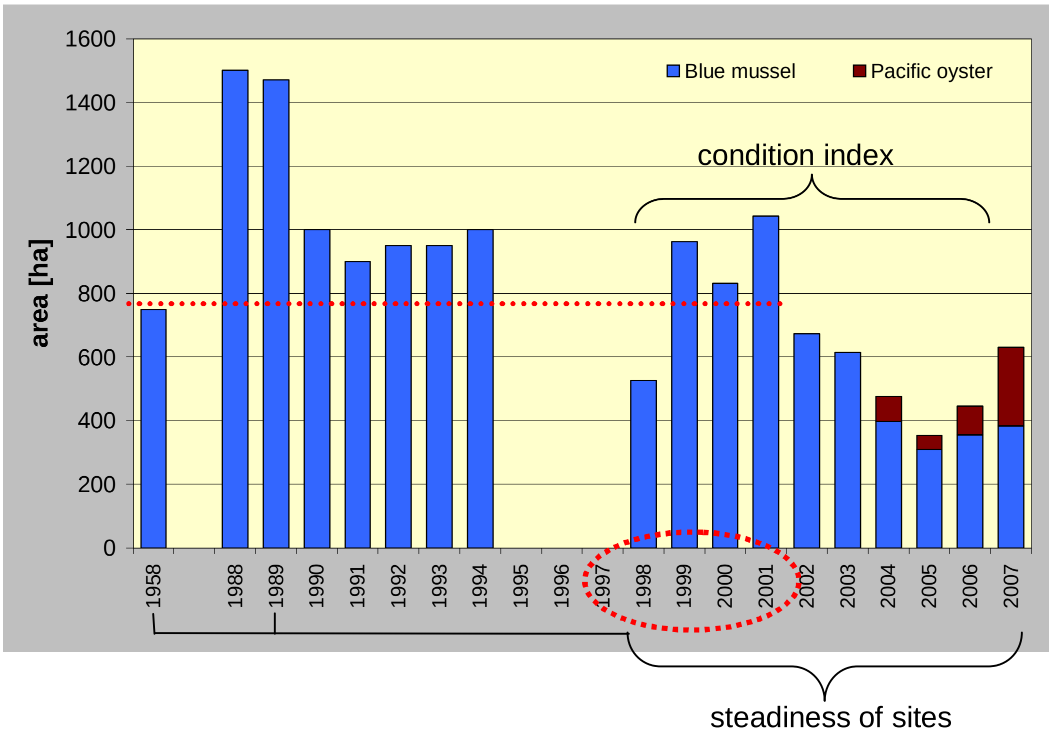

Fig. 14: Area of sites dominated by Blue mussels and by Pacific oysters. Red line indicates data which are used for references of mussel bed area and steadiness of sites. Encircled years are used as data basis for references of further parameters.

Reference values for steadiness of sites and mussel bed area

<u>Steadiness of mussel bed sites</u>

As reference for steadiness we suggest those sites which were found in nearly all years (at least in 11 years). Additionally sites are included which were found in 1958 or in 1989 and at least in five years of the monitoring between 1998 and 2007. Sites which were populated in all years during the monitoring (1998-2007) but not in 1958 or 1989 should be included too.

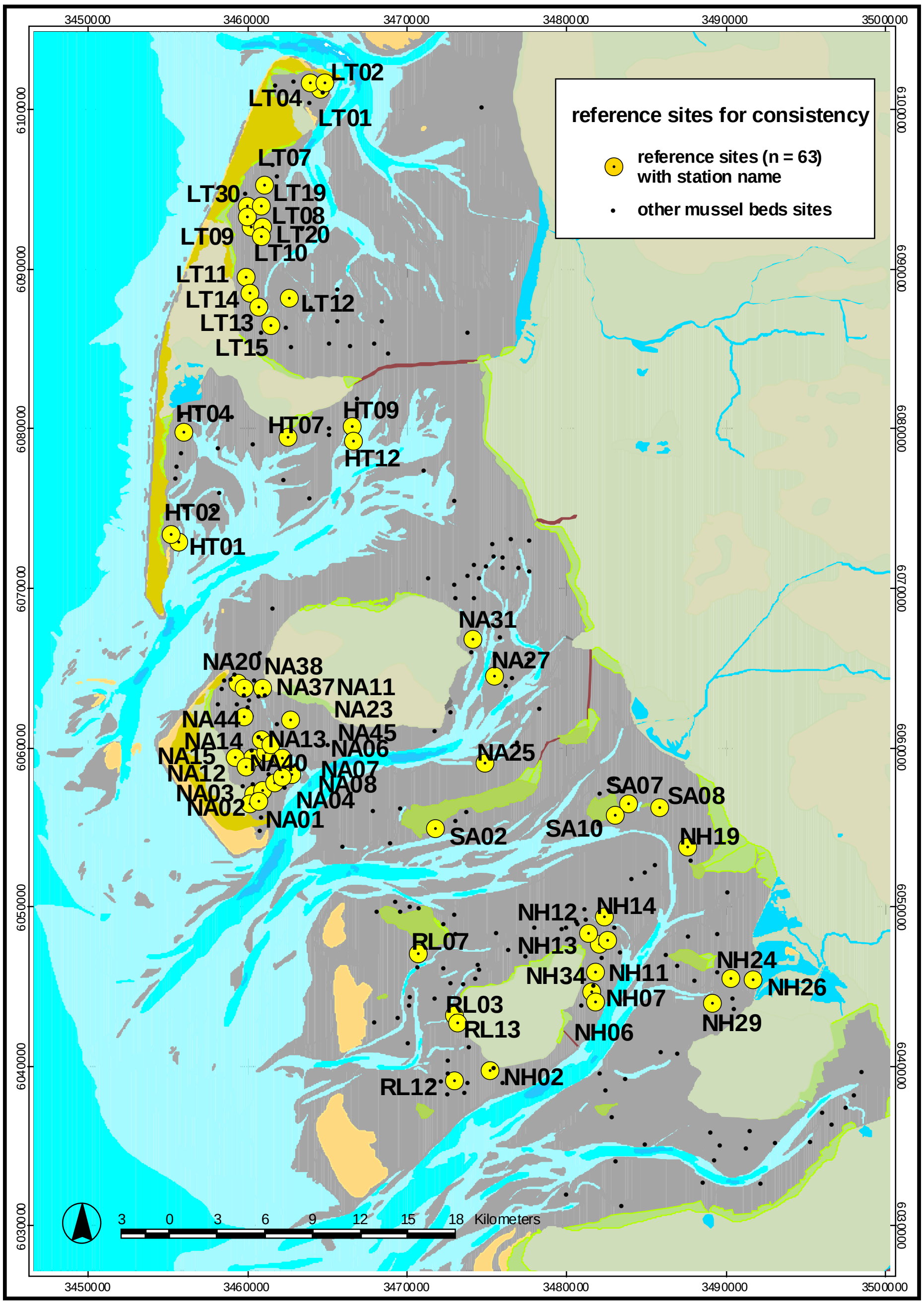

Fig. 15: Reference mussel beds sites (with bank name) for steadiness evaluation of sites (selection criteria are mentioned in the text).

From this follows, that 63 sites (Fig. 15) should be populated by Blue mussel beds regularly. The WFD covers six year for every evaluation period. At best all 56 sites are populated in all six year which could be described as 378 occasions.
Of these 63 sites, between 42 and 56 sites were found in the considered years (Tab. 3). Total area of all reference sites was highest in 2001 (894 ha) and lowest in 2005 (229 ha). The increasing numbers of sites as well as the area since 2005 result from the increasing amount of oysters which repopulate former mussel sites.

Tab. 3: Number and area of reference sites with mussel beds present in each year.

year	1958	1989	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
number of sites	44	50	48	50	42	55	56	55	53	46	48	52
total area in ha	344	652	477	776	738	894	567	426	355	229	318	382

Area of mussel beds

We recommend deriving the reference value of the total mussel bed area by taking the mean value of the years 1958, 1988-1994 and the mean of 1998-2001. Data since 2002 should not be included in the reference as mussel bed area is declining since then. Mussel bed area in the Wadden Sea of Dithmarschen is not included.
This results in a mean value of 991 ha. We recommend 990 ha as lower level for a high status. As eutrophication is likely to support Blue mussels, doubling of mussel bed area (>2000 ha) or more is regarded as to be negative and leads to downgrading in the evaluation.

4.2 EVALUATION OF DIFFERENT MONITORING PARAMETERS

To derive reference values for different monitoring parameters for a good ecological status in terms of the WFD we focus on different time periods for the different parameters (see chapter "General remarks on reference values").

Coverage

Mussel beds consist of populated mussel heaps and unpopulated areas in-between. Therefore, coverage within the mussel bed area could differ between sites and years. This parameter is important to calculate the total biomass (life wet weight). Storms and ice can affect coverage.

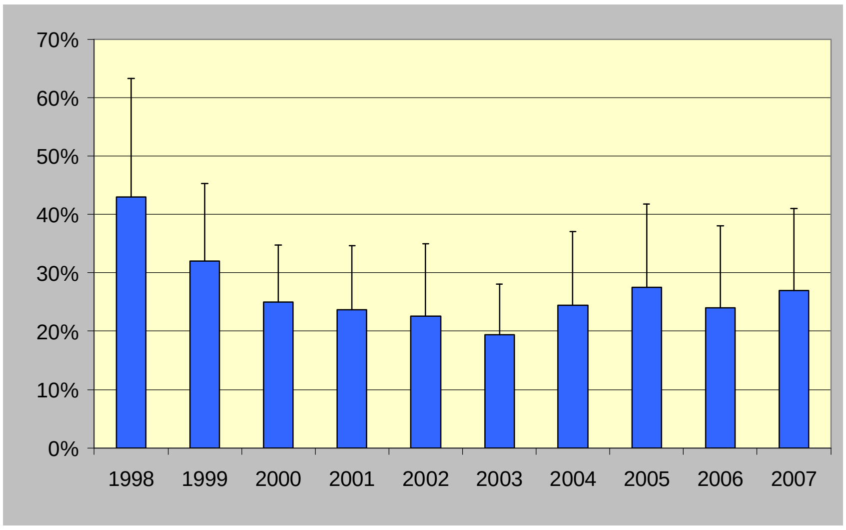

Fig. 16: Amount of the mussel bed area which was covered with Blue mussels.

The coverage within mussel beds decreased until 2003 (Fig. 16) but it has to be considered that this parameter is determined within the outline of a bed and that the coverage and the area may develop contrastingly. Nethertheless, declining coverage occurred in all tidal basins. Higher values since 2004 result probably from the fact that former mussel beds are not longer classified as beds but rather as „Streufeld“ and that oysters became more and more abundant building dense layers.

We recommend no usage of this parameter "coverage" for evaluation of mussel beds as it could vary strongly in time and space.

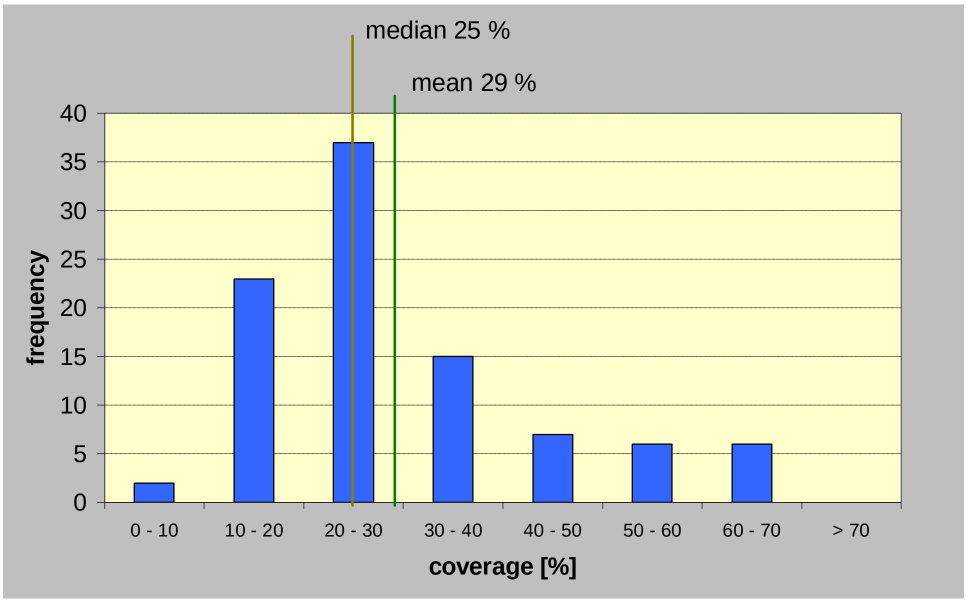

Fig. 17: Frequency distribution of mussel bed coverage between 1998 and 2001.

Mussel density

A mussel density (ind./m²) varies between sites and years in response to reproduction and mortality. In particular spatfall leads to high densities which become sparser in the following time due to competition for space, spreading of mussels and natural mortality. Absence of recruitment leads to decreasing densities. Mussel densities were highest in the first years of the monitoring and decreased clearly in all tidal basins between 1998 and 2007 (Fig. 18). Regarding these high fluctuation we recommend not including this parameter for mussel bed evaluation.

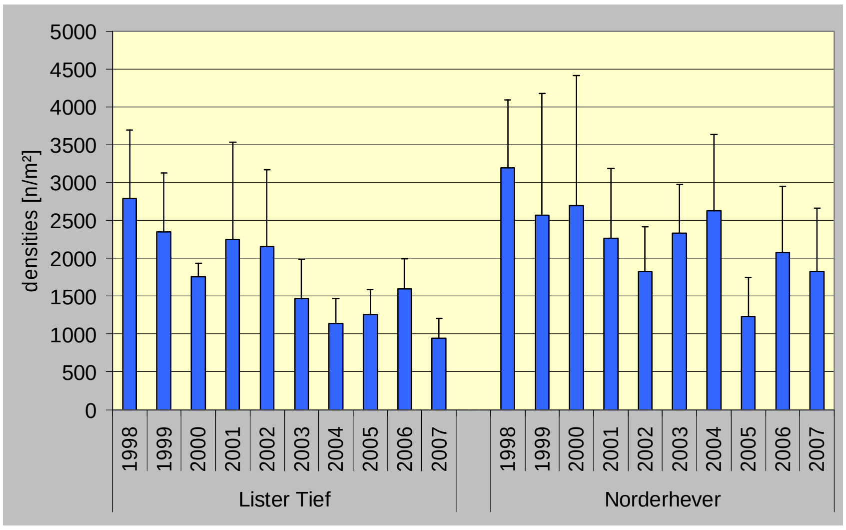

Fig. 18: Mean densities (± SD, including samples taken in March, April or May) of Blue mussels in two tidal basins of the Wadden Sea of Schleswig-Holstein.

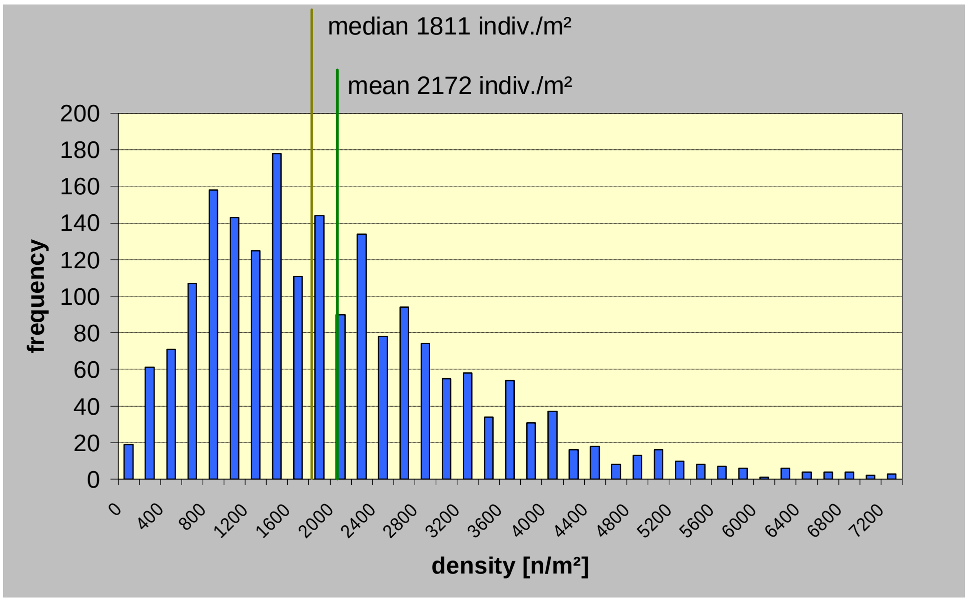

Fig. 19: Frequency distribution of mussel densities in 1998 until 2001 without spatfall (< 20mm).

Age structure

In the beginning of the monitoring the age-structure of the mussel beds was dominated by the spatfall from 1996 which became more and more heterogeneous in the following years because of recruitment failure. Generally, regular spatfall is favourable to compensate mortality losses and to ensure maintenance of mussel beds.

In most mussel beds, the spatfall can be defined as mussels smaller than 20 mm. In particular, spatfall is identifiable in autumn, whereas values ranged between 280 mussels/m² in 1998 (Lister Deep) and 4040 mussels/m² in 1999 (Norderhever; Fig. 21). A newly established mussel bed may consist of 20.000 – 50.000 mussels/m². Partly, spatfall occurs also in spring and could be an important factor for mussel bed maintenance with up to 6000 mussels/m².

Regular spatfall leads to a characteristic age-structure with several (at least three) cohorts in the length-frequency distribution (Fig. 20). Right-skewed distributions show the obsolescence of mussel beds.

Because this parameter varies strongly in response to erratic spatfall events we recommend no application of this parameter for mussel bed evaluation.

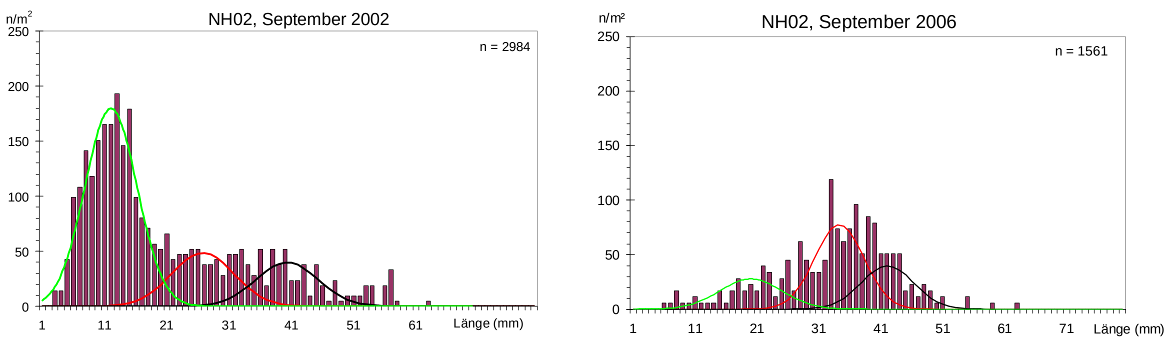

Fig. 20: Two examples of length-frequency distributions.

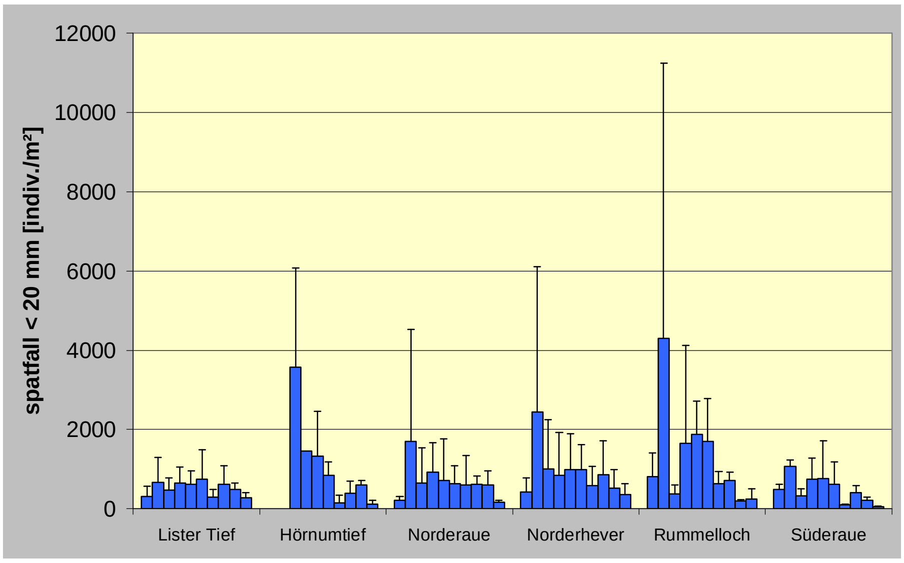

Fig. 21: Spatfall within existing mussel beds in different tidal basins between 1998 and 2007. Given is the mean density ±SD of mussels < 20 mm in samples taken between September and November.

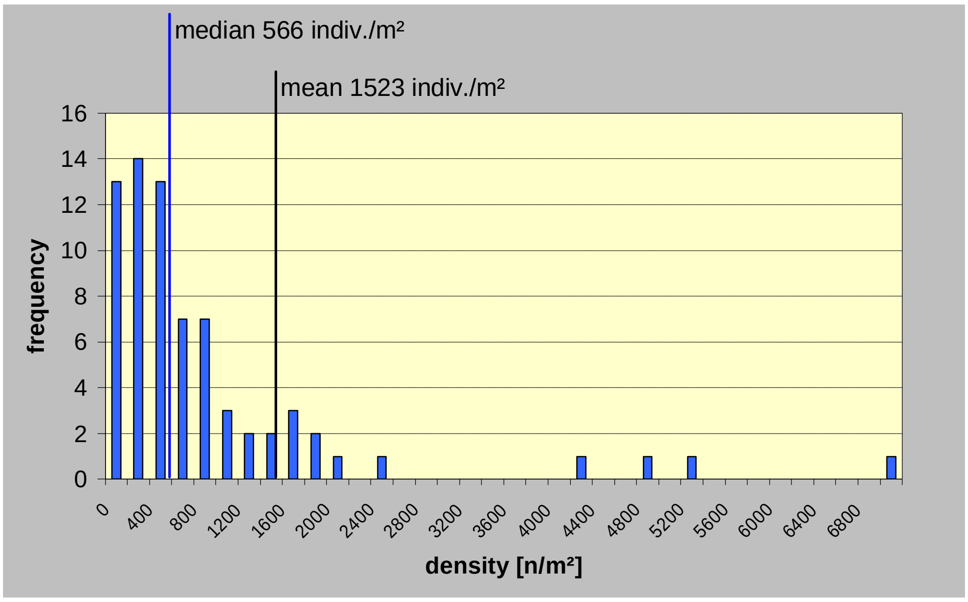

Fig. 22: Frequency distribution of mean mussel spatfall densities in autumn, considered are the years 1998 until 2001 (spatfall = < 20mm).

Biomass

Biomass of the mussel beds is determined mainly as live-wet-weight (LWW), which is calculated by the mussel length using the formula lnLWW= 2,919ln (length in mm)-8,764 (Nehls 1995). In the Wadden Sea of Schleswig-Holstein LWW varies between 4 and 25 kg/m². A significantly negative development since 1998 is apparent from the data of the mussel monitoring (Fig. 23).
We recommend the median value of LWW in the years 1998-2001 as reference (Fig. 24). This parameter is easy to obtain as it can be calculated from length-frequency distributions.

As eutrophication is likely to support Blue mussels growth, increasing mussel biomass is regarded negative and leads to downgrading in the evaluation (compare chapter 4.1).

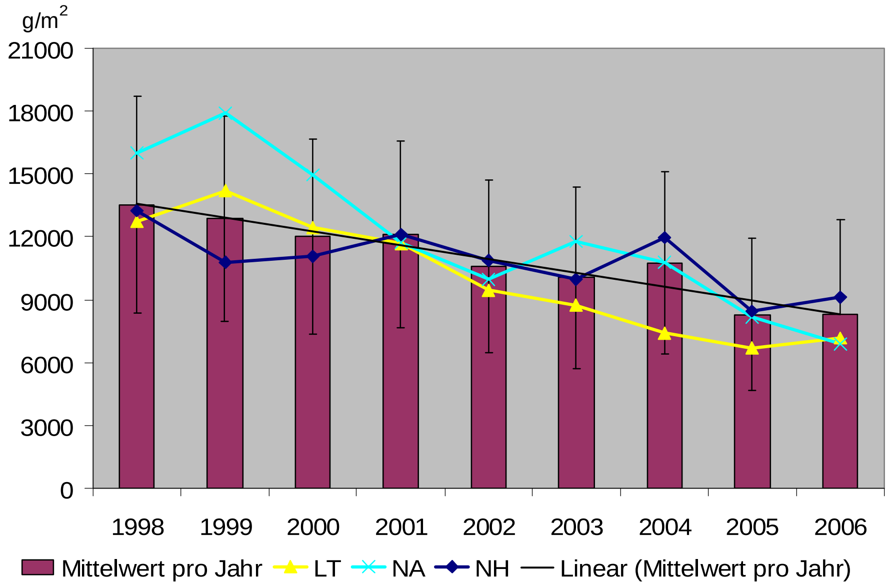

Fig. 23. Mean biomass values (LWW) of mussel beds in the North-Frisian Wadden Sea. NH = Norderhever/Rummelloch, NA = Norderaue, LT = Lister Deep.

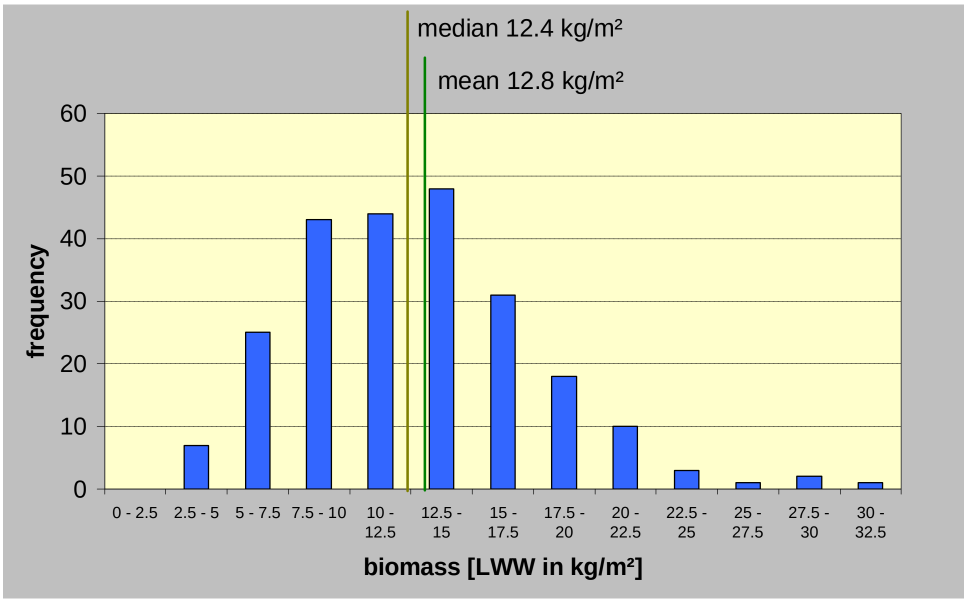

Fig. 24: Frequency distribution of mussel biomass considering the years 1998 until 2001.

Flesh content

Flesh weight is determined from a sub sample for each mussel bed to obtain a condition-index (a-parameter, without any dimension). The calculation is done using the program MUSSEL (Brinkman 1993) and bases on the function WF=a*Lb (WF = cooked flesh weight, L = length of the mussel in mm, b = constant with 2.8).

Flesh content of blue mussel varies seasonally. Generally values are lowest at the end of the winter and highest in the beginning of autumn. At all, this parameter gives information about the condition of mussels. Flesh content relates to different parameters (e.g. age of the mussel, spawning, food supply, tidal elevation, weather conditions during the year).

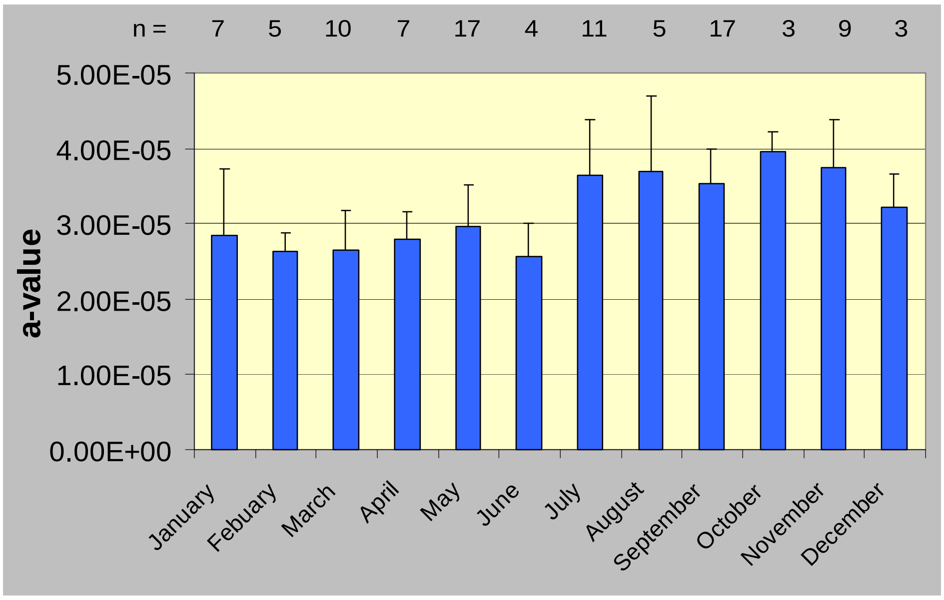

Fig. 25: Annual development of the a-parameter of 20-49mm mussels between 1998 and 2006 (mean ± SD) on the mussel beds NH24, NH26 and NH29 (n = number of surveys).

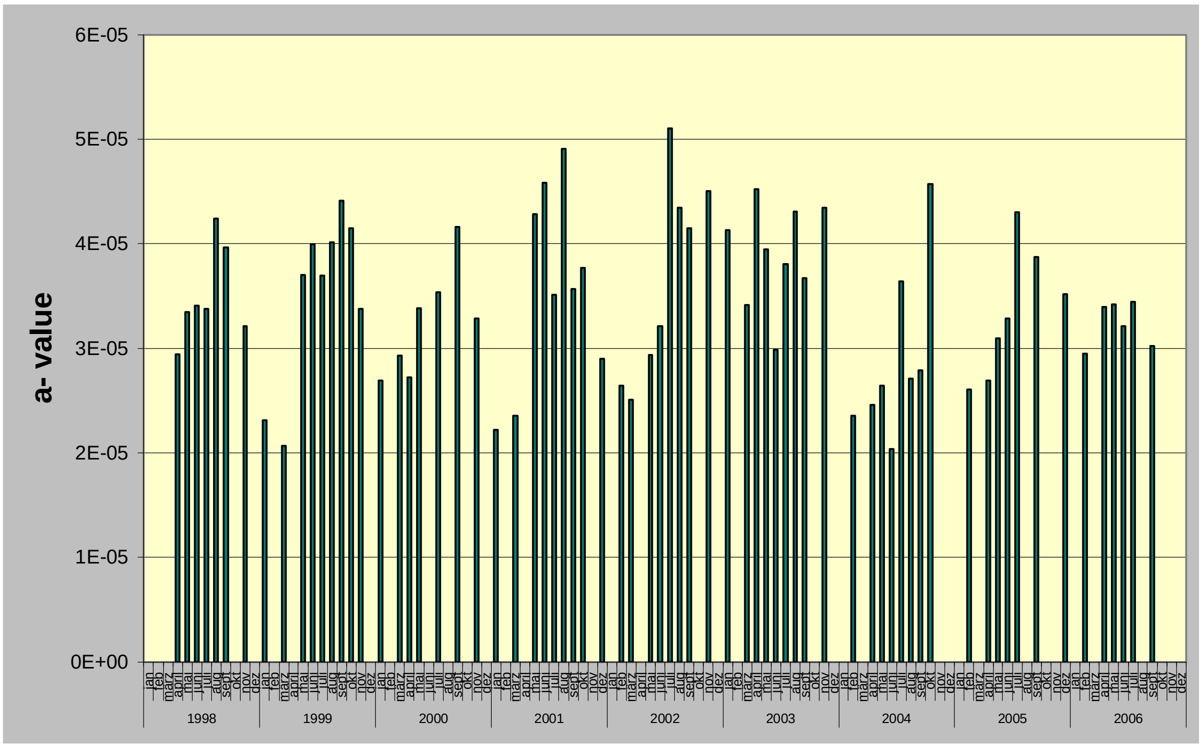

Fig. 26: Development of the a-parameter of 20-49mm mussels between 1998 and 2006 (mean values, number of considered mussel beds differs between months and years).

Using data of all sizes classes could lead to decreasing trends of flesh-content in response the age structure but not reflecting environmental changes. Therefore we recommend for this parameter to use a limited size group from 20 to 49 mm and selected mussel beds which are monitored continuously (LT01, LT07, LT13, NH02, NH07, NH24, NH25, NH29, HT09, NA06, NA12, SA07, SA08). Additionally, the evaluation must be linked to seasonal reference values. Winter data would be favourable, but a complete monitoring in this season is not feasible. We recommend the following seasonal references and the EQR for this parameter should be obtained by averaging over the four seasons:

Winter (December – February):	2.84E-05
Spring (March – May):	3.23E-05
Summer (June – August):	3.65E-05
Autumn (September – November):	3.70E-05

Because the a-parameter of 20 - 49 mm mussels did not show a general significant trend in the monitoring until 2006 (Nehls & Büttger 2009), mean values of the years 1998 until 2006 are taken for the four seasonal reference values.

Maximum length

Mussels grow as long as they live. Young mussels grow faster and the length increment gets smaller which increasing age. Consequently, growth is strongly site specific due to emersion time and food supply. Assuming regular spatfall, each mussel bed should reach a site specific asymptotic maximum length of Blue mussels. Significant changes of this maximum length can be expected in response to environmental changes.

Maximum length is determined as mean value of the largest 3 % of all mussels sampled during an inspection of a mussel bed. While the maximum mussel length from about 5 cm increased to about 6 cm in the Norderhever (Fig. 27), mussel length decreased in the Lister Deep from about 6 – 7cm to about 5 – 6 cm. Decreasing values on beds in the Lister Deep are pronounced since 2005 and are likely induced by Pacific oysters.

As some aspects of changing maximum length are still unclear we recommend no usage of this parameter for mussel bed evaluation.

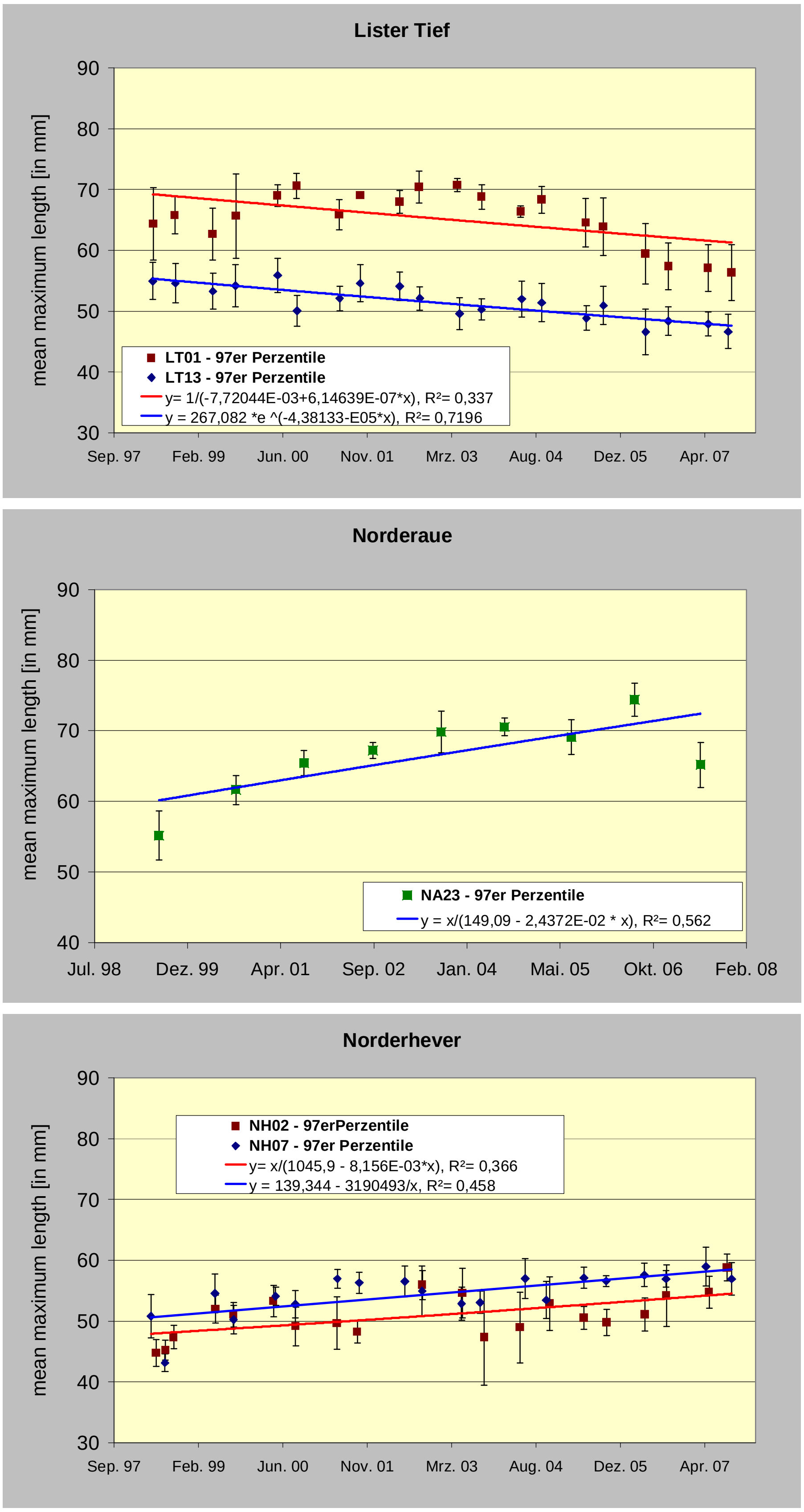

Fig. 27: Maximum length given as mean maximum length of the largest 3% of Blue mussels. Plotted are mussel beds in three tidal basins (Lister Deep and Norderhever). Red and blue lines show the function which was derived by a curve fitting.

4.3 Recommendations for reference values and evaluation of changes

References

Considering the different parameters presented we recommend the following reference values (Tab. 4). These values refer to the North-Frisian part of the Wadden Sea of Schleswig-Holstein. This approach encounters that a strong increase of these parameters indicate high nutrient loads in the water and therefore the evaluation includes downgrading if values increase to strong.

Tab. 4: Reference recommendations and assessment of variances.

EQS (mean amongst 6 years)	**reference**	**high**	**good**	**moderate**	**poor**	**bad**
area [ha]	990 ha	2000 ≥ 990	2250 ≤ 991 or 989 ≤ 750	2500 ≤ 2251 or 749 ≤ 500	2750 ≤ 2501 or 499 ≤ 250	>2751 or <249
steadiness	63 sites	all sites in all six years 378 – 340 (≤10%)	339 ≤ 291x *(11 ≥ 25%)*	290 ≤ 189x *(26 ≥ 50%)*	188 ≤ 95x *(51 ≥ 75%)*	94 ≤ 0x *(≥ 76%)*
biomass [LWW in kg/m²]	12,4	20 - 12,4	12,3 ≤ 9,4 or 25 ≥ 20,1 *(± ≥ 25 %)*	9,4 ≤ 6,2 or 25,1 ≥ 30 *(± 26 ≥ 50%)*	6,2 ≤ 3 or 30,1 ≥ 35 *(± 51 ≥ 75%)*	2,9 ≤ 0 or ≥ 35,1 *(± ≥ 76%)*
condition (a-parameter, 20 -49mm)	Winter 2.48E-05 Spring 3.23E-05 Summer 3.84E-05 Autumn 3.86E-05	*± 10%* 3.12E-05 ≥ 2.55E-05 3.55E-05 ≥ 2.90E-05 4.02E-05 ≥ 3.29E-05 4.07E-05 ≥ 3.33E-05	*11 ≤ 20%* ≥ 2.27E-05 ≥ 2.58E-05 ≥ 2.92E-05 ≥ 2.96E-05	*21 ≤ 30 %* ≥ 1.99E-05 ≥ 2.26E-05 ≥ 2.56E-05 ≥ 2.59E-05	*30 ≤ 40 %* ≥ 1.70E-05 ≥ 1.94E-05 ≥ 2.19E-05 ≥ 2.22E-05	*> 50%* ≥ 1.42E-05 ≥ 1.61E-05 ≥ 1.83E-05 ≥ 1.85E-05

Several pressures affect the Wadden Sea in former and recent times and influence mussel beds as well. These are fisheries, eutrophication, contaminant load or introduction of invasive species. “Land reclamation, closure of the sea arm and construction of dikes have impacted the system and confine the Wadden Sea to human defined borders” (Van Hoey et al. 2007). Several former mussel beds are now dominated by oysters (Nehls & Büttger 2006, 2007; compare Fig. 14 and see chapter 5.1. Neozoa). These sites should be excluded from evaluation. We define sites as “dominated by oysters” when oyster biomass (live wet weight) is higher than biomass of mussels. Therefore, sites from the Lister Deep have to be excluded from the evaluation since 2004 and sites in the Norderaue at least since 2007. Values of the different parameters including oyster beds are given in brackets (compare Tab. 6).

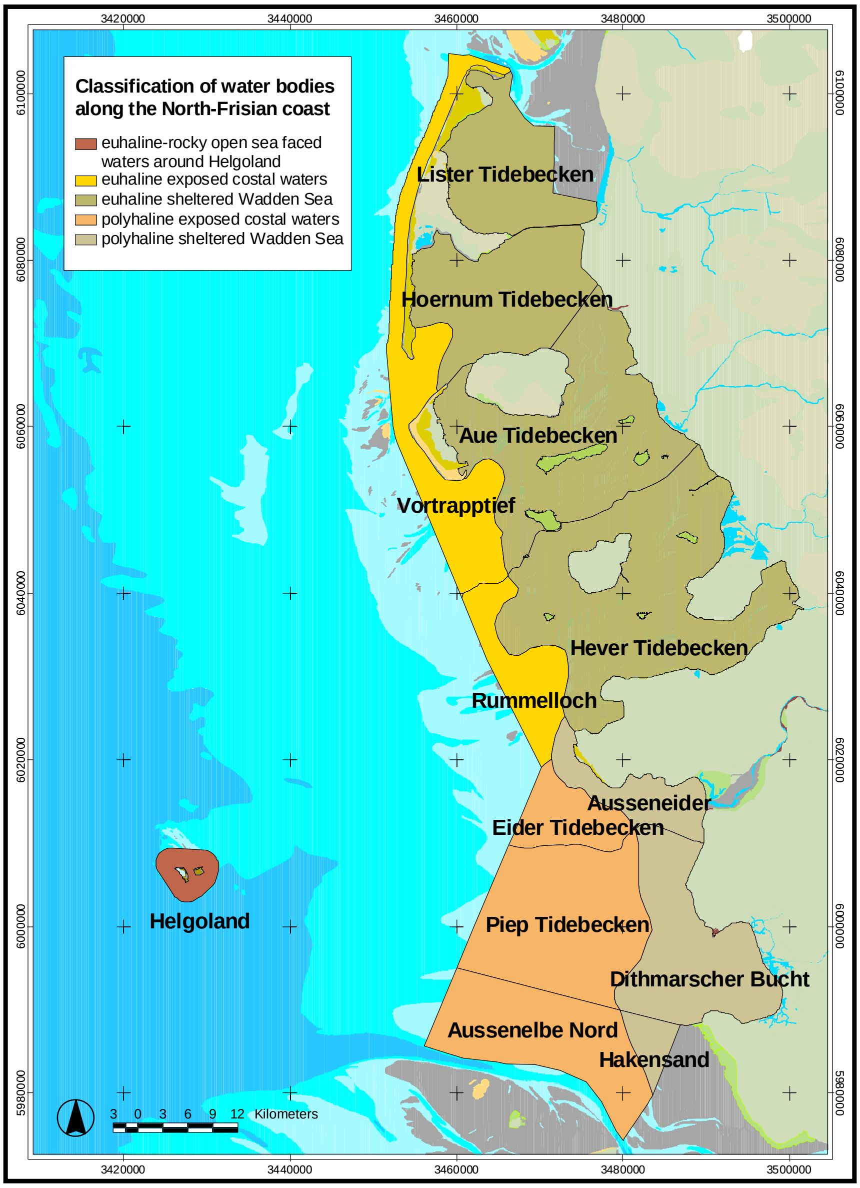

Fig. 28: Classification of water bodies along the North-Frisian coast according to the WFD (allocated by Schleswig-Holstein Agency for Coastal Defence, National Park and Marine Conservation - National Park authority)

This presented first approach refers to North-Frisian part of the Wadden Sea in Schleswig-Holstein which belongs to the sheltered euhalin water bodies and is divided in four subareas (Fig. 28). Subareas should be evaluated separately. Generally references could be defined for the several subareas, but some areas are rather small and contain no or few mussel beds making such an approach impossible or difficult. For all exposed areas (N1 and N3) as well as for the “Ausseneider” and “Hakensand” no comparable data basis exists so that no references values could be derived. In the area of “Dithmarscher Bucht” only few mussel

beds are known and the long-term data basis in small in comparison to the North-Frisian area.
At least, it might be only possible to define specific references for “Lister Tidebecken”, “ Hörnum Tidebecken”, “Aue Tidebecken” and “Hever Tidebecken”. But as all these water bodies are sheltered euhalin water bodies it might be preferable to evaluate them in one step. Such a differentiated evaluation needs further research and has to be tested.

Actually, beds which are now dominated by Pacific oysters may be treated separately. Guidelines for distinction between Blue mussel beds and oyster beds are currently developed for a TMAP manual (Nehls & Büttger 2007).

Assessment standardisation

The values for the different parameters have to be converted into linear ecological quality ratios (EQRs) from bad (0) to highest status (1). Class sizes were defined for each parameter and they have to be transformed to the five classes which are defined in the WFD.

- high: 1 – 0.8
- good: 0.8 – 0.6
- moderate: 0.6 – 0.4
- poor: 0.4 – 0.2
- bad: 0.2 – 0

Therefore, we converted the values in EQR using the following equation (according to Meyer et al. 2008):

$$EQR = Gmin + (Ialt - Imin) \times (0,2/(Imax - Imin))$$

with:

Imin = lower class boundary of the index-class
Imax = upper class boundary of the index-class
Gmin = lower boundary of the WFD classes
Gmax = upper boundary of the WFD classes

Exemplary assessment

To test the recommended parameters and reference values, we evaluate the data for the period 1998 – 2003 (Tab. 5).

Tab. 5: First evaluation period 1998 – 2003 (six years)

EQS (mean amongst 6 years)	1998	1999	2000	2001	2002	2003	**value**	**EQS**
area [ha]	526	963	831	1043	672	508	757	0,606
steadiness	48	50	42	55	56	55	306 x	0,663
biomass [LWW in kg/m²]	13.5	12.9	12.0	12.1	10.6	10.1	11.9	0,772
condition (a-parameter, 20 -49mm)	- 3.31E-05 3.61E-05 3.66E-05	2.31E-05 3.51E-05 3.88E-05 4.22E-05	2.69E-05 3.18E-05 3.53E-05 4.07E-05	2.56E-05 3.98E-05 4.33E-05 3.58E-05	2.64E-05 2.89E-05 4.13E-05 4.28E-05	4.13E-05 3.96E-05 3.78E-05 3.76E-05	2.87E-05 (= +1.03% 3.40E-05 (= +5.33%) 3.88E-05 (= +6.21% 3.90E-05 (= +5.26%)	0,845
							mean EQR	0,747

For the first evaluation period mussel beds would be classified to be in a good status basing on the recommended evaluation and references.
To indicate a first trend, the evaluation for the second period 2004 – 2007 is shown in Tab. 6. The results indicate a slight decrease reflecting the negative development of the main parameters.

Tab. 6: Values for the second evaluation period 2004 – 2009 (* = including sites which are dominated by oysters). EQS are not calculated due to missing monitoring data in 2008 and 2009.

EQS (mean amongst 6 years)	**reference**	2004	2005	20006	2007	*2008*	*2009*	**value**	**EQS**
area [ha]	900	298 *(378)	191 *(236)	260 *(350)	302 *(544)	xx	xx		
steadiness	63 (all sites in all six years = 378 x)	37 *(53)	30 *(46)	30 *(48)	22 *(52)	xx	xx		
biomass [LWW in kg/m²]	12,6	11,6 *(10.8=	8,6 *(8.1)	8.6 *(8.3)	8.5 *(7.5)	xx	xx		
condition (a-parameter, 20 -49mm)	Winter 2.84E-05 Spring 3.33E-05 Summer 3.65E-05 Autumn 3.73E-05	2.35E-05 *(2.35E-05) 2.60E-05 *(2.60E-05) 2.81E-05 *(2.81E-05) 3.06E-05 *(3.06E-05)	3.06E-05 *(3.06E-05) 2.99E-05 *(2.99E-05) 3.45E05 *(3.45E-05) 3.85E-05 *(3.85E-05)	2.95E-05 *(2.95E-05) 3.56E-05 *(3.56E-05) 3.33E-05 *(3.33E-05) 3.07E-05 *(3.07E-05)		xx	xx		
								mean EQR without steadiness	

Conclusion about the evaluation of mussel beds with Monitoring-Parameters

Evaluating several mussel bed parameters from the mussel monitoring in Schleswig-Holstein since 1998, we propose to use the four parameters “mussel bed area, steadiness of sites, biomass and condition” for an evaluation according to the WFD. Reference values for a high ecological status could be derived from the monitoring. All other parameters (e.g. coverage, spatfall) seem not to be suitable as they vary strongly. Furthermore they are reflected in the four recommended parameters. For example, sufficient spatfall would be apparent in steady or increasing mussel bed area and mussel biomass.

We assume that references can be derived comparatively for the Wadden Sea of Lower Saxony. If necessary, parameters might be left aside or others could be included. As the EQR is calculated as mean of all parameters and no weighting of single parameters is recommended, it is considered to allow a variable approach.

The presented references refer to the North-Frisian part of the Wadden Sea of Schleswig-Holstein, however, the WFD requires evaluations of different water bodies (sheltered/exposed and euhalin/polyhalin). Due to the fact that not in all water bodies mussel beds occur it will not be possible to define references and evaluate each water bodies separately based on structural parameters or data on macrobenthic communities of mussel beds.

Transferability to the requirements of the Habitat Directive

Based on the comparison of rating matrices according to the WFD and HD (Fig. 2) we assume that the presented approach might be useable both in term of the HD and WFD. The favourable conservation status (green, HD) could be considered as comparable to the good ecological status (WFD). At least these two directive and their evaluation schemes must be comparable otherwise any evaluation would be contradictory.

Besides this comparability of the evaluation schemes, the recommended structural parameters are regarded as useful parameters in term of the HD as well. As characteristic features of the LRT 1140 “mudflats and sandflats” the parameters steadiness, area, biomass and condition respectively are considered as most meaningful to describe and evaluate the present status of mussel beds and therewith to evaluate whether the continuance and favourable conservation status of the LRT could be ensured or not.

5 ASSESSMENT OF THE ASSOCIATED COMMUNITY OF MUSSEL BEDS

The second part of this report presents the assessment of the associated community of mussel beds in Wadden Sea in terms of the WFD with the MarBIT-tool (for explanation please see chapter 1 Introduction and 6.2 MarBIT). As shown in the first part of the report and by Nehls & Büttger (2006) Blue mussel beds are changing in size and structure. It has to be asked whether the evaluations with MarBIT reflect structural changes of mussel beds or if the associated community is independent from these observed structural changes.
The Blue mussel monitoring provides macrobenthic data of mussel beds since 1999 and last to 2005 at the moment. This data basis permits a test of MarBIT for this ecotop.
At first, available information (e.g. papers, reports) about the associated macrobenthic community of mussel beds in the Wadden Sea are summarized and thereafter the assessment with MarBIT is described.

5.1 INFORMATION ABOUT ASSOCIATED TAXA OF BLUE MUSSEL BEDS

Associated species in the waterbody N2

Historical data
Historical data on mussel bed communities are available from the North Frisian and Danish Wadden Sea (Plath 1943, Remane 1940, Thamdrup 1935, Smidt 1951, Wohlenberg 1931, 1937, Hagmeier & Kändler 1927). Further information is available from the Wadden Sea of Lower Saxony (Linke 1939, Michaelis 1969, Hauser & Michaelis 1975, Meyer & Michaelis 1980, Michaelis 1987, compare Grotjahn 2006).
Most of those assessments took place in the waterbody N2 (euhalin). Regarding the waterbody N4 (polyhalin) two assessments (Michaelis 1969, Hauser & Michaelis 1975) deliver data for Blue mussel beds. All these reports were conducted after 1960. Since then, strong anthropogenic influences are supposed; therefore Grotjahn (2006) defined 1960 as limit for historical data.
The different surveys did not use comparable methods and thus did not provide complete and habitat specific species lists. Because of different methods and changes in taxonomy surveys from the beginning of the 19th century contain semi-quantitative information which might result in incomplete species lists (Grotjahn 2006). In fact, the authors studied the different habitat in the Wadden Sea and list the most obvious species they found. Therefore these reports and papers contain information about the most abundant species which could be named as characteristic species of Blue mussel beds but they do not provide a complete species list with quantitative information basing on surveys 100 years ago.
Information from these papers and reports about mussel beds and their associated fauna are summarized.

Wohlenberg (1937) listed the following species which he found on mussel beds:

Balanus balanoides
Capitella capitata
Chiton marginatus
Colobranchius ciliatus
[Eupagurus and Buccium after storms, subtidal species]
Gammarus zaddachi
Gattyana cirrosa
Jaera marina
Littorina litorea
Littorina obtusata
Pelosolex bendeni
Trachydermon cinereus

Statements by Hagmeier & Kändler (1927) belong to oyster beds of *Ostrea edulis*. This species settled in the upper subtidal area and not in the intertidal. Those species information cannot be adopted for intertidal Blue mussel beds. But the authors mention *Polydora ciliata* und *Membranipora reticulum* (today *Conopeum reticulum*) which they found on *Mytilus edulis*.

Thamdrup (1935) investigated the tidal flats around Skallingen (Denmark) along two transects which crossed a mussel bed. The author mentions epibenthic species like *Littorina littorea* and *Balanus improvisus*. From his information could be inferred that he found *Cardium* (today *Cerastoderma*) *edule* too. But it is not distinguished between mussel heaps and unpopulated areas in-between. However this survey contains additional references but no detailed information.

Remane (1940) summarized those surveys above and added further references:

> „Die Muschelbänke bevorzugen im Küstengebiet der Nordsee das Eulitoral, fallen also meist trocken. Sie bilden sich sowohl auf Sand- wie auf Schlickboden, nehmen hier aber verschiedene „Wuchsformen“ an. Auf Schlick bieten meist lebende oder tote *Cardium* [heute *Cerastoderma*] den Ansatzpunkt, und bald entsteht ein Nest, in dem Miesmuscheln mit zahlreichen Cardien, Mya-Schalen, jungen Mya zu einem Klumpen versponnen sind. In den Lücken dieser Klumpen leben verschiedene Tiere, auch Nemertinen und Polycheaten, auf Myaschalen bisweilen Trachydermon cinereum. Weiterhin kann sich Mytilus in großer Zahl mit *Fucus* im Weichboden-Eulitoral verspinnen. Die stärkste Entwicklung zeigen die Miesmuscheln jedoch auf Sandboden, über den eine Gezeitenströmung hinweggeht. Hier entstehen lange Bänke mit dichter Massenpackung an Muscheln. Auch hier ist die primäre Ansiedlung ein festheften von Muscheln an irgendwelche Festkörper, durch neuen Ansatz von Mytilus an diesen Kern entstehen aber schließlich die großen, dem Sand aufliegenden Bänke. Das Innere dieser Bänke ist meist mit sapropelartigem schwarzem Schlamm erfüllt, der von zahlreichen zerfallenden Muschelschalen durchsetzt ist. Dieser „Innenweichboden“ entsteht durch die Muschel selbst. Zunächst wirkt das Lückensystem zwischen den Muscheln als Stillwasserraum, in dem Sandkörner und Sinkstoffe sedimentieren (Hagmeier 1927 berichtet, daß auf Felsboden Miesmuscheln Sand im Innern der Bank ansammelten), zweitens werden die Abfallstoffe aus der Strudeltätigkeit der Muscheln zum großen Teil ins Innere der Bank gelangen und hier einen sich allmählich erhöhenden Mudd schaffen. Die Miesmuschelbänke selbst werden nun von einer Reihe anderer Organismen besiedelt, meist sind es euryöke und euryhaline Tiere. Im oberen Eulitoral kann *Balanus balanoides* und *B. improvius* die Muscheln

> an ihrer Außenseite mit einer dicken weißen Kruste überziehen. Hier leben *Litorina litorea*, seltener *L. abtusata*, der Hydroidpolyp *Lafoea fruticosa*, zwischen den Muscheln lebt *Gammarus locusta*, *Jaera albifrons*, junge *Carcinus maenas*, *Gattyana cirrosa*, Harpactididen, Nematoden, stellenweise *Polydora ciliata*, *Fabricia sabella*, *Nereis pelagica*, *Lepidonotus squamatus*. Im inneren Mudd der Bänke fand Wohlenberg 1937 den Polychaeten *Colobranchus ciliatus* und den Oligochaeten *Peloscolex bendeni*, also typische Sapropelbewohner. Lincke 1939 nennt als Endobiose der Wattenmeer-Mytilus-Bänke *Nereis diversicolor*, *Heteromastus filiformis*, *Pygospio elegans*, *Corophium volutator*, vereinzelt *Sargatia troglodytes*, *Phyllodoce maculata*, *Lepidonotus squamatus*."

In 1936, Plath (1943) investigated the fauna of the tidal flats around the island of Pellworm. He describes broad mussel beds in the eastern parts but he does not mention surveys of mussel beds. The authors mentions that mussel settle independently of substrata, mussel bed occur on sand as well as on mud. Mussel beds become more muddy over the time and mussel beds are socialized with *Nereis diversicolor* and *Scrobularia plana*, species which are typical for muddy areas.

Smidt (1951) does not provide a complete species list but names some epibenthic species which live on mussels, stones or other mobile objects. The author lists Hydroidea, *Membranipora reticulum* and Balanus (two species). This paper includes autecological information about several species.

Considering all these surveys and reports up to 1960 the following species are known for mussel beds:

Balanus improvisus
Capitella capitata
Carcinus maenas
Cerastoderma (= *Cardium*) *edule*
Chiton marginatus
Conopeum (=Membranipora) reticulum
Corophium volutator
Fabricia sabella
Gammarus locusta
Gammarus zaddachi
Gattyana cirrosa
Hediste (= Nereis) diversicolor
Heteromastus filiformis
Jaera albifrons (= *Jaera marina)*
Lafoea dumosa
Lepidochitona (= Trachydermon) cinereus
Lepidonotus squamatus
Littorina littorea
Littorina obtusata
Malacocerus tetracerus (früher *Colobranchius ciliatus)*
Mytilus edulis
Nereis pelagica
Phyllodoce maculata
Polydora ciliata
Pygospio elegans
Sagartia troglodytes
Scrobularia plana
Semibalanus (=Balanus) balanoides
Tubificoides benedenii (= Peloscolex bendeni)

(Semi-) historical information – after 1960

		Mytilus edulis
	11	Proben
Aufwuchsform	N	Besiedl.-Dichte
Balanus crenatus	11	I - III
Elminius modestus	10	II - IV
Schlauchdiatomeen	5	I - III
Laomedea dichotoma	6	I - IV
Polydora ciliata	9	II - III
Conopeum reticulum	6	II - III
Littorina littorea	4	I - II
Sertularia cupressina	2	I
Lanice conchilega (vorw. Aulophora-Larven)	2	I
Alcyonidium sp.	1	I
Autolytus sp.	4	I - II
Farrella repens	2	II
Tergipes despectus	2	I
Unbest. Grünalgen	3	I
Hydractinia echinata	1	III
Polydora ligni	2	I - II
Jaëra albifrons	3	I
Lepidochiton cinereus	2	I
Gammarus sp.	2	I - IV
Metridium senile	2	I
Sagartia troglodytes	1	I
Anaitides sp.	1	I
Carcinus maenas (inf. u. Megalopae)	3	I
Asterias rubens (vorw. inf.)	2	I
Tubularia larynx		
Harmothoë impar	1	I
Eteone longa		
Crepidula fornicata	1	I
Mytilus edulis (vorw. inf.)		
Laomedea longissima		
Harmothoë sarsi	1	I
Unbest. Scyphostoma	1	II
Nereis diversicolor (inf.)	1	I
Nereis succinea (inf.)	1	I
Pygospio elegans	2	I
Bougainvillia ramosa		
Perigonimus sp.		
Campanulina lacerata		
Campanularia johnstoni		
Laomedea angulata		
Laomedea loveni	1	II
Sagartiogeton undatus		
Harmothoë imbricata	1	I
Eulalia viridis		
Capitella capitata	1	I
Balanus improvisus		
Idotea chelipes		
45 Tierarten, 2 Algenformen		31 Tierarten, 2 Algenformen

Fig. 29: Detail of table 2 in the paper of MEYER & MICHAELIS (1980).

Between 1973 and 1975, Meyer & Michaelis (1980) surveyed the macrozoobenthic community of the tidal flat in the western part of the Hohe-Weg-Watt. Listed are epibenthic species mainly. Species like *Balanus crenatus, Elminius modestus, Laomedea dichotom, Polydora ciliata, Conopeum recticulum, Littorina littorina, Autolytes* sp, *Jaera albifrons, Megalopae* and *Carcinus maenas* (juvenile) were found with high steadiness and densities (Fig. 29; described in the paper). Whereas the authors mention that *Littorina littorea, Lanice conchilega, Sertularia cupressina, Lepidochiton cinereus* and *Carcinus maenas* (adult) are inhabitants of mussel beds.

Michaelis (1987) conducted macrobenthic surveys of the Jadebusen in the years 1975, 1976 und 1977. At all 34 species were found (compare Fig. 30).

Tabelle 21: Tierarten des Biotops "Miesmuschelbänke, Beete" (5 Stationen)

Art	Stetigkeit (%)	Abundanz (Individuen/m²) Mittel	Abundanz (Individuen/m²) Maximum	Biomasse (g AFG/m²) Mittel	Biomasse (g AFG/m²) Maximum	Anteil an d. Gesamtbiomasse (%)
Balanus crenatus	100	-	-	-	-	-
Elminius modestus	100	-	-	-	-	-
Mytilus edulis	100	3822	12147	781	1660	97,7
Capitella capitata	100	173	408	0,01	0,056	0,0014
Macoma baltica	100	111	339	4,43	16,95	0,554
Carcinus maenas	100	57	169	0,68	1,3	0,085
Heteromastus filiformis	80	520	1864	0,43	1,93	0,054
Tharyx marioni	80	128	400	0,024	0,10	0,003
Nereis succinea	80	39	176	1,15	5,49	0,14
Tubificoides benedeni	80	26	56	-	-	-
Polydora ligni	60	127	512	-	-	-
Gammarus salinus	60	53	248	-	-	-
Littorina littorea	60	41	113	1,01	4,11	0,13
Cerastoderma edule	60	38	176	0,33	1,65	0,04
Jaëra albifrons	60	25	104	-	-	-
Mya arenaria	60	18	56	0,01	0,07	0,002
Pygospio elegans	60	12	56	-	-	-
Nereis diversicolor	40	26	128	0,32	1,61	0,04
Nephtys hombergi	40	5,2	16	0,06	0,29	0,007
Corophium sp.	40	2	8		-	-
Hydrobia ulvae	20	42840	214200	9,77	48,85	1,2
Nereis virens	20	23	113	-	-	-
Scoloplos armiger	20	0,8	4	-	-	-
Harmothoë sp.	20	0,4	2	-	-	-
Gammarus locusta	20	0,4	2	-	-	-
Crangon crangon	20	0,4	2	-	-	-

Funde aus qualitativen Proben:

Laomedea longissima	x
Sertularia cupressina	x
unbest. Aktinie	x
Polydora ciliata	x
Lanice conchilega	x
Nymphon grossipes	x
Pinnotheres pisum	x
Tergipes despectus	x

Fig. 30: Species list of MICHAELIS (1987).

Oldest surveys in the North-Frisian Wadden Sea which include complete species list and quantitative information (abundances/biomass) were done by Asmus (1987) and Dittmann (1987, 1990, see Tab. 7). Both examined in 1983 and 1984 respectively the associated community of a mussel beds (located in the „Oddewatt", Königshafen, Sylt).

Tab. 7: Species lists of a mussel bed examined by Asmus (1987) and Dittmann (1987, 1990).

Asmus (1987)
Ampharete acutifrons
Amphiporus lactifloreus
Anaitides mucosa
Arenicola marina
Ascidien
Asterias rubens
Balanus crenatus
Capitella capitata
Carcinus maenas
Crepidula fornicata
Elminius modestus
Eteone longa
Eumida sanguinea
Gammarus locusta
Harmothoe sarsi
Heteromastus filiformis
Jaera albifrons
Kefersteinia cirrata
Lepidochiton cinereus
Lepidonotus squamatus
Lineus viridis
Litorina littorea
Littorina mariae
Macoma balthica
Malacoceros fuliginosus
Membranipora membranacea
Microphthalmus sp.
Mya arenaria
Mytilus edulis
Nereis diversicolor
Nereis virens
Polydora ciliata
Sagartia troglodytes
Scoloplos armiger
Semibalanus balanoides
Tharyx killariensis
Tubifex spec.
Tubificoides benedenii

Dittmann (1987 und 1990)
Ampharete finmarchica
Amphiporus lactifloreus
Aphelochaeta marioni
Arenicola marina (juv.)
Asterias rubens
Autolytus spec.
Balanus crenatus
Capitella capitata
Carcinus maenas
Cephalotrix linearis
Cerastoderma edule
Crangon crangon
Echiurus echiurus
Eteone longa
Eulalia viridis
Eumida sanguinea
Gammarus locusta
Halichondria panicea
Harmothoe elizabethae/impar
Harmothoe imbricata
Hediste diversicolor
Heteromastus filiformis
Hydrobia ulvae
Idothea chelipes
Jaera albifrons
Kefersteinia cirrata
Lepidonotus squamatus
Littorina littorea
Littorina obtusata
Macoma balthica
Malacocerus fuliginosus
Malacocerus tetracerus
Metridium senile
Microphthalmus aberrans
Mya arenaria
Mytilus edulis
Neanthes succinea
Neoamphitrite figulus
Nymphon grossipes
Pagurus bernhardus
Paranais litoralis
Pholoe minuta
Phyllodoce mucosa
Polydora ciliata
Polydora cornuta
Polydora quadrilobata
Pygospio elegans
Scoloplos armiger
Semibalanus balanoides
Tubificoides benedeii
Tubificoides pseudogaster
Lineus viridis
Polydora ligni
Tharyx marioni

Associated species in the waterbody N4

Only two surveys provide information about mussel beds in the intertidal area of the polyhalin Wadden Sea (N4). No older surveys are known for this part.

Michaelis (1969) gives little information about the associated community of mussel beds on the „Knechtsand" in the year. Te author lists occurrence of *Heteromastus* between mussel beds and points at epibenthic species like *Balanus* (mostly *crenatus*), *Littorina* and single *Lepidonotus*. *Laomedea gelatinosa* is inconspicuous on mussel beds. Further, *L. flexuosa* is mentioned.

Hauser & Michaelis (1975) regard their surveys as continuation and extension of the work done by Michaelis (1969). They mention *Balanus crenatus, B. improvius, Elminius modestus*, *Littorina littorea, Laomedea dichotoma* (*Obelia dichotoma*) and *Lepidochiton cinereus* as well as the endobenthic taxa *Heteromastus, Arenicola* and *Mya* as frequent on shell and mussel beds.

Habitat specific characterisation of the macrozoobenthic community in Lower Saxony (after Grotjahn 2006)

Grotjahn (2006) analyzed different data source to obtain habitat specific lists of macrobenthic communities. This incorporates all water bodies of the coast of Lower Saxony. The analysis led to 38 taxa for mussel beds within the water type N2 and 64 taxa for the water type N4.
The work bases on an intersection of point data with information about the fauna (covering the years 1984 until 2005) with a sediment map including information about mussel beds and seagrass. Therefore the macrobenthic community for each habitat could be described. For mussel beds in type N2 six surveys were available which were used to determine the taxa steadiness.
Three species (*Capitella capitata, Heteromastus filiformis* and *Pygospio elegans*) were found at five out of six stations (which is equivalent to a steadiness of about 80%). Therefore Grotjahn (2006) define these species as character species „Leitarten", species which occurred in 30 to 80% of the stations are defined as accompanied species „Begleitarten".
For the water type N4 surveys at five positions were used. Here, *Lanice conchilega* and Nemertea were found at all positions. Further character species ("Leitarten", occurring at least at 80% of the positions) are *Capitella capitata, Carcinus maenas, Crangon crangon, Heteromastus filiformis, Macoma balthica, Pygospio elegans, Scoloplos armiger* and *Tubificoides benedeni* (Grotjahn 2006).
This list is not basing on historical data as requested by the WFD (Grotjahn 2006). The authors propose to use „species diversity in the whole area of the ecotype, species presence and steadiness at different positions and mean population densities for evaluation". Since quantitative references of historical surveys are missing Grotjahn (2006) suggest evaluating changes of qualitative data.

Data from the monitoring in Schleswig-Holstein

As part of the mussel monitoring in Schleswig-Holstein the associated macrobenthic community of certain mussel beds is monitored annually since 1999. Until 2002 10 samples were taken from 10 mussel beds in September, five located in the Lister Deep and five in the Norderhever (compare Fig. 3, Nehls & Büttger 2006). Since 2003 in each tidal basin only two mussel beds are surveyed but each with 25 samples. Hence the total number of samples is the same within each tidal basin.

The associated community has to be evaluated for different water bodies (Fig. 28). Because the monitoring covers different mussel beds in two tidal basins (which belong to the water bodies “Lister Tidebecken” and “Hever Tidebecken”) the question arose if species composition of mussel beds differ across tidal basins and within tidal basins? Can we find pronounced differences of species and their abundances between mussel beds and between tidal basins? The results are important for data handling: could data from different mussel beds within a tidal basin (=water body) be pooled for evaluation in terms of the WFD.

First, we present some general results of these monitoring data followed by the analysis which should answer the questions above. For analysis we use multivariate data analysis (MDS-plot and ANOSIM) with the program package Primer TM (Clarke & Warwick 2001). Presence/absence-data are derived for each mussel bed if taxa were found at least in one sample. For abundances and biomass (AFDW) each sample is taken into account.

The Pacific Oyster (*Crassostrea gigas*) is spreading in Wadden Sea and many former mussel beds (especially in the Lister Deep) are now overgrown by oysters (Nehls & Büttger 2006). First investigations show that oysters might lead to changes in species composition or dominance structure (Görlitz 2005, Markert 2006, Kochmann 2007, Büttger et al. 2008).

Changes in the associated macrobenthic community

Many taxa occur more or less regular in the monitoring samples while others were found infrequently (Tab. 8). Furthermore, several alien species became common in the last decade in particular (e.g. *Crassostrea gigas, Balanus improvius, Tharyx killariensis, Aphelochaeta marioni, Crepidula fornicata, Elminius modestus*, compare Nehring & Leuchs 1999).

Mussel beds in the North-Frisian Wadden Sea showed pronounced increasing biomass values from 1999 to 2003 which declined afterwards again (Fig. 31). This development was stronger in the Lister Deep than on beds in the tidal basin of the Norderhever.

Abundances fluctuated strongly between years and tidal basins (Fig. 31). Increasing abundances belong to epibenthic species like barnacles and mobile fauna (*Carcinus maenas* or *Littorina littorina*, Nehls & Büttger 2006). Spatfall of barnacles varies strongly between years (Buschbaum 2002) as well as appearance of mobile taxa like *Littorina* or *Carcinus maenas* is subjected to temporal and spatial variations (compare Albrecht & Reise 1994, Saier 2000, 2002, Thiel & Dernedde 1994). Abundances of these taxa can fluctuate strongly between years.

Tab. 8: Species steadiness based on all samples (n = 529) taken between 1999 and 2005 (samples in the Lister Deep since 2003 are not included).

Art	Stetigkeit
Mytilus edulis	99.2
Carcinus maenas	95.5
Balanus crenatus	79.0
Oligochaeta undet.	77.5
Heteromastus filiformis	72.6
Elminius modestus	67.7
Semibalanus balanoides	65.0
Neanthes succinea	50.1
Littorina littorea	46.7
Membranipora membranacea	45.6
Polydora cornuta	45.4
Tharyx killariensis	42.7
Nereidae undet.	39.7
Actiniaria undet.	37.8
Capitella capitata	34.0
Tubificoides benedeii	32.9
Macoma balthica	32.3

Art	Stetigkeit
Jaera albifrons	29.9
Hydrobia ulvae	28.4
Lepidochitona cinereus	28.4
Cerastoderma edule	28.0
Malacocerus tetracerus	26.3
Chaetogammarus marinus	25.3
Nemertini undet.	23.8
Aphelochaeta marioni	23.4
Lanice conchilega	23.4
Phyllodoce mucosa	19.7
Crepidula fornicata	16.8
Polydora ciliata	15.5
Balanus improvisus	15.1
Neanthes virens	13.8
Gammarus oceanicus	13.4
Harmothoe imbricata	12.5
Sertularia cupressina	12.1
Ampharete acutifrons	11.9

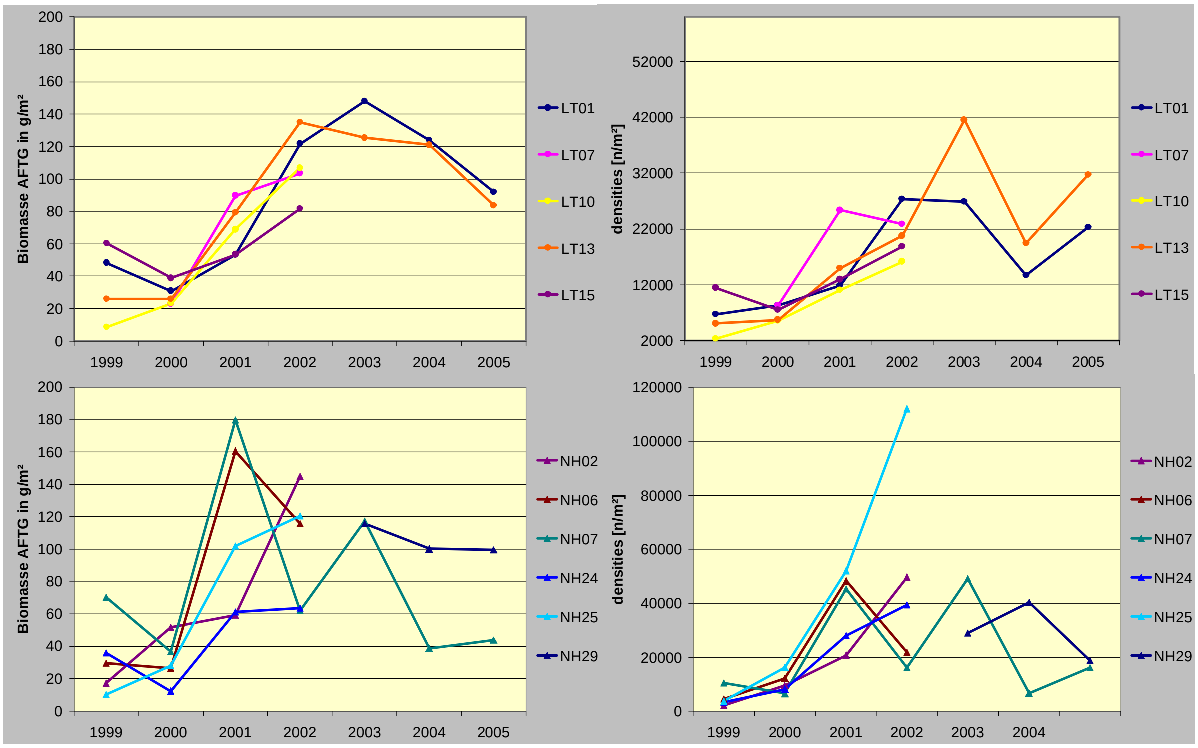

Fig. 31: Mean biomass (AFDW in g/m²; left figures) and mean densities (n/m²) of the associated macrobenthic community of different mussel beds in the Lister Deep (LT, figure on the top) and in the Norderhever (NH). Pacific oysters and Blue mussels are not included.

Especially values on mussel bed NH07 are fluctuating between years. This bed differs from the other mussel beds as it is covered with the algae *Fucus vesiculosus* forma *mytili.* Albrecht & Reise (1994) demonstrated that *Fucus*-cover affects mussel density as well as associated species. Diversity of epibenthic species is higher with *Fucus*-cover (Albrecht 1991). Taxa like *Littorina littorea*, barnacles and *Carcinus maenas* occur in lower densities below *Fucus* while *Gammarus marinus, Jaera albifrons* and *Littorina mariae* benefit from the coverage and were found in higher abundances.

Fucus cover is comparatively high on mussel bed NH07 (Fig. 32) while it decreased in the Lister Deep even before oysters became abundant (compare LT01 and LT13). *Fucus* does not possess any holdfasts therefore it cannot anchor itself on mussel beds. *Fucus* belongs to the byssus threads of Blue mussels which attach them. Therefore sites with oyster dominance are generally sparse colonized.

Decreasing coverage in the Lister Deep probably facilitated increasing biomass and densities values (Büttger et al. 2008). Other mussel beds in the Norderhever (NH24, NH25 and NH29) show similar tendencies. Densities developed similar to the biomass changes.

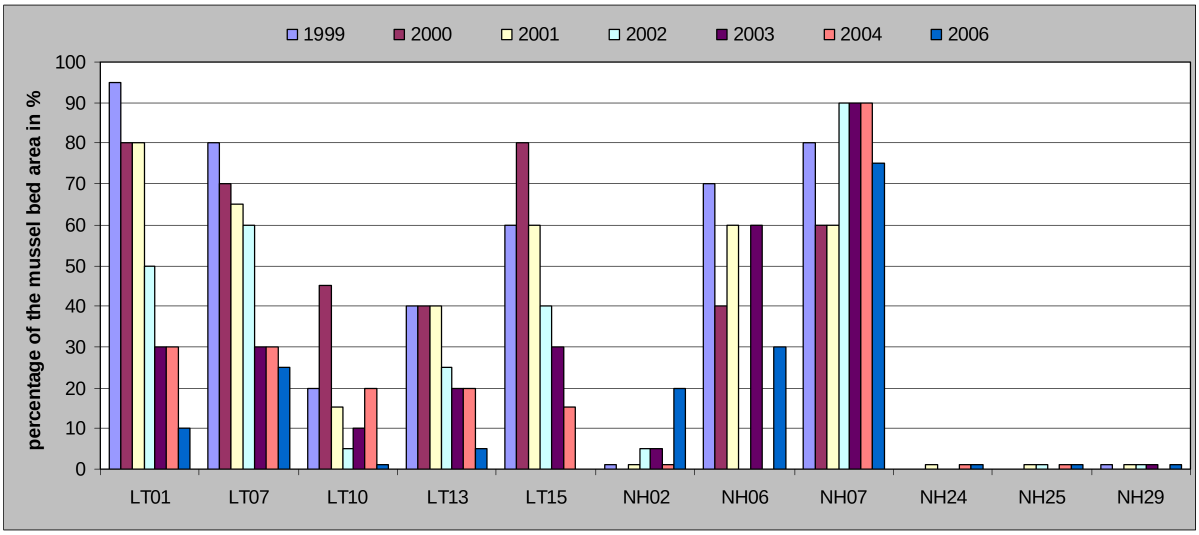

Fig. 32: Coverage with *Fucus vesiculosus* on mussel beds (LT= Lister Deep, NH = Norderhever) where the macrozoobenthic was sampled too (1999 – 2005).

Differences in species composition across and within tidal basins

At all, ANOSIM did not reveal significant differences in species composition between the Lister Deep and the Norderhever (one-way ANOSIM, R = 0,114, p = 0.1%, basing on annual presence/absence-data for each mussel bed). No species occurs on one mussel bed with high steadiness and not on other beds. Over the years species composition changed (Fig. 33). Fig. 33 indicates that in 2004 and 2005 mussel beds within a tidal basin are more similar to each other than to mussel beds in the other tidal basin. This impression could not be statistically verified (ANOSIM for the mussel beds LT01, LT13, NH07 and NH29 in the years 2004 and 2005; R = 0,484, p = 2.9%). The SIMPER-analysis shows that some species are more frequent in one of the two tidal basins and lead to higher similarity within a tidal basin. For example epibenthic species like *Jaera albifrons* or *Lepidochitona cinereus* are more common in the Lister Deep while *Cerastoderma edule* (epibenthic attached by the byssus threads of mussels) and *Hydrobia ulvae* occur more frequently on mussel beds in the Norderhever.

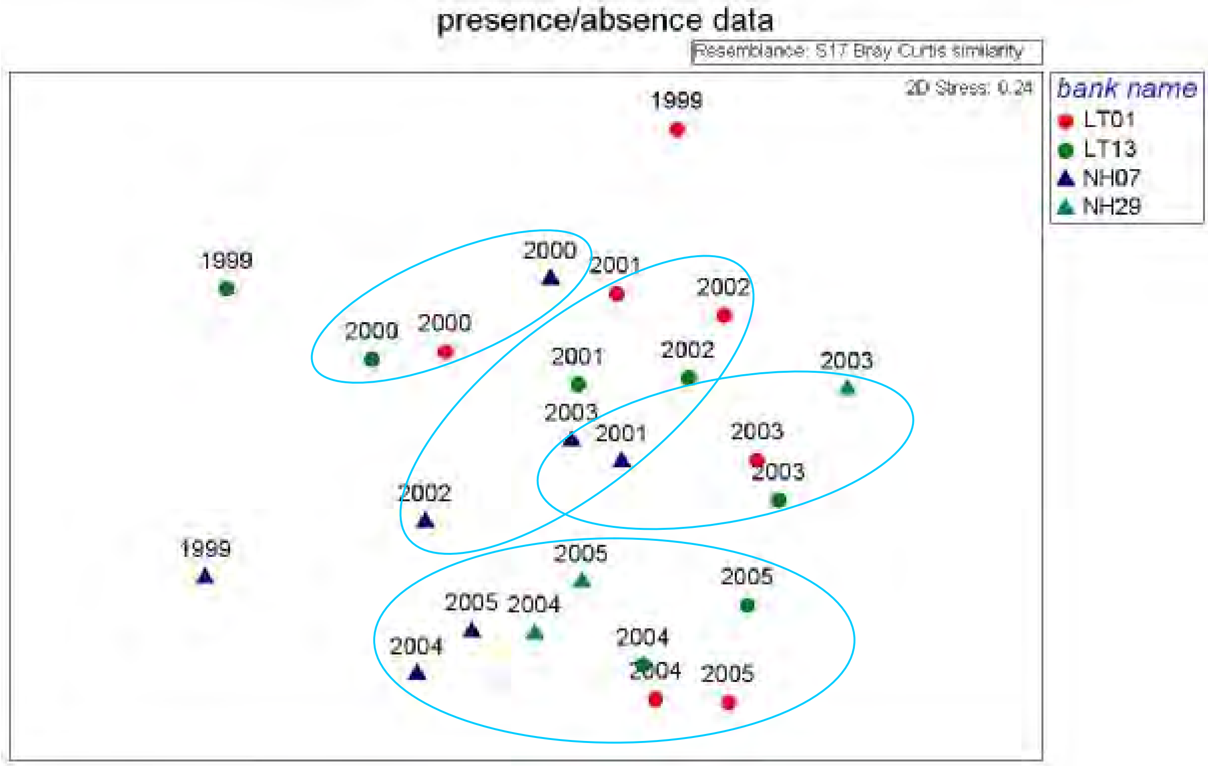

Fig. 33: MDS-Plots (Bray-Curtis-Similarity) using presence/absence data of associated macrobenthic taxa of selected mussel beds in the Lister Deep and Norderhever. Unconsidered are *Crasssotrea gigas* and *Mytilus edulis*. For legibility reasons, some samples of the same years are encircled in bright blue.

In summary these analyses show that the associated macrobenthic community of mussel beds does not differ significantly between sites and tidal basins. Only few taxa occur in higher abundances in one tidal basin while others are more frequent in the other one. But no taxa were found in high abundances and with high steadiness exclusively on one mussel bed or in one tidal basin. Except oysters which occur in higher abundances in the Lister Deep since 2003. Because they are habitat engineers themselves they have to be regarded apart.

Altogether we can define a single reference list for macrobenthic taxa on mussel beds (compare chapter 5.2 MarBIT) in the water type N2. Macrobenthic data taken on different mussel beds within a tidal basin could be pooled for the evaluation with MarBIT.

Neozoa

Several species were introduced to the German coast and Wadden Sea by chance or deliberately. Nehring & Leuchs (1999) list all species and give additional information. Introduced species occur also on mussel beds. The barnacle *Balanus improvisus* is spreading especially during the last years and competes with the native species Semibalanus balanoides for space (Franke & Gutow 2004). At the island of Helgoland the alien barnacle displayed almost the native species: Mild winters in the last years facilitated their spread at the expense of *Semibalanus* (Franke 2008). So far for other species no serious problems emerged (Nehring & Leuchs 1999). New species also might lead to a higher diversity as they offer new structures.
Pacific oysters (*Crassostrea gigas*) have a special role as they took over several mussel beds in the German as well as in the Dutch and Danish Wadden Sea (Nehls & Büttger 2006, 2007).

Following species are introduced and settle on Blue mussel beds (for status compare Nehring & Leuchs 1999):

Aphelochaeta marioni	Neozoa incerta (1966)
Balanus improvisus	Neozoa actualia (around 1858)
Crassostrea gigas	Neozoa actualia (1971)
Crepidula fornicata	Neozoa actualia (1934)
Elminius modestus	Neozoa actualia (1943)
Marenzelleria cf. wireni	Neozoa actualia (1979)
Mya arenaria	Neozoa actualia (13. century)
Neanthes virens	Neozoa incerta (at least since 1923)
Petricola pholadiformes	Neozoa actualia (1896)
Tharyx killariensis	Neozoa incerta (1972)

According to the WFD the reference conditions have to be undisturbed and therefore without anthropogenic introduced species which normally would not reach an area. However, neozoans are omnipresent today and as some species, like the slipper limpet, have been introduced in the Wadden Sea some decades ago, no data are available on mussel beds without any neozoans. It has also be brought into the minds, that today neozoans already dominate marine benthic communities and on the mussel beds of the Lister Deep, up to 80% of the benthic individuals origin from distant marine waters. Excluding neozoans from an evaluation approach would thus result in ignoring the main part of the community, making the detection of changes induced by other factors more difficult. There is thus a strong need to conclude on approach incorporating introduced species, which is currently under discussion in the European Commission.

Blue mussel beds and Pacific oysters

Pacific oysters (*Crassostrea gigas*) were introduced in the Wadden Sea. Since the early 1990ies the population increased in the north Frisian Wadden Sea and this spread started in the end of the 1990ies in the East Frisian Wadden Sea. Because this species is not native, from a nature conservation view it is still unclear if oyster beds should be treated like mussel beds. Oyster beds harbour a similar associated community like Blue mussel beds (compare Tab. 9) but with altered dominance structures (Görlitz 2005, Markert 2006, Kochmann 2007, Büttger et al. 2008). At present reference values in term of the WFD are hard to define barely because it is a relatively young process developing very fast.

Nature conservation of oyster reefs is a basic question which is still in discussion and lead to different opinions of stakeholders. This question cannot be answered here. The transition from Blue mussel beds to oyster beds and its effects on the ecological functioning within the ecosystem has to be investigated further.

Tab. 9: Species steadiness in 98 samples taken in the Lister Deep since 2003.

scientific_name	Stetigkeit NUR Austernproben	scientific_name	Stetigkeit NUR Austernproben
Mytilus edulis	100.0	*Asterias rubens*	7.1
Oligochaeta undet.	98.0	*Phyllodoce maculata*	6.1
Carcinus maenas	98.0	*Harmothoe elizabethae/impar*	6.1
Elminius modestus	98.0	*Mya arenaria*	6.1
Balanus crenatus	95.9	Nephtyidae undet.	5.1
Semibalanus balanoides	85.7	*Sagartia troglodytes*	5.1
Crassostrea gigas	83.7	*Gammarus oceanicus*	5.1
Nereidae undet.	75.5	*Eteone longa*	4.1
Actiniaria undet.	74.5	*Cerastoderma edule*	4.1
Littorina littorea	72.4	*Mysella bidentata*	3.1
Polydora cornuta	71.4	*Eulalia viridis*	3.1
Heteromastus filiformis	65.3	*Scoloplos armiger*	3.1
Lepidochitona cinereus	59.2	*Abra alba*	3.1
Malacoceros tetracerus	53.1	*Polydora ciliata*	3.1
Crepidula fornicata	51.0	Ascidiacea undet.	3.1
Neanthes succinea	46.9	*Chaetogammarus marinus*	3.1
Capitella capitata	46.9	*Littorina obtusata*	3.1
Lanice conchilega	44.9	*Hydrobia ulvae*	2.0
Nemertini undet.	35.7	*Petricola pholadiformes*	2.0
Spionidae undet.	29.6	*Gammarus locusta*	2.0
Ampharete acutifrons	25.5	*Hydractinia echinata*	2.0
Neanthes virens	25.5	*Electra crustulenta*	2.0
Phyllodoce mucosa	24.5	*Nymphon sp.*	2.0
Phyllodocidae undet.	22.4	*Pagurus bernhardus*	2.0
Balanus improvisus	22.4	*Molgula manhattensis*	1.0
Tubificoides benedeii	22.4	*Lineus ruber*	1.0
Macoma balthica	20.4	*Pectinaria koreni*	1.0
Harmothoe imbricata	20.4	*Angulus tenuis*	1.0
Polychaeta undet.	20.4	*Lagisca extenuata*	1.0
Polynoidae undet	17.3	*Spio filicornis*	1.0
Jaera albifrons	16.3	*Eumida sanguinea*	1.0
Pygospio elegans	15.3	*Phyllodoce groenlandica*	1.0
Tharyx killariensis	15.3	*Crangon crangon*	1.0
Polydora sp.	14.3	*Ophelina acuminata*	1.0
Spiophanes bombyx	8.2	*Lepidonotus squamatus*	1.0
Bylgides [Harmothoe] sarsi	8.2	*Chaetozone cf. Setosa*	1.0
Aphelochaeta marioni	7.1	*Malacoceros fuliginosus*	1.0
Littorina saxatilis	7.1	*Membranipora membranacea*	1.0

5.2 MarBIT

The evaluation of Blue mussel bed communities should be tested with the index tool MarBIT. Primarily, the tool was developed by MariLim (Kiel) for the Baltic Sea (Meyer et al. 2008) and was tested for single habitats in the Wadden Sea to check its applicability (Meyer et al. 2007). Here a further application in the Wadden Sea is presented.
The data of the macrozoobenthic sampling on Blue mussel beds (1999-2005) are a good basis to calculate the EQRs with MarBIT and discuss the results and the applicability.

Data import in MarBIT, calculation of the EQRs and species accumulation plots (bootstrap-analysis) were done by Torsten Berg (MariLim, Kiel).

The MarBIT-tool – a short summary

The MarBIT-tool is a multi-metric assessment system which uses four criteria (species composition, abundances, sensitive and tolerant taxa) which are obligatory for the assessment in terms of the WFD. First, for each ecotope a species reference list has to be derived which bases on autecological informations. The reference list is the basis to determine references for species composition, sensitive and tolerant taxa.
Assessment evaluates a data-set with the reference by using the four criteria as follows:

- Species composition: comparison of reference composition based on taxonomic spread (TSI) which considers taxonomic diversity and species number.
- Abundances are statistically compared as abundance distribution (Kolmogorov-Smirnov-test supplemented with Lillefors-test) with a log-normal distribution.
- The amount of sensitive taxa on the reference list is defined and compared with the number in the data-set. The criteria for sensitive taxa are habitat specialisation, food specialisation, K-strategist and Red List status.
- Tolerant taxa are defined by their r-strategy and the amount in the data-set is compared with the number of tolerant taxa on the reference list.

Each criterion could be used independently and it could yield index values with different class boundaries which are transformed to equal classes (class width 0.2) between 0 and 1. The EQR is calculated as median.
Details are explained in Meyer et al. (2008, http://www.marilim.de/marbit/index.html).

Additions in MarBIT

As MarBIT was developed for the Baltic Sea and although first adaptations were carried out for the ecotype “N2 - sublitoral, 0-5 m” in the euhaline Wadden Sea (Meyer et al. 2007), further additions had to be developed for the utilization on Blue mussel beds in the Wadden Sea.
MarBIT bases on autecological informations for each taxon therefore autecological information about all taxa which could occur potentially on mussel beds had to be added in the data base (literature is listed in chapter 8 “Literature with autecological informations”). This leads to the question which criteria define the ecotop “Blue mussel bed” in the Wadden

Sea and lead to its characteristic associated community with its specific habitat requirements. First, we defined these criteria and secondly added autecological information for all taxa in the data base of MarBIT.

Ecotype characterisation

This evaluation considers mussel beds in the Wadden Sea, which occur in the intertidal. The tidal flats are distinguished in euhalin-sheltered and polyhalin-sheltered water bodies (Fig. 1). Therefore, references have to be defined for both ecotypes. Mussel beds consist of endobenthic and epibenthic species which is an important characteristic of mussel beds.

Additionally, we had to check if the criteria „mussel bed" could be or has to be used or if other criteria (e.g. "mud") for substrate-/habitat-requirements are sufficient to derive a complete reference list.

According to this, the ecotypes N2 and N4 are characterised as follows:

Ecotype N2:

- Habitat → range → **intertidal**
- habitat → salinity → **euhalin**
- habitat → substrate-/habitat-requirements → **mud / mussel bed**
- habitat → vertical habitat → **epibenthic**
- habitat → vertical habitat → **endobenthic**

Ecotype N4:

- habitat → range → **intertidal**
- habitat → salinity → **polyhalin**
- habitat → substrate-/habitat-requirements → **mud / mussel bed**
- habitat → vertical habitat → **epibenthic**
- habitat → vertical habitat → **endobenthic**

Basing on these characterizations, species reference lists for intertidal mussel beds in the Wadden Sea are derived from autecological data.

Mussel beds which are covered with *Fucus vesiculosus* are not evaluated separately.

Autecological information

To derive reference lists autecological information had to be completed for the relevant criteria and species. We supposed that we achieved a complete species list of all possible benthic species which might occur on mussel beds (basing on papers and sources presented in chapter 5.1). Besides these papers additional sources are used for autecological information (chapter 8). We checked ecological information even for those species which are rare on mussel beds.

Treatment of sensitive and tolerant taxa

Tolerant taxa are defined as taxa which are r-strategist and tolerant against eutrophication. The list of sensitive taxa is defined by using the parameters habitat specialisation, food specialisation, K-strategist and Red List status. If one of these four criteria is fulfilled, the taxon occurs on the reference list for sensitive taxa. Existing autecological information about habitat specialisation, food specialisation and r-/K-strategist in the MarBIT data base was assumed to be valid for the Wadden Sea too. Therefore, only the Red List status was adopted for the Wadden Sea.

Some further remarks:

- Some taxonomic difficulties exist with the genus *Littorina*. The Wadden Sea harbours three species (*Littorina littorea*, *L. saxatilis* and *L. fabalis*, compare Seidel 2002). *L. fabalis* is synonymous with *L. mariae* and *L. obtusata* looks similar to *L. fabalis*. Due to the fact that species identification is complex (basing on certain characteristics of the penis of males and to the pigment coating of the ovipositor of females, Seidel 2002), we suggest to summarize *L. mariae* and *L. fabalis* as *L. obtusata* for evaluations.

- Data basis for mussel beds in the water type N4 is comparatively small. Grotjahn (2006) analyzed six positions for his type with a total of 64 taxa. Within this water type N4 in Schleswig-Holstein no sampling of mussel bed communities has been conducted yet. Therefore no EQRs could be calculated. Autecological informations for further species, listed by Grotjahn (2006), were completed and at least a reference list could be presented.

- Parameters (habitat specialist, food specialist, K-strategist, red list status) to identify sensitive taxa are described by Meyer et al. (2007, 2008). In terms of the Wadden Sea only the Red List status had to be revised while the other parameters are assumed to be valid for the species no matter if the species live in the Baltic or the Wadden Sea.

- Several individuals occur in the samples which cannot be determined on species level due to the fact that sometimes only fragments of individuals remain or they are damaged. Furthermore, polychaets like Nephtyidae (*Nephtys* sp.) and Nereidae (*Nereis* sp., *Hediste* sp., *Neanthes* sp.) have to be at least 2 cm long for species determination, smaller individuals are determined only on higher taxonomic level (Sach pers. comment).

- Individuals of Nemertini indet. are found regularly in different densities and individuals of *Tetrastemma* sp. and *Lineus ruber* are found sporadically. Because indetermined individuals might be also included in biomass and abundances data of Nemertini indet., only the phylum level should be used.

- Amongst indetermined individuals of Actiniaria there could be masked individuals of *Edwardsia* sp. (which were found in a single sample only) and *Sagartia troglodytes*. Because the amount of indetermined Actiniaria is high and determination is only possible in a fresh status all proofs should be summarized under Actiniaria indet. Methods for sample conservation used in the mussel monitoring do not permit species determination of Actiniaria (Sach pers. comment).

- As far as possible, abundance data are used but individuals are not counted for all species, therefore the following taxa are included with presence/absence-data only:
    - *Alcyonidium hirsutum*
    - *Electra crustulenta*
    - *Electra pilosa*
    - *Hydractinia echinata*
    - *Laomedea flexuosa*
    - *Membranipora membranacea*
    - *Obelia longissima*
    - *Sertularia cupressina*

- Between 1999 and 2002 10 mussel beds (five in the Lister Deep and five in the Norderhever) with 10 samples each were sampled. Since 2003, four mussel beds (two beds in each tidal basin) are sampled with 25 samples each. Evaluating single mussel beds with 10 samples only is insufficient and could hardly be compared with the data since 2003. Therefore we pooled the data within the two tidal basins to obtain EQRs for all available monitoring years.

Changes and additions in MarBIT

The data base of MarBIT already contains most species of the Wadden Sea (Meyer et al. 2007). Only four species had to be added to MarBIT data base:

- *Jassa falcata*
- *Malacoceros fuliginosus*
- *Lagisca extenuata*
- *Cirratula cirratus*

Additionally, clay (“Ton”), organic clay (“Klei”) and peat (“Torf”) were added to the list of possible substrate/habitat-requirements.

Results

Ecotype characterisation

We tried to obtain the references by trying different substrate-/habitat-requirements: mussel bed, mud, mussel bed and mud, mussel bed or mud. All parameters besides “mussel bed” led to insufficient and incomplete reference lists. This may be due to the fact that mussel beds offer a certain kind of habitat which is unique in the Wadden Sea and assimilate a certain community. “Mussel bed” has to be included as parameters as Blue mussels are ecosystem engineers which offer a very special habitat in the Wadden Sea which could hardly be compared with other substrates.

Therefore, we recommend the following parameters to characterize the ecotop:

Ecotype N2:

- habitat → range → **intertidal**
- habitat → salinity → **euhalin**
- habitat → substrate-/habitat-requirements → **mussel bed**
- habitat → vertical habitat → **epibenthic**
- habitat → vertical habitat → **endobenthic**
- distribution → range → **Wadden Sea** (Schleswig-Holstein)

Ecotype N4:

- habitat → range → **intertidal**
- habitat → salinity → **polyhalin**
- habitat → substrate-/habitat-requirements → **mussel bed**
- habitat → vertical habitat → **epibenthic**
- habitat → vertical habitat → **endobenthic**
- distribution → range → **Wadden Sea** (Schleswig-Holstein)

We added information about proofs of these species in the Wadden Sea and on mussel beds in the Wadden Sea.

References

The reference lists for the ecotype N2 and N4 contain 53 taxa each but species composition differs (without introduced taxa 49 and 47 respectively; Tab. 10 and Tab. 11).

As several introduced taxa occur on the reference list we also present the evaluation without Neozoa. Therefore taxa determined as “Neozoa actualia” by Nehring & Leuchs 1999 were excluded from the assessment and results will be compared with those which include Neozoa (“Neozoa actualia” after Nehring & Leuchs (1999): *Crassostrea gigas, Crepidula fornicata, Elminius modestus, Marenzelleria cf. wireni, Petricola pholadiformes, Tharyx killariensis, Balanus improvisus).*

Tab. 10: Reference list of the associated macrobenthic community for Blue mussel beds in the tidal flats in the Wadden Sea of Schleswig-Holstein (N2).

Actiniaria	*Hydrobia ulvae* (Pennant, 1777)
Alcyonidium mytili Dalyell, 1847	*Jaera albifrons* Leach, 1814
Ampharete acutifrons (Grube, 1860)	*Lanice conchilega* (Pallas, 1766)
Anaitides maculata (L., 1767)	*Lepidochitona cinerea* (L., 1767)
Anaitides mucosa (Ørsted, 1843)	*Lepidonotus squamatus* (L., 1758)
Aphelochaeta marioni (de Saint-Joseph, 1894)	*Littorina littorea* (L., 1758)
Balanus crenatus Bruguière, 1789	*Littorina obtusata* (L., 1758)
Bylgides sarsi (Kinberg in Malmgren, 1865)	*Macoma balthica* (L., 1758)
Capitella capitata (Fabricius, 1780)	*Malacoceros fuliginosus* (Claparède, 1868)
Carcinus maenas (L., 1758)	*Malacoceros tetracerus* (Schmarda, 1861)
Cerastoderma edule (L., 1758)	*Membranipora membranacea* (L., 1767)
Conopeum reticulum (Linnaeus, 1767)	*Mytilus edulis* L., 1758
Crangon crangon (L., 1758)	*Neanthes succinea* (Frey & Leuckart, 1847)
Crassostrea gigas (Thunberg, 1793)	*Neanthes virens* (M. Sars, 1835)
Crepidula fornicata (Linneaus, 1758)	Nemertini
Electra pilosa (L., 1768)	*Neoamphitrite figulus* (Dalyell, 1853)
Elminius modestus Darwin, 1854	*Nephtys hombergii* Savigny, 1818
Eteone longa (Fabricius, 1780)	*Nereis longissima* (Johnston, 1840)
Eulalia viridis (L., 1767)	*Nereis pelagica* L., 1758
Eumida sanguinea (Ørsted, 1843)	*Polydora ciliata* (Johnston, 1838)
Gammarus locusta (L., 1758)	*Polydora cornuta* Bosc, 1802
Gammarus zaddachi Sexton, 1912	*Pygospio elegans* Claparède, 1863
Gattyana cirrosa (Pallas, 1766)	*Scoloplos armiger* (O. F. Müller, 1776)
Harmothoe imbricata (L., 1767)	*Semibalanus balanoides* (Linnaeus, 1766)
Harmothoe impar (Johnston, 1839)	*Styela clava* Herdman, 1881
Hediste diversicolor (O. F. Müller, 1776)	*Tharyx killariensis* (Southern, 1914)
Heteromastus filiformis (Claparède, 1864)	

Tab. 11: Reference list of the associated macrobenthic community for Blue mussel beds in the tidal flats in the Wadden Sea of Schleswig-Holstein (N4).

Actiniaria	*Hydrobia ulvae* (Pennant, 1777)
Ampharete acutifrons (Grube, 1860)	*Jaera albifrons* Leach, 1814
Anaitides maculata (L., 1767)	*Kefersteinia cirrata* (Keferstein, 1862)
Anaitides mucosa (Ørsted, 1843)	*Lanice conchilega* (Pallas, 1766)
Aphelochaeta marioni (de Saint-Joseph, 1894)	*Laomedea flexuosa* Alder, 1857
Balanus crenatus Bruguière, 1789	*Lepidochitona cinerea* (L., 1767)
Balanus improvisus Darwin, 1854	*Lepidonotus squamatus* (L., 1758)
Bylgides sarsi (Kinberg in Malmgren, 1865)	*Littorina littorea* (L., 1758)
Capitella capitata (Fabricius, 1780)	*Littorina obtusata* (L., 1758)
Carcinus maenas (L., 1758)	*Macoma balthica* (L., 1758)
Cerastoderma edule (L., 1758)	*Malacoceros fuliginosus* (Claparède, 1868)
Conopeum reticulum (Linnaeus, 1767)	*Malacoceros tetracerus* (Schmarda, 1861)
Crangon crangon (L., 1758)	*Membranipora membranacea* (L., 1767)
Crassostrea gigas (Thunberg, 1793)	*Mytilus edulis* L., 1758
Crepidula fornicata (Linneaus, 1758)	*Neanthes succinea* (Frey & Leuckart, 1847)
Electra pilosa (L., 1768)	*Neanthes virens* (M. Sars, 1835)
Elminius modestus Darwin, 1854	*Neoamphitrite figulus* (Dalyell, 1853)
Eteone longa (Fabricius, 1780)	*Nephtys hombergii* Savigny, 1818
Eulalia viridis (L., 1767)	*Nereis pelagica* L., 1758
Eumida sanguinea (Ørsted, 1843)	*Pholoe balthica* Ørsted, 1843
Gammarus locusta (L., 1758)	*Polydora ciliata* (Johnston, 1838)
Gammarus zaddachi Sexton, 1912	*Polydora cornuta* Bosc, 1802
Gattyana cirrosa (Pallas, 1766)	*Pygospio elegans* Claparède, 1863
Harmothoe imbricata (L., 1767)	*Scoloplos armiger* (O. F. Müller, 1776)
Harmothoe impar (Johnston, 1839)	*Semibalanus balanoides* (Linnaeus, 1766)
Hediste diversicolor (O. F. Müller, 1776)	*Styela clava* Herdman, 1881
Heteromastus filiformis (Claparède, 1864)	

Tab. 12: List of sensitive taxa on intertidal and subtidal mussel beds (for criteria see text).

Actiniaria	
Crangon crangon	(L., 1758)
Crepidula fornicata	(Linneaus, 1758)
Electra pilosa	(L., 1768)
Gammarus locusta	(L., 1758)
Gammarus zaddachi	Sexton, 1912
Gattyana cirrosa	(Pallas, 1766)
Laomedea flexuosa	Alder, 1857
Lepidochitona cinerea	(L., 1767)
Lepidonotus squamatus	(L., 1758)
Littorina littorea	(L., 1758)
Littorina obtusata	(L., 1758)
Membranipora membranacea	(L., 1767)
Nephtys hombergii	Savigny, 1818
Nereis pelagica	L., 1758
Obelia longissima	(Pallas, 1766)
Pagurus bernhardus	(Linnaeus, 1758)
Psammechinus miliaris	
Sertularia cupressina	

Species accumulation plots (bootstrap-analysis)

An important aspect is the necessary amount of samples needed to find all taxa. Species accumulation plots are used to show how many taxa could be found with a certain number of samples at best or at worst. The plots are based on 100 iterations and contain points with different colours. Brighter points indicate that the according number of taxa was found more often for a certain number of samples than it was the case for darker points.

Exemplarily, species accumulation plots for the Lister Deep are presented. Results are similar for the Norderhever:

The following analysis considers only those taxa which belong to the reference list. All other taxa are excluded. However, only these taxa are relevant for the evaluation.

Between 1999 and 2005 44 taxa were found in the Lister Deep (the reference lists contains 49 taxa). On average 12 taxa with 162 individuals occurred in a sample. If all samples in one year are pooled about 34-42 taxa are found each year. Lowest numbers were found in 2004 and 2005 e.g. due to absence of some sensitive taxa.

First, all years are summarized to achieve some general information (Fig. 34). All 334 samples contain 44 taxa. The curve shows the typical form of a species accumulation plot with a rampant curve in the left part which is flattening in the right part. A number of 312 samples give the guarantee that all taxa are found which belong to the reference. At best all taxa are found with 20 samples but in the opposite case it would only be 32 taxa.

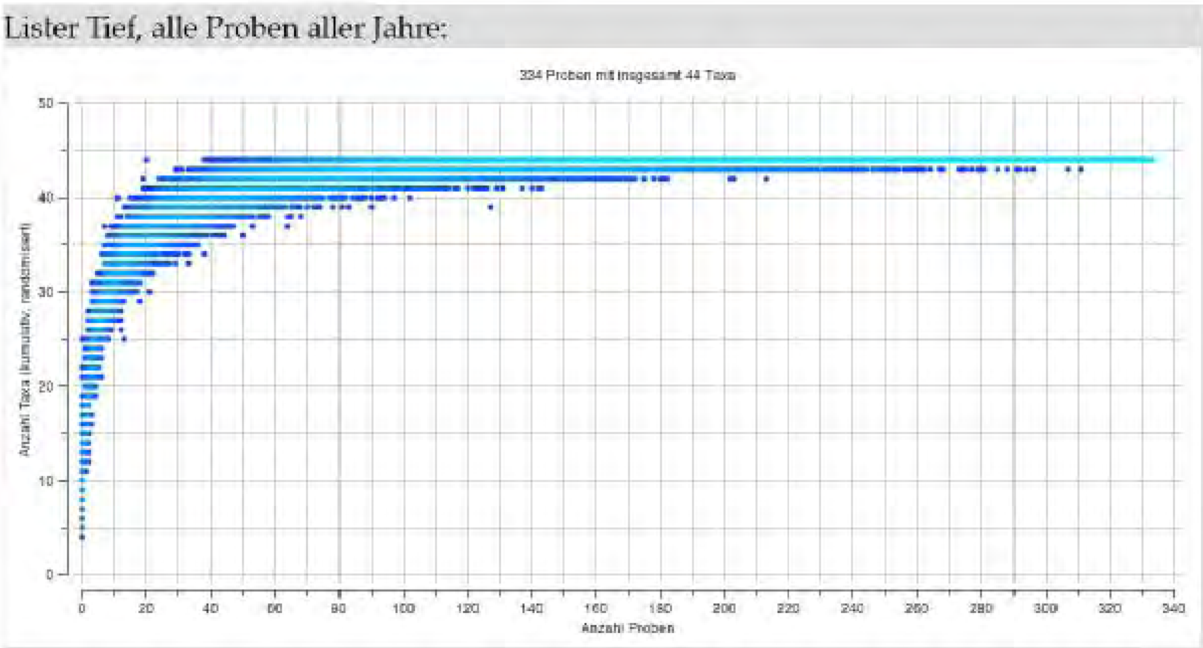

Fig. 34: Species accumulation plot (bootstrap-analysis) with all data (all years and all mussel beds) in the Lister Deep.

About 70% of the taxa on the reference list have to be found to obtain a good status with MarBIT for the parameter “species composition” which corresponds to 34 taxa. This number could be achieved on average with 20 samples. But a number of 20 samples is still in the ascending part of the curve. And from 40-60 samples the curve is flattening and the chance to find all 44 taxa increases.

Considering the data of one site (LT01) over all monitoring years 40 of 49 taxa were found (Fig. 35). The curve characteristic is similar to Fig. 34. But additional samples are necessary to obtain 34 taxa in terms of a good ecological status for species composition. With 20-22 samples 70% of the reference taxa are typically found. With 43 and more samples the necessary number of taxa would be found for sure.

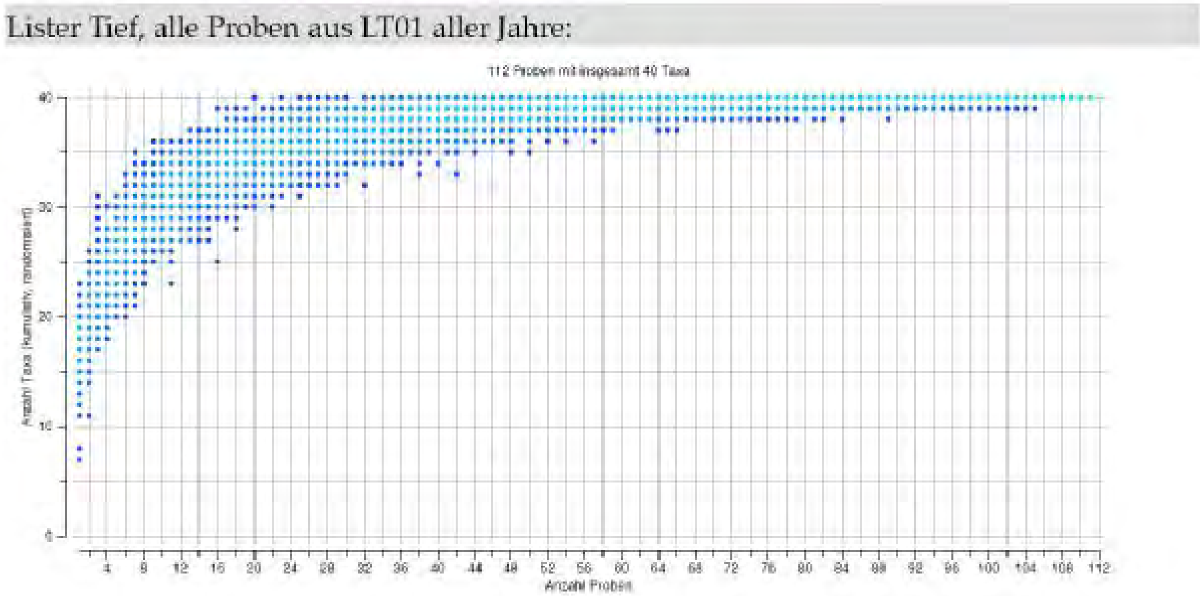

Fig. 35: Species accumulation plot (bootstrap-analysis) with all data from sites LT01 in the Lister Deep.

If all data of one year are pooled for a tidal basin/water body (which is likely in further analysis, Fig. 36) the curve is flat and shows a small slope in the left part. This is because of a comparatively small number of samples (n = 50) and the according small total number of taxa (n = 36). To obtain good status 34 taxa are needed which could be found at best with 30-32 samples and are guaranteed from 47 samples upwards.

This means that at least 50 samples for each water body are needed for evaluation with MarBIT. A smaller number of samples might lead to an apparently moderate status and would count as a methodical artefact.

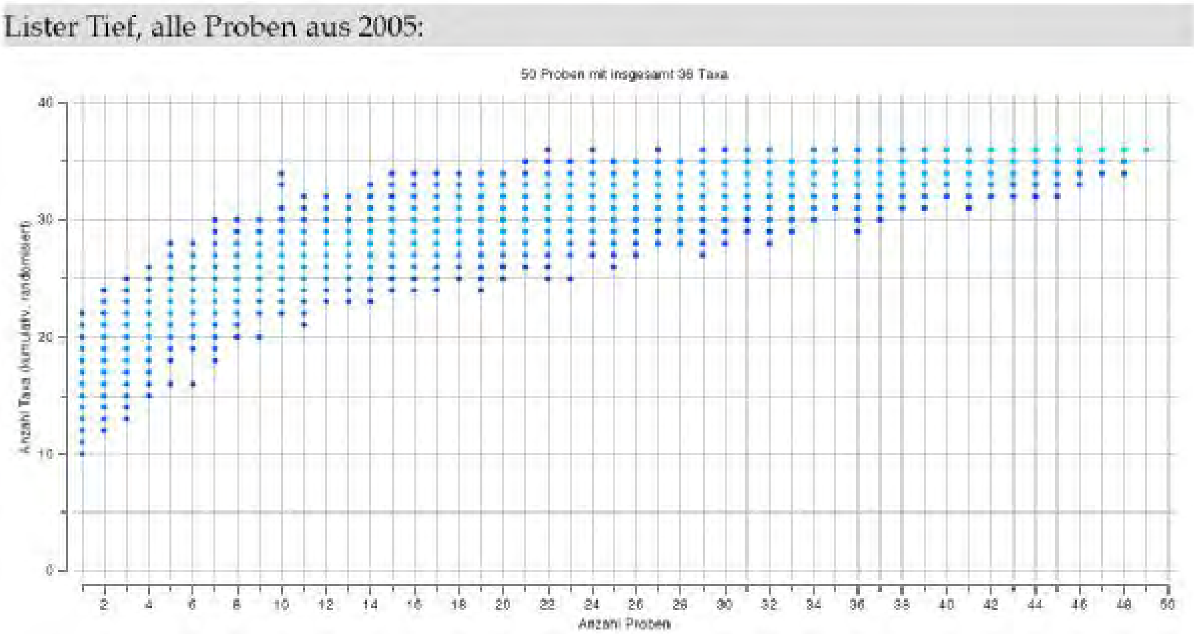

Fig. 36: Species accumulation plot (bootstrap-analysis) with all data in the Lister Deep 2005.

Evaluation with the data-sets of the mussel monitoring

The evaluation resulted in good and moderate EQRs (Tab. 13). The Lister Deep is evaluated with a good status in most years while the Norderhever is evaluated as moderate in most years (including Neozoa). Excluding Neozoa from the evaluation, most EQRs become better except for the years 2001 and 2003 in the Lister Deep and 2004 and 2005 in the Norderhever (Tab. 14).

Tab. 13: Ecological quality ratios (EQRs) basing on the macrobenthic community of Blue mussel beds in two tidal basins in the Wadden Sea of Schleswig-Holstein (LT = Lister Deep, NH (Norderhever).

including neozoa

samples	reference	species number	diversity	abundances	sensitive taxa	tolerant taxa	EQR
Apool-LT-1999	Muschelbank, N2, Muscheln	0,77 (41/53)	0.611	0.447	0.61	0.761	0,610 (gut)
Apool-LT-2000	Muschelbank, N2, Muscheln	0,83 (44/53)	0.714	0.802	0.657	0.724	0,719 (gut)
Apool-LT-2001	Muschelbank, N2, Muscheln	0,87 (46/53)	0.73	0.805	0.705	0.741	0,735 (gut)
Apool-LT-2002	Muschelbank, N2, Muscheln	0,81 (43/53)	0.68	0.53	0.61	0.715	0,645 (gut)
Apool-LT-2003	Muschelbank, N2, Muscheln	0,85 (45/53)	0.722	0.761	0.705	0.764	0,742 (gut)
Apool-LT-2004	Muschelbank, N2, Muscheln	0,72 (38/53)	0.558	0.593	0.343	0.731	0,575 (mäßig)
Apool-LT-2005	Muschelbank, N2, Muscheln	0,70 (37/53)	0.6	0.802	0.4	0.721	0,661 (gut)
Apool-NH-1999	Muschelbank, N2, Muscheln	0,75 (40/53)	0.596	0.195	0.471	0.69	0,534 (mäßig)
Apool-NH-2000	Muschelbank, N2, Muscheln	0,77 (41/53)	0.611	0.274	0.543	0.698	0,577 (mäßig)
Apool-NH-2001	Muschelbank, N2, Muscheln	0,75 (40/53)	0.598	0.58	0.543	0.718	0,589 (mäßig)
Apool-NH-2002	Muschelbank, N2, Muscheln	0,75 (40/53)	0.583	0.548	0.543	0.718	0,565 (mäßig)
Apool-NH-2003	Muschelbank, N2, Muscheln	0,75 (40/53)	0.627	0.198	0.61	0.69	0,618 (gut)
Apool-NH-2004	Muschelbank, N2, Muscheln	0,53 (28/53)	0.461	0.415	0.229	0.693	0,438 (mäßig)
Apool-NH-2005	Muschelbank, N2, Muscheln	0,62 (33/53)	0.554	0.763	0.4	0.681	0,618 (gut)

without neozoa

samples	reference	species number	diversity	abundances	sensitive taxa	tolerant taxa	EQR
Apool-LT-1999	Muschelbank, N2, Muscheln	0,80 (39/49)	0.684	0.468	0.592	0.773	0,638 (gut)
Apool-LT-2000	Muschelbank, N2, Muscheln	0,84 (41/49)	0.775	0.805	0.646	0.726	0,751 (gut)
Apool-LT-2001	Muschelbank, N2, Muscheln	0,88 (43/49)	0.792	0.689	0.697	0.745	0,721 (gut)
Apool-LT-2002	Muschelbank, N2, Muscheln	0,82 (40/49)	0.738	0.588	0.592	0.717	0,655 (gut)
Apool-LT-2003	Muschelbank, N2, Muscheln	0,86 (42/49)	0.784	0.661	0.697	0.768	0,733 (gut)
Apool-LT-2004	Muschelbank, N2, Muscheln	0,71 (35/49)	0.58	0.587	0.308	0.73	0,583 (mäßig)
Apool-LT-2005	Muschelbank, N2, Muscheln	0,69 (34/49)	0.63	0.704	0.369	0.719	0,667 (gut)
Apool-NH-1999	Muschelbank, N2, Muscheln	0,80 (39/49)	0.696	0.195	0.515	0.708	0,606 (gut)
Apool-NH-2000	Muschelbank, N2, Muscheln	0,82 (40/49)	0.726	0.421	0.592	0.717	0,655 (gut)
Apool-NH-2001	Muschelbank, N2, Muscheln	0,78 (38/49)	0.68	0.578	0.515	0.728	0,629 (gut)
Apool-NH-2002	Muschelbank, N2, Muscheln	0,78 (38/49)	0.655	0.468	0.515	0.728	0,585 (mäßig)
Apool-NH-2003	Muschelbank, N2, Muscheln	0,78 (38/49)	0.713	0.197	0.592	0.699	0,646 (gut)
Apool-NH-2004	Muschelbank, N2, Muscheln	0,53 (26/49)	0.494	0.199	0.185	0.695	0,347 (unbefriedigend)
Apool-NH-2005	Muschelbank, N2, Muscheln	0,63 (31/49)	0.592	0.544	0.369	0.686	0,568 (mäßig)

Tab. 14: Comparison of the evaluations including and excluding introduced species.

	including neozoa	without neozoa	difference:
Apool-LT-1999	0,610 (gut)	0,638 (gut)	+0,028
Apool-LT-2000	0,719 (gut)	0,751 (gut)	+0,032
Apool-LT-2001	0,735 (gut)	0,721 (gut)	-0,014
Apool-LT-2002	0,645 (gut)	0,655 (gut)	+0,010
Apool-LT-2003	0,742 (gut)	0,733 (gut)	-0,009
Apool-LT-2004	0,575 (mäßig)	0,583 (mäßig)	+0,008
Apool-LT-2005	0,661 (gut)	0,667 (gut)	+0,006
Apool-NH-1999	0,534 (mäßig)	0,606 (gut)	+0,072
Apool-NH-2000	0,577 (mäßig)	0,655 (gut)	+0,078
Apool-NH-2001	0,589 (mäßig)	0,629 (gut)	+0,040
Apool-NH-2002	0,565 (mäßig)	0,585 (mäßig)	+0,020
Apool-NH-2003	0,618 (gut)	0,646 (gut)	+0,028
Apool-NH-2004	0,438 (mäßig)	0,347 (unbefriedigend)	-0,091
Apool-NH-2005	0,618 (gut)	0,568 (mäßig)	-0,050

Two aspects are of special interest. First, differences between these two approaches - with and without alien species - become more obvious in the evaluation for the tidal basin Norderhever than for the Lister Deep. Mussel beds in the Norderhever are still dominated by Blue mussels. Pacific oysters and other alien taxa are found seldom in comparison to the Lister Deep.

Secondly, mussel beds in the Lister Deep taken over by Pacific oysters since 2003. Interestingly, in 2005 54% of all individuals found on one mussel bed in the Lister Deep belonged to introduced species (Büttger et al. 2008) while on the second mussel bed the amount reached about 79%. However, EQRs in the Lister Deep did not change in particular since oysters and other alien species (e.g. *Crepidula fornicata*, *Elminius modestus*) became more abundant.

Interannual changes of EQR values were highest for the index “abundances” in the Norderhever (Fig. 37). Values range from poor to good. Changes are less pronounced in the Lister Deep. Furthermore, 2004 and 2005 the EQR for “sensitive taxa” dropped to poor conditions in both tidal basins. The indexes “diversity” and “tolerant taxa” are comparatively stable and range in most of the years within the good status. But since 2004 “diversity”-values slightly dropped too and belong to the moderate status in the Norderhever.

The change of the EQR is mostly due to the relative fluctuations of the abundance distribution. This parameter is sensitive to changes and disruptions from a „smooth“ distribution of species abundance to a more discontinuous with few very abundant species and many species with a very low abundance.

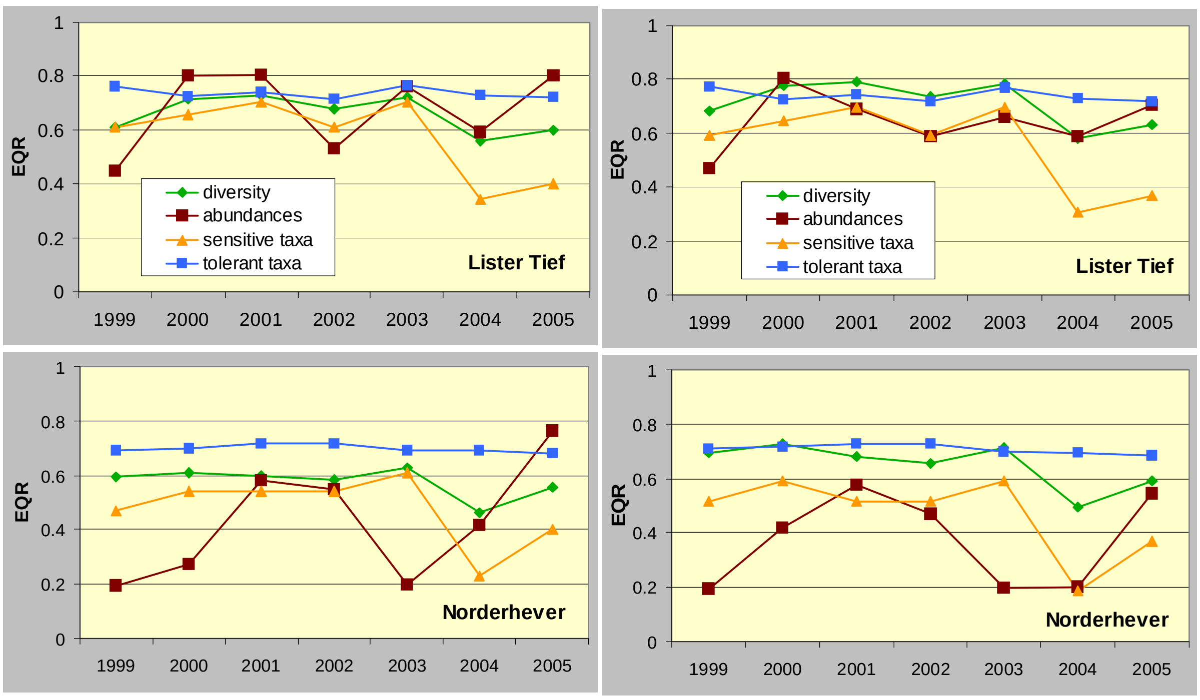

Fig. 37: Development of the four MarBIT-parameters in the Lister Deep and Norderhever (1999-2005, Neozoa are included in the left figures, Neozoa are excluded in the right figures).

Applicability of MarBIT and evaluation of results

The evaluation of the MarBIT tool with macrobenthic data from the mussel monitoring should answer the following question: Can the ecological status of the associated macrobenthic communities of Blue mussel beds in the Wadden Sea be evaluated with the MarBIT tool?
This includes if the reference list is sufficient and if existing data and further monitoring provide a satisfactory number of samples. And second part of the question is if the evaluation with MarBIT leads to meaningful results.

Basically, the application of the MarBIT-tool on Blue mussel beds in Wadden Sea seems to be possible. The taxa reference list is adequate, it is not too short or too long. At least 50 samples are needed from each water body for evaluation with MarBIT. Currently two tidal basins (= water bodies) are monitored. In three additional water bodies ("Hörnumer Tidebecken", "Aue Tidebecken" and "Dithmarscher Bucht", Fig. 28) occur several mussel beds while the other water bodies do not contain mussel beds ("Ausseneider" and "Hakensand") or belong to the exposed water bodies with subtidal areas. The evaluation of these residual five water bodies requires 250 samples at all.
Basing on the presented criteria and the resultant reference list (5.2) accompanied with a number of 50 samples each year and in each water body an evaluation is possible which reflects the real situation. In this case 44 of 49 reference taxa would be obtained and the evaluation with 50 samples would lead to good status.
Higher sampling effort would reflect the real ecological situation better but it would mean a multiplication of samples and the benefit will not justify the increasing effort.
To solve this problem between economy and the demand of the evaluation tool an adopted reference list might be possible. This adopted reference does not contain rare taxa and will be shorter. Therefore, sampling effort could be reduced to display the ecological status satisfactory. Those species which are rare and excluded from the adopted reference list could be considered if they are listed as potential guests and their occurrence will not be incorporated in the evaluation.
Problems arise in this case, as excluding or including taxa to reference always affects the other three indices too. Additionally, rare taxa are often also sensitive.
The Swedish tool BQI accounts for this attribute by defining rare taxa as sensitive, too.
These taxa could not be ignored or excluded as they are important for the whole evaluation and they are normative demand of the WFD. Therefore, only taxa could be excluded which are rare but not sensitive. If this approach leads to useful and designated results could only be concluded after further detailed analysis. This, however, requires further research and is not possible within the scope of the present study.

In general, the results of MarBIT correspond to those results shown in chapter 5.1 (Data from the monitoring in Schleswig-Holstein): Species composition of the associated macrobenthic community of mussel beds is almost stable and did not show pronounced changes. So far, structural changes of mussel beds do not affect macrobenthic community of mussel beds.

For this aspect we have to mention that samples are always taken in populated mussel heaps. Observed structural changes of mussel beds do not affect the associated community directly. Until biomass and densities of mussels are not decreasing under a certain threshold accompanied with less than 10 % coverage - when a site would only be classified as "Streufeld" and not as mussel bed anymore – the associated macrobenthic community will not be affected. If the "habitat engineer" disappears the associated community will disappear too. This aspect emphasizes the need to combine the assessment of the macrobenthic community with the presented approach basing on structural parameters of mussel beds.

Increasing or decreasing abundances do not always influence the EQR of MarBIT in the same manner. The MarBIT-index is most sensitive to changing abundances of "normal" taxa and it is insensitive to changing abundances of rare or abundant taxa. This parameter is the one which is fluctuating mainly in the Norderhever. Maybe, this parameter is less suitable in the Wadden Sea with natural high fluctuations of abundances. Leaving it aside might be possible. But as abundances are a demand of the WFD this index has to be considered. Beyond, increasing abundances of species which do not belong to reference list are not included in the evaluation.

Open questions and recommendations

In addition to the evaluation and the discussion of the MarBIT some questions remain and we want to give some recommendations.

- It is unclear how to deal with alien species in the evaluation. The discussion about this question is still in progress and a decision by the EU is to be awaited.
  Schories & Selig (2006) recommend including alien species in evaluations but they should lead to down-weighting. On the other hand, mostly alien species are tolerant and euryoecious species so that their absence indicates unfavourable ecological conditions (Meyer et al. 2007). And most alien species cannot be removed from the Wadden Sea and occur in almost all samples. If aliens lead to down-weighing, EQRs could never become good or high as long as alien occur. It cannot be the aim to remove aliens apart from the fact that this will not be possible and no adequate measures exists (Meyer et al. 2007).
  Besides several alien species, Pacific oysters exhibit a special situation in the Wadden Sea. In many parts (Lister Deep, Norderaue as well as in Wadden Sea of Denmark, the Dutch Wadden Sea or in Lower Saxony; see Nehls & Büttger 2007) oysters are dominating former Blue mussel beds and became the new habitat engineer. As far as the MarBIT tool shows, the evaluation is not significantly different to those times when sites were mussel beds. This aspect fits with other observations which showed that oyster beds inhibit the similar community as blue mussel beds but changes became obvious in dominance structures and in increasing diversity (Görlitz 2005, Markert 2006, Kochmann 2007, Büttger et al. 2008). The spread of the oysters and their effects on the associated community are very young and are probably not completed yet.
  We recommend including oyster beds in the evaluation although they should be evaluated separately. Oyster beds cannot be removed from the tidal flats without a negative impact. As mussel beds are declining since several years, oyster beds fulfil a similar function: they serve as habitat for many endobenthic and epibenthic species, they offer food and protection. Some species like Common Eiders do not take the same benefits from oyster beds as from Blue mussel beds (Scheiffarth et al. 2008). Therefore evaluation should be critical reviewed and further spread has to be taken into account.
  In the Lister Deep all former mussel are now dominated by oysters. If oysters are not used for the evaluation, the water body "Lister Tidebecken" has to be evaluated in bad status and as long as mussel bed do not return the status wont change. But although pure mussel beds are missed the ecological status of the Lister Deep is not regarded as bad.

- The MarBIT-tool does not include biomass changes so far. Benthic biomass increased in the North Sea (see summary given by Westerhagen & Dethlefsen 2003). Species number and biomass are varying according to water temperature in winter

and spring (indicated by NAO-Index, see Kröncke et al. 1998). Cold winters lead to decreasing species numbers and biomass while increasing spring temperatures lead to increasing species numbers, abundances and biomass (Kröncke et al. 2001). Generally, biomass is an important parameter in the North Sea as well as in the Wadden Sea.
Including this parameter would be favourable. But the question would be how to define a reference and which variations are acceptable.
The BEQI-index is a tool which includes biomass for evaluation. It uses the proportion between macrobenthic biomass and primary production (reference is 10:1).

- We recommend combining the MarBIT-tool with evaluations of further parameters like spatial distribution and size of mussel beds. It is possible to include such parameters as additional indices in the MarBIT assessment system because the assessment is transparent with respect to a number of parameters. Alternatively, it might be possible to include MarBIT as third level (evaluation of changes in the benthic community) in BEQI (Meyer et al. 2007). The first level – ecosystem functioning - evaluates the relation between macrobenthic biomass and system primary production (van Hoy et al. 2007). The second level – habitat and eco-element evaluation – compares the area of habitats. This level is somehow comparable with the first part of this report. Although we include several other parameters which are mussel bed specific and do not evaluate the spatial amount of different habitats. But we recommend including additional parameters like biomass, condition or others to evaluate mussel beds.

- It would be favourable to test MarBIT with other data sets (if available) from mussel beds in the water type N4 and from Lower Saxony, Denmark or The Netherlands to improve the tool and the database.

6 EVALUATION OF BLUE MUSSEL BEDS WITH OTHER INDICES

For the evaluation in terms of the WFD the M-AMBI is generally adopted for Germany. Our neighbouring countries Denmark and the Netherlands use other assessment methods. Below these indices are presented briefly and their suitability for mussel beds is stated.

AMBI and M-AMBI

The AMBI (AZTI's Marin Biotic Index) was developed by Borja et al. (2000) for the north-Atlantic coast of Spain and Heyer (2006) tested its application for the Wadden Sea. AMBI evaluates the response of communities to changes of water quality. The tool is useful for some habitats in the Wadden Sea (Heyer 2006), but "AMBI is not suitable for classifying naturally mud rich habitats (muddy or organic enriched sediments, mussel beds)" and thus not suitable to evaluate Blue mussel beds in Wadden Sea (Heyer 2006).

The M-AMBI (multivariate AMBI) combines AMBI with species richness and diversity (Shannon). Mussel beds have not been assessed with M-AMBI (Heyer 2006), but similar problems are likely as the AMBI is part of the assessment

DKI

The Danish assessment method is composed of a number of species and individuals, diversity (Shannon's H) and AMBI (Scholle & Dau 2007). Because the AMBI is not suitable for mussel beds we assume the multimetric DKI not to be useful for mussel beds too, but this has not been tested yet.

BEQI

The Benthic Ecosystem Quality Index (BEQI) has been adopted for the Dutch costal waters and includes a multilevel scale-dependent approach (Ysebaert & Hermann 2004, Van Hoey et al. 2007). This includes three levels: the ecosystem, habitats and communities within the habitats. The ecosystem functioning is evaluated with the relation between macrobenthic biomass and system primary production. The habitat level compares area sizes and shares of the different habitat with a reference. The third level deals with the community changes including densities, biomass, species richness and species composition. For details see Van Hoey et al. (2007).

This approach defines references based on data sets from before 1983, thus, they cannot be considered as real historical and undisturbed conditions.

Using data from the 1970s or 1980s for references is difficult because this is the period which is probably most affected by human activities. However, the approach leaves the possibility to define new references if new data lead to better references. Additionally, the BEQI includes biomass as a parameter which is known to be very important and which increased in the Wadden Sea recently. The amount of sensitive and tolerant taxa is not evaluated particularly as the MarBIT does.

Mussel beds in the Wadden Sea are naturally muddy and organic enriched habitats, few species which are eutrophication sensitive would occur and tolerant or indifferent taxa are common. Therefore biomass might be a good parameter for mussel bed assessment.
Until now, mussel beds are evaluated on level 2 only due to the lack of monitoring data in the Netherlands to derive the references from, but in general the applicability for mussel beds (on level 3) is to be supposed (van Hoey pers. comment). Monitoring data from Schleswig-Holstein are quite new. But as the first years of the monitoring might represent a typical mussel bed structure, they can be assumed as a good reference basis which might be compared those first surveys on mussel beds done by Asmus (1987) in the Lister Deep. However, we would not recommend using only data from Asmus (1987) as reference as they originate from one mussel bed only and this mussel bed is known storing high biomass values due to its placement within the tidal basin.

7 LITERATURE

Albrecht, A. (1991) Einfluß der Braunalge *Fucus vesiculosus* auf die Lebensgemeinschaft von Miesmuschelbänken im Wattenmeer. Diplomarbeit, Universität Göttingen.

Albrecht, A. & K. Reise (1994) Effects of *Fucus vesiculosus* covering intertidal mussel beds in the Wadden Sea. Helgol. Meeresunters. 48: 243-256.

Asmus, H. (1987) Secondary production of an intertidal mussel bed community related to its storage and turnover compartments. Mar. Ecol. Prog. Ser. 39: 251-266.

Borja, A., Franco, J. & V. Perez (2000) A marine biotic index to establish the ecological quality of soft-bottom benthos within European Estuarine and Coastal Environments. Marine Pollution Bulletin, 40: 1100-1114.

Brinkmann, A. G. (1993) Estimation of length and weight growth parameters in populations with a discrete reproduction characteristic. IBN research report 93/5, Wageningen.

Buschbaum, C. (2002) Siedlungsmuster und Wechselbeziehungen von Seepocken (Cirrepedia) auf Muschelbänken (*Mytilus edulis* L.) im Wattenmeer. Ber. Polarforsch. Meeresforsch. 408.

Büttger, H., H. Asmus, R. Asmus, C. Buschbaum, S. Dittmann & G. Nehls (2008) Community dynamics of intertidal soft-bottom mussel beds over two decades. Helgol. Mar. Res. 62: 23-36; DOI: 10.1007/s10152-007-0099-y

CWSS (2004) Report of the Workshop “Water Framework Directive and Wadden Sea cooperation”. Unpubl. Report.

Dittmann, S. (1987) Die Bedeutung der Biodeposite für die Benthosgemeinschaft der Wattsedimente unter besonderer Berücksichtigung der Miesmuschel *Mytilus edulis* L.. Dissertation, Universität Göttingen.

Dittmann, S. (1990) Mussel beds – amensalism or amelioration for intertidal fauna? Helgol. Meeresunters. 44: 335-352.

Görlitz, S. (2005) Neue Riffe im Wattenmeer: Die Pazifische Auster *Crassostrea gigas* und ihre assoziierte Lebensgemeinschaft. Diplomarbeit, Universität Kiel.

Franke, H. D. (2008) Änderung des Ökosystems der Deutschen Bucht im Zuge des Klimawandels. Vortrag, BSH Meeresumwelt-Symposium 2008, Hamburg. http://www.bsh.de/de/Das_BSH/Veranstaltungen/MUS/2008/Kurzfassungen.pdf

Franke, H.D. & L. Gutow (2004) Long-term changes in the macrozoobenthos around the rocky island of Helgoland (German Bight, North Sea). Helgol Mar Res 58:303-310

Grotjahn, M. (2006) Habitatspezifische Charakterisierung der MZB-Gemeinschaft in den Küstengewässern der FGE Ems, Weser und Elbe. Vorl. Entwurfsfassung. Aqua –Marin, Norden.

Gutiérrez J. L., C. G. Jones, D. L. Strayer & O. O. Iribane (2003) Mollusks as ecosystem engineers: the role of shell production in aquatic habitats. Oikos 101:79-90.

Hagmeier, A. & R. Kändler (1927) Neue Untersuchungen im nordfriesischen Wattenmeer und auf fiskalischen Austernbänken. – Wiss. Meeresunters. Abt. Helgoland 16: 1-90.

Hauser, B. & H. Michaelis (1975) Die Makrofauna der Watten, Strände, Riffe und Wracks um den Hohen Knechtsand in der Wesermündung. - Jber. 1974, Forsch. - Stelle Küste., 26: 85-120.

Hertzler, I. (1995) Nahrungsökologische Bedeutung von Miesmuschelbänken für Vögel (Laro-Limikolen) im Nordfriesischen Wattenmeer. Diplomarbeit, Universität Göttingen.

Heyer, K. (2006) Anpassung des AMBI-Bewertungsverfahrens an das Schleswig-Holsteinische Watt (Abschlussbericht). Bericht für das Landesamt für Natur und Umwelt Schleswig-Holstein.

Jones CG, J. H. Lawton & M. Shachak (1994) Organisms as ecosystem engineers. Oikos 69:373-386

Kochmann, J. (2007) Different ecosystem engineering by alien oysters and native mussels – a field experiment in the Wadden Sea. Master Thesis. University of Southern Denmark Odense.

Linke, O. (1939) Die Biota des Jadebusenwattes. - Helgol. Wiss. Meersesunters. 1: 201- 348.

Marencic, H. & K. Essink (2004) The EU Water Framework Directive – Implications for the Wadden Sea. Wadden Sea Newsletter 2004-1: 5-7.

Markert, A. (2006) Untersuchung der Lebensgemeinschaft eines durch die Pazifische Auster (*Crassostrea gigas*) neu entstandenen Austernriffs im Ostfriesischen Wattenmeer. Diplomarbeit, University of Berlin, Germany

Michaelis, H. (1969) Makrofauna und Vegetation der Knechtsandwatten. - Jber.1967,Forsch.-Stelle f. Insel- u. Küstenschutz 19, Norderney: 147-175.

Michaelis, H. (1987) Bestandsaufnahme des eulitoralen Makrobenthos im Jadebusen in Verbindung mit einer Luftbildanalyse. - Jber. 1986, Forsch.-Stelle Küste 38: 13-98.

Meyer, M. & H. Michaelis (1980) Das Makrobenthos des westlichen "Hohen Weges". - Jber.1979, Forsch. - Stelle f. Insel- u .Küstenschutz 31, Norderney: 91-155.

Meyer, T., T. Berg & K. Führhaupter (2006) Bewertung von Makrozoobenthos im Küstengwässer der FGE Weser und Elbe nach WRRL. Test einer MarBIT-Erweiterung. MariLim Gewässeruntersuchung, Kiel. Im Auftrag des Niedersächsischen Landesbetriebes für Wasserwirtschaft, Küsten- und Naturschutz, Brake.

Meyer, T., T. Berg & K. Führhaupter (2008) Ostsee-Makrozoobenthos-Klassifizierungssystem für die Wasserrahmenrichtlinie. Referenzartenlisten, Bewertungsmodell und Monitoring. MariLim Gewässeruntersuchung, Kiel. Im Auftrag der Universität Rostsock.

Nehls, G. (1995) Strategien der Ernährung und ihre Bedeutung für Energiehaushalt und Ökologie der Eiderente (*Somateria mollissima* (L., 1758)). Dissertation, Universität Kiel.

Nehls, G. & C. Ketzenberg (2002) Do Common Eiders *Somateria mollissima* exhaust their food resources? A study on natural mussel Mytilus edulis beds in the Wadden Sea. Dan Rev Game Biol 16:47-61

Nehls, G. & M. Thiel (1993) Large-scale distribution patterns of the Blue Mussel (*Mytilus edulis*) in the Wadden Sea of Schleswig-Holstein: Do storms structure the ecosystem? Neth. J. Sea Res. 31: 181-187.

Nehls. G. & H. Büttger (2006) Miesmuschelmonitoring 1998 – 2005 im Nationalpark Schleswig-Holsteinisches Wattenmeer. Unveröff. Bereicht im Auftrag des Landesamtes für den Nationalpark Schleswig-Holsteinisches Wattenmeer.

Nehls. G. & H. Büttger (2007) Spread of the Pacific Oyster *Crassostrea gigas* in the Wadden Sea – causes and consequences of a successful invasion. HARBASINS-Report in behalf of The Common Wadden Sea Secretariat, Wilhelmshaven.

Nehls. G. & H. Büttger (in prep.) Miesmuschelmonitoring 2006 und 2007 im Nationalpark Schleswig-Holsteinisches Wattenmeer. Unveröff. Bereicht im Auftrag des Landesamtes für den Nationalpark Schleswig-Holsteinisches Wattenmeer.

Plath, M. (1943) Die biologische Bestandsaufnahme als Verfahren zur Kennzeichnung der Wattsedimente und die Kartierung der nordfriesischen Watten. – Westküste, Kriegsheft, S.: 7-45.

Reise K (1983) The role of predation on intertidal flats. In: Dankers, H., Kühl, Wolff, W.J. (Eds.), Invertebrates of the Wadden Sea, Balkema, Rotterdam.

Reise, K. (1985) Tidal flat ecology. Springer Verlag.

Reise K., Herre E., & Sturm M. (1989) Historical changes in the benthos of the Wadden Sea around the island of Sylt in the North Sea. Helgoländer Meeresunters. 43: 417-433.

Remane, A. (1940) Die Sand- und Weichböden-Coenosen der Gezeitenzone des Küstengebietes (Eulitoral). – In: Die Tierwelt der Nord- und Ostsee, Grimpe, G. & E. Wagler (Hrsg.), S.: I.a 91-I.a 237.

Ruth, M. (1994) Untersuchungen zur Biologie und Fischerei von Miesmuscheln im Nationalpark Schleswig-Holsteinisches Wattenmeer. Unveröff. Bericht Ökosystemforschung Schleswig-Holsteinisches Wattenmeer.

Ruth, M. (undated) Die Muschelfischerei in Deutschland seit dem zweiten Weltkrieg. ULR: http://www.royal-frysk.de/start_d.html.

Saier, B. (2001) Ecological comparison of intertidal and subtidal mussel beds (*Mytilus edulis* L.) in the Wadden Sea. Dissertation, Universität Hamburg.

Saier, B. (2002) Subtidal and intertidal mussel beds (*Mytilus edulis* L.) in the Wadden Sea: diversity differences of associated epifauna. Helgoland Marine Research 56: 44-50.

Scholle, J. & K. Dau (2007) Reference conditions of biological quality components in accordance with the EU Water Framework Directive in coatsl and transitional waters in NL, D and DK. Status of development and comparison with the targets of the trilateral Wadden Sea Plan. HARBASINS-Report in behalf of The Common Wadden Sea Secretariat, Wilhelmshaven.

Schories, D. & U. Selig (2006) Die Bedeutung eingeschleppter Arten (*alien species*) für die Europäische Wasserrahmenrichtlinie am Beispiel der Ostsee. Rostock. Meeresbiolog. Beitr. 15:147-158.

Schürmann, A. (1998) Bestand und Biomasse der Miesmuschel (*Mytilus edulis* L.) im Königshafen unter Berücksichtigung verschiedener Muschelbankstrukturen. Diplomarbeit, Technische Hochschule Aachen, Germany

Seidel, B. (1999) Küstenfischerei in Nordfriesland. Schriftreihe des Nordfriesischen Schiffahrtsmuseums Husum, Band3.

Smidt, E. L. B. (1951) Animal Production in the Danish Wadden Sea. Meddel. Komm. Denmarks Fisk. Havundersög. Ser. Fisk. 11: 1-151.

Stoddard, P. (2003) Reconstruction of Blue Mussel Beds Using Aerial Photographs from 1989 and 2002 of the North Frisian Wadden Sea, Germany. Unpubl. Report, BioConsult SH, Hockensbüll.

Thamdrup, H. M. (1935) Beiträge zur Ökologie der Wattenfauna auf experimenteller Grundlage. Meddel. Komm. Denmarks Fisk. Havundersög. Ser. Fisk. 10: 1-125.

Van Hoey, G., J. Drent, T. Ysebaert & P. Herman (2007) The Benthic Ecosystem Quality index (BEQI), intercalibration and assessment of Dutch Coastal and Transitional Waters for the Water Framework Directive. NIOO rapport 2007-02

Westernhagen, H. v. & V. Dethlefsen (2003) Änderung der Artenzusammensetzung in Lebensgemeinschaften der Nordsee. In: Lozan, J. L., E. Rachor, K. Reise, J. Sündermann & H. v. Westernhagen (Hrsg.) Warnsignale aus der Nordsee und Wattenmeer – Eine aktuelle Umweltbilanz. Wissenschaftl. Auswertungen, Hamburg.

Wohlenberg, E. (1931) Die grüne Insel in der Eidermündung, eine entwicklungsphysiologische Untersuchung. Arch. Dt. Seewarte, 50: 1-34.

Wohlenberg, E. (1937) Die Wattenmeer-Lebensgemeinschaft im Königshafen von Sylt. Helgol. Wiss. Meeresunters. 1: 1-92.

Ysebaert, T. & P. M. J. Herman (2004) The assessment of the ecological status of coastal and transitional waters based on benthic macroinvertebrates: classification and intercalibration within the Water Framework Directive. NIOO-CEME Report 2004.1

8 LITERATURE WITH AUTECOLOGICAL INFORMATION

Albrecht, A. (1991) Einfluß der Braunalge *Fucus vesiculosus* auf die Lebensgemeinschaft von Miesmuschelbänken im Wattenmeer. Diplomarbeit, Universität Göttingen.

Albrecht, A., Reise, K. (1994) Effects of *Fucus vesiculosus* covering intertidal mussel beds in the Wadden Sea. Helgol. Meeresunters. 48: 243-256.

Ankel, W.E. (1936) Die Pantoffelschnecke auf deutschen Austernbänken. Nat Volk 66: 11-13

Asmus, H. (1987) Secondary production of an intertidal mussel bed community related to its storage and turnover compartments. Mar. Ecol. Prog. Ser. 39: 251-266.

Ballerstedt, S. (2005) *Ligia oceanica*. Common sea slater. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 13/09/2007]. Available from: http://www.marlin.ac.uk/species/Ligiaoceanica.htm

Beukema, J.J. (1992) Dynamics of juvenile shrimp *Crangon crangon* in a tidal-flat nursery of the Wadden Sea after mild and cold winters. Mar Ecol Prog Ser 83:157-165

Budd, G.C. (2002) *Gammarus salinus*. A gammarid shrimp. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Gammarussalinus.htm

Budd, G.C. (2007) *Abra alba*. A bivalve mollusc. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Abraalba.htm

Budd, G.C. (2007) *Asterias rubens*. Common starfish. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Asteriasrubens.htm

Buhs F. & K. Reise (1997) Epibenthic fauna dredged from tidal channels in the Wadden Sea of Schleswig-Holstein: spatial patterns and a long-term decline. Helgoländer Meeresunters. 51: 343-359.

Buschbaum, C. (2002) Siedlungsmuster und Wechselbeziehungen von Seepocken (Cirrepedia) auf Muschelbänken (*Mytilus edulis* L.) im Wattenmeer. Ber. Polarforsch. Meeresforsch. 408.

Buschbaum, C. & G. Nehls (2003) Effekte der Miesmuschel- und Garnelenfischerei, In: Lozán, J.L., E. Rachor, K. Reise, J. Warnsignale aus Nordsee & Wattenmeer : eine aktuelle Umweltbilanz ; mit 50 Tabellen / Hrsg.: José L. Lozán .... Hamburg : Büro "Wiss. Auswertungen", 250-255

Carter, M.C. (2005) *Angulus tenuis*. Thin tellin. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 13/09/2007]. Available from: http://www.marlin.ac.uk/species/Angulustenuis.htm

Davis, M. H., J. Lützen, M. E. Davis (2007) The spread of *Styela clava* Herdman, 1882 (Tunicata, Ascidiacea) in European waters. Aquatic Invasions 2: 378-390.

de Vlas, J., B. Brinkman, C. Buschbaum, N. Dankers, M. Herlyn, P.S. Kristensen, G. Millat, G. Nehls, M. Ruth, J. Steenbergen & A. Wehrmann (2005): Intertidal Blue mussel beds. In: Essink, K., C. Dettmann, H. Farke, K. Laursen, G. Lüerßen, H. Marencic & W. Wiersinga (Eds.): Wadden Sea Quality Status Report 2004. Wadden Sea Ecosystem No. 19..

Diederich, S. (2005) Invasion of Pacific oysters (*Crassostrea gigas*) in the Wadden Sea: competitive advantage over native mussels. PhD thesis, University of Kiel, Germany

Dittmann, S. (1987) Die Bedeutung der Biodeposite für die Benthosgemeinschaft der Wattsedimente unter besonderer Berücksichtigung der Miesmuschel *Mytilus edulis* L.. Dissertation, Universität Göttingen.

Dittmann, S. (1990) Mussel beds - amensalism or amelioration for intertidal fauna? Helgol Meeresunters 44:335-352

ERMS by MARBEF, http://www.marbef.org/data/erms.php

Farke, M. (1979) Population dynamics, reproduction and early development of *Tharys marioni* (Polychaeta, Cirratulidae) on tidal flats of the German Bight. Veröff. Meeresforsch. Bremerh. 18:69-99

George, J. D. (1971) The Effects of Pollution by Oil and Oil-Dispersants on the Common Intertidal Polychaetes, *Cirriformia tentaculata* and *Cirratulus cirratus*. J Applied Ecology 8:411-420

Grotjahn, M. (2006) Habitatspezifische Charakterisierung der MZB-Gemeinschaft in den Küstengewässern der FGE Ems, Weser und Elbe. Vorl. Entwurfsfassung. Aqua –Marin, Norden.

Günther, C.-P. (1996): Development of small *Mytilus* beds and its effects on resident intertidal macrofauna. P.S.Z.N.I: Mar. Ecol. 17: 117-130.

Hagmeier, A. & R. Kändler (1927) Neue Untersuchungen im nordfriesischen Wattenmeer und auf fiskalischen Austernbänken. – Wiss. Meeresunters. Abt. Helgoland 16: 1-90.

Hartmann-Schröder, G. (1996) Die Tierwelt Deutschlands und der angrenzenden Meeresteile nach ihren Merkmalen und nach ihrer Lebensweise. Teil 58 Annelida, Borstenwürmer, Polychatea. 2., neubearb. Aufl., Gustav Fischer Verlag, Jena.

Hauser, B. & H. Michaelis (1975) Die Makrofauna der Watten, Strände, Riffe und Wracks um den Hohen Knechtsand in der Wesermündung. - Jber. 1974, Forsch. - Stelle Küste., 26: 85-120

Hayward, P., T. Nelson-Smith & C. Shields (1996) Sea Shore of Britain and Europe. Collins Pocket Guide

Hayward, P.J. J. S. Ryland (1995) Handbook of the marine fauna of North-West Europe. Oxford University press.

Heard, J.R. (2005) *Pycnogonum littorale*. A sea spider. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 13/09/2007]. Available from: http://www.marlin.ac.uk/species/Idoteabaltica.htm

Hempel, C. (1957) Über das Festsetzen der Larven und die Bohrtätigkeit der Jugendstadien von *Polydora ciliata* (Polychaeta sedentaria). Helgol. Mar. Res. 7: 80-92.

Hertlein, A. (1997) Assoziierte Epifauna der Miesmuschelbänke (*Mytilus edulis* L.) im Sylter Wattenmeer. Diplomarbeit, Universität Bonn.

Hertzler, I. (1995) Nahrungsökologische Bedeutung von Miesmuschelbänken für Vögel (Laro-Limikolen) im Nordfriesischen Wattenmeer. Diplomarbeit, University of Göttingen, Germany

Hill, J.M. (2000) *Jassa falcata*. An amphipod. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Jassafalcata.htm

Hill, J.M. (2006) *Ensis* spp.. Razor shell. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 09/01/2007]. Available from: http://www.marlin.ac.uk/species/Ensisspp..htm

Hiscock, K. (2007) *Halichondria panicea*. Breadcrumb sponge. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Halichondriapanicea.htm

Hughes, J.R. (2007) *Crassostrea gigas*. Pacific oyster. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 13/09/2007]. Available from: http://www.marlin.ac.uk/species/Crassostreagigas.htm

Jackson, A. (2000) *Hydrobia ulvae*. Laver spire shell. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Hydrobiaulvae.htm

Jackson, A. (2007) *Littorina littorea*. Common periwinkle. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Littorinalittorea.htm

Lee, C.-G., M. Huettel, J.-S. Hong & K. Reise (2004) Carrion feeding on the sediment surface at nocturnal low tides by the polychaete *Phyllodoce mucosa*, Marine biology, 145, 575-583, doi:10.1007/s00227-004-1334-6 .

Linke, O. (1939) Die Biota des Jadebusenwattes. - Helgol. Wiss. Meersesunters. 1: 201- 348.

Luther, G. (1987) Seepocken der deutschen Küstengewässer. HMR 41: 1- 43

Lützen, J. (1999) *Styela clava* Herdman (Urochordata, Ascidiacea), a successful immigrant to North West Europe: ecology, propagation and chronology of spread. Helgol Meeresunters 52: 383-391.

Meyer, M. & H. Michaelis (1980) Das Makrobenthos des westlichen "Hohen Weges". - Jber.1979, Forsch. - Stelle f. Insel- u .Küstenschutz 31, Norderney: 91-155.

Michaelis, H. (1969) Makrofauna und Vegetation der Knechtsandwatten. - Jber.1967,Forsch.-Stelle f. Insel- u. Küstenschutz 19, Norderney: 147-175.

Michaelis, H. (1987) Bestandsaufnahme des eulitoralen Makrobenthos im Jadebusen in Verbindung mit einer Luftbildanalyse. - Jber. 1986, Forsch.-Stelle Küste 38: 13-98.

Neal, K.J. & S. Ballerstedt (2006) *Cirratulus cirratus*. A bristleworm. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 25/03/2008]. Available from: http://www.marlin.ac.uk/species/Cirratuluscirratus.htm

Neal, K.J. & P. Avant (2006) *Corophium volutator*. A mud shrimp. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Corophiumvolutator.htm

Nehls. G. & H. Büttger (2006) Miesmuschelmonitoring 1998 – 2005 im Nationalpark Schleswig-Holsteinisches Wattenmeer. Unveröff. Bereicht im Auftrag des Landesamtes für den Nationalpark Schleswig-Holsteinisches Wattenmeer.

Nehls. G. & H. Büttger (2007) Spread of the Pacific Oyster *Crassostrea gigas* in the Wadden Sea – causes and consequences of a successful invasion. Report in behalf of The Common Wadden Sea Secretariat, Wilhelmshaven.

Nehring S. & H. Leuchs (1999) Neozoa (Makrozoobenthos) an der deutschen Nordseeküste – Eine Übersicht. Bundesamt für Gewässerkunde, Koblenz. Bericht BfG-1200, pp 131

Obert, B. & H. Michaelis (1991) History and ecology of the mussel beds (*Mytilus edulis* L.) in the catchment area of a Wadden Sea tidal inlet. In: Elliott M, Ducrotoy J (eds) Estuaries and coasts: spatial and temporal intercomparisons. Olsen & Olsen, Fredensborg, p 185–194

Pizzolla, P.F. (2007) *Littorina obtusata*. Common flat periwinkle. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 13/09/2007]. Available from: http://www.marlin.ac.uk/species/Littorinaobtusata.htm

Plath, M. (1943) Die biologische Bestandsaufnahme als Verfahren zur Kennzeichnung der Wattsedimente und die Kartierung der nordfriesischen Watten. – Westküste, Kriegsheft, S.: 7-45.

Rayment, W.J. (2007) *Crepidula fornicata*. Slipper limpet. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Crepidulafornicata.htm

Reise, K. (1982) Long-term changes in the macrobenthic invertebrate fauna of the Wadden Sea: are polychaetes about to take over? Netherlands Journal of Sea Research 16: 29-36.

Reise, K. (1983) The role of predation on intertidal flats. In: Dankers, N., Kühl, H., Wolff, W.J. (Eds.), Invertebrates of the Wadden Sea, Balkema, Rotterdam.

Reise, K. (1990) Karl Möbius: Dredging the first community concept from the bottom of the sea. Dt. Hydrographische Zeitung 22/90: 149-151.

Reise, K. (1998).Pacific oysters invade mussel beds in European Wadden Sea, Senckenbergiana maritima, 28, 167-175.

Reise K. & A. Schubert (1987) Macrobenthic turnover in the subtidal Wadden Sea: the Norderaue revisited after 60 years. Helgoländer Meeresunters. 41: 69-82.

Reise K., E. Herre & M. Sturm (1989) Historical changes in the benthos of the Wadden Sea around the island of Sylt in the North Sea. Helgoländer Meeresunters. 43: 417-433.

Reise K., E. Herre, & M. Sturm (1994) Biomass and abundance of macrofauna in intertidal sediments of Königshafen in the northern Wadden Sea. Helgoländer Meeresunters. 48: 201-215.

Reise, K. & I. Bartsch (1990) Inshore and offshore diversity of epibenthos dredged in the North Sea. Neth. J. Sea Res. 25: 175-179.

Reise, K., S. Gollasch & W.-J. Wolff (1999).Introduced marine species of the North Sea coasts, Helgoländer Meeresuntersuchungen, 52, 219-234.

Reiss, H. & I. Kröncke (2001). Spatial and temporal distribution of macrofauna in the Otzumer Balje. In: Kröncke, I. M. Türkay & J. Sündermann (eds): Burning issues of North Sea ecology, Proceedings of the 14th international Senckenberg Conference "North Sea 2000", Senckenbergiana maritima, 31 (2): 283-298.

Remane, A. (1940) Die Sand- und Weichböden-Coenosen der Gezeitenzone des Küstengebietes (Eulitoral). – In: Die Tierwelt der Nord- und Ostsee, Grimpe, G. & E. Wagler (Hrsg.), S.: I.a 91-I.a 237.

Remane, A. (1958): in : Remane, A. & Schlieper C.: Die Biologie des Brackwassers. Die Binnengewässer 22:1-348

Riesen, W. & K. Reise (1982): Macrobenthos of the subtidal Wadden Sea: revisited after 55 years.- Helgoländer Meeresunters. 35: 409-423.

Saier, B. (2001) Ecological comparison of intertidal and subtidal mussel beds (*Mytilus edulis* L.) in the Wadden Sea. Dissertation, Universität Hamburg.

Saier, B. (2002) Subtidal and intertidal mussel beds (*Mytilus edulis* L.) in the Wadden Sea: diversity differences of associated epifauna. Helgoland Marine Research 56: 44-50.

Seidel, D. (2002) Zur Verbreitungsökologie der Flachen Strandschnecke *Littorina fabalis* im Sylter Wattenmeer. Diplomarbeit, Universität Hamburg

Smidt, E.L.B. (1951) Animal Production in the Danish Wadden Sea. Meddel. Komm. Denmarks Fisk. Havundersög. Ser. Fisk. 11: 1-151.

Thamdrup, H. M. (1935) Beiträge zur Ökologie der Wattenfauna auf experimenteller Grundlage. Meddel. Komm. Denmarks Fisk. Havundersög. Ser. Fisk. 10: 1-125.

Thiel, M. & T. Dernedde (1994) Recruitment of shore crabs *Carcinus maenas* on tidal flats: mussel clumps as an important refuge for juveniles. Helgol Meeresunters 48:321-332

Thiel M. & T. Dernedde (1996) Reproduction of *Amphiporus lactifloreus* (Hoplonemertini) on tidal flats: implications for studies on the population biology of nemertines. Helgol Mar res 50:337-351

Thieltges, D.W., M. Strasser & K. Reise (2003) The American slipper limpet *Crepidula fornicata* (L.) in the northern Wadden Sea 70 years after its introduction. Helgol Mar Res 57:27-33

Tyler-Walters, H. (2003) *Mya arenaria*. Sand gaper. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Myaarenaria.htm

Tyler-Walters, H. (2003) *Obelia longissima*. A hydroid. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Obelialongissima.htm

Tyler-Walters, H. (2005) *Electra pilosa*. A sea mat. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Electrapilosa.htm

Tyler-Walters, H. (2005) *Idotea baltica*. An isopod. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 13/09/2007]. Available from: http://www.marlin.ac.uk/species/Idoteabaltica.htm

Tyler-Walters, H. (2007) *Cerastoderma edule*. Common cockle. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Cerastodermaedule.htm

Tyler-Walters, H. & S. Ballerstedt (2005) *Conopeum reticulum*. An encrusting bryozoan. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/09/2007]. Available from: http://www.marlin.ac.uk/species/Conopeumreticulum.htm

Wehrmann, A. (1999) Long-term survival of epibenthic *Cerastoderma edule* (L.) in bivalve clusters on backbarrier tidal flats, North Sea. Senckenb. Marit. 30: 47-61

Wehrmann, A. (2003) Biogenic and taphonomic processes affecting the development of shell assemblages: an actuopaleontological case study from mussel banks on the North Sea tidal flats. Facies 49: 19-30

Wehrmann, A., M. Herlyn, F. Bungenstock, G. Hertweck & G. Millat (2000) The distribution gap is closed—first record of naturally settled Pacific oysters (*Crassostrea gigas*) in the East Frisian Wadden Sea, North Sea. Senckenb Marit 30:153–160

Westheide, W. (1966) Zur Polychaetenfauna des Eulitorals der Nordseeinsel Sylt. Helgol Mar Res 13:203-209.

Westphalen, A. (2006): Assoziierte Lebensgemeinschaften von natürlichen Muschelbänken und Muschelkulturflächen im Wattenmeer. Diplomarbeit, Universität Göttingen.

Wohlenberg, E. (1931) Die grüne Insel in der Eidermündung, eine entwicklungsphysiologische Untersuchung. Arch. Dt. Seewarte, 50: 1-34.

Wohlenberg, E. (1937) Die Wattenmeer-Lebensgemeinschaft im Königshafen von Sylt. Helgol. Wiss. Meeresunters. 1: 1-92.

Wolff, W. (1983) Ecology of the Wadden Sea. Volume one – chapter 4 Invertebrates of the Wadden Sea. A. A. Balkema, Rottderdam.

Wolff, W.J. & N. Dankers (1981). Preliminary checklist of the zoobenthos and nekton species of the Wadden Sea, in: Dankers, N. et al. (1981). Invertebrates of the Wadden Sea: final report of the section 'Marine Zoology' of the Wadden Sea Working Group. Wadden Sea Working Group Report, 4: pp. 24-60.

Ziegelmeier, E. (1957) Die Muscheln (Bivalvia) der deutschen Meeresgebiete. Helgol. Wiss. Meeresunters. 6. 1-59.

Ziegelmeier, E. (1966) Die Schnecken (Gastropoda Prosobranchia) der deutschen Meeresgebiete und brackigen Küstengewässer. Helgol. Wiss. Meeresunters. 13: 1-61.