Evaluation of blue mussel beds in the North-Frisian Wadden Sea – according to the EU Water Framework Directive and EU Habitats Directive

Heike Büttger[1], Torsten Berg[2], Georg Nehls[1],
h.buettger@bioconsult-sh.de (corresponding author), berg@marilim.de, n.nehls@bioconsult-sh.de
[1]BioConsult SH, Brinckmannstr. 31, D-25813 Husum, [2]MariLim Gewässeruntersuchung Kiel, Heinrich-Wöhlk-Str. 14, D-24232 Schönkirchen

1. Introduction

Mussel beds are special, characteristic and long living surface and near-surface habitats within the Wadden Sea. They provide a habitat for many endobenthic as well as epibenthic species. Diversity and biomass is higher on mussel beds than on the surrounding tidal flats. Within the dynamic Wadden Sea, mussel beds are stable structures that can survive over decades at the same site. Changes which might affect the macrobenthic community become apparent on long-established mussel beds.

The assessment of the conservation status within such 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 between mild winters and 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 extent and the structure of intertidal benthic communities of the Wadden Sea thus shows much stronger annual fluctuations than in 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'. Thus, any assessment of the ecological status of benthic communities of the Wadden Sea must be based on a solid description of their characteristics 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 could be easily distinguished from other benthic communities.

According to the EU Water Framework Directive (WFD), all member states have to bring their water bodies (including the German coast of the Wadden Sea) into a good ecological state by 2015. Already the Wadden Sea Quality Status Report 2004 (Essink *et al.*, 2005) mentioned that "The biotope 'intertidal blue mussel bed at stable sites' should be considered within the WFD as a biological quality element for coastal waters". The continuing mussel monitoring in the National Park of the Wadden Sea Schleswig-Holstein offers more than ten years of data, which is a good basis for an initial assessment of the WFD evaluation criteria.

Furthermore, blue mussel beds are a characteristic feature of the habitat type 1140 "mudflats and sandflats" under the Habitats Directive (HD). The HD demands the maintenance of favourable conservation status of specified habitat types, including 1140 and its mussel beds.

This paper presents an approach to the assessment of blue mussel beds within the terms of the WFD, which will also meet the requirements of the HD.

2. Approach to derive references

Structural parameters (*e.g.* number of mussel beds, age structure, biomass, stability of mussel beds and others) are reviewed for an evaluation of the ecological status and references for the high ecological status will be given.

The evaluation of the associated community of mussel beds as required by the WFD is examined by using the index-tool MarBIT, a system developed by MariLim (Kiel) for the Baltic Sea (Meyer *et al.*, 2008).

3. Structural parameters

3.1 Mussel bed area and steadiness of sites

The analysis of aerial photographs from 1958 identified 126 blue mussel beds covering an area of about 750 ha. Information about comparatively small mussel harvests in the 1950s (Seidel, 1999), the lack of fishery traces on intertidal mussel beds (with one exception) on the aerial pictures, the absence of ice winters in the years before 1958 (pers. comment BSH, 2008) and statements about the general development of mussel stocks in the Wadden Sea (Reise *et al.,* 1989; Michaelis, 1987), lead to the conclusion that mussel stocks in 1958 have not been unduly affected. Therefore, the digitalized mussel bed area in 1958 is assumed to be within a typical range and these data are used as a measuring point to determine references of mussel bed area and stability of sites.

The reference value of the total mussel bed area was calculated as a mean value of the years 1958, 1988-1994 (Ruth, 1994; Stoddard, 2003) and 1998-2001, which results in a mean value of 991 ha. As eutrophication is likely to support blue mussels, a strong increase of mussel bed area is regarded as negative and leads to downgrading within the WFD evaluation.

To assess stability of sites, we define steadiness of sites which were found in nearly all years (at least in 11 years), which were found in 1958 or in 1989 and in at least in five years of monitoring between 1998 and 2007. Sites which were populated in all years during the monitoring (1998-2007) but not in 1958 or 1989 are also included. Using these criteria, it follows that 63 sites should be populated by blue mussel beds regularly. The WFD covers six years for every evaluation period, which means that all sites could be populated 378 times at best.

3.2 Biomass

Biomass of the mussel beds is determined mainly as live-wet-weight (LWW), which is calculated by using the formula lnLWW= 2,919ln (length in mm)-8,764 (Nehls 1995). 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 and no marked change of the baseline occurred until 2001. Therefore we suggest using data between 1998 and 2001: the frequency distribution indicates the median value of LWW as 12.4 kg/m² in these years and we use this as the reference point. As eutrophication is likely to support blue mussel biomass, increasing mussel biomass leads to downgrading in the evaluation.

3.4 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). Using data from all size classes could lead to decreasing trends of flesh-content in response to the age structure, but would not reflect environmental changes. Therefore we recommend using a limited size group from 20 to 49 mm and selected mussel beds which are monitored continuously. Because the a-parameter of 20 to 49 mm mussels did not show a general significant trend in the monitoring until 2006 (Nehls and Büttger, 2009), seasonal reference values are determined as the mean values of the years 1998-2006.

3.5 Other parameters

Further parameters like density, age-structure (cohorts) or spatfall occurrences and maximum shell-length were evaluated, but due to high variability between years, seasons or mussel bed sites, we do not recommend to use these parameters for an evaluation. These parameters are reflected by the four recommended parameters. For instance, sufficient spatfall would be apparent in steady or increasing mussel bed area and mussel biomass.

3.6 Recommendations for reference values and evaluation of changes

Considering the different parameters presented, we recommend the reference values listed in Table 1 which refer to the North-Frisian Wadden Sea of Schleswig-Holstein. Mean values of the parameters for the first evaluation period 1998-2003 are converted into linear ecological quality ratios (EQRs) from bad (0) to highest status (1) according to the procedure of Meyer *et al.* (2008). The overall status is calculated as mean value of the four EQRs.

3.7 Exemplary assessment

For the first monitoring period 1998 – 2003 the conservation status is classified as green (Table 1). For the second period (2004-2009) the data from 2004 – 2007 indicate a worsening situation.

These proposed references refer to the North-Frisian part of the Wadden Sea of Schleswig-Holstein. As the number and stability of sites and area is much smaller in Dithmarschen, references and class limits for structural parameters could hardly be defined. The WFD requires evaluations of different water bodies. But mussel beds do not occur in all water bodies. It will not be possible to define references and evaluate each water body separately by using structural parameters of mussel beds.

Table 1:
Proposed reference values for the parameters 'area', 'biomass', 'steadiness of sites' and 'condition' in order of an evaluation of the North-Frisian Wadden Sea of Schleswig-Holstein according to the WFD. Resulting EQRs for the first monitoring period 1998-2003 are given.

	Reference	High	Good	Moderate	Poor	Bad	1998-2003	EQR
Area [ha]	990 ha	2000 ≥ 990	2250 ≤ 991 or 989 ≤ 750	2500 ≤ 2251 or 749 ≤ 500	2750 ≤ 2501 or 499 ≤ 250	>2751 or <249	757	0,606
Steadiness	63 sites (in all six years 378 x)	378 – 340 (≤10%)	339 ≤ 291x *(11 ≥ 25%)*	290 ≤ 189x *(26 ≥ 50%)*	188 ≤ 95x *(51 ≥ 75%)*	95 ≤ 0x *(≥ 76%)*	306 x	0,663
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%)*	11,9	0,772
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	2.87E-05 3.40E-05 3.88E-05 3.90E-05	0,945
							Overall status	0,747

3.8 Transferability to the requirements of the Habitats Directive

Basing on the comparison of rating matrices according to the WFD and HD (proposal by M. Stock, Schleswig-Holstein Agency for Coastal Defence, National Park and Marine Conservation - National Park authority) we assume that the presented approach might me useable both in terms of the HD and WFD. The favourable conservation status (green, HD) can be considered as comparable to the good ecological status (WFD). The evaluation schemes for these two directives must be comparable.

4. Associated community – adoption of the MarBIT-tool

This chapter presents the MarBIT-tool assessment of the associated community of mussel beds in the Wadden Sea for the WFD. The tool is a multi-metric assessment system which uses four obligatory criteria: species composition, abundances, sensitive and tolerant taxa. The blue mussel monitoring provides macrobenthic data of mussel beds since 1999 and data until 2005 were used for this MarBIT test .

For each ecotope, a species reference list has to be derived, based on autecological information and which is the basis to determine references for species composition, sensitive and tolerant taxa. Each of these criteria is evaluated separately and merged in the EQR as mean. For more details about MarBIT please read Meyer *et al.*, (2008) and www.marilim.de/marbit/index.html.

4.1 Additions in MarBIT

As MarBIT was developed for the Baltic Sea, further additions had to be developed for its utilization on blue mussel beds in the Wadden Sea.

First, autecological information about all taxa which could occur potentially on mussel beds had to be added into the database. The ecotope "intertidal blue mussel bed in the Wadden Sea" was characterised with different parameters (habitat range intertidal; habitat salinity euhalin (N2) or polyhalin (N4), substrate-/habitat-requirements mussel bed, vertical habitat epibenthic or endobenthic; distribution range Wadden Sea, Schleswig-Holstein). Basing on the ecotope characterization, species reference lists are derived from autecological data.

4.2 Results

The reference lists for the ecotype N2 and N4 contain 53 taxa each, but species composition differs (without introduced taxa 49 and 47 respectively). As several introduced taxa occur on the reference list we also present the evaluation without Neozoa (defined as "Neozoa actualia" by Nehring and Leuchs, 1999).

An important aspect is the necessary amount of samples needed for a useful evaluation. About

70% (= 34 taxa) of the taxa on the reference list have to be found to obtain a 'good' status with MarBIT. This number could be found at best with 30-32 samples and is guaranteed from 47 samples upwards, therefore at least 50 samples for each water body are needed. A smaller number of samples might lead to an apparently 'moderate' status and would count as a methodical artefact. Therefore, macrobenthic data of each tidal basin were pooled for the evaluation.

4.3 Evaluation with the data-sets of the mussel monitoring

The overall evaluation resulted in good and moderate EQRs (Table 2). The evaluation of the Lister Deep does not change in general if Neozoa are in- or excluded from the species reference list. In the Norderhever, evaluation is worse in the first years and better in the last three years if Neozoa are included in the reference. Differences between including or excluding Neozoa from the evaluation become more obvious in the evaluation of the Norderhever where Neozoa are found seldomly in comparison to the Lister Deep. Mussel beds in the Lister Deep have been dominated by Pacific oysters (*Crassostrea gigas*) 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. Values range between poor and 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 dropped slightly and belong to the 'moderate' status in the Norderhever.

The EQR changes 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 situation, with few very abundant species and many species with a very low abundance.

5. Applicability of MarBIT and evaluation results

Basically, the application of the MarBIT-tool on blue mussel beds in the Wadden Sea seems to be possible. Basing on min. 50 samples per water body, the evaluation of five water bodies (where mussel beds occur) requires a total of 250 samples. To solve this problem between economy and the demand of the evaluation tool, an adapted (shorter) reference list might be possible. Taxa which are rare but not sensitive could be excluded. However, this approach requires further research.

In general, the results of MarBIT correspond to those results shown by Nehls and Büttger (2006) and Büttger *et al.,* 2008: 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 composition of mussel beds.

The MarBIT-index is most sensitive to changing abundances of "normal" taxa and it is insensitive to changing abundances of rare or abundant taxa. Perhaps this parameter is less suitable in the Wadden Sea because of its naturally high fluctuations of abundances. Leaving it aside might be possible. But the parameter 'abundance' is a demand of

Table 2: Evaluation of the macrobenthic community of blue mussel beds in the tidal basins Lister Deep (LT) and Norderhever (NH) between 1999 and 2005 with the MarBIT-tool.

	including neozoa	without neozoa
Apool-LT-1999	0,610 (good)	0,638 (good)
Apool-LT-2000	0,719 (good)	0,751 (good)
Apool-LT-2001	0,735 (good)	0,721 (good)
Apool-LT-2002	0,645 (good)	0,655 (good)
Apool-LT-2003	0,742 (good)	0,733 (good)
Apool-LT-2004	0,575 (moderate)	0,583 (moderate)
Apool-LT-2005	0,661 (good)	0,667 (good)
Apool-NH-1999	0,534 (moderate)	0,606 (good)
Apool-NH-2000	0,577 (moderate)	0,655 (good)
Apool-NH-2001	0,589 (moderate)	0,629 (good)
Apool-NH-2002	0,565 (moderate)	0,585 (moderate)
Apool-NH-2003	0,618 (good)	0,646 (good)
Apool-NH-2004	0,438 (moderate)	0,347 (poor)
Apool-NH-2005	0,618 (good)	0,568 (moderate)

the WFD. Furthermore, increasing abundances of species which are not on the reference list will not affect the evaluation.

The MarBIT-tool does not include biomass changes so far. Generally, biomass is an important parameter in the North Sea (see summary given by Westerhagen and Dethlefsen, 2003; Kröncke *et al.*, 1998, 2001) as well as in the Wadden Sea. Including this parameter might be worthwhile. But the questions would be how to define a reference for it and what variations would be acceptable.

6. Open questions and recommendations

It is unclear how to deal with alien species in the evaluation and the discussion is still in progress. Schories and Selig (2006) recommend including alien species in evaluations but they should lead to down-weighting. On the other hand, most alien species are tolerant and euryoecious species so that their absence indicates unfavourable ecological conditions (Meyer *et al.*, 2007). Most aliens cannot be removed from the Wadden Sea. If aliens lead to down-weighing, EQRs could never become 'good' or 'high' as long as aliens occur. But removal will not be feasible for most species (Meyer *et al.*, 2007).

Pacific oysters exhibit a special situation in the Wadden Sea. In many areas, oysters are dominating former blue mussel beds and becoming the new habitat engineers (Nehls and Büttger, 2007). 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 that showed that oyster beds inhabit a similar community composition as blue mussel beds but changes became obvious in dominance structures and in increasing diversity (Kochmann, 2007; Büttger *et al.*, 2008; Markert *et al.*, 2009). As mussel beds have declined for several years, oyster beds have fulfilled a similar function: they serve as habitat for many endobenthic and epibenthic species, they offer food and protection. Although, some species like common Eiders do not derive the same benefits from oyster beds as from blue mussel beds (Scheiffarth *et al.*, 2008). The spread of the oysters is a comparatively recent process and its effects on the associated communities and the food web are not yet completely known.

In order to evaluate the ecological status of the Wadden Sea based on mussel beds, we recommend enhancing the MarBIT-tool with evaluations of further parameters like spatial distribution and size of mussel beds. A combined evaluation leads to a more reliable result reflecting different aspects of this unique habitat in the Wadden Sea. It would be meaningful to test this first approach with data from Lower Saxony, Denmark or The Netherlands for improvement.

References

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

Büttger, H., Asmus H., Asmus R., Buschbaum C., Dittmann S. and Nehls G., 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.

Essink K., Dettmann C., Farke H., Laursen K., Lüerßen G., Marencic H. and Wiersinga W. (Eds.), 2005. Wadden Sea Quality Status Report 2004. Wadden Sea Ecosystem No. 19. Trilateral Monitoring and Assessment Group, Common Wadden Sea Secretariat, Wilhelmshaven, Germany.

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.

Kröncke I., Dippner J.P., Heyen H. and Zeiss B., 1998. Long-term changes in macrofauna communities off Norderney (East Frisia, Germany) in relation to climate variability. Mar. Ecol. Prog. Ser. 167: 25-36.

Kröncke I., Zeiss B. and Rensing C., 2001. Long-term variability in macrofauna species composition of the island of Norderney (East Frisia, Germany) in relation to changes in climatic and environmental conditions. Senckenb Marit 31:65-82.

Markert A., Kröncke I. and Wehrmann A., 2009. Recently established Crassostrea-reefs vs. native Mytilus-beds: Differences in habitat engineering affects the macrofaunal communities (Wadden Sea of Lower Saxony, southern German Bight). Biol. Invasions DOI 10.1007/s10530-009-9425-4.

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

Meyer T., Berg T. and Führhaupter K., 2007. 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., Berg T. and Führhaupter K., 2008. Ostsee-Makrozoobenthos-Klassifizierungssystem für die Wasserrahmenrichtlinie. Referenzartenlisten, Bewertungsmodell und Monitoring. MariLim Gewässeruntersuchung, Kiel. Im Auftrag der Universität Rostock.

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

Nehls G. and Büttger H., 2006. Miesmuschelmonitoring 1998 – 2005 im Nationalpark Schleswig-Holsteinisches Wattenmeer. Unveröff. Bericht im Auftrag des Landesamtes für den Nationalpark Schleswig-Holsteinisches Wattenmeer.

Nehls G. and Büttger H., 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. and Büttger H., 2009. Miesmuschelmonitoring 2006 und 2007 im Nationalpark Schleswig-Holsteinisches Wattenmeer. Unveröff. Bereicht im Auftrag des Landesamtes für den Nationalpark Schleswig-Holsteinisches Wattenmeer.

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

Reise K., Herre E. and 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.

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

Scheiffarth G., Ens B. and Schmidt A., 2007. What will happen to birds when Pacific Oysters take over the mussel beds in the Wadden Sea. Wadden Sea Newsletter 33: 10-14.

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

Seidel B., 1999. Küstenfischerei in Nordfriesland. Schriftreihe des Nordfriesischen Schifffahrtsmuseums Husum, Band3.

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.

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