**Final Report**

# FEHMARNBELT FIXED LINK
# Marine Biology Services (FEMA)

## Marine Fauna and Flora - Baseline

## Benthic Flora of the Fehmarnbelt Area

**E2TR0020 Volume I**

**Prepared for: Femern A/S**

**By: DHI/IOW/MariLim Consortium**
in association with Cefas and DTU Aqua

**Responsible editor:**
FEMA consortium / co DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark

FEMA Project Director: Hanne Kaas, DHI
www.dhigroup.com

**Please cite as:**
FEMA (2013). Fehmarnbelt Fixed Link EIA.
Marine Fauna and Flora – Baseline
Benthic Flora of the Fehmarnbelt Area.
Report No. E2TR0020 - Volume I

Report: 145 pages

**May 2013**

**ISBN 978-87-92416-38-4**

**Maps:**
Unless otherwise stated:
DDO Orthofoto: DDO®, copyright COWI
Geodatastyrelsen (formerly Kort- og Matrikelstyrelsen), Kort10 and 25 Matrikelkort
GEUS (De Nationale Geologiske Undersøgelser for Danmark og Grønland)
HELCOM (Helsinki Commission – Baltic Marine Environment Protection Commission)
Landesamt für Vermessung und Geoinformation Schleswig-Holstein (formerly Landes-vermessungsamt Schleswig-Holstein) GeoBasis-DE/LVermGeo SH
Model software geographic plots: Also data from Farvandsvæsenet and Bundesamt für Seeschifffahrt und Hydrographie

**Photos:**
Photos taken by consortium members unless otherwise stated



Co-financed by the European Union
Trans-European Transport Network (TEN-T)

## *LIST OF CONTENTS*

Lists of figures and tables are included as the last pages of the report

## *APPENDICES*



Note to the reader:
In this report the time for start of construction is artificially set to 1 October 2014 for the tunnel and 1 January 2015 for the bridge alternative. In the Danish EIA (VVM) and the German EIA (UVS/LBP) absolute year references are not used. Instead the time references are relative to start of construction works. In the VVM the same time reference is used for tunnel and bridge, i.e. year 0 corresponds to 2014/start of tunnel construction; year 1 corresponds to 2015/start of bridge construction etc. In the UVS/LBP individual time references are used for tunnel and bridge, i.e. for tunnel construction year 1 is equivalent to 2014 (construction starts 1 October in year 1) and for bridge construction year 1 is equivalent to 2015 (construction starts 1st January).

## *EXTENDED SUMMARY*

**Present report**
The present L2 report provides the technical documentation of the baseline investigation on marine benthic vegetation conducted as part of the baseline investigations for the Fehmarnbelt Fixed Link.

The report covers two year field study conducted in the Fehmarnbelt and adjacent areas to provide recent data on macroalgal and flowering plant communities.

The results are related to available historical information on the vegetation of the investigation area. Furthermore they are discussed in relation to the Water Framework Directive (WFD) and legislative conservation objectives.

Finally, the importance of the benthic vegetation communites is assessed.

**Purpose of the benthic vegetation baseline investigation**
The purpose of the benthic vegetation baseline investigation is to describe the distribution and abundance of benthic vegetation in Fehmarnbelt and adjacent areas before the Fehmarnbelt Fixed Link construction work starts. The investigation shall

- to document and describe patterns in the composition, distribution and abundance of benthic macroalgae and flowering plants in the proposed alignment area and in the adjacent areas possibly impacted by the construction or operation of a fixed link.
- to document and describe patterns in the distribution and abundance of marine benthic vegetation in the potential affected Natura 2000 areas.
- to provide basis for impact assessment of the proposed technical solutions
- to provide baseline data in the potential impact area and in reference areas for a possible later monitoring of the development in benthic vegetation during and after the establishment of the fixed link across Fehmarnbelt.
- to collect existing and historical data on benthic flora in the Fehmarnbelt area from local monitoring programmes and scientific studies
- to carry out additional quantitative frame sampling of macroalgae and eelgrass at a limited number of sites during winter and spring to describe the seasonal variation in variables essential to calibration of the ecosystem model which will be used for the impact assessment.

**Field study 2009 and 2010**
The field study cover macroalgal and flowering plant communities. The investigation area can be seen in Figure 1.

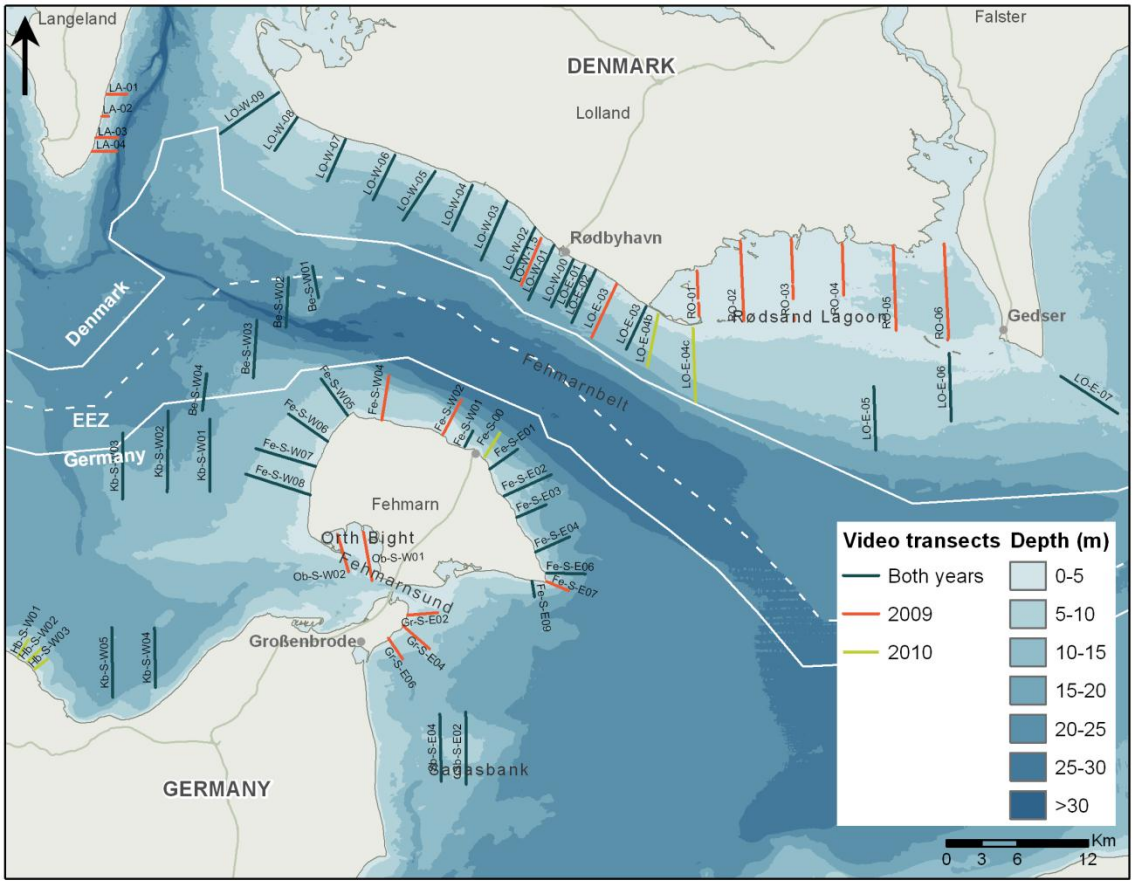



*Figure 1 Investigation area with position of video transects.*

In 2009 the programme consisted of the following investigations in the period from mid-June till ultimo August:

- cover, biomass and spatial distribution of key macroalgal communities
- cover, biomass, shoot density (only eelgrass (*Zostera marina*), depth limit and spatial distribution of flowering plants (angiosperms)

In 2010 the programme was optimised and the programme included the following investigations:

- cover, biomass and spatial distribution of key macroalgal communities
- additional biomass sampling of key macroalgal communities and eelgrass communities in winter and spring 2010
- cover and biomass of key macroalgal communities in reference areas

Vegetation cover and depth distribution were assessed by video recording and by in situ observations by divers. Within predefined depth intervals the divers collected samples for species determination, biomass analysis and shoot density (only for eelgrass).

## Vegetation communities

Five hard bottom macroalgae communities, two soft bottom communities constituted of flowering plants and one mixed algae-flowering plant community were identified.

*Hard bottom macroalgal communities*
The five hard bottom (macroalgae) communities were: *Fucus*-community, *Furcellaria*-community, *Phycodrys/Delesseria*-community, *Saccharina*-community and filamentous species-community.

The *Fucus*-community was found at depths between 1–5 m, but was spatially restricted to a few locations. Key species for this community were serrated wrack (*Fucus serratus)* and bladderwrack (*Fucus vesiculosus).* Accompanying species were the perennial red alga *Ahnfeltia plicata* and the filamentous alga *Polysiphonia fucoides*.

The *Furcellaria*-community was growing at depths between 2–8 m and was widely distributed along the Danish coast. The aggregated taxa group *Coccotylus /Phyllophora* was abundant and occurred mixed with *Furcellaria* stocks as well as with epiphytic growing algae of the genus *Ceramium.*

The *Phycodrys/Delesseria*-community was found at depths between 5–19 m and had a large spatial distribution in the study area. Key species were the perennial red algae *Phycodrys rubens* and *Delesseria sanguinea.* These red algae were accompanied by different other red algae like *Coccotylus/Phyllophora, Membranoptera alata, Brongniartella byssoides, Cystoclonium purpureum* and/or *Rhodomela confervoides*.

The *Saccharina*-community was found at depths between 12–19 m. Key species is the perennial brown alga *Saccharina latissima.* Accompanying species are rare and are morstly annual, filamentous algae (e. g. *Desmarestia aculeata*, *Polysiphonia stricta*) or a key species of other communities (e. g. *Delesseria sanguinea*).

Many sites within the study area showed a dominance of filamentous, opportunistic algae (the filamentous algae community). The species composition and abundance of this group is very variable between sites and depths. No single species can be listed as key species.

*Flowering plants*
The two soft bottom (angiosperm) communities are an eelgrass- and a tasselweed/dwarf eelgrass-community.

The eelgrass-community was found at depths between 1–5 m and was widely distributed in most of the shallow soft bottom areas. Key species for this community is the common eelgrass (*Zostera marina).* Accompanying species are small tiny epiphytic growing algae (*Aglaothamnion/Callithamnion* and/or *Ceramium tenuicorne)*.

The tasselweed/dwarf eelgrass-community was more shallow and distributed between 0.25–1.5 m and spatially restricted to the sheltered shallow water zones of Rødsand Lagoon and Orth Bight. Key species are the narrow-leaf angiosperms tasselweed (*Ruppia cirrhosa/maritima*) and dwarf eelgrass (*Zostera noltii*). These angiosperms are accompanied by different characeans (*Chara aspera, Chara baltica, Tolypella nidifica*) and other angiosperms like the pondweeds *Potamogeton pectinatus* or *Zannichellia palustris.*

The mixed eelgrass/algae community was found at depths between 1 and 5–6 m and the distribution was scattered along the more exposed outer coastline. Contrary to the above mentioned communities, it was found both in sandy bottom areas and in areas with coarse sediments. Key species for this community are

common eelgrass (*Zostera marina)*,different perennial macroalgae characteristic for this depth and filamentous algae.

**Species diversity**

A total of 69 macroalgae species were identified; including 17 green algae, 25 brown algae and 27 red algae species. 15 of the species are listed in the German Red List of the Baltic Sea. None of the species are red-listed in Denmark.

Overall six angiosperm (flowering plants) species and six charophyte species were recorded. Eight of these species are red listed in Germany. None of the species are red-listed in Denmark.

Species diversity at sample sites showed a bell-shaped pattern with depth. The lowest diversity was found in the deepest growing *Saccharina*-community (for description of communities). The highest mean species richness was found in the *Phycodrys/Delesseria* (2009) and in the *Furcellaria* (2010) communities occupying the intermediate depths. I both years the mean species richness was only marginally lower in the *Fucus*- -community, which occupied the more shallow depths. Species diversity was also low in the filamentous species-community which was characteristic for the very shallow water

**Distribution and cover**

Figure 2 shows the distribution and coverage of the benthic vegetation communities within the investigation area.

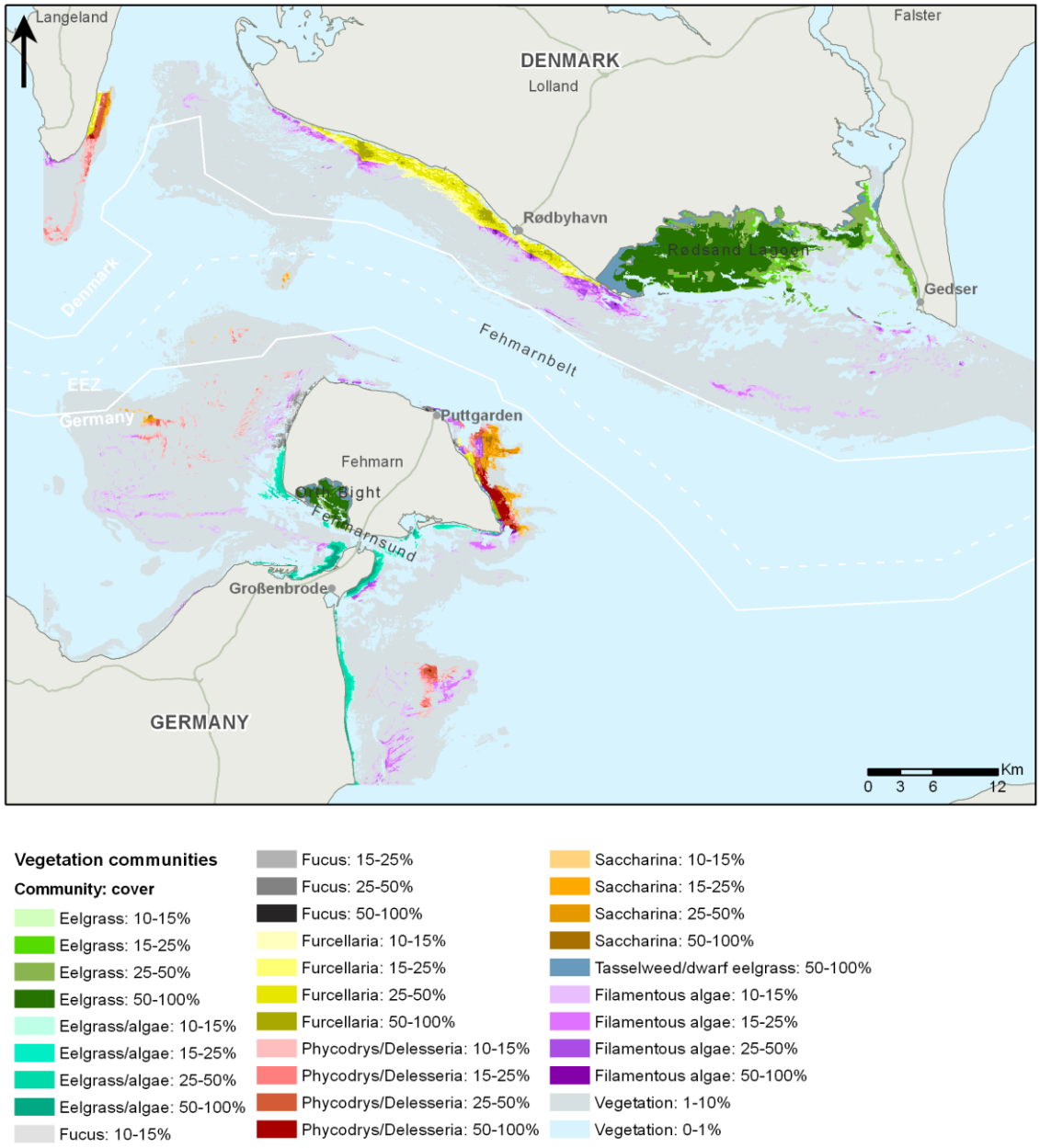



*Figure 2* *Distribution and coverage of the different vegetation communities within the investigation area.*

*Macroalgae*

Total cover of macroalgae was significantly related to availability of hard substrate, resulting in the highest percentage covers between 0 and 10 m and decreasing cover with depths below 10 m due to limited hard substrates. When hard substrate was present the substrate specific cover was relatively high along the whole depth gradient.

Along the coast of Lolland, including the vicinity of the proposed alignment area (approximately ± 10 km), the dominating benthic vegetation was the *Furcellaria*-community and the filamentous algae community. Due to limited availability of hard substrate the total cover of these two communities ranged between 15–50%. Only in restricted areas with sufficient hard substrate the cover was > 50%.

Along the east coast of Fehmarn, hard substrate is widely distributed. The amount of hard substrate increased with increasing distance to the the proposed alignment. All five macroalgal communities occured on the hard substrate. In shallow waters the filamentous algae community was dominant and the *Fucus*-community occurred in small, single spots. The *Furcellaria*-community was found at intermediate water depths while the *Phycodrys/Delesseria* and *Saccharina* community occurred in deeper areas. Both communities were widely distributed in very high densities, especially at the south-eastern part of the coastline (approximately 4 km away from the alignment) belonging to the Natura 2000 area Staberhuk.

Along the north coast of Fehmarn, west of the proposed alignments (e. g. ± 10 km), the cover of benthic vegetation was low due to lack of hard substrate. Stone are found in a narrow stribe along the whole coastline although in low density. In some of these stoney areas the stones are covered by the *Fucus* community; in particular in a small area 0.5 km west of Puttgarden harbour and on the west coast of Fehmarn (approximately 10 km west the proposed alignment area). In deeper areas a high dominance of blue mussels occurred and only filamentous algae were located there. Below 8–10 m water depth the *Phycodrys/Delesseria*- and the *Saccharina*-community covered the patchy distributed stones. The *Fucus*-community had the highest cover (with 25-50% coverage) of all the communities found at the westcoast.

Within the deeper part of Fehmarnbelt most areas are unsuitable for vegetation (sand and silt bottom). Only within the western part an area with scattered hard substrates is located. These stones were covered with the *Phycodrys/Delesseria*- and *Saccharina*-community down to about 20–21 m but total coverage did not exceed 25% due to the scarcity of suitable substrate. The area is part of the Natura 2000 area Fehmarnbelt.

Along the coastline of Langeland the *Furcellaria*- and the *Phycodrys/Delesseria*-community were the dominant vegetation forms. At the lower depth limit the *Saccharina*-community occurred within a small stripe. The algae cover was between 25 and 50%. This area is part of the Natura 2000 area Langeland. At Sagasbank (10 km south of Fehmarn) the *Phycodrys/Delesseria*- and the filamentous algae-community were distributed with up to 50% coverage in the central part. This area is part of the Natura 2000 area Sagasbank.

*Flowering plants*
The flowering plant communities (eelgrass, tasselweed/dwarf eelgrass) were widely distributed within the soft bottom dominated areas of western Rødsand Lagoon and Orth Bight. Due to the soft bottom and sheltered conditions in these areas both communities occurred with high coverage (> 50%). Both areas are part of different Natura 2000 areas (Rødsand and Eastern Kiel Bight).

The eelgrass-community was also located outside of the sheltered bays: along the south and south-west of Fehmarn, east and west of Wagrien and south of Großenbrode with coverages of 25–50%. In these areas the eelgrass-community was associated with different macroalgal communities, normally filamentous algae, forming the eelgrass/algae-community. The areas are partly included in different Natura 2000 areas. The eelgrass community did also occur in very low densities along the western part of the Lolland coastline and in some very small spots along the north coast of Fehmarn. The high exposure and mixed sediment prevent high coverages for this community type.

*Depth limits*
The depth limits of benthic macroalgae were 26 m off Langeland, 20 m in Fehmarnbelt (single *Saccharina latissima* plants occurred down to 32 m), 19 m in

some parts of the west coast of Fehmarn and 17-19 m at Staberhuk. In these areas the depth limit is most probably set by light. Different epifauna communities (sponges, bryozoans) covered the deeper occurring hard substrates.

In other areas depth limits of macroalgae were lower: Lolland coast (10-14 m), north-west coast of Fehmarn (8–10 m), Großenbrode (10 m) and Sagasbank (10-16m). In these areas the lower depth limit is not set by light but by the availability of suitable substrate.

The depth limit for eelgrass was 4.3-5.2 m in the eastern light limited part of Rødsand Lagoon and 4.5-4.8 m in Orth Bight.

*Biomass*
Perennial macroalgae are generally regarded as stable components of the benthic vegetation, in contrast to annual macroalgae, which exhibit large temporal fluctuations. However, results from this study proved that the populations show a marked spatial variability even within the same depth intervals.

Analysis of the compiled dataset for macroalgae biomass showed that biomass was most variable in the shallow waters where physical disturbance is large due to wave and wind exposure. Spatial variability in biomass decreased with depth. The dataset reveals that despite the large variation in abundance along the depth gradient there was a distinct decrease in the maximum attainable biomass along the depth gradient (Figure 3).

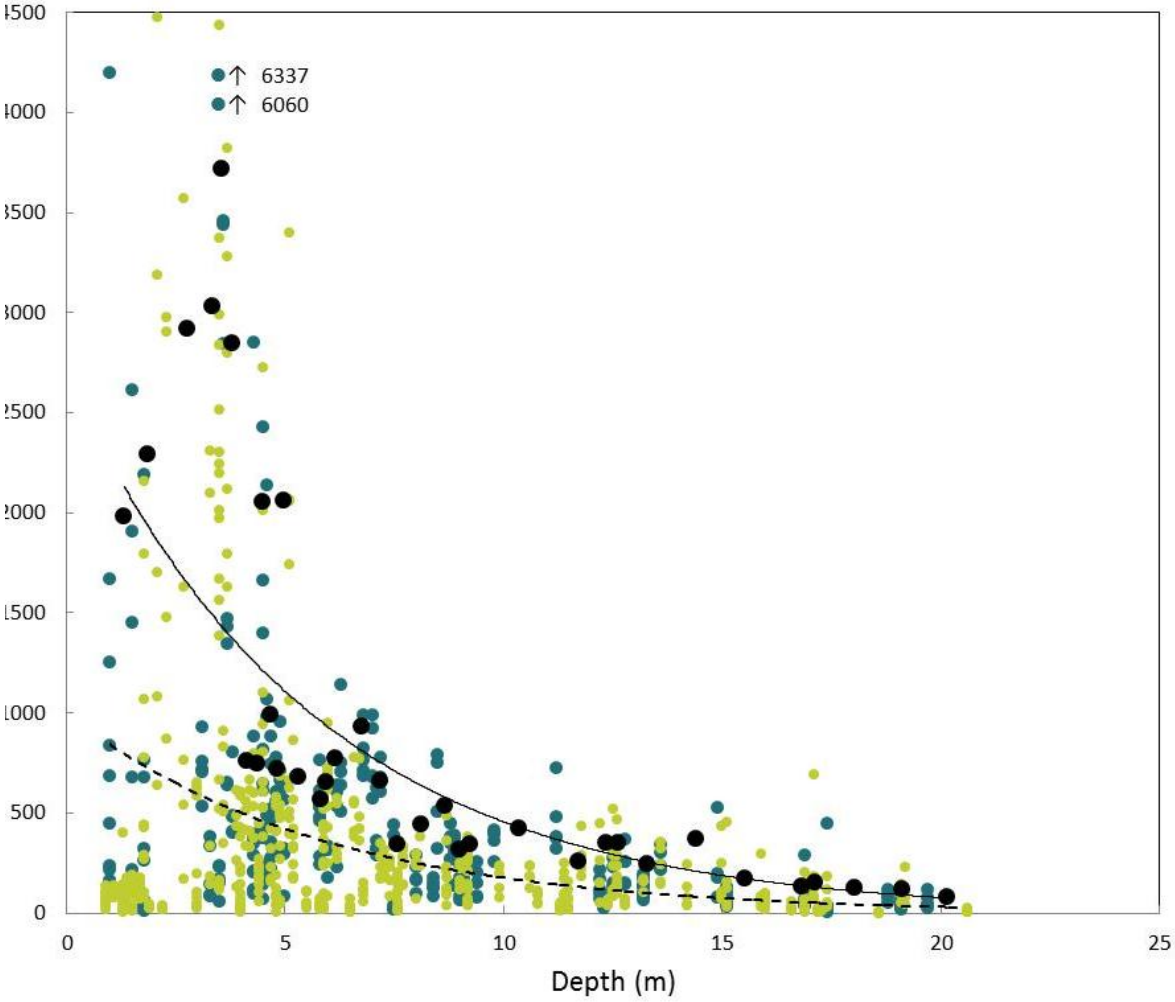



*Figure 3* *Total biomass of subsamples in 2009 (blue circles) and 2010 (green circles) and 90% percentiles of grouped observations (black circles) as a function of depth. Filamentous species communities are not included. The lines describe the exponential decrease in biomass (dotted line= average trend, solid line= 90% percentile of grouped data) with depth.*

Light, nutrients and physical factors play an important role in regulation of macroalgal biomass at a given depth and contribute to a complex regulation of the biomasses and thereby results in very variable and unpredictable mean biomass. Nevertheless, because light availability sets an upper limit to the biomass at a given depth, and the slope of the upper limit of macroalgal biomass vs. depth can be expected to change uniformly with light availability. Therefore the upper limit is a more robust indicator of patterns in biomass and has been used in this study for assessment of the depth distribution.

The decrease in the upper limit of macroalgae biomass with depth explains the difference in average biomass of the key communities/species. *Fucus*-communities growing in shallow water, where light barely limits photosynthesis and growth, had very high mean biomass. *Furcellaria*-communities - growing in intermediate depths, where light partly limits photosynthesis - had the second highest mean biomass. *Delesseria/Phycodrys*- and *Saccharina*-communities occupy deeper zones - where light further constrains biomass - and have the lowest average biomass.

Any changes in the depth distribution of these key communities are therefore expected to have an effect on the average biomass of key communities.

The total biomass of eelgrass is within the ranges of summer biomasses reported from Europe, USA and Japan (collected in Olesen & Sand-Jensen 1994). Eelgrass biomass for Rødsand Lagoon was lower than for Orth Bight and Großenbrode, but was similar to earlier reports of eelgrass biomass from Rødsand Lagoon.

*Seasonal and year to year variability*
Seasonal variability in cover-corrected biomass was expected to show a pattern of low biomasses in winter and increasing biomasses from spring to summer. Eelgrass and *Furcellaria* communities are dominated by perennial species with high biomass. They both showed the expected pattern with cover-corrected biomass increasing from March to summer months. *Phycodrys/ Delesseria* and *Saccharina* communities as well as the filamentous species showed a similar tendency but with more variability. The higher variability could be due to the biomass samples of key communities dominated by species with relatively low biomasses like filamentous species and *Phycodrys/ Delesseria* being more affected by occational occurrence of other larger perennial species, this may cause higher spatial variability. Likewise the different size and heterogenic occurrence of *Saccharina latissima* may contribute to higher variability *Saccharina* communities.

Biomass and shoot density of eelgrass is highest during the summer season. The mean leaf biomass in this summer investigation was approximately three times higher than the mean biomass found during autumn and winter 2008/2009 (FEMA 2009). Rhizome biomass was approximately four times higher in summer. The mean shoot density was also highest in summer although sites with many small shoots were found in Rødsand in winter, resulting in only a small difference between mean summer and winter shoot density for this area. No clear pattern was found in the depth distribution of eelgrass leaf biomass although shoot density and rhizome biomass showed a tendency to decrease with increasing depth.

Although sampling sites were not exactly the same in the 2009 and the 2010 sampling the patterns of species diversity, key-community coverage and biomass was remarkably similar in 2009 and 2010. Probably reflecting that there were no large changes in the most important factors controlling the distribution of species and biomasses (e.g. light and physical exposure).

Two years of sampling is not sufficient to expose the complete natural variability.
Lack of long time series of biomass or coverage data from the area prevent a thorough analysis of the year to year variability. However, at 14 sites biomass has been measured 3 or 4 years. These data were used to get a hint of the natural variability. The data originate from EIA work in connection with establishment of the windmill farm in Rødsand and from German national monitoring. The biomasses represent the biomass in dense vegetation at the sites and is a mix of macroalgae and eelgrass data. The yearly deviation was on average ±22%. The pattern was not totally random suggesting that the variation could be a consequence of variable conditions for growth between years.

*Historical perspective*
The key communities found in this study have been important parts of the coastal ecosystem in the Western Baltic for decades (Hoffmann 1952, Schwenke 1964). Historical information mainly exists from the German areas.

Until the 1960s *Fucus vesiculosus* was distributed down to 10 m depth, *Fucus serratus* even to 13 m depth (Hoffmann 1952, Schwenke 1964). Today *Fucus* is rarely growing deeper than 4–5 m (Fürhaupter et al. 2007). The mapping in the 1950s showed large areas with *Fucus* along the north-west coast, along the whole

east coast and the south-eastern coast of Fehmarn with partly high densities. The mapping in the 1960s confirmed these results and showed additional *Fucus* areas northwest of Puttgarden. *Fucus* can still be found in the same areas today, but the overall occupied area has been strongly reduced as well as the coverage.

The reduction in these areas may be due to marine stone fishery as in these areas the most intensive fishery activity took place. Isolated *Fucus* stands seems to have a very low recovery potential due to a restricted dispersal ability (Eriksson and Johansson 2005a). The remains of the population have not been able to colonize other hard substrate areas again.

Information about the historical distribution of *Furcellaria* is scarce but like the *Fucus*-community, this community formed dense beds down to about 10 m in the Baltic Sea area in former times (Hoffmann 1952) and single plant occured down to 25 m (Schwenke 1964). According to Schwenke (1964) this community was distributed along the northwest coast and the whole east coast of Fehmarn. Today the *Furcellaria*-community only exists at some locally restricted spots along the east coast of Fehmarn. In the north-western area of Fehmarn this community type has disappeared completely. But along the southern coast of Lolland large areas with a dominance of *Furcellaria lumbricalis* still exist.

Historically the perennial red algae species *Phycodrys rubens* and *Delesseria sanguinea* are known to grow down to about 20–30 m, depending on the availability of suitable hard substrate. Surveys from the 1950s and 1960s showed high densities in the north-west area of Fehmarn, along the whole east coast of Fehmarn and at Sagasbank; this coincides with the findings of the baseline survey. It seems that the depth limit of this community has not been changed significantly compared to the historical limits. Overall it is estimated that no drastic reduction of the spatial extent has occurred. But as more or less precise historical density or biomass values are lacking, no conclusion about a reduction of the overall abundance can be made.

Compared to the historical depth limit of *Saccharina latissima* of around 22–23 m (Schwenke 1964) or 30 m (Reinke 1889), changes in the depth limit are less evident. In the first survey year the deepest occurrence of *Saccharina latissima* was around 30 m. From other investigations within the Western Baltic also findings down to 25 to 30 m are known (Meyer 2004). As *Saccharina latissima* is less dependent on hard substrates with greater grain sizes for settling, it has a large-scale distribution and is not restricted to single spots. This large-scale distribution combined with very low densities makes it quite difficult to determine the exact distribution range and the lower depth limit of this community.

*Existing pressures*
Eutrophication, changes in the availability of hard substrate and physical disturbance by fishery are some of the most serious existing pressures on marine macrophytes.

The Baltic Sea has been exposed to very high loads of nutrients throughout the last 50–80 years. Macrophyte communities are affected by eutrophication in different ways. Firstly, increased nutrient richness stimulates the growth of planktonic algae and thereby reduces water clarity and reduce light availability for the vegetation (e. g. Nielsen et al. 2002). The reduction of light penetration has been suggested to be one of the main causes of the decline in vertical distribution of characteristic vegetation communities (soft and hard bottom) of the Baltic that has been observed in long-term studies (Rönnberg & Mathiesen 1998, Eriksson et al. 2002).

Secondly, higher nutrient levels increase the growth of opportunistic macroalgae species (Borum 1985), and may result in changed species composition and dominance structure of the communities (Schramm 1999).

The amount of suitable hard substrates has been reduced along the coasts due to intensive marine stone fishery in the past. In Germany more than 3.5 million tons of stones were used to build up spur dykes, harbours or different buildings on land (Bock et al. 2003). In Denmark it has been assumed that approximately 50 $km^2$ of stone reef have been removed from the coastal areas due to stone fishery in the last 50 years (Dahl et al. 2003).

Constructions of harbours, wind farms or deepening of waterways result in a loss of substrates in the direct impact area and in a sediment spill. No harbours have been built around Fehmarn within the last decades. The building of Puttgarden (ferry) harbour and the Fehmarnsund Bridge in the 1960s were the last marine construction projects on a greater scale along the German coastline of the investigation area. Within the investigation area two wind farms have been built recently, one of them - Rødsand II - is still under construction. Based on the EIA for Rødsand II impacts on the structure and function of the benthic community in the Lagoon of Rødsand is assessed to be insignificant.

Commercial trawl fishery has a large impact on benthic vegetation. Macrophytes can be cut loose from the hard substrate or get damaged by the heavy shear trawl doors and forerun chains.

**Importance**

The importance of benthic vegetation was defined by their functional value for the ecosystem. Benthic vegetation is a valuable part of the coastal ecosystem due to its function as a three-dimensional habitat as well as a nursery, breeding or feeding ground for invertebrates and fish (to a lesser extent to birds and marine mammals). This is also reflected by international and national guidelines and legislation, which characterise and protect habitats by their specific vegetation communities. The habitat function of vegetation is dependent on the complexity and longevity of their key species as well as the size and coverage of the habitat itself.

These parameters have been the basis for the classification of the importance of the benthic vegetation communities. For the German water, national legislation has added a regulatory dimension as the German Nature conversation act (Bundesnaturschutzgesetz, *BNatSchG §30*) lists specific macrophytes. Consequnetly the functionally based classification criteria have been adjusted for German waters to fulfil the regulatory conditions. The importance matrix based on the different key communities is described in Table 1 and illustrated in a map of importance (Figure 4).

*Very high importance*
The *Fucus*, *eelgrass*, tasselweed/dwarf eelgrass and the eelgrass/algaecommunities are of very high importance. For the Baltic Sea region, the importance of these communities is reflected in different international and national guidelines and legislations. HELCOM has red listed the key species of these communities as well as the habitats they are forming (HELCOM 1998, 2007). The Habitat Directive lists eelgrass, tasselweed and dwarf eelgrass as characteristic species for different habitat types (see chapter 9.2.1). A high proportion of key species and associated macrophyte and fauna species are red listed in Germany (Merck & von Nordheim 1996) and seagrass meadows as well as vegetation stands of perennials are law protected in Germany (§30 BNatSchG). Therefore, all perennial macrophytes communities are of "very high" importance in Germany.

The key species of these communities are large species with upright growth and sparsely branches. The species are perennial and thus creating high habitat stability. *Fucus* e. g. has a life span of several years (Lüning 1985). The sesonal variation of its biomass is low and a high proportion of the biomass is persistent during the winter. For *eelgrass* or tasselweed/dwarf eelgrass the seasonal biomass variation is higher, but a proportion is also persistent during the winter (Hemminga & Duarte 2000).

A precondition for the very high importance is that the *Fucus*-, *Zostera*-, tasselweed/dwarf eelgrass, eelgrass/algae-communities and perennial macrophyte communities in German waters have a high coverage. The defined criterias were therefore a coverage > 50%. If the coverage criterium is not fulfilled the community is downgraded one importance class.

*High importance*
The perennial red algae communities (*Furcellaria*, *Phycodrys/Delesseria)* and the *Saccharina*-community have a high importance value. The perennial red algae key species like *Coccotylus truncatus, Furcellaria lumbricalis, Delessseria sanguinea* or *Phycodrys rubens* are medium branched and have an upright growth, but have also relative small thalli. *Saccharina latissima*, although having a large thalli, is lying on the ground and is unbranched. The habitat stability of the *Phycodrys/Delesseria*-community is lower than for *Fucus* and *Zostera* as the thallus and density is reduced during winter. *Furcellaria* and *Saccharina latissima* have a life span comparable to *Fucus* (2-5 years, Lüning 1985) and a high proportion of the biomass is persistent during the winter.

The Habitat Directive lists no specific species for the habitat type reef (see chapter 9.2.1) as the species composition depends on the climatic region. The Directive is only mentioning a "variety of green, brown and red algae" for this habitat type. Only a few key species of these communities are directly red listed in Germany, but a high proportion of associated macrophyte and fauna species are red listed (Merck & von Nordheim 1996).

A precondition for the high importance is that the *Furcellaria*-, *Phycodrys/Delesseria*- and the *Saccharina*-community have a high coverage and are distributed over a larger area. The defined criterias were therefore a coverage > 50%. If the coverage criterium is not fulfilled the community is downgraded one importance class.

*Medium importance*
All perennial vegetation communities with a density > 10%, but not fulfilling the criteria for high or very high importance have been defined to have a medium importance level. As hard substrates areas with high densities, > 50% are rare and scattered, areas with lower densities can serve as stepping-stones for the associated fauna and flora.

*Minor importance*
Filamentous, opportunistic macroalgae communities and all perennial benthic vegetation communities with less than 10% cover are of minor importance. Key species of filamentous communities are small in size and highly branched. The habitat stability is low as key species are most often annual forms with high biomass variability during the year. During winter season these species have a biomass close to zero. Macroalgae with less than 10% cover are not regarded as a benthic vegetation community.

*Table 1 Importance matrix for benthic vegetation in the investigation area.*

| Importance level | DE | | DK | |
|---|---|---|---|---|
| | **Community** | **Coverage** | **Community** | **Coverage** |
| **Very high** | All (beside filamentous algae) | ≥ 50 % | Eelgrass | ≥ 50 % |
| | | | Eelgrass/ algae | |
| | | | Tasselweed/ dwarf eelgrass | |
| | | | *Fucus* | |
| **High** | All (beside filamentous algae) | 25–50 % | *Furcellaria* | ≥ 50 % |
| | | | *Phycodrys/ Delesseria* | |
| | | | *Saccharina* | |
| | | | Communities listed in very high | 25–50 % |
| **Medium** | All (beside filamentous algae) | 10–25 %, | Communities listed in very high | 10–25 % |
| | | | Communities listed in high | 10–50 % |
| **Minor** | Filamentous algae | Independent of density | Filamentous algae | Independent of density |
| | Vegetation stands | 1–10 % | Vegetation stands | 1–10 % |

Large areas of "very high" importance are located within Rødsand Lagoon and Orth Bight. In both areas this classification is based on the large-scale occurrence of eelgrass- and tasselweed/dwarf eelgrass-communities with high coverages (densities). The significance of both areas as a specific and valuable part of the marine environment has led to the allocation as Natura 2000 areas (DK006X238, DE 1631-392); soft bottom vegetation forms a dominant and characteristic component of the habitat type 1160 Shallow bays and inlets, which is assigned at least partly to Rødsand Lagoon and Orth Bight (see chapter 9.2.1). Additionally Orth Bight or parts of Orth Bight have a long nature conservation tradition in Germany (as NSG – National Nature Conversation Area and BSPA – Baltic Sea Protected Area), which verifies the very high importance of the communities occurring in this area.

"Very high" importance areas also occur along the east coast of Fehmarn, with *Furcellaria*-, *Phycodrys/Delesseria*- and *Saccharina*-communities with coverages of more than 50%. Some of the areas are included in the Natura 2000 area Staberhuk. In Germany, these areas are protected by the nature conservation law (§30 BNatschG).

Besides these large areas some smaller areas of "very high" importance exist around Wagrien (mainland south of Fehmarn). This classification is based on the occurrence of the mixed eelgrass/algae-community with a coverage of more than 50%. Especially the mixing of these communities is of ecological importance as different associating species are favoured resulting in a higher overall diversity. These areas are included in different Natura 2000 areas (DE 1631-392, DE 1632-392). Additionally spots of "very high" importance exist around Fehmarn: Directly west of Puttgarden and in a narrow stretch along the west coast of Fehmarn, dense *Fucus* belts are situated. In addition there is a small area of "very high" importance in the deeper water west of Fehmarn.

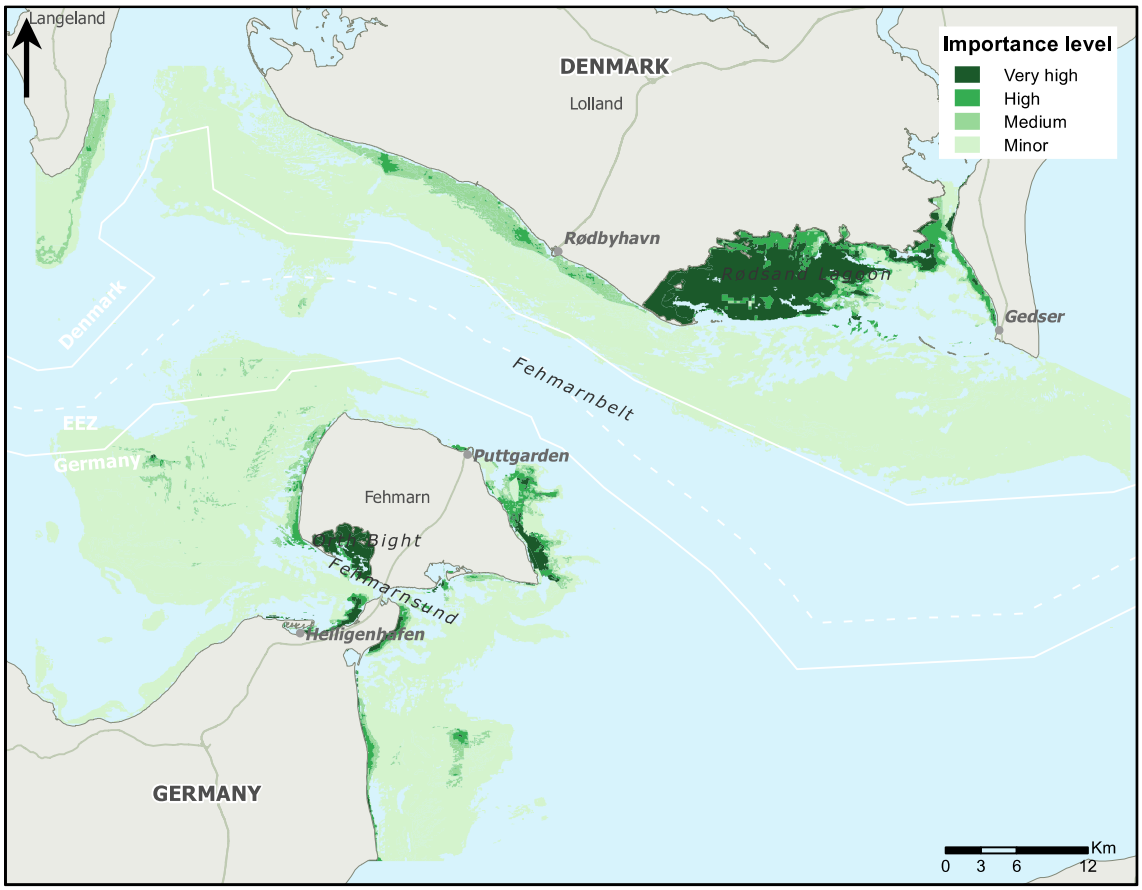



*Figure 4 Map of importance for benthic vegetation in the investigation area.*

"High" importance areas are more or less located around the "very high" importance areas. In these areas the *Fucus*-, eelgrass-, eelgrass/algae- and tasselweed/dwarf eelgrass-communities have a coverage of less than 50% and are therefore downgraded one class. Within the large-scale "high" importance areas around Wagrien the mixed eelgrass/algae-community is occurring, but neither eelgrass nor algae occur with high coverages. "High" importance areas also occur along the coastline of Lolland, Langeland with *Furcellaria*-, *Phycodrys/Delesseria*- and *Saccharina*-communities with coverages of more than 50% and along the east coast of Fehmarn where coverage are lower than 50%. "High" importance areas are also located in other areas around Fehmarn, in deep water areas of Sagasbank, Fehmarnbelt and scattered in Eastern Kiel Bight.

Large "medium" importance areas are located along the coastline of Lolland, Langeland where perennial macroalgae occur with coverages of 10-50%. "Medium" importance areas are also located around Fehmarn, at Sagasbank, Fehmarnbelt and scattered in Eastern Kiel Bight. Within these "medium" classified areas perennial macroalgae communities (*Furcellaria*, *Phycodrys/Delesseria, Saccharina)* occur with low coverages (< 10–25%), as suitable substrate is the limiting factor.

"Minor" importance areas are distributed all over the investigation area, as filamentous algae and perennial vegetation stands with coverages < 10% are widely distributed.

*WFD*

The objective of the European Water Framework Directive (WFD) is to secure a good ecological status for European surface waters.

In Germany WFD-monitoring has been carried out since 2006, and since then the water body Fehmarnbelt has been assessed to be in a good ecological status (at the borderline between good and moderate) (Fürhaupter et al. 2008a, Fürhaupter et al. 2009). The results of the vegetation baseline survey confirm the WFD evaluation. In addition to Fehmarnbelt only one other water body along the German Baltic Sea coastline reaches the "good" classification.

In Denmark, the ecological status is currently only assessed by one metric, the depth limit of eelgrass. According to the Vandplan the areas 'Femerbælt' and 'Rødsand' can not be classified. For the 'Femerbælt' no data are available on depth limits for eelgrass . In 'Rødsand' data is available for only one year, and this is considered as insufficient for a classification.

# 1 INTRODUCTION

Marine benthic vegetation represents a conspicuous and valuable component of shallow coastal environments, being very productive and able to establish large biomasses (Mann 1973). Their roles in the ecosystem include providing habitat for fish, epifauna and other plants; absorbing wave energy and nutrients and producing oxygen; improving water clarity and stabilizing bottom sediment.

Marine benthic vegetation includes macroalgae communities in areas with hard substrate and flowering plants (angiosperms) in soft bottom areas.

The hard bottom vegetation in Danish and German waters are confined to areas of firm substrates such as stones and mussels. A feasibility study was carried out in Fehmarnbelt in the autumn of 1997. The study described the macroalgae communities as mainly dominated by red algae species in both deep and shallow waters (COWI-Lahmeyer 1998). Filamentous species like *Polysiphonia* sp. and *Cystoclonium purpureum* dominated shallow waters and perennial species like *Coccotylus truncatus*, *Phyllophora* sp., *Delesseria sanguinea* and *Phycodrys rubens* as well as *Cystoclonium purpureum* dominated in the deeper waters. A mixture of *Fucus*/*Furcellaria* dominated in other areas.

The feasibility study is the most recent larger study of the hard bottom vegetation on the Danish side of Fehmarnbelt. The study described large areas with dense coverage of shallow water red algal community along the coast of Lolland from Vesterskov to Hyllekrog. The Danish monitoring programme also included one transect along the south coast of Lolland in 1994, 1995, 1996 and 1997. Substrate specific cover of macroalgae species was estimated in depth intervals along the transect. Filamentous species were dominating the vegetation and the most abundant perennial species were *Furcellaria lumbricalis* and *Phycodrys/Delesseria*.

The hard bottom area south of Rødsand has been studied at a limited number of sites as a contribution to the EIAs of the Nysted Offshore wind farm (2003 to 2005) and the wind farm Rødsand II (2006). The diversity and biomass of the macroalgal community were low and dominated by red filamentous species both at the turbines and also at the nearby stone reef Schönheiders Pulle.

Gedser reef and Schönheiders Pulle were monitored as a part of the national Danish monitoring programme in 1992. Schönheiders Pulle in the depth interval 10–12 m and Gedser reef in the depth interval between 4 and 12 m. The pattern was the same at the two sites; mostly filamentous species were observed and in general very low cover.

The Helcom monitoring provide the most recent sampling on the German side of Fehmarnbelt (year) and the studies show that at the west coast of Fehmarn the substrate consists of a mix of stones, gravel, sand and clay reefs, resulting in a diverse structure of the benthic vegetation with eelgrass-, *Fucus*-, red algae- and filamentous algae-communities, each of them with low coverage/biomass values. At the east coast of Fehmarn hard substrates are dominanting in the whole depth range. A dense cover of red algae-communities is found between 4 and 10 m and filamentous algae are dominating in the upper sublitoral.

The soft bottom vegetation is dominated by the marine flowering plant eelgrass (*Zostera marina*), in both Danish and German waters. Eelgrass beds increase sediment stability (Ward et al. 1984), play an important role in regulation of nutrient transport from land to sea and serve as spawning and nursery ground for fish and invertebrates (Hemminga & Duarte 2000) as well as a source of food for swans.

The latter aspect is especially relevant in the Fehmarnbelt area, where Rødsand Lagoon and Orth Bight both are bird protection areas.

Other plants are also a characteristic part of the soft bottom communities. In shallow water other common species are *Ruppia* sp., fennel pondweed (*Potamogeton pectinatus*), horned pondweed (*Zannichellia palustris*) and stoneworts (e. g. *Chara*).

The soft bottom vegetation in Fehmarnbelt and its sorroundings are found in Rødsand Lagoon, Orth Bight and Großenbrode.

The distribution and abundance (cover and biomass) of benthic vegetation are regulated by a complex of physical and chemical factors. Salinity, temperature, substrate availability and nutrients are important for the horizontal distribution and abundance of species. Physical disturbance (e. g wave exposure) and light availability for photosynthesis are important for the vertical distribution.

## 1.1 Objectives

The objectives of this report is to present the results of the FEMA benthic vegetation baseline investigation. The investigation was focused on a two year sampling programme in 2009-10. The purpose of the sampling programme was:

- to document and describe patterns in the composition, distribution and abundance of benthic macroalgae and flowering plants in the proposed alignment area and in the adjacent areas possibly impacted by the construction or operation of a fixed link.
- to document and describe patterns in the distribution and abundance of marine benthic vegetation in the potential affected Natura 2000 areas.
- to provide basis for impact assessment of the proposed technical solutions
- to provide baseline data in the potential impact area and in reference areas for a possible later monitoring of the development in benthic vegetation during and after the establishment of the fixed link across Fehmarnbelt.
- to collect existing and historical data on benthic flora in the Fehmarnbelt area from local monitoring programmes and scientific studies
- to carry out additional quantitative frame sampling of macroalgae and eelgrass at a limited number of sites during winter and spring to describe the seasonal variation in variables essential to calibration of the ecosystem model which will be used for the impact assessment.

The assessment of the results in relation to the Natura 2000 areas will be reported in a separate report.

## 1.2 The Report

The Baseline Report is divided into the following sections plus references:

- Summary and Conclusion – an extended summary of the main findings
- Introduction (Chapter 1) – shortly describes benthic vegetation in the area, lists the objectives and outlines the structure of the report.

- Materials and Methods (Chapter 2) – outlines the study area, decribes the field programme and the methods and analyses used

- Environmental Conditions (Chapter 3) – shortly describes the most important parameters for the distribution and abundance of marine benthic vegetation

- Macroalgae communities (Chapter 4) – defines macroalgal key communities and describes patterns of species diversity, coverage and biomass

- Flowering plant (angiosperm) communities (Chapter 5) – defines flowering plant key communities and describes patterns of species diversity, coverage and biomass

- Benthic vegetation mapping (Chapter 6) – describes benthic vegetation distribution in the Fehmarnbelt area

- Temporal variability and trends (Chapter 7) – hints of year to year variability and long-term trends

- WFD (Chapter 8) – Water Framework Directive assessment

- Law protected benthic vegetation (Chapter 9) – lists law protected habitats and species

- Importance (Chapter 10) – definition and mapping of importance

- Existing pressures (Chapter 11) – describes the existing pressures on benthic vegetation in Fehmarnbelt and neighbouring areas

In this report different place names are used to describe the distribution of the vegetation. Maps with names of locations are included in Appendix 10.

# 2 MATERIALS AND METHODS

## 2.1 Investigation area

The area of investigation is defined by the requirements set by the objectives of the baseline study; i. e. it must ensure that it is possible to a) determine the basic characteristics of benthic vegetation in the Fehmarnbelt area and in the nearest Natura 2000 sites, and b) determine impacts of the EIA scenario.

The extent of area of investigation has been defined based on existing knowledge on local conditions and impacts from physical structures and sediment spill as well as on the need for unaffected reference sites. For benthic vegetation, impacts are only plausible in an area close to the Fixed Link, i.e. in a corridor of 15-20 km around the alignment area.

The investigation area include sites outside the expected impact areas in order to assess the limits and significance of the impacts and in order to provide information of possible unaffected reference areas to support the design of a possible future monitoring programme.

For the identification and evaluation of potential reference areas it was necessary first to identify all benthic vegetation key communities in the Fehmarnbelt area (this was done in 2009) and secondly to identify and sample suitable reference locations in (done in 2010). The identification, definition and documentation of reference areas is described in Appendix 9.

Natura 2000 areas are by definition areas of special interest and the areas to be included in the investigation have been chosen to ensure that baseline and impact assessment are possible, if needed, even in the more remotely lying areas.

The following Natura 2000 areas have been included in the benthic vegetation baseline investigations:

- DK00VA200 Reef southwest of Langeland (abbreviation: Langeland)
- DK006X238 Rødsand Lagoon
- DE 1332-301 Fehmarnbelt
- DE 1533-301 Staberhuk
- DE 1631-392 Marine areas of Eastern Kiel Bight (abbreviation: Eastern Kiel Bight)
- DE 1632-392 Coastal landscapes of Großenbrode and offshore areas (abbreviation: Großenbrode)
- DE 1733-301 Sagasbank

The whole investigation area including the locations of the marine Natura 2000 areas is shown in Figure 2.1.

## 2.2 Field programme 2009 and 2010

A baseline vegetation field study was performed in 2009 and 2010. Main sampling was carried out between June 15$^{th}$ and August 31$^{st}$ each year as this period lies within the growth season of marine benthic vegetation and within the sampling season of the German and Danish national monitoring programme. Additionally biomass sampling was carried out at selected sites in winter and spring 2010.

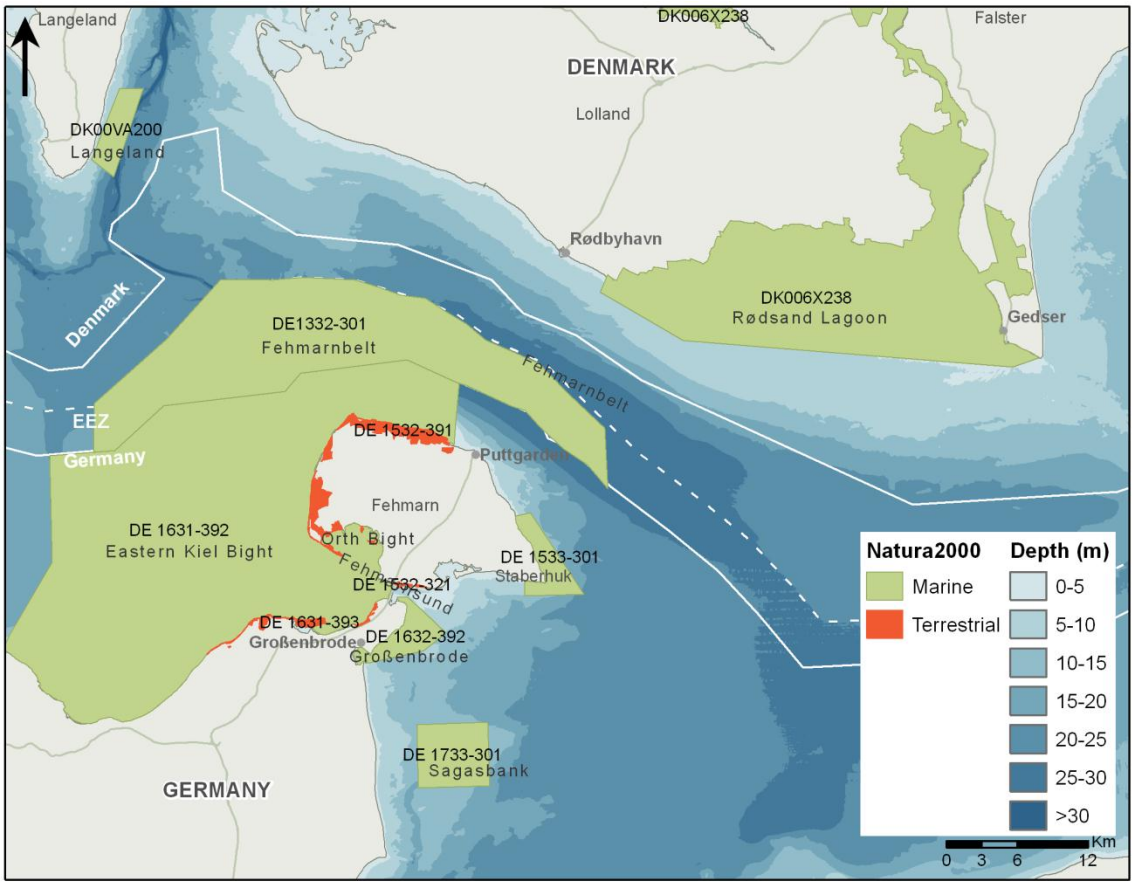



*Figure 2.1 Investigation area with marine Natura 2000 areas included in the survey.*

Sampling was not possible in military areas and in the construction area for the offshore wind farm Rødsand II. Moreover sampling was restricted between December 2009 and February 2010 due to severe weather conditions and ice cover within the investigation area.

In 2009 the programme consisted of the following investigations:

- cover, biomass and spatial distribution of key macroalgal communities
- cover, biomass, shoot density (only eelgrass), depth limit and spatial distribution of flowering plants (angiosperms).

In 2010 the programme was optimised; it included the following investigations:

- cover, biomass and spatial distribution of key macroalgal communities
- additional biomass sampling of key macroalgal communities and eelgrass communities in winter and spring 2010
- cover and biomass of key macroalgal communities in reference areas.

The sampling consisted of video recording along transects, coverage estimates in 25 $m^2$ and frame sampling of coverage and biomass in depth intervals. Table 2.1, Figure 2.2 and Figure 2.6 give an overview of the overall distribution of transects and sites. As sampling and site number were slightly different for sampling of macroalgal and flowering plants also separate tables (Table 2.2 and Table 2.3) are included. At some transects both macroalgal and flowering plant, investigations were possible. The methods used are described in chapter 2.3.

*Table 2.1 Overview of sampling in 2009 and 2010. The number of video transects and sites investigated by diving for cover estimates and sampling.*

| **Activity** | **Video transects** | | **Sites** | | | |
|---|---|---|---|---|---|---|
| | | | **Site cover estimates** | | **Site cover estimates and sampling** | |
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| Overall | 58 | 47 | 436 | 135 | 143 | 113 |
| Danish waters | 28 | 18 | 214 | 51 | 76 | 50 |
| German waters | 30 | 29 | 222 | 84 | 67 | 63 |
| German coastal zone | 26 | 25 | 214 | 76 | 61 | 55 |
| German EEZ | 4 | 4 | 8 | 8 | 6 | 8 |
| DE 1332-301 Fehmarnbelt | 4 | 4 | 8 | 8 | 6 | 8 |
| DE 1533-301 Staberhuk | 5 | 4 | 59 | 24 | 15 | 15 |
| DE 1631-392 Eastern Kiel Bight | 13 | 12 | 75 | 28 | 18 | 19 |
| DE 1632-392 Großenbrode | 3 | 0 | 38 | 0 | 14 | 0 |
| DE 1733-301 Sagasbank | 2 | 2 | 12 | 5 | 5 | 5 |
| DK00VA200 Langeland | 4 | 0 | 34 | 0 | 10 | 0 |
| DK006X238 Rødsand Lagoon | 6 | 0 | 49 | 0 | 17 | 0 |
| Variables measured | Cover of vegetation, mussel, stone and sand | | Cover of substrate, total vegetation and key species | | Species composition, cover, biomass | |

*Table 2.2 Overview of macroalgae sampling in 2009 and 2010. The number of video transects, 25 $m^{-2}$ coverage estimates and frame sampling sites are given.* 5 replicates at each site. In general both angiosperms and macroalgae have been registered at all transects and 25$m^2$ coverage estimates, but only those dominated by macroalgae are shown in this table. Off Großenbrode mixed vegetation occur and the data is included in this table as well as in table 2.2.*

| **Activity** | **Video transects*** | | **Site cover estimates (25 $m^2$)** | | **Frame cover sample sites (0.25 $m^2$)*** | | **Biomass sample sites (0.0625 $m^2$) *** | |
|---|---|---|---|---|---|---|---|---|
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| Overall | 52 | 47 | 357 | 135 | 112 | 113 | 112 | 113 |
| Danish waters | 22 | 18 | 165 | 51 | 59 | 50 | 59 | 50 |
| German waters | 30 | 29 | 192 | 84 | 53 | 63 | 50 | 64 |
| German coastal zone | 26 | 25 | 184 | 76 | 47 | 55 | 62 | 56 |
| German EEZ | 4 | 4 | 8 | 8 | 6 | 8 | 6 | 8 |
| DE 1332-301 Fehmarnbelt | 4 | 4 | 8 | 8 | 6 | 8 | 6 | 8 |
| DE 1533-301 Staberhuk | 5 | 4 | 59 | 24 | 15 | 15 | 15 | 15 |
| DE 1631-392 Eastern Kiel Bight | 13 | 12 | 51 | 28 | 9 | 19 | 9 | 19 |
| DE 1632-392 Großenbrode | 3 | 0 | 32 | 0 | 8 | 0 | 8 | 0 |
| DE 1733-301 Sagasbank | 2 | 2 | 12 | 5 | 5 | 5 | 5 | 5 |
| DK00VA200 Langeland | 4 | 0 | 34 | 0 | 10 | 0 | 10 | 0 |
| Variables measured | Cover of vegetation, mussel, stone and sand | | Cover of substrate, total vegetation and key species | | Species composition, cover | | Species composition, biomass | |

*Table 2.3* *Overview of flowering plant (angiosperm) surveys in 2009. The number of video transects, 25 $m^{-2}$ coverage estimates and frame sampling sites are given. ** 3 replicates at each site. In general both angiosperms and macroalgae have been registered at all transects and 25$m^2$ coverage estimates, but only those dominated by angiosperms are shown in this table. Off Großenbrode mixed vegetation occur and the data is included in this table as well as in Table 2.1.*

| **Activity** | **Video transects** | **Site cover estimates (25 $m^2$)** | **Frame cover sampling sites (0.25 $m^2$)**** | **Frame biomass sampling sites (0.0625 $m^2$)**** | **Core biomass sampling sites (0.01 $m^2$)** |
|---|---|---|---|---|---|
| | 2009 | 2009 | 2009 | 2009 | 2009 |
| Overall | 11 | 79 | 31 | 31 | 31 |
| Danish waters | 6 | 49 | 17 | 17 | 17 |
| German waters | 5 | 30 | 14 | 14 | 14 |
| German coastal zone | 5 | 30 | 14 | 14 | 14 |
| German EEZ | 0 | 0 | 0 | 0 | 0 |
| DE 1631-392 Eastern Kiel Bight | 2 | 24 | 8 | 8 | 8 |
| DE 1632-392 Großenbrode | 3 | 6 | 6 | 6 | 6 |
| DK006X238 Rødsand Lagoon | 6 | 49 | 17 | 17 | 17 |
| Variables measured | Cover of vegetation, mussel, stone and sand | Cover of substrate, total vegetation and key species | Species composition, cover | Species composition, biomass | Below-ground biomass |

*Supplementary data*

The benthic fauna sampling programme also included some recordings of occurence and coverage of benthic vegetation. The data have been used as supplementary data to describe the spatial distribution of macroalgae, flowering plants and key-communities. An overview of the "fauna" data used are given in Table 2.4.

*Table 2.4 Data from the benthic fauna sampling programme used to support the benthic vegetation study.*

| Data type | Number of stations/ observations | Time |
|---|---|---|
| Qualitative data on the occurrence of *Laminaria*, *Fucus,* perennial red algae, filamentous algae within dredge samples | 59 stations | Spring and autumn 2009 and 2010 |
| Coverage data at all shallow water infauna and epifauna sites | 231 observations | Spring and autumn 2009, summer 2009 |
| | 189 observations | Spring and autumn 2010, summer 2010 |

## 2.3 Field methods

### 2.3.1 Video Transects

*Position and depth range of the transects*
Video recordings along transects perpendicular to the coast were carried out in both hard bottom and soft bottom areas. The purpose of the video recordings was to establish and document the spatial distribution, including depth limits, of marine benthic vegetation and to define suitable biomass sampling sites.

Video transects were distributed as shown in Figure 2.2. On the Lolland coast, transects were distributed most densely close to the proposed alignment area, in order to increase the ability to determine changes in the vegetation in the close vicinity of the alignment. On the Fehmarn side transects were less dense in the alignment area because vegetation was already known to be scarce there.

In areas situated further away from the proposed alignment, videos were only recorded once (i. e. either in 2009 or 2010). Overview of the number of transects within the different geographical ranges (e. g. Danish waters, German waters, EEZ) and survey campaigns are listed in Table 3.1 and Table 3.2. The start and end coordinates, depth ranges and the approximate length of video transects are shown in Appendix 1.

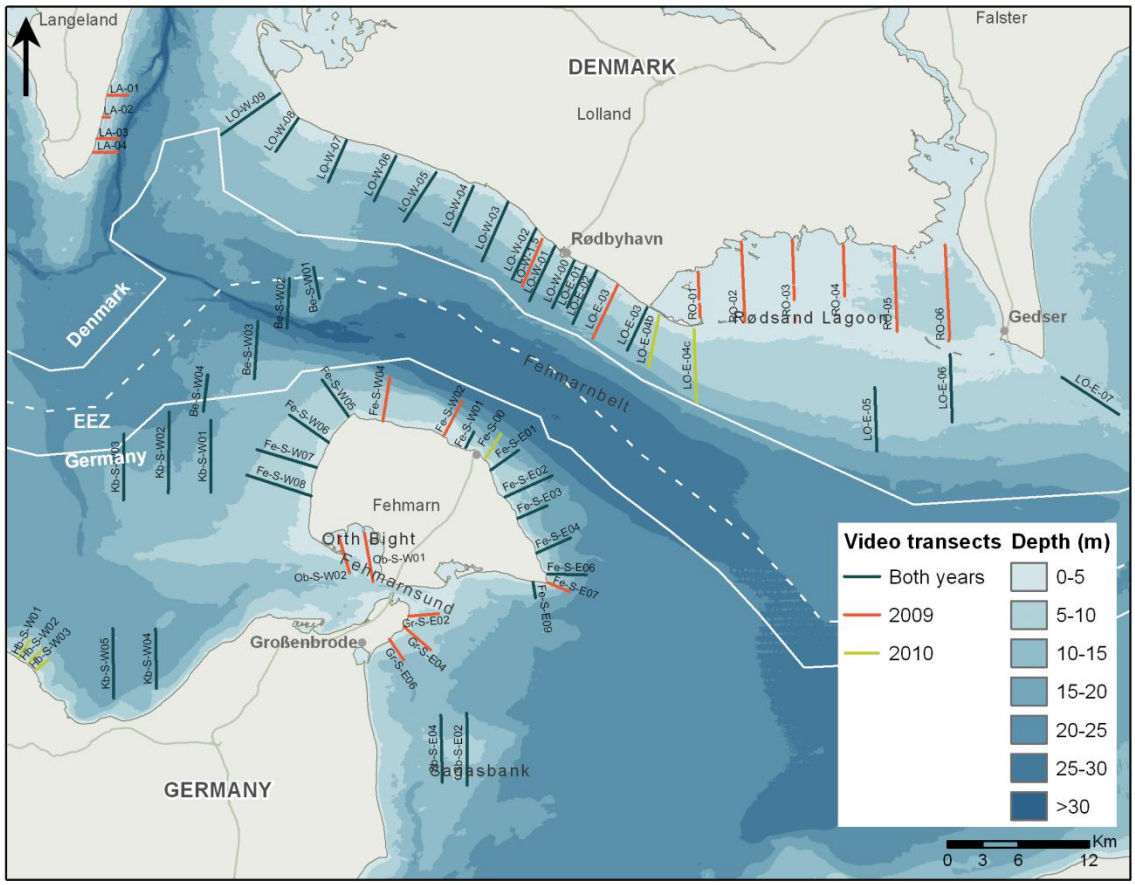



*Figure 2.2 Distribution of video transects in 2009 and 2010.*

*Video recording and analysis*

Video systems were drop-down systems towed by boat at low speed (Figure 2.3) and connected with the onboard recording systems by a data transfer cable. The under water camera is mounted on a specific video sled allowing movement above the bottom with least disturbance of sea bottom habitats.

*Figure 2.3 Danish (left side) and German (right side) Drop-down video camera system used during the baseline investigations and tested at the method harmonizing workshop. Danish equipment used in 2010 was similar to the German.*

Important track information (coordinates, depth, transect name etc.) is faded into the video sequence. The video recordings were, if possible, coupled with synchronised GPS- and depth-data storage in a log file, in order to simplify video

processing. Video tracks were recorded continuously (if possible) from shoreline to the lower depth limit of the vegetation with very low cruising speeds of 1–2 kn to assure high quality recording.

*Video analysis*
Coverage of specific vegetation elements as well as rough sediment characteristics and mussel coverage were estimated along each transect. Coverage of the following biotic and sediment categories were estimated: eelgrass, *Fucus, Laminaria* (*Saccharina latissima* included), red algae, green algae, drifting algae, blue mussels, tasselweed (*Ruppia)* and pondweed (*Potamogeton), s*and and stones.

The following coverage scale (adapted Brown-Blanquet-scale, 1951) was used: 0: not present; 1: < 10% coverage; 2: ≥ 10–25% coverage; 3: ≥ 25–50% coverage; 4: ≥ 50–75% coverage; 5: ≥ 75–100% coverage; 6: 100% coverage.

Coverage estimates were carried out either while recording and then spot-wise checked afterwards or the whole analysis was performed afterwards. Position and depths, where changes in coverages occurred, were noted manually. No image analysis software could be used as vegetation structures are too complex to allow effective and correct analysis. But, if possible, data of position and depth was stored in a log file and combined with manually assignment of coverage estimations. This was done either by using a software or just importing the logged data into an excel sheet (Figure 2.4). Or all data were manually typed into an excel file.

Gr-S-E02

| Time | Latitude | Longitude | E1 | E2 | Depth | Total | Zos | Myt | Fuc | Lami | Red | Green | Drift | Pot | Rup | Sand | Stone | Remark |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11:53:27 | 54°22,801'N | 11°07,852'E | 0 | 0 | 2,3 | 4 | 4 | 1 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 5 | 2 | |
| 11:52:23 | 54°22,808'N | 11°07,895'E | 53,5 | 53,5 | 2,4 | 3 | 3 | 2 | 1 | 0 | 1 | 1 | 2 | 0 | 0 | 5 | 2 | |
| 11:48:41 | 54°22,825'N | 11°08,038'E | 173,9 | 227,4 | 2,9 | 3 | 3 | 3 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 5 | 2 | |
| 11:47:21 | 54°22,837'N | 11°08,084'E | 61,4 | 288,8 | 3 | 3 | 3 | 4 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 4 | 3 | |
| 11:46:21 | 54°22,844'N | 11°08,122'E | 48,4 | 337,2 | 2,5 | 4 | 4 | 4 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 4 | 3 | |
| 11:45:45 | 54°22,849'N | 11°08,142'E | 26,6 | 363,8 | 2,8 | 4 | 4 | 4 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 4 | 3 | |
| 11:45:41 | 54°22,850'N | 11°08,145'E | 3,9 | 367,7 | 2,8 | 4 | 4 | 4 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 4 | 3 | |
| 11:43:49 | 54°22,866'N | 11°08,207'E | 86,1 | 453,8 | 2,5 | 4 | 4 | 4 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 3 | |

*Figure 2.4 Example excel file for video analysis for the transect Gr-S-E02 with positions, depth and coverage values of the different vegetation components (e. g. Zos = Zostera or Fuc = Fucus).*

### 2.3.2 Cover estimates and biomass sampling

*Macroalgae*
Cover estimates and biomass sampling were made along transects within depth intervals. Depth intervals were 0–2 m, 2–5 m, 5–10 m, 10–15 m, 15–20 m and 20 m to the lower vegetation limit.

The coverage estimates were performed within an area of 25 $m^2$ at three sites within each depth interval. Two sites were positioned randomly within the depth interval, while the third site was at the position where biomass sampling was done. At each sampling point the diver outlines the area by using a peg with a 2.8 m string attached. The diver describes the vegetation in the circle outlined by the outstretched string.

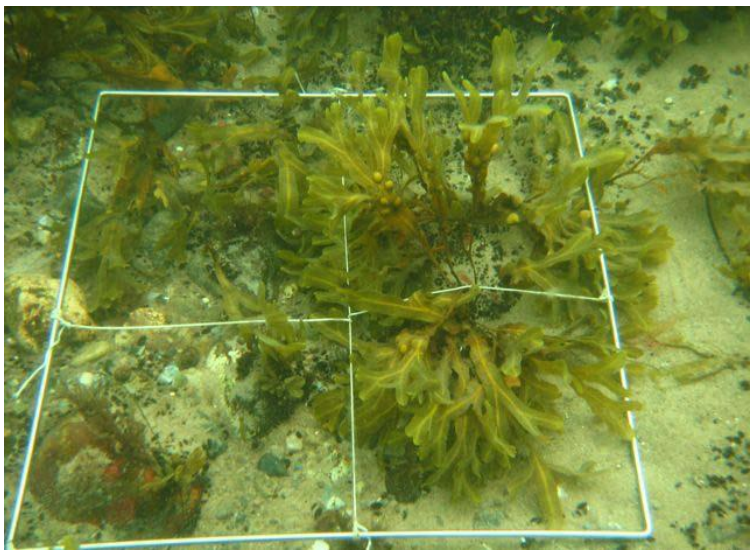


*Figure 2.5 Frames used for macroalgae biomass sampling.*

At each site the coverage of sediment (boulders, cobbles, pebbles, gravel, sand, clay/mud/silt and clay reef) was estimated. The proportion of hard substrate suitable for growth of perennial macroalgae, the cover of blue mussel and the substrate-specific cover of vegetation on hard and soft bottom were estimated. Moreover, the substrate specific cover was estimated for at least the following key species: *Fucus* spp., *Coccotylus/Phyllophora*, *Furcellaria lumbricalis*, *Delesseria sanguinea*, *Saccharina*, other perennial red algae, eelgrass, tasselweed, pondweed and filamentous algae. Estimations of suitable hard substrate and substrate specific coverages follows the methods in the Danish monitoring programme (Krause-Jensen et al 2004).

At one of the coverage estimation sites in each depth interval biomass was sampled. Biomass samples were preferably taken in areas where the vegetation was well established and representative for the area and depth. Species cover was estimated in frames with a size of 0.25 $m^2$ and samples of biomass were collected using $^1/_4$ of the frame size (0.0625 $m^2$, Figure 2.5). Five replicates were collected at each sampling site. The overall sampling procedure followed the standard given in the HELCOM Combine programme (HELCOM 1999) and the German SOP (BLMP 2008) for phytobenthos sampling.

*Flowering plants (angiosperms)*

Flowering plants were sampled in Rødsand Lagoon, Orth Bight and Großenbrode in 2009. Cover estimates and biomass sampling were made along transects within the depth intervals 0–1 m, 1–2 m, 2–4 m and 4–6 m to the lower depth limit of eelgrass.

The coverage estimates at the sites were performed identical to the estimates for macroalgae (3 sites per depth interval, size 25 $m^2$, randomly choosen, comparable categories). Species cover was estimated in frames with a size of 1 $m^2$ and samples of biomass were collected using $^1/_4$ of the frame size (0.25 $m^2$). Below-ground biomass was sampled by a core with an area of 0.01 $m^2$. Three replicates were collected at each sampling site. Biomass samples were preferably taken in areas where the vegetation was well established and representative for the area and depth. The overall sampling procedure followed the standard given in the HELCOM Combine programme (HELCOM 1999) and the German SOP (BLMP 2008) for phytobenthos sampling.

Sampling of macroalgae and/or flowering plants was only carried out in depth intervals where adequate vegetation cover (at least 10%) was present. Suitable locations for sampling were identified on the basis of the video recordings. However, if a decrease to < 10% vegetation cover was observed from the first year of sampling to the second year, the sites or intervals will stay in the sampling programme to detect any possible decrease in cover and biomass of the vegetation.

Survey sites for macroalgae and angiosperm sampling were distributed as shown in Figure 2.6

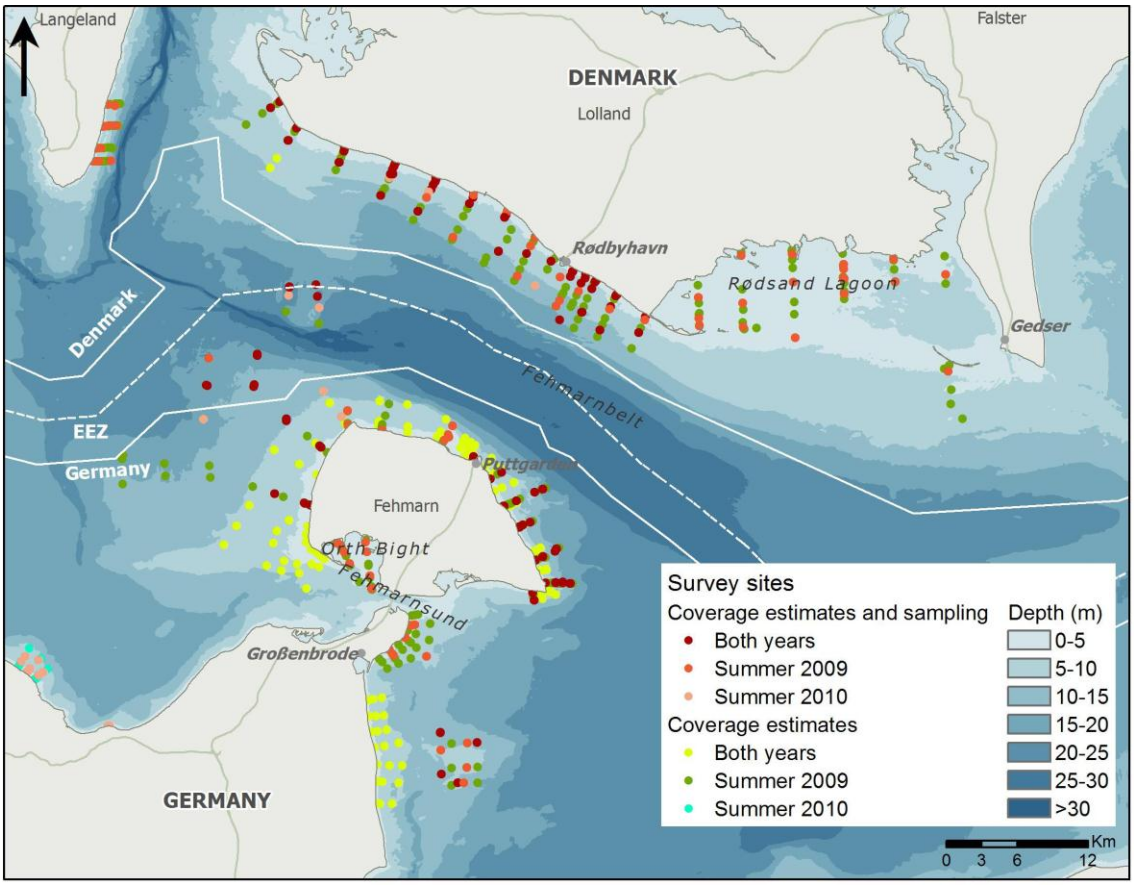



*Figure 2.6 Positions of coverage estimation and biomass sampling sites in the investigation area.*

### 2.3.3 Additional biomass sampling

Additional seasonal biomass sampling of macroalgae and eelgrass was carried out in winter and spring 2010 at a limited number of sampling sites to support the calibration of a dynamic ecological model. The model will be used to predict the impact of the construction of the Fehmarnbel Fixed Link on the benthic vegetation. The sampling was done in November 2009, March, April and May 2010 on the German side and in January, March, April and May 2010 on the Danish side. Due to icecover sampling in Rødsand Lagoon was not possible in the January.

Macroalgae were sampled at two transects along the coast of Lolland in the depth intervals 2-5, 5-10 and 10-15 m, at one transect on the east side of Fehmern in the 2-5, 5-10, 10-15 15-20 m depth intervals and at one transect on the west side of Fehmarn in the 2-5 and 5-10 m depth intervals.

Eelgrass was sampled at two sites in each depth interval in Rødsand lagoon and at one site per depth interval in Orth Bight in the 1-2, 2-4 and 4-6 m depth intervals. At each sampling site cover was estimated in areas of 25 $m^2$ and biomass was sampled with three replicates at macroalgae sites and two replicates at eelgrass sites. Survey sites for seasonal sampling sites were distributed as shown in Figure 2.7.

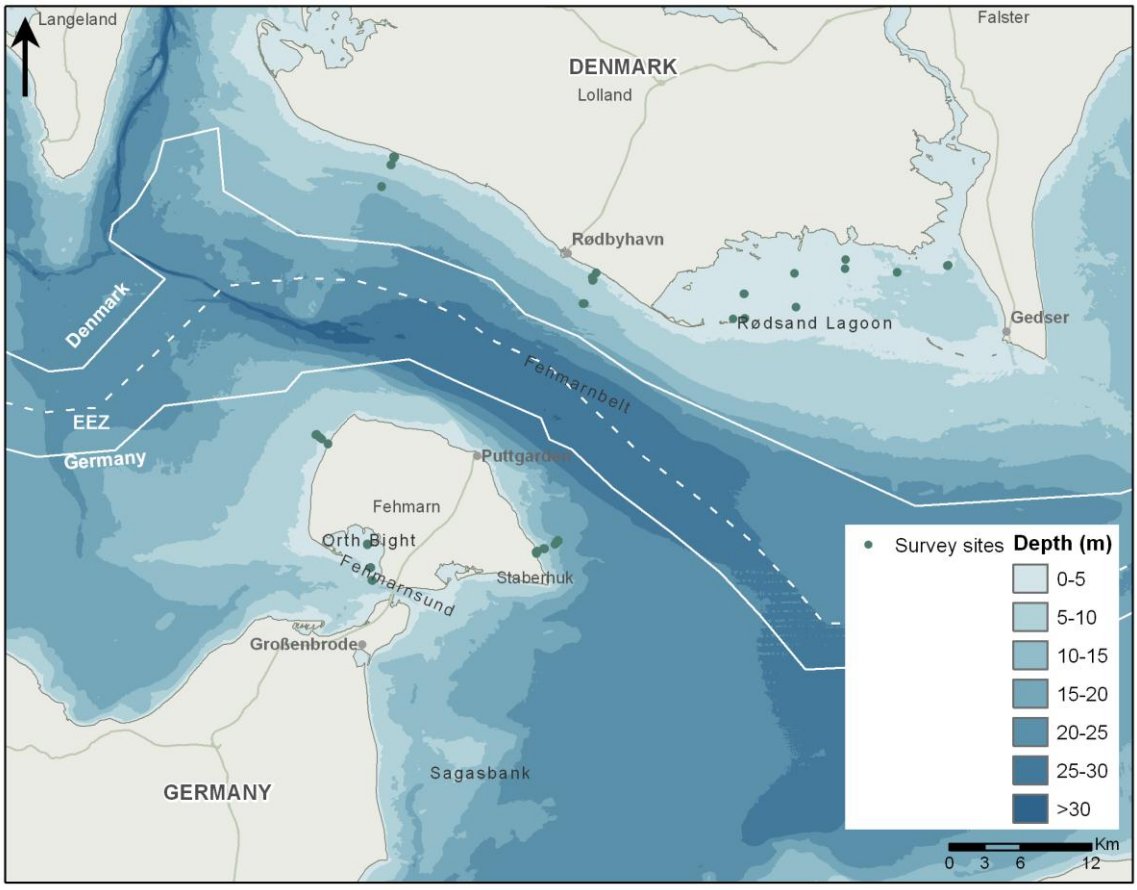



*Figure 2.7 Positions of sample sites for additional biomass sampling.*

### *2.3.4 Biomass Sample Processing*

Each biomass sample was placed in a net bag and transported to the surface. The samples were then labelled and kept cool on board of the ship until they were frozen by the end of the day.

In the laboratory, samples were defrosted, sorted and identified to species level, if possible. In cases that identification of species was not possible after freezing, a higher taxonomic level was listed (e. g. *Aglaothamnion/Callithamnion*, *Ulva* sp., *Ectocarpus/Pylaiella*). For nomenclature the current and official scientific name according to ERMS/WoRMS (European/World Register of Marine Species) was used.

For biomass determination excess water was removed from the plant material after species identification. Each taxon was transferred into an appropriate pre-weighed dish. Subsequently, samples were dried at 60 °C in a laboratory drying chamber until constant weight (at least 24 h). Dry weight was measured with 0.1 g accuracy.

The eelgrass shoots were counted within the categories unfertile, fertile and shoots with seeds. Decomposed, brown leaves were sorted out. Rhizome parts, if present, were cut from each shoot and only the above ground parts of the shoots were used for biomass determination. Below-ground biomass samples were rinsed and remaining sand etc. was removed before dry weight was determined.

### 2.3.5 *Quality Assurance*

To ensure harmonization in sampling, analysing methods and identical data quality among the different working teams a quality assurance workshop has been conducted. During this workshop equipment was tested and the field and laboratory methods were demonstrated and exercised. Content and results of this workshop are described in detail in Appendix 2.

For the identification of taxonomic differences between the involved laboratories a ring test was conducted with some "extra" samples taken in different vegetation communities and depth intervals. The result of the ring test showed a high level of agreement between laboratories in species identification. The found differences were taken into account during data analyses and will not influence the results of the baseline study or the Environmental Impact Assessment. Content and results of this ring test are described in detail in Appendix 2.

## 2.4 *Supplementary Data Used in the Report*

Data on benthic vegetation (e. g. spatial or depth distribution, species composition, coverage and/or biomass) within the area are also available from other sources than this benthic vegetation baseline sampling. These include historical data and results from the Fehmarnbelt Fixed Link habitat mapping (e. g. aerial photography survey). The data are briefly described here.

### 2.4.1 *Historical Vegetation Data*

Data on benthic vegetation in the Fehmarnbelt area exist from the feasibility study, the Danish and German national monitoring programmes, German mapping surveys and from EIAs on offshore wind farms in the Rødsand area. The data types (e. g. cover estimates, biomasses, depth intervals sampled) as well as the spatial distribution (Figure 2.8) and frequency of sampling are highly varying between studies.

The benthic vegetation along the coast of Fehmarn has been monitored regularly between 1996 and 2009 by Landesamt für Landwirtschaft, Umwelt und ländliche Räume des Landes (LLUR). In contrast, the benthic vegetation along the coast of Lolland has been monitored only sparsely as part of the Danish national monitoring programme. Only a single transect along the south coast of Lolland was visited in the years 1994–97; Gedser reef and Schönheiders Pulle were visited in 1995 and the predominant benthic soft vegetation in Rødsand Lagoon has been visited in 1995 and 2007. Additionally, some data on the vegetation in Rødsand are available from the EIA of the offshore wind farms.

An overview of the data is given in Table 2.5. As most of the data are not directly comparable to the data collected in this benthic vegetation baseline sampling programme, the data are only partly included in the analysis of baseline data. A short summary of the studies is given below.

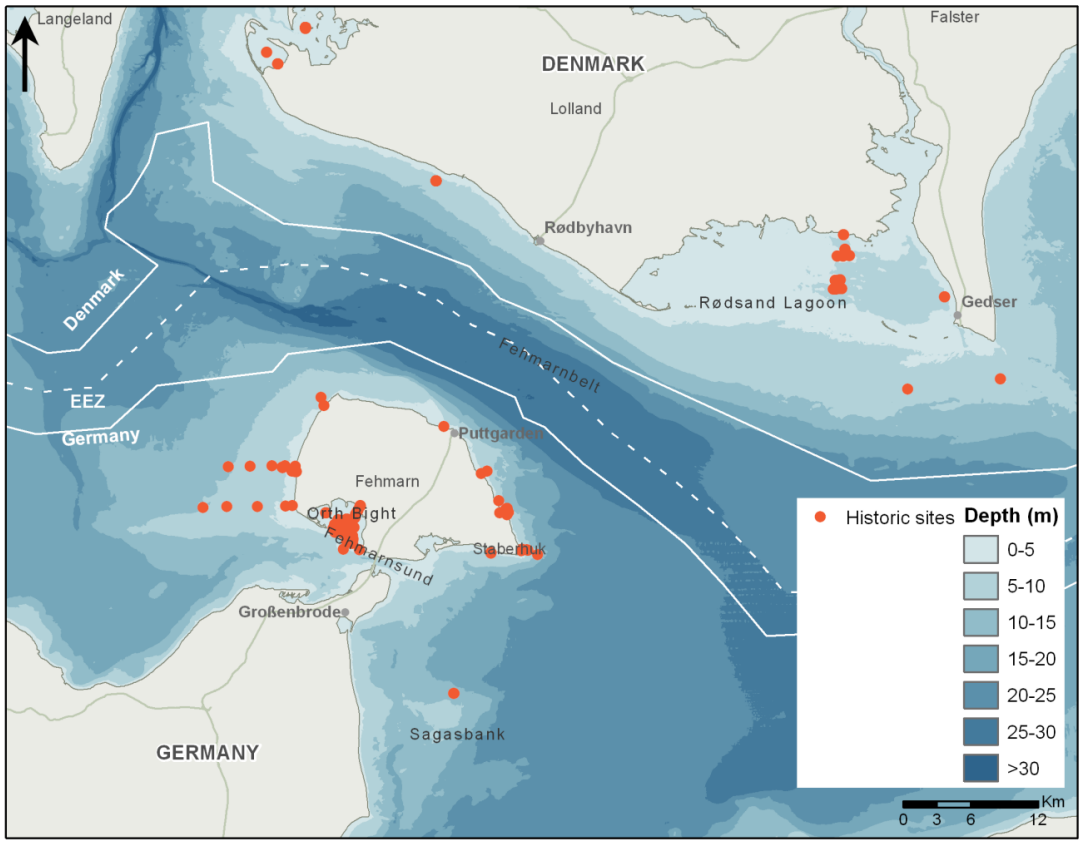



*Figure 2.8* *Historical sample sites within the investigation area, for which data are stored in the database. The data types are coverage estimates or biomass samples.*

*Table 2.5* *Overview of the different historical data sources from the investigation area.*

| Source and monitoring programme | Data | No. of samples sites/ transecst | Years | Application |
|---|---|---|---|---|
| *Data from LLUR* | | | | |
| HELCOM | Coverage and/or biomass data in specific depths/ positions, depth limit of macroalgae and eelgrass | 2 transects, Fehmarn East (Katharinenhof) and Orth Bight (Orther Bucht)<br>4 transects, Fehmarn West (2 transects) and Orth Bight (2 transects) | 1996-2003<br>1998-2004 | Calibration of predictive mapping results and documentation of temporal variations in macrophyte assemblages |
| Water Framework Directive (WFD) | Coverage and/or biomass data in specific depths/positions, depth limit of *Fucus* and eelgrass | Max. 10 transects, Fehmarn West (Wallnau, Westermarkelsdorf), Fehmarn North (Puttgarden) Fehmarn East (Klausdorf, Katharinenhof, Staberhuk) Fehmarn South (Burg, | 2006-2010 | Calibration of predictive mapping results and documentation of WFD classification |

| Source and monitoring programme | Data | No. of samples sites/ transecst | Years | Application |
|---|---|---|---|---|
| | | Strukkamphuk), Orth Bight (Lemkenhafen) | | |
| Vegetation mapping | Coverage of *Fucus* and eelgrass down to 6 m, qualitative abundance data for *Fucus*, eelgrass, *Furcellaria*, *Laminaria* and red algae down to 20 m | Along the coastline of Schleswig-Holstein exclusive military areas - completly around Fehmarn | 1950-1952 | Documentation of temporal variations in macrophyte assemblages |
| | Qualitative abundance data for *Fucus*, eelgrass, *Furcellaria*, *Laminaria* and red algae from 5 to 20 m | Along the coastline of Kiel Bight and parts of Mecklenburg Bay exclusive military areas - completly around Fehmarn | 1960-1964 | Documentation of temporal variations in macrophyte assemblages |
| | Coverage of *Fucus*, eelgrass and red algae down to 6 m | Along the coastline of Kiel Bight – only west coast of Fehmarn | 1987-88 | Documentation of temporal variations in macrophyte assemblages |
| | Coverage of *Fucus* and eelgrass down to 3-4 m | Along the coastline of Schleswig-Holstein - completly around Fehmarn | 2003 | Calibration of predictive mapping results |
| *Data from Fehmarn A/S* | | | | |
| Feasibility study | Coverage and biomass data in specific depths/ positions, macroalgae and eelgrass | 19 transects on the Danish and German coasts | 1997 | Documentation of temporal variations in macrophyte assemblages |
| *Data from other Danish sources* | | | | |
| National monitoring programme | Coverage, macroalgae species | 1 transect, Lolland coast | 1994-1997 | Documentation of temporal variations in macrophyte assemblages |
| | | Gedser Reef and Schönheiders Pulle | 1992 | Documentation of temporal variations in macrophyte assemblages |

| Source and monitoring programme | Data | No. of samples sites/ transecst | Years | Application |
|---|---|---|---|---|
| | Coverage, macroalgae species<br>Zostera max. depth | Gedser | 1995 | Documentation of temporal variations in macrophyte assemblages and depth distribution limits |
| | Coverage, macroalgae species | Rødsand south of Gedser | 1995 | Documentation of temporal variations in macrophyte assemblages |
| | Coverage angiosperms | 5 transects in Rødsand | 2007 | Calibration of predictive mapping results |
| *Nysted Offshore Wind Farm and Rødsand II* | Eelgrass biomass | 6 stations, Rødsand | 2001, 2002, 2003 | Calibration of predictive mapping results |
| | Total biomass red, green and brown algae | 6 stations, Rødsand | 2001, 2002, 2003 | Calibration of predictive mapping results |

*HELCOM-Monitoring (Germany)*
The benthic vegetation has been monitored regularly between 1996 and 2004 by Landesamt für Landwirtschaft, Umwelt und ländliche Räume des Landes (LLUR) in the Baltic Sea Protected Areas (BSPA) Fehmarn West, Orth Bight and the East coast of Fehmarn. Coverage and species composition was studied by underwater video surveys and quantitative sampling. At Fehmarn West and the East coast of Fehmarn sampling was done by divers at 2, 4, 6, 8 and 10 m depth with three replicates per depth. In Orth Bight at five positions between 2 and 4 m sampling was carried out.

*WFD-Monitoring (Germany)*
With the implementation of the Water Framework Directive (WFD) a new monitoring programme started in 2006 and is now carried out every year. Relevant water bodies for this investigation are (1) Fehmarnbelt, reaching from the southwest cape of Fehmarn (Flügge) to the east coast of Fehmarn and (2) Fehmarnsound along the whole south coast of Fehmarn as outer coastal water types as well as (3) Orth Bight as an inner coastal water type.

*Mapping surveys – benthic vegetation (Germany)*
Benthic vegetation was mapped along the coast of Schleswig-Holstein during different time periods with varying spatial solutions and data quality:

- 1950–52: A comprehensive mapping around Fehmarn of *Fucus* and eelgrass by visible observation down to 6 m depth; also mapping of *Furcellaria, Laminaria (Saccharina)* and red algae with single dredge trawls between 6 and ~ 20 m (Hoffmann 1952).

- 1960–64: Mappings around Fehmarn of *Fucus*, eelgrass, *Furcellaria, Laminaria (Saccharina)* and red algae by single dredge trawls from ~ 5 m down to ~ 20 m (Schwenke 1964, 1966, 1969).
- 1987–88: A comprehensive mapping at the west coast of Fehmarn of *Fucus*, eelgrass and red algae by visible observation down to 6 m depth (Schramm & Vogt 1988).
- 2003: A comprehensive mapping around Fehmarn of *Fucus* and eelgrass by visible observation down to 3 m depth (Fürhaupter et al. 2008b).

These different surveys have been georeferenced and converted to shape files by Meyer et al. (2005). All historical maps shown in this baseline report refer to this reference.

*Fehmarnbelt feasibility study – benthic vegetation*
A baseline survey of the benthic vegetation in Fehmarn Belt was carried out during the autumn of 1997. The distribution, coverage and species composition of the benthic vegetation were studied by underwater video survey, aerial photography and quantitative sampling. The methods were different from the methods used in this baseline study and the results therefore not directly comparable.

*Nysted Offshore Wind Farm*
In Rødsand Lagoon benthic vegetation was studied along the planned cable connection to Nysted offshore wind farm in 2001 and 2002. After the construction of the cable trench the sites were visited again in 2003. The study included biomass sampling of eelgrass and macroalgae.

The hard bottom communities on the foundations in Nysted Offshore wind farm were studied in 2003, 2004 and 2005. In order to compare the new community on the 'artificial reefs' with a natural hard bottom community the benthic vegetation on a nearby stone reef, Schönheiders Pulle, was also studied in 2004. The study included results on diversity and biomass of macroalgae.

*Rødsand II*
As a contribution to the EIA of Rødsand II a survey of benthic vegetation was carried out in August 2006. Coverage of eelgrass, tasselweed, pondweed and macroalgae was recorded in the area of the planned wind farm (and alternatives) and in the Rødsand Lagoon.

*Danish monitoring programme*
Gedser reef and Schönheiders Pulle were monitored in 1992. Schönheiders Pulle in the depth interval 10–12 m and Gedser reef in the depth interval between 4 and 12 m. The programme included coverage estimates of benthic vegetation.

In 2007 the cover of eelgrass, tasselweed and pondweed was determined along 5 transects. The depth limit of eelgrass was determined to 5 m along one transect in Rødsand in 1995.

### 2.4.2 Aerial Photos

Aerial photography was used to identify and describe shallow water habitats as a part of the Fehmarnbelt Fixed Link habitat mapping (FEMA 2013). Benthic vegetation was classified as: algae, algae on hard substrate, algae on hard substrate in shallow water, algae/mussel, eelgrass, eelgrass/algae.

For the vegetation baseline description the above mentioned categories were lumped together as one algae category and all categories not describing the vegetation were removed. Aerial photography identified habitats to a depth of 6–10 m depending on the quality of the photos. The resulting map is shown in Figure 2.9.

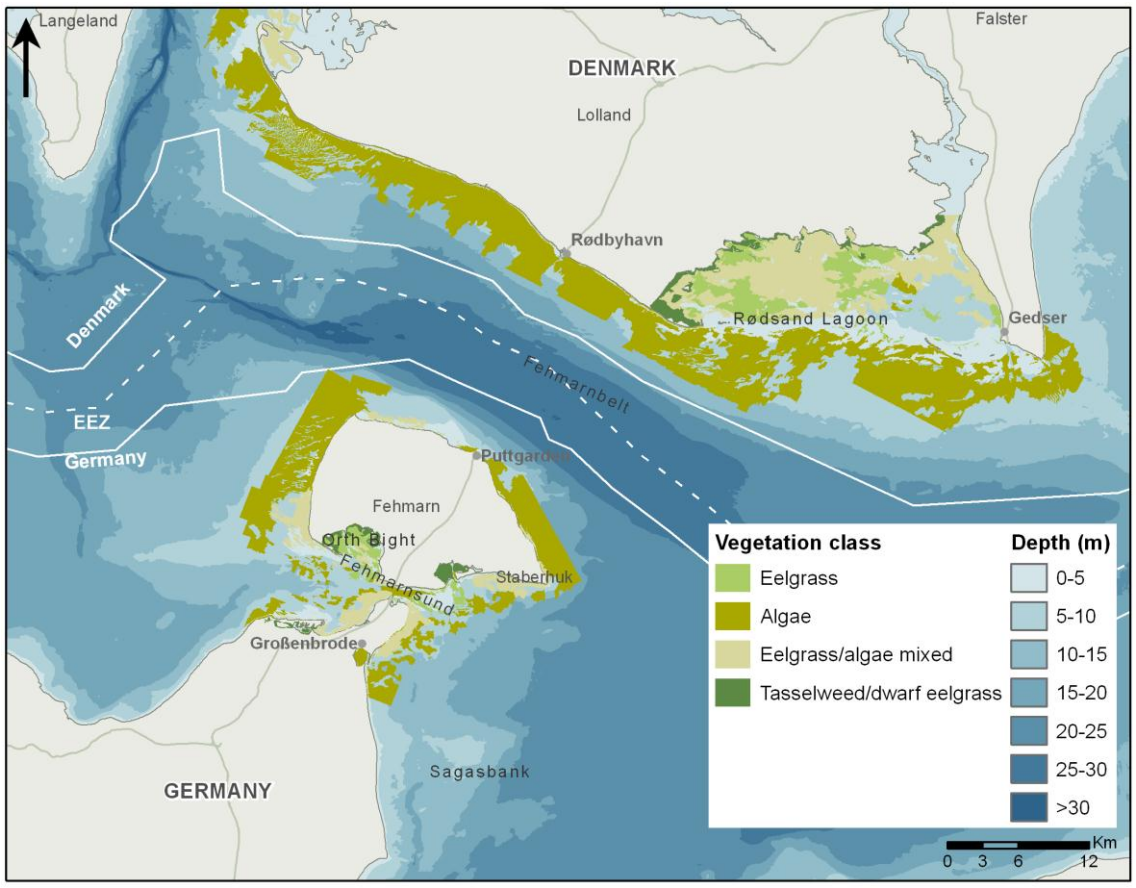



*Figure 2.9* *Areas of bottom vegetation in the Fehmarnbelt area in the summer of 2009. The map is based on results from the aerial photo survey and results from video recordings along transects.*

### *2.4.3 Environmental data*

Environmental data were collected and used to describe the physico-chemical conditions for benthic vegetation in Fehmarnbelt and used as input data for predictive mapping of eelgrass and macroalgae cover (see Data Analysis).

Fehmarnbelt Fixed Link Hydrographic Services (FEHY) has collected data on the hydrographic and water quality conditions and has established a dynamic model describing the existing environmental conditions of the Fehmarnbelt area (FEHY 2013). Data used were those available in October 2010, which for this purpose has the same quality as later updated versions. Data from this models is used to describe salinity, temperature, secchi depth, nutrient concentrations, bathymetry, bed shear stress and current speed in the area and at the sample sites. The model data covers a 12-month period (October 2008 – September 2009).

Knowledge about availability of hard substrate is essential to predict the occurrence of macroalgae. The distribution of hard substrate was estimated using all available information about the sea bottom. The information used was a map of the Danish sea bed (GEUS Havbundstyper), a map of the German sea bed (Reimers 2010), a

substrate map prepared as part fo the Fehmarnbelt Fixed Link habitat mapping (FEMA 2013), diver estimates of hard substrate in Denmark obtained from the Danish National Environmental Research institute (NERI), data on stone cover from baseline video recordings and diver estimates of hard subtrate in the present baseline investigation. Details on the method for estimating the hard substrate is given in Appendix 7.

## 2.5 Data Analysis

### 2.5.1 Key Communities

Different methodological approaches can be used in vegetation classification. A comprehensive description of the methods used are given in Appendix 3. The following sections concentrate on the most relevant analysis steps.

*Multivariate analysis*
Key communities of macroalgae and flowering plants were identified using a set of different multivariate analysis tools. Absolute biomass data were chosen for the analyses. The use of the coverage estimations in frames or circles was checked for this purpose, but as some species cannot be identified underwater, the biomass data gave the most detailed and precise species information and therefore showed the best results. Coverage data from frames and sites were used afterwards to assign the results to a greater spatial scale.

Cluster analysis and multidimensional scaling (MDS) were used to identify groups of samples with similar species composition. The analyses were based on the Bray-Curtis dissimilarity index (Bray & Curtis 1957), which quantifies the (biological community) dissimilarity between all pairs of sites. To downweight the influence of dominant (large) species and to stress the importance of rare (small) species, biomass data were square root transformed before calculation of Bray-Curtis dissimilarity index.

$$BC_{ij} = \sum \frac{|n_{ik} - n_{jk}|}{(n_{ik} + n_{jk})}$$

with n = number of individuals, i + j = species and k = area.

The results of a cluster analysis are displayed in a hierarchical tree-like structure called a dendrogram. On the dendrogram, firstly two groups are defined, and within these groups subgroups are defined. Subsequently, subgroups within the subgroups are defined. This process is called group average and is continued until all stations are grouped. Sites that are most alike will cluster (group) together, whereas those sites that are more dissimilar are unlikely to join the same cluster. In MDS plots each point represents one sample. The closer the points, the more similar the species assemblages are in those samples.

The overall significance of the difference between samples or sites was assessed using analysis of similarities (ANOSIM). ANOSIM is used for testing hypotheses about spatial differences and temporal changes in assemblages and in particular for detecting environmental impacts (Chapman & Underwood 1999). ANOSIM generates a value of R (global R), which is scaled to lie between -1 and +1, a value of zero representing the null hypothesis (no difference among a set of samples). Generally, R lies between zero and +1. Negative values have been considered unlikely because they would indicate greater dissimilarity among replicate units within samples than occurs between samples (Chapman & Underwood 1999). When negative values occur, they should not simply be ignored as anomalies. In fact,

they identify important ecological information and identify issues about the design of sampling (Chapman & Underwood 1999). In natural assemblages, negative *R* values were found when assemblages were very patchy so that replicates were variable, but each sample had similar amounts of variability among replicates. Large negative values of *R* were particularly common when either or both samples contained an outlier, or when the assemblage being sampled had 2 different states and the replicates had sampled each of these states. Negative values of *R* may therefore indicate the need for stratification of the sampling design, or problems of positive correlation between the different sets of samples.

SIMPER (SIMilarity PERcentage) analysis was used to identify the species that were primarily responsible for the observed differences between groups of samples (sites).

TWINSPAN (TWo-way INdicator SPecies ANalysis) was used to classify species and samples and produce an ordered two-way table of their occurrence. An interesting feature of TWINSPAN is that it forms what is termed pseudospecies. These are separate variables for the different levels of abundance of a species. Samples are ordinated using Reciprocal Averaging (RA). A dichotomy is then made using the RA centroid line to divide the samples into two groups (negative and positive). This dichotomy is then refined using an iterative procedure. The clusters of samples obtained are then ordered so that similar clusters are near each other. This procedure continues in a hierarchical fashion to subdivide the groups until the minimum group size initially selected by the user is obtained. Species are then classified using the sample (quadrate) classification. In the original output a table is then produced showing species-by-site (quadrate or sample) relationships (Seaby & Henderson 2007).

*Macroalgae key communities*: Cluster/MDS, ANOSIM, SIMPER and TWINSPAN analyses were conducted per depth interval (0–2 m, 2–5 m, 5–10 m, 10–15 m, 15–20 m). Identical symbols and colours in Cluster/MDS plots mark samples belonging to the same sub-areas within the investigation area. Additionally it was outlined in the figures, which samples belong to which community, if possible. Plots and data analyses are listed in Appendices 3–5.

*Flowering plant (angiosperm) key communities:* Cluster/MDS, ANOSIM, SIMPER and TWINSPAN analyses were conducted on the basis of biomass data. Depth intervals had to be analysed together to provide enough data for multivariate analyses. Samples belonging to the same investigation area were marked by identical symbols in Cluster/MDS. Additionally it was outlined in the figures, which samples belong to which community, if possible. Plots and data analyses are listed in Appendices 3–5.

Not all depth intervals are represented in all sampling areas due to lack of hard substrates or differences in maximum depth of the areas. Table 2.6 gives an overview of the depths which were present in each sampling area for macroalgae and angiosperm analysis, respectively. Figure 2.10 show the names and location of the sampling areas.

*Table 2.6 Depth intervals present in the different sampling areas. Abbreviations of the areas used in figures and text is given in brackets.*

| **Area** | **Macroalgae analysis** | | | | |
|---|---|---|---|---|---|
| | 0–2 m | 2–5 m | 5–10 m | 10–15 m | 15–20 m |
| Danish waters | | | | | |
| Langeland (LA) | | x | x | x | |
| Lolland (LO) | x | x | x | x | |
| German waters | | | | | |
| Fehmarn East (FeE) | x | x | x | x | x |
| Fehmarn West (FeW) | x | x | x | | |
| Fehmarnbelt (Be) | | | | x | x |
| Großenbrode (Gr) | x | x | x | | |
| Sagasbank (Sb) | | | x | x | |

| **Area** | **Flowering plants analysis** | | | |
|---|---|---|---|---|
| | 0–1 m | 1–2 m | 2–4 m | 4–6 m |
| Danish waters | | | | |
| Rødsand Lagoon (RO) | x | x | x | x |
| German waters | | | | |
| Orth Bight (Ob) | x | x | x | x |
| Großenbrode (Gr) | | | x | x |

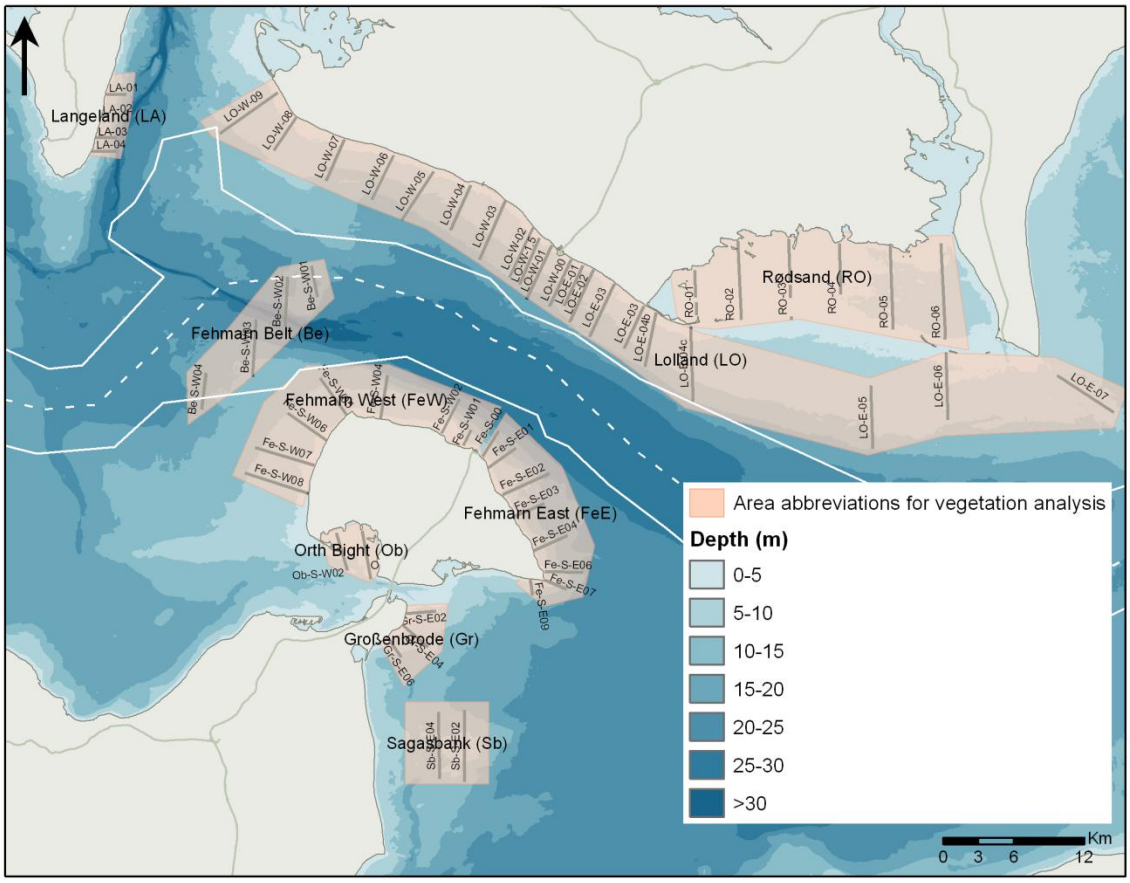



*Figure 2.10 Names and abbreviations for geographical regions used for the community analysis.*

### 2.5.2 Species Diversity

Several parameters can be used as diversity measures. A comprehensive description of the principles of diversity parameters are given in Appendix 3. The following sections concentrate on the most relevant analysis steps.

Species diversity at the sampling sites was described by the number of species, Simpson's dominance index and Shannon-Wiener diversity index.

The number of species is a basic measure of diversity, but the communities can be very different depending on the relative abundance of the species in the community, also called evenness. Simpson's Index of Diversity (1-D) was used to describe diversity:

$$1 - D = 1 - \sum_{i=1}^{S} \left(\frac{n_i}{N}\right)^2$$

where $n_i$ = abundance of the $i^{th}$ species, N = total abundance, S = total number of species. The Shannon-Wiener index (H) combines species richness (number of species within the community) and species evenness:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

Where S = species richness (total number of species present), $p_i$ = proportion of total sample belonging to the ith species. Given a very large sample size, with more than 5 species, the S-W index values (H) can range from 0 to ~ 4.6 using the natural log (ln). A value near 0 would indicate that every species in the sample is the same. A value near 4.6 would indicate that the species abundance is evenly distributed between all the species.

The three measures of species diversity were used to describe average species diversity in the communities and the patterns of species diversity with depth. Species richness showed a bell-shaped pattern with depth and was therefore fitted using a second degree polynomial function. The data for species richness and Shannon-Wiener diversity index fitted to a normal distribution (Kolomogorov-Smirnov one-sample test, $p > 0.1$). The data for Simpson's evenness index did not fit a normal distribution, but since transformation of the data did not increase the goodness of fit to the normal distribution, non-transformed data were used.

### *2.5.3 Cover and Biomass*

Average of total cover, substrate specific cover, and biomass at the sampling sites were calculated for total macroalgal vegetation and for key communities and/or key species. Since not all data were normally distributed both average and median values are given. Because total cover of macroalgae is closely related to the cover of hard substrate in the Danish and German waters, substrate specific cover was included as a measure of cover that takes into account the variable availability of hard substrate. Substrate specific cover is defined as the cover of the macroalgae relatively to the area of suitable hard substrate (see section 2.3.2). Total cover is estimated based on algal cover relatively to the area of suitable hard substrate and the proportion of suitable hard substrate of the total area.

Multiplying the biomass of macroalgae in well established vegetation by the cover at the site provides an estimate of the average biomass at the whole station. This is called the cover-corrected biomass.

Total macroalgal biomass decreased with depth but was very variable along the whole depth gradient. A regression model based on the biomass data express the average trend but only explained a minor part of the overall variation in the data set. However, the maximum biomass vs. depth showed a clear exponential decrease with depth. If the data was grouped and the 90$^{th}$ percentile of the grouped data used in the regression model the explanatory power of the exponential model increased.

The choice of an appropriate number of class for describing the upper bound was based on the method described by Blackburn (1992): The total number of observations were grouped into various numbers of classes. For each class of data the 90$^{th}$ percentile was calculated and the data fitted to an exponential function and the slope was calculated. For a small and large number of classes the slope of the upper bound varied markedly with the number of classes, whereas for intermediate number of classes (15–20) the slope of these bounds became stable (Figure 2.11). The stable level of the bound slope at intermediate numbers of classes represents the "true" upper bound of the distribution. To describe the upper boundary of the present biomasses, the data were therefore grouped into 17 classes The exponential decrease in biomass with depth was described by the linear relationship be-

tween ln (biomass) and depth. Ln (biomass) data could in all cases be fitted to a normal distribution (Kolomogorov-Smirnov one-sample test, P > 0.15).

Areas with flowering plants are characterised by few species compared to macroalgae communities. The distribution and abundance (cover and biomass) of eelgrass, tasselweed and pondweed are described without averaging or other estimations. Other species are briefly mentioned.

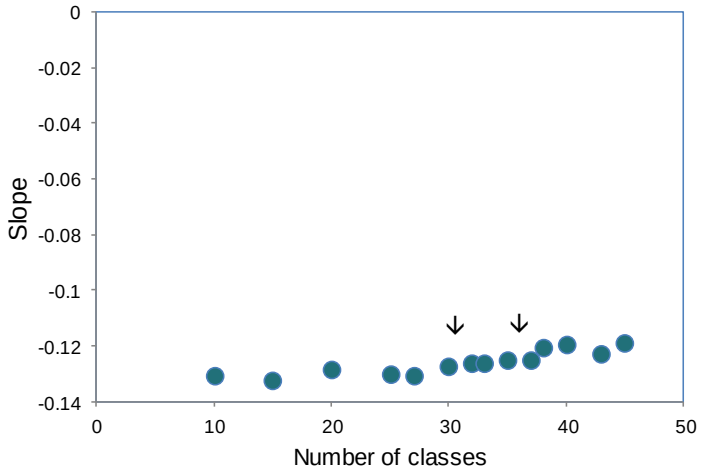



*Figure 2.11 Relationship between estimates of upper bound slopes and number of depth classes. For each depth class 90th percentile of biomass was used to characterise the upper bound.*

### 2.5.4 Prediction of vegetation distribution and cover

Spatial distribution and cover of vegetation are difficult to estimate because of the high patchiness of vegetation cover and biomasses. For both soft bottom and hard bottom vegetation it is therefore often difficult to make reliable interpolations between data points using conventional interpolation methods (e. g. nearest neighbour or kriging).

Instead, the interpolation has been done by predictive habitat mapping using Generalised Additive Modelling (GAM) statistics. Significant relationships between the physico-chemical factors most important to the distribution and the abundance of benthic flora in 2009 was used to predict the distribution and abundance within the sampled area.

The resulting maps show the potential area of suitable habitats for eelgrass and macroalgae vegetation. These predictive maps were combined with the aerial mapping results. Outside the area covered by the aerial survey map only the predictive mapping was used.

For each key community, specific relationships between cover and cover-corrected biomass were estimated based on 2009 data and these relationships were used to produce a map of cover-corrected biomass of the total benthic vegetation.

*Mapping of key communities*
Areas covered by the key communities were estimated combining the predicted map of benthic vegetation distribution (macroalgae and angiosperms) with the

identification of key communities determined at all sampling sites. A list and description of allocation rules for communities are given in Appendix 3. In some areas an overlapping of macroalgae and flowering plant cover occured due to mixed sediment conditions. In such areas an eelgrass/algae-community was assigned.

# 3 ENVIRONMENTAL CONDITIONS IN FEHMARNBELT

The distribution and abundance of marine benthic vegetation is regulated by a complex of factors. The importance of these factors depends on the spatial and temporal scale in focus.

The depth and substrate of the seabed are likely to be the most important parameters to explain the differences in distribution and abundance of the benthic vegetation at the scale of Fehmarnbelt and neighbouring areas. Depth combines the effect of reduced light availability and reduced exposure with depth. The soft bottom species like eelgrass are not able to grow in high exposure. Likewise exposure is a key factor for the vertical distribution of macroalgae species. Substrate is of high importance as macroalgae depends on availability of hard substrate and likewise flowering plants depend on soft bottom.

Salinity and temperature are important parameters to explain the distribution and abundance of marine benthic vegetation over large geographical scales. Likewise variations in water quality (light and nutrient availability) may directly influence the presence and dominance of species and may also limit their growth and depth distribution. These parameters, however, show only small variations throughout the area and they are therefore not expected to be important to explain the difference in abundance of benthic vegetation at the scale of Fehmarnbelt and neighbouring areas.

In this report a short description of the parameters used for analysis and benthic vegetation mapping is presented. The data on hard substarte is collected in this study and the other data are obtained from dynamic modelling as described in the methods section.

*Seabed*
The deepest part of Fehmarnbelt is approximately 30 m deep. Water depth measured at the coverage estimation/sampling sites during field surveys ranged between 0.3 and 21.2 m.

Suitable hard substrate for macroalgae colonisation and growth varied between 0 and 100% at the investigated sites. The cover was very variable between 0 and 10 m depth, but showed a clear decrease below 10 m (Figure 3.1).

Usually suitable hard substrate include boulders, cobbles and pebbles but in some places with low exposure, mussels and smaller stones are also available as substrate, but mostly for filamentous species. The average coverage for all type of suitable substrate was 41.9% (± 3.2,Table 3.1), whereas the average value of boulders, cobbles and pebbles was 34.4% (± 2.8) (only hard bottom area included in the estimation). The derived map of hard substrate, produced to support dynamic and predictive mapping of macroalgae, are shown in Figure 3.2.

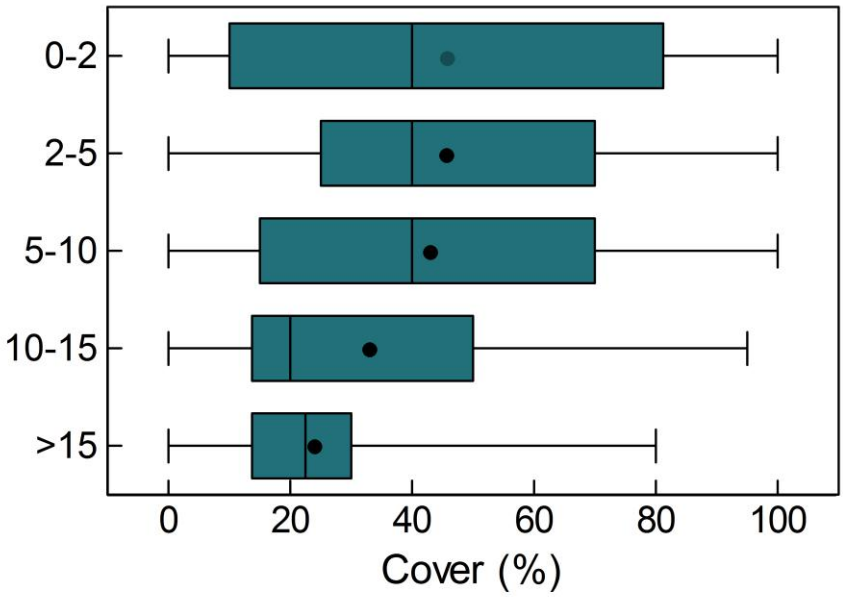



*Figure 3.1* *Cover of suitable hard substrate as a function of depth at 357 sites in Fehmarnbelt in the summer of 2009. Circles represent mean values of cover in each depth interval, vertical lines represent medians, boxes represent 25-75% percentiles, and whiskers represent 10-90% percentiles.*

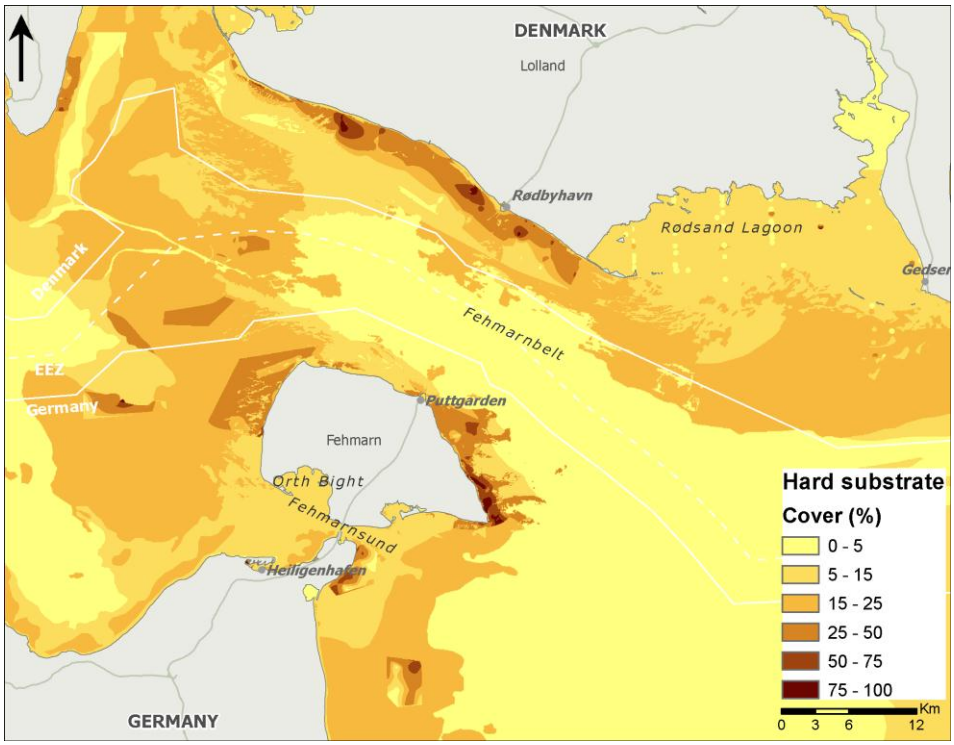



*Figure 3.2* *Percentage cover of suitable hard substrate for macroalgae vegetation, details of the method used for the mapping is described in Appendix 7.*

*Hydrodynamic parameters*

Fehmarnbelt and the neighbouring areas are situated in one of the world's largest estuaries, where low saline surface water flows from the Baltic Sea to the North Sea and high saline bottom water enters from the North Sea into the Baltic Sea. The

modelled average bottom salinity (2009) varied between 11.8 and 25.3 psu at the sampling sites and average summer bottom temperature varied between 11.7 and 17.0 °C (Table 3.1).

The average maximum annual current speed at the sampling sites was 0.25 m $s^{-1}$ and about four times as high as the average mean current speed of 0.06 m $s^{-1}$. Bed shearstress (current and wave) varied between 0 and 72 N $m^{-2}$.

*Water quality*
The modelled Secchi depth (defined as the depth reached by 15% of surface irradiance) ranged between 5.7 and 7.8 m. Nutrient concentrations was highest in winter where mean total nitrogen ranged between 18 and 27 µmol $l^{-1}$ and total phosphorus between 0.86 and 1.12 µmol $l^{-1}$ at the benthic vegetation sample sites.

*Table 3.1 Mean coverage of seabed substrates (calculated from all substrate data collected by divers), and seabed depth and slope (from FEHY mapping of the bathymetry), as well as summer means of hydrographical and water quality parameters (modelled data) at the 2009 sample sites in Fehmarnbelt. For substrate only hard bottom areas are included. Ranges between sample sites are given in brackets.*

| Parameter | Unit | Mean (range) |
|---|---|---|
| ***Seabed*** | | |
| Suitable hard substrate | % | 41.9 (0-100) |
| Boulders, cobbles and pebbles | % | 34.4 (0-100) |
| Depth | m | 6.5 (0.3-21.2) |
| Slope | degree | 0.37 (0.003-4.6) |
| ***Hydrographical*** | | |
| *Salinity* | | |
| Annual bottom 2009 | psu | 15.8 (11.8-25.3) |
| *Temperature* | | |
| Summer bottom 2009 | °C | 16.0 (11.7-17.0) |
| *Current speed* | | |
| Annual max | $m\ s^{-1}$ | 0.25 (0.06-0.65) |
| Annual mean | $m\ s^{-1}$ | 0.06 (0.014-0.14) |
| *Bed shear stress* | | |
| *Current and wave* | $N\ m^{-2}$ | 20.2 (0-71.9) |
| ***Water quality*** | | |
| *Secchi depth* | m | |
| *Summer mean* | | 7.4 (5.7-7.8) |
| *Total Nitrogen* | | |
| Summer mean | $\mu mol\ L^{-1}$ | 18.3 (15.5-29.4) |
| Winter mean | $\mu mol\ L^{-1}$ | 20.4 (17.9-27.4) |
| *Total Phosphorus* | | |
| Summer mean | $\mu mol\ L^{-1}$ | 0.84 (0.5-1.8) |
| Winter mean | $\mu mol\ L^{-1}$ | 1.0 (0.86-1.12) |

# 4 MACROALGAE COMMUNITIES IN FEHMARNBELT AND NEIGHBOURING AREAS

## 4.1 Species Composition and Definition of Key Communities

Species analysis and definition of communities was based on the 2009 data set. 2010 data have been used to review the 2009 analyses and to check if results differ between sampling years. The overall conclusion is that at sites with perennial vegetation the 2010 data confirmed the analyses of 2009. Only at sites with a dominance of annual (filamentous) vegetation species composition differed in comparison to 2009, but this is expected for annual/filamentous vegetation communities.

### 4.1.1 Communities in the 0-2 m Depth Interval

Macroalgae species composition and biomass in the 0–2 m depth interval were highly variable between areas, but a significant separation between areas was only obtained between Großenbrode and Lolland (ANOSIM, R = 0.753, p = 0.001). The difference was mainly due to relatively high biomasses of *Polysiphonia fucoides* and *Cladophora* sp. in the Lolland area and a high abundance of *Ceramium virgatum* in Großenbrode. These three species are filamentous species typical of the surf zone. Fehmarn East (FeE) and Großenbrode (Gr) as well as Fehmarn East and Fehmarn West (FeW) showed no separation at all.

The average similarity between samples within the areas was highest for Lolland (SIMPER, 50.8%). Hence, most of the replicates of this area were therefore grouped together. The average similarity of species in Fehmarn West (30.7%), Fehmarn East (24.5%) and Großenbrode (23.7%) was low compared to Lolland(Lo).

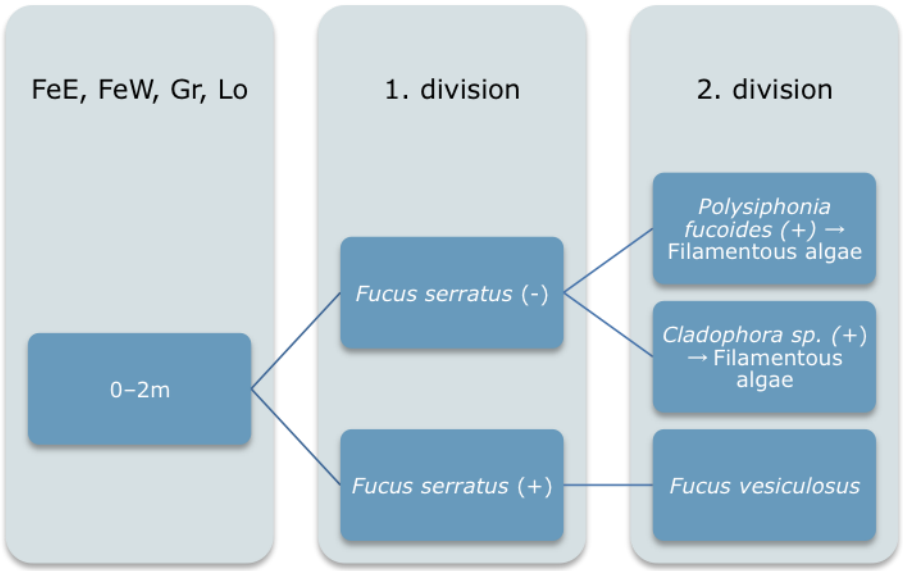



*Figure 4.1* *Macroalgae communities in the depth interval 0-2m in the summer of 2009. Grouping of samples are based on TWINSPAN-analysis of 106 samples in the 0-2m depth interval.FeW = Fehmarn West, FeE=Fehmarn East, Gr= Großenbrode.*

The samples were grouped (TWINSPAN) into replicates where *Fucus serratus* was present (+) or absent (-). Where *F. serratus* is missing a classification could be made upon the presence/absence of *Polysiphonia fucoides* or *Cladophora* sp.

(Figure 4.1). However, these filamentous algae species are not functionally different than other filamentous algae in the ecosystem and they were therefore not used to characterize a separate plant community.

### 4.1.2 *Communities in the 2-5m Depth Interval*

Variability of species composition and abundance between samples in the 2–5m depth interval was also very high, but the separation of the areas was not so pronounced as in the 0-2m interval. Communities of Fehmarn West and Lolland were clearly different (ANOSIM, R = 0.669, p = 0.001). The difference was mainly due to high biomasses of *Furcellaria lumbricalis* along the coast of Lolland and a high abundance of *Fucus serratus* and to a less extent *Fucus vesiculosus* in Fehmarn West. The *Fucus* species did not occur at all in the Lolland area. All other areas were either barely separable or did not show any separation at all.

The average similarity between samples within areas was highest for Lolland (SIMPER, 42.9%), and these samples are grouped into one big cluster together with some samples of other areas. Again, the responsible species for the higher average similarity between samples from Lolland was *Furcellaria lumbricalis*. The average similarity for samples within Langeland (36.7%), Fehmarn East (29.8%), Fehmarn West (25.2%) and Großenbrode (20.8%) was low.

The samples were grouped (TWINSPAN) into replicates where *Fucus serratus* was present (+) or absent (-). A further division of samples with *F. serratus* could be made upon the presence/absence of *Fucus vesiculosus.* Where *F. serratus* is absent a further division of samples could be made upon the presence/absence of *Furcellaria lumbricalis* (Figure 4.2). All other groupings/divisions ended up with filamentous algae.

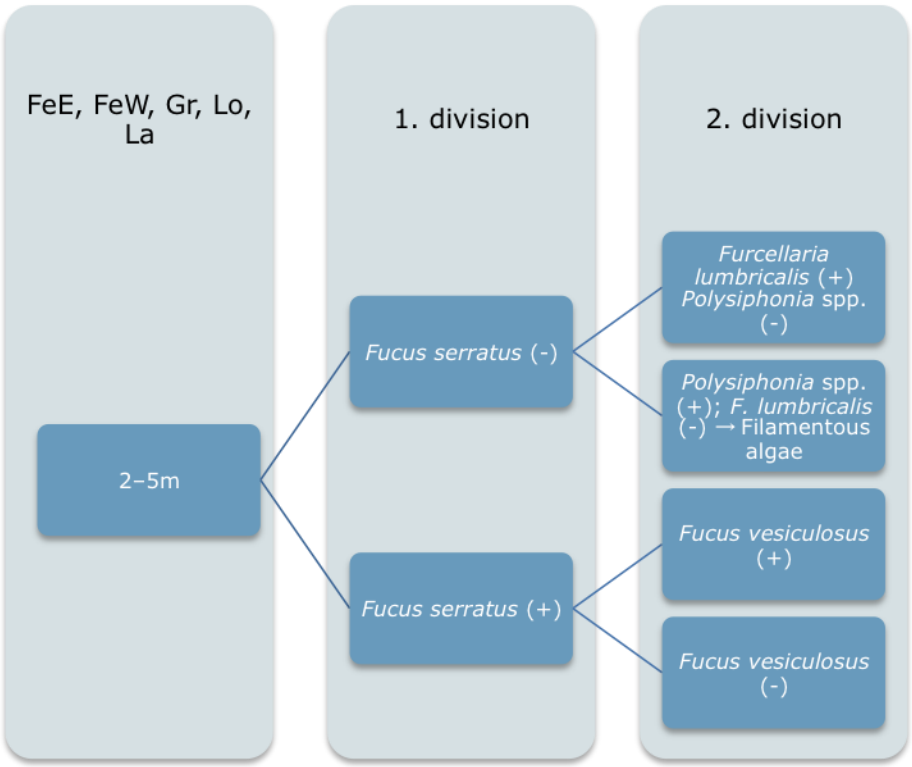



*Figure 4.2* *Macroalgae communities in the 2-5 m depth interval in the summer of 2009. Groupings of samples are based on TWINSPAN-analyses of 135 samples in the 2-5 m depth interval. FeW = Fehmarn West, FeE=Fehmarn East, Gr= Großenbrode, Lo=Lolland, La=Langeland.*

### 4.1.3 *Communities in the 5-10m Depth Interval*

Macroalgae species composition and biomass in the 5–10 m depth interval showed high variability between samples and areas, but the variability was slightly lower than in the shallow water. Communities of Fehmarn West and Lolland (as in the 2–5 m interval; ANOSIM, R = 0.670, p = 0.001) as well as Großenbrode and Langeland were overlapping but clearly different (R = 0.580, p = 0.001). The differences between communities on the Fehmarn West coast and the coast of Lolland arose due to the high abundances of *Coccotylus/Phyllophora*, *Polysiphonia fucoides* and *Furcellaria lumbricalis* in the Lolland area and the occurrence of *Delesseria sanguinea* and *Phycodrys rubens* in Fehmarn West. Langeland communities showed a high abundance of the perennial red algae (*Coccotylus/Phyllophora, Delesseria sanguinea, Phycodrys rubens*), which are missing or have only low abundances in Großenbrode. All other areas were either barely separable or did not show any separation at all.

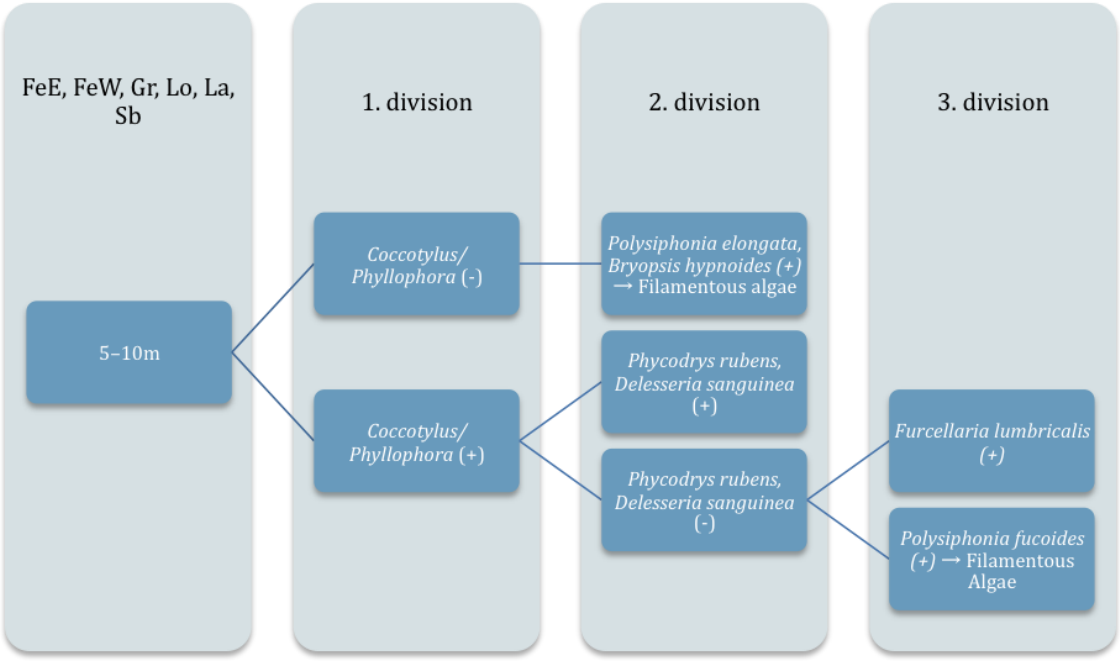



*Figure 4.3* *Macroalgae communities in the 5-10 m depth interval in the summer of 2009. Groupings of samples are based on TWINSPAN-analyses of 162 samples in the 5-10 m depth interval. FeW = Fehmarn West, FeE=Fehmarn East, Gr= Großenbrode, Lo=Lolland, La=Langeland, Sb=Sagasbank.*

The average similarity (SIMPER) between samples within the subareas was between 40 and 50%. Again Fehmarn West showed a very low similarity (29.4%). The average similarity between samples was highest for Langeland (49.9%) and Fehmarn East (47.9%). This was due to high abundances of the species *Phycodrys rubens, Coccotylus/Phyllophora* and *Delesseria sanguinea* for Fehmarn East and *Coccotylus/Phyllophora* and *Delesseria sanguinea* for Langeland.

Samples were grouped (TWINSPAN) into sites where *Coccotylus/Phyllophora* was present (+) or absent (-). A further division of samples with *Coccotylus/Phyllophora* was made upon the presence/absence of *Phycodrys rubens* and *Delesseria sanguinea*. A further division of samples without *Phycodrys rubens* and *Delesseria sanguinea* was made upon the presence/absence of *Furcellaria lumbricalis* (Figure 4.3). All other groupings/divisions ended up with filamentous algae.

### 4.1.4 Communities in the 10-15m Depth Interval

Within the 10-15m depth interval the variability in species composition and biomass between samples and areas was generally lower than in more shallow waters. The communities of Lolland could be well separated (ANOSIM, R = 0.783-0.877, p = 0.001) from all other subareas (Fehmarn West, Fehmarn East, Langeland, Sagasbank). The perennial red algae species *Coccotylus/Phyllophora, Delesseria sanguinea* and *Phycodrys rubens* were absent from this depth interval along the coast of Lolland, but the species occurred in the other subareas with high abundances. All other areas were barely separable from each other.

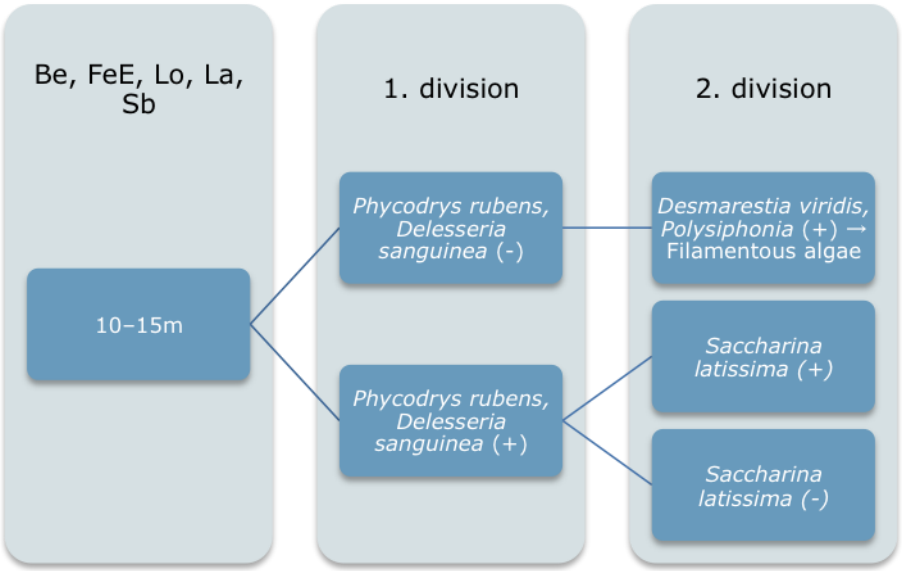



*Figure 4.4 Macroalgae communities in the 10-15 m depth interval in the summer of 2009. Groupings of samples are based on TWINSPAN-analyses of 89 samples in the 10-15 m depth interval. Fehmarnbelt=Be, West, FeE=Fehmarn East, Lo=Lolland, La=Langeland, Sb=Sagasbank.*

The average similarity (SIMPER) between samples within the subarea was high for Fehmarn East (69.9%), Sagasbank (67.8%) and Langeland (58.4%). The high similarity was caused by a high abundance of *Phycodrys rubens, Coccotylus/ Phyllophora* and *Delesseria sanguinea*. The similarity between samples was lower for Fehmarn Belt (43.0%) and Lolland (36.4%).

Samples were grouped (TWINSPAN) into sites where *Phycodrys rubens* and *Delesseria sanguinea* were present (+) or absent (-). A further division of samples with *Phycodrys rubens* and *Delesseria sanguinea* was made upon the presence/ absence of *Saccharina latissima* (Figure 4.4). All other groupings/divisions ended up with filamentous algae.

### 4.1.5 Communities in the 15-20 m Depth Interval

Only few samples were collected within the 15–20 m depth interval due to a lack of suitable hard substrate there. The data set is therefore too small to give suficient confidence in the multivariate results. Variability in species composition and biomass between samples and areas was high although only few species occurred. There were no significant differences between areas, because variability between single samples within one area was higher than the variability between areas (ANOSIM, R = -0.0006, p = 0.465).

The average similarity (SIMPER) between samples within subareas was high in both areas (Fehmarnbelt: 61.6%, Fehmarn East: 54.0%). The responsible species was *Phycodrys rubens* in both areas. TWINSPAN grouped samples first into sites where

*Saccharina latissima* was present (+) or absent (-). A further division of samples without *Saccharina latissima* could be made upon the presence/absence of *Delesseria sanguinea*, but this is also doubtful because of the limited data set (Figure 4.5).

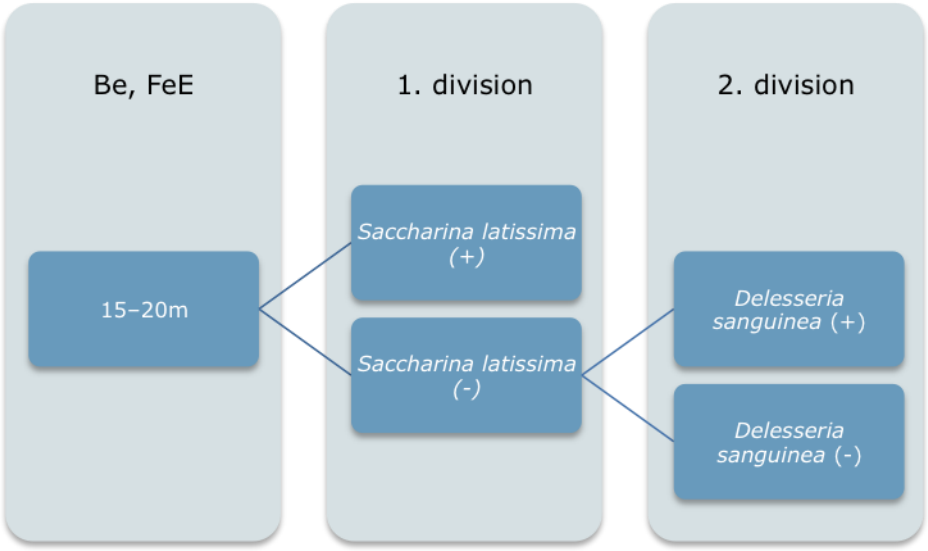



*Figure 4.5* *Macroalgae communities in the 15-20 m depth interval in the summer of 2009. Groupings of samples are based on TWINSPAN-analyses of 27 samples in the 15-20 m depth interval. Fehmarnbelt=Be, West, FeE=Fehmarn East.*

### *4.1.6 Key Macroalgae Communities*

In summary, using TWINSPAN, five different key communities could be identified within the investigation area: the *Fucus* community, the *Furcellaria* community, the *Phycodrys/Delesseria* community and the *Saccharina* community (Figure 4.6). Apart from these communities, which are named by characteristic key species in the area, a filamentous algae community was additionally defined.

The identified four key species macroalgal communities are comparable with historical observations on plant communities in the Western Baltic (Schwenke 1964). Only perennial, non-filamentous algae with a stable occurrence in ecologically confined habitats (normally depth or substrate specifications) were used to define these communities. Some of the key species were abundant in more than one community. In such cases they were not defined as key species but as accompanying species in different communities.

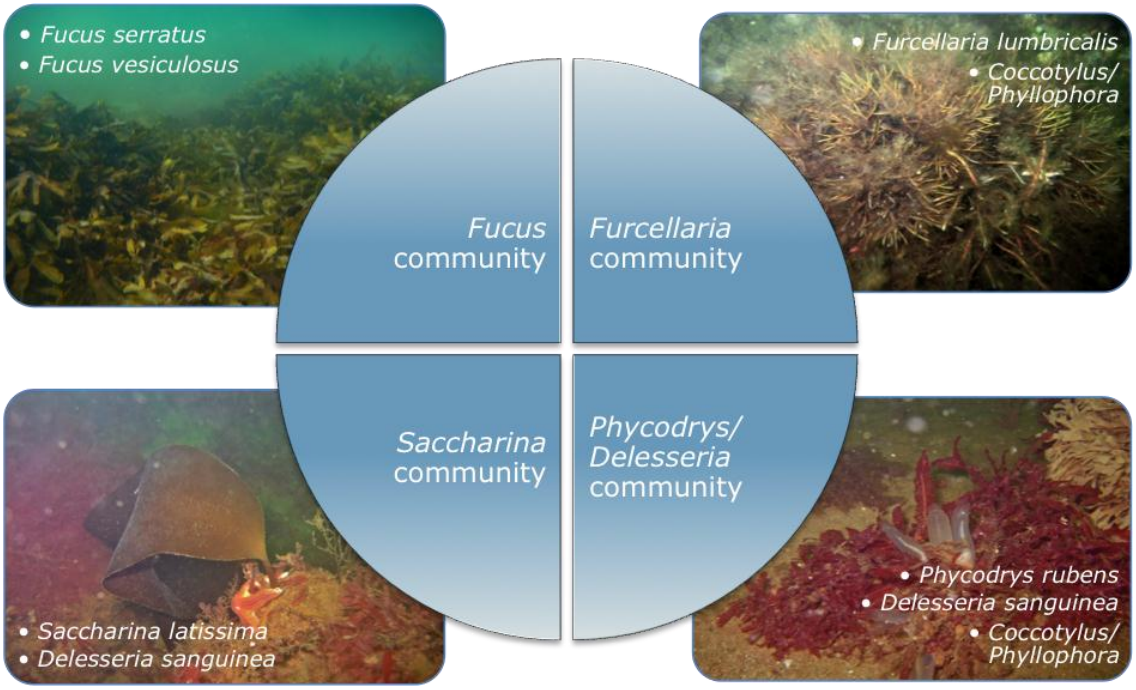
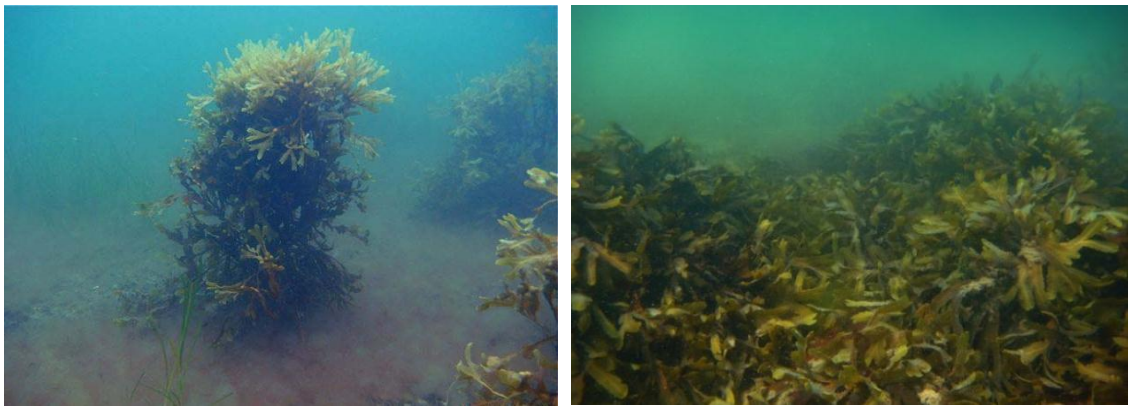



*Figure 4.6 Characteristic hard bottom macroalgae communities within the investigation area.*

*Fucus-community*

The *Fucus*-community is characteristic of shallow sublittoral, semi-exposed to exposed areas with predominantly hard substrates (boulder, cobbles and pebbles) or mixed sediment (coarse sediment). In the Fehmarnbelt area the communities were found in depths between 1–5 m, but single plants of *Fucus* could occur down to about 6–7 m. As stony areas are scarce within the investigation area the community was spatially restricted to few locations. Normally, the occurrence of the community is patchy (Figure 4.7), but if hard substrates are dense enough a belt-like growth could be found also within the investigation area (Figure 4.7).

Key species for this community are the serrated wrack *Fucus serratus* and the bladderwrack *Fucus vesiculosus.* These species can occur together in mixed stocks or build up single species stocks. The overall plant species diversity is low compared to the deeper growing plant communities. Accompanying species are the perennial red alga *Ahnfeltia plicata* and the filamentous alga *Polysiphonia fucoides*.



© MariLim GmbH

*Figure 4.7* *Canopy-like growth form of Fucus vesiculosus at Strukkamphuk/South coast of Fehmarn (left side; photo made for WFD-Monitoring) and a dense belt-like growth form of Fucus serratus at Westermarkelsdorf/NW coast of Fehmarn (right side).*

*Furcellaria-community*

The *Furcellaria*-community is characteristic for shallow sublittoral, semi-exposed to exposed areas with predominant hard substrates (boulder, cobbles and pebbles) or mixed sediment (coarse sediment). *Furcellaria*-communities were growing in depths between 2–8 m. Single plants of *Furcellaria lumbricalis* occurred down to about 10 m. As pure stony areas are scarce within the investigation area the community was also spatially restricted to few locations. At many sites *Furcellaria lumbricalis* was socialised with other perennial macroalgae (*Fucus, Coccotylus/ Phyllophora*) or filamentous algae.


*Figure 4.8* *Cartilaginous growth form of Furcellaria lumbricalis with fertile (yellow) tips (left side) and typical Furcellaria community with numerous epiphytic filamentous algae, mainly Ceramium spp. (right side).*

*Furcellaria* is often overgrown by various epiphytes (Figure 4.8). Especially the annual species *Ceramium tenuicorne* and *Ceramium virgatum* occurred in high densities. The thallus of *Furcellaria lumbricalis* is small compared to *Fucus* and it has numerous dichotomous branching and thick, cartilaginous branches (Figure 4.8).

Key species for this community is *Furcellaria lumbricalis*. The overall plant species diversity was low compared to the deeper growing plant communities and to the Fucus-community. *Coccotylus/Phyllophora* is an abundant and steadily accompanying taxa group in mixed *Furcellaria* stocks.

*Phycodrys/Delesseria-community*

The *Phycodrys/Delesseria*-community is characteristic of deeper, sublittoral areas with predominant hard substrates (boulder, cobbles and pebbles) or mixed sediment (coarse sediment). The community was found in depths between 8–19 m, but single plants of *Phycodrys rubens* or *Delesseria sanguinea* occurred down to about 21 m. These species utilise low light efficiently and are able to build up dense communities in depths of 10 m, where other macroalgae are light limited. The *Phycodrys/Delesseria*-community had a large spatial distribution in the study area. There are no large canopy forming species in the community and therefore no single species has a structuring role (Figure 4.9), but rather the whole network of algae forms the habitat.

Key species are the perennial red algae *Phycodrys rubens* and *Delesseria sanguinea.* These red algae are accompanied by different other red algae like *Coccotylus/Phyllophora, Membranoptera alata, Brongniartella byssoides, Cystoclonium purpureum* and/or *Rhodomela confervoides*. Especially *Coccotylus/ Phyllophora* was very frequent and abundant in this community and is mainly forming the first vegetation layer on which the other algae can grow. The overall plant species diversity is the highest of all vegetation communities within the investigation area.

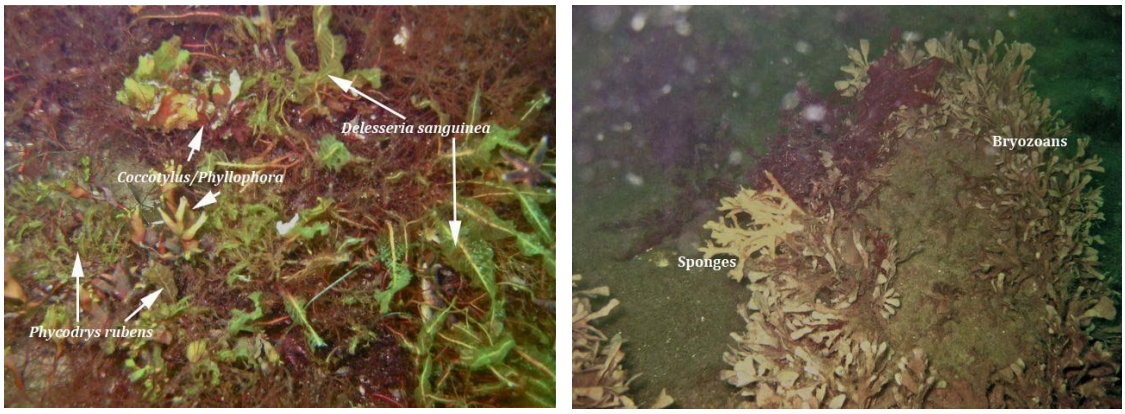



*Figure 4.9* *Characteristic network of different perennial red algae forming the Phycodrys/Delesseria community (left side). Yellow-green tips of thalli are due to the condition of the species. At the lower distribution limit sponges and bryozoans compete with perennial red algae for settling space (right side).*

*Saccharina-community*

The *Saccharina*-community is characteristic of deep, sublittoral areas with mixed sediments (coarse sediment) or gravel bottoms. Compared to the other hard bottom algal communities the *Saccharina*-community is less dependent on stony bottoms, as the key species are mainly growing on small stones (pebbles, gravel). The community was growing in depths between 12–19 m, but single plants of *Saccharina latissima* could occur down to about 32 m. The community was growing at nearly the same depth levels as the *Phycodrys/Delesseria*-community and the division of these two communities is not distinct, especially as number of sample sites within these depth intervals were low due to the generally low vegetation cover. In other purely marine environments this community is characteristic for the upper sublittoral fringe. But the low salinity of the Baltic Sea causes a shift in depth distribution towards depths deeper than 10 m (beneath the summer halocline), where the salinity is higher.

*Saccharina latissima* has a very long (up to 2 m), broad non-branching phylloid (= blade) (Figure 4.10). Therefore single plants can build up high biomasses in depths, where light availability is low. On the more or less slippery surface

epiphytes are rare. If other algae are socialised with *Saccharina latissima* they grow around the stem or the holdfast. Due to this fact the *Saccharina*-community has only a minor role in structuring the habitat and the overall biodiversity is low compared to other plant communities.

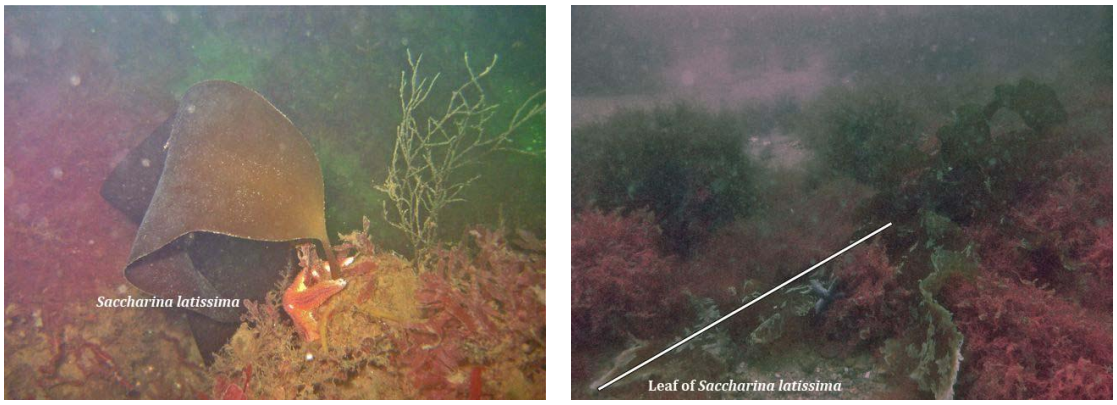



*Figure 4.10 Unbranched leaf of Saccharina latissima (left side), which can grow up to about 2 m length (right side).*

Key species is the perennial brown alga *Saccharina latissima.* Another perennial brown alga - *Laminaria digitata* - is also known to occur in the investigation area, but this species is even more rare than *Saccharina latissima,* and was not observed during this first baseline survey, but occurred at one site in 2010. Accompanying species are rare and belong to the annual, filamentous functional algal group (e. g. *Desmarestia aculeata*, *Polysiphonia stricta*) or are a key species of other communities (e. g. *Delesseria sanguinea*).

*Filamentous species-community*
Many sites within the investigation area showed a dominance of filamentous, opportunistic algae. The species composition and abundance within this functional group is extremely varying between sites and depths as well as survey years. Many filamentous algae are annual species and show naturally high variabilities in density and biomass. Therefore no specific species defines the plant community. But a short overview of the most important species and characteristics of this functional group is given below.

Normally the filamentous algae dominate down to about 1-2 m depth (Schwenke 1964), depending on the exposition degree of the coastline. The more exposed a coastline is, the deeper this zone could be found. The filamentous algae mix and compete with perennial algae, normally the *Fucus*-community. Abundance (coverage) of filamentous, opportunistic algae was high within this specific zone. Typical filamentous algae of the sublittoral fringe are green algae, which are adapted to high light intensities, e. g. *Cladophora* spp. (Figure 4.11). Also filamentous red algae of the genius *Ceramium* are often found in shallow waters. The high light intensity results in a strong seasonal cycle compared to deeper areas. Species like the annual brown alga *Scytosiphon lomentaria* and the annual red alga *Dumontia contorta* occur during spring and early summer and disappear during later months of the year. Other filamentous algae like *Pylaiella littoralis* and *Ectocarpus* sp. occur during the whole growth season (Mar/Apr until Sep/Oct) but show a mass occurrence during springtime, often overgrowing all other vegetation and mussels.

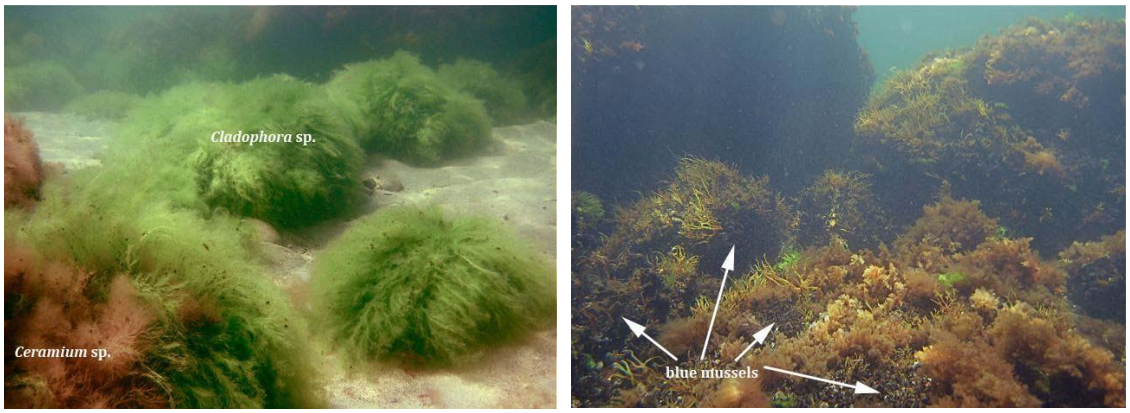



*Figure 4.11 Characteristic filamentous algae of the upper sublittoral zone (left side). Blue mussels are covered with epiphytic filamentous algae, e. g. Ceramium spp., Scytosiphon lomentaria or Dumontia contorta (right side).*

Filamentous algae can also dominate in deeper areas, where sediment conditions are unstable. Mussel beds, for example, form an unstable habitat within the Western Baltic, as they are often affected by a heavy predation pressure (ducks and sea stars) in combination with a high variability in reproductive success and larvae settlement. Opportunistic algae often use blue mussels as suitable substrate (Figure 4.11), whereas perennial algae never (or only in low densities) occur on mussel beds.

### 4.1.7 Spatial Distribution of Key Macroalgal Communities

Figure 4.12 shows the distribution of the defined key communities within the investigation area and Table 4.1 shows the distribution of key communities in the Danish and German areas in 2009. The 2010 data confirm the distribution pattern of the communities and are illustrated in Appendix 11.

*Table 4.1 Number of sites with specific macroalgae communities in 2009.*

| **Area** | **Filamentous algae** | ***Fucus*** | ***Furcellaria*** | ***Phycodrys/ Delesseria*** | ***Saccharina*** |
|---|---|---|---|---|---|
| | 2009 | 2009 | 2009 | 2009 | 2009 |
| Overall | 132 | 18 | 51 | 42 | 31 |
| Danish waters | 73 | 2 | 42 | 14 | 10 |
| German waters | 59 | 16 | 9 | 28 | 21 |
| German coastal zone | 59 | 16 | 9 | 28 | 15 |
| German EEZ | 0 | 0 | 0 | 0 | 6 |
| DE 1332-301 Fehmarnbelt | 0 | 0 | 0 | 0 | 6 |
| DE 1533-301 Staberhuk | 18 | 0 | 8 | 11 | 13 |
| DE 1631-392 Eastern Kiel Bight | 10 | 7 | 0 | 6 | 2 |
| DE 1632-392 Großenbrode | 19 | 3 | 1 | 0 | 0 |
| DE 1733-301 Sagasbank | 2 | 0 | 0 | 5 | 0 |

| Area | Filamentous algae | *Fucus* | *Furcellaria* | *Phycodrys/ Delesseria* | *Saccharina* |
|---|---|---|---|---|---|
| | 2009 | 2009 | 2009 | 2009 | 2009 |
| DK00VA200 Langeland | 6 | 2 | 6 | 8 | 10 |

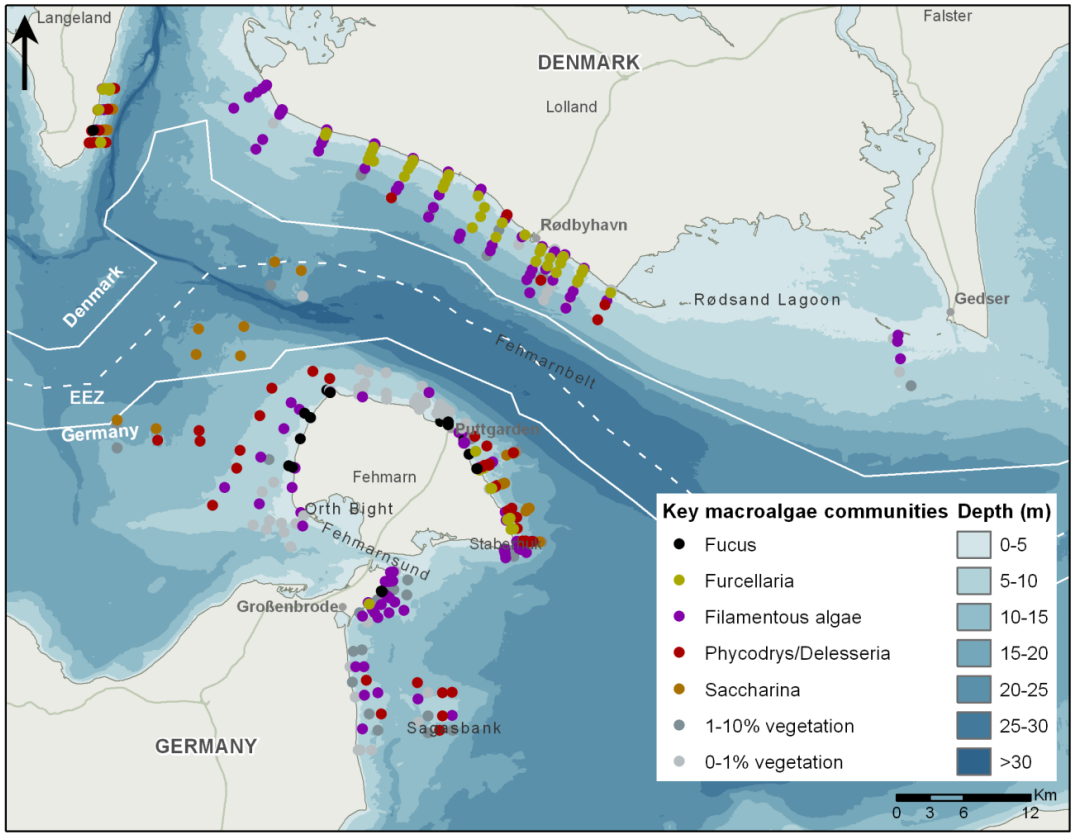



*Figure 4.12 Distribution of key macroalgae communities in the investigation area.*

The *Fucus*-community is distributed to a larger scale along the westcoast of Fehmarn and in a smaller area directly west of Puttgarden harbour. Single sites with a *Fucus*-community occur east of Puttgarden, at Großenbrode and Langeland. Overall 18 sites of the investigation area could be classified into a *Fucus* community.

The *Furcellaria*-community is widely distributed along the coast of Lolland. This community occur also but in a restricted area at Langeland and the eastcoast of Fehmarn and at one site at Großenbrode. Overall 51 sites of the investigation area could be classified into a *Furcellaria*-community.

The *Phycodrys/Delesseria*-community occurs only in deeper areas. It is widely distributed along the west- and eastcoast of Fehmarn and occurs in a restricted spatial scale at Langeland, Sagasbank and at a single sites along the Lolland coast. Overall 42 sites of the investigation area could be classified into a *Phycodrys/Delesseria*-community.

The *Saccharina*-community occurs also only in deeper areas. It is widely distributed along the west- and eastcoast of Fehmarn and occur in restricted areas at

Langeland, Sagasbank and only at single sites along the Lolland coast. Overall 31 sites of the investigation area could be classified into a *Saccharina*-community.

The filamentous algae community is widely distributed within the whole investigation area and the majority of sites (132) could be classified into this community. It occurs in shallow areas as well as at intermediate depths; only in depths > 15 m it does not exist. This community is dominating along the Lolland coast (deeper than the *Furcellaria*-community), at Großenbrode, at the south east coast of Fehmarn (Staberhuk) and at the west coast of Fehmarn between the *Fucus*- and *Phycodrys/Delesseria*-community. All of those areas are known to have a high coverage of blue mussels, often used by filamentous algae as substrate.

## 4.2 Species Diversity

### 4.2.1 Species diversity in Fehmarnbelt and neighbouring areas

The total number of macroalgal taxa in the whole study area in 2009 and 2010 was 69; including 17 green algae, 25 brown algae and 27 red algae species (Table 4.2). The number of species recorded reflects the diversity of the area but also depends on the number of samples collected. More samples would increase the total number of species in the study area, but at a rapidly decreasing rate (Figure 4.13). The saturation of the species-area curve at a high number of sample sites shows that the sampling is sufficient for estimating the species richness in the area.

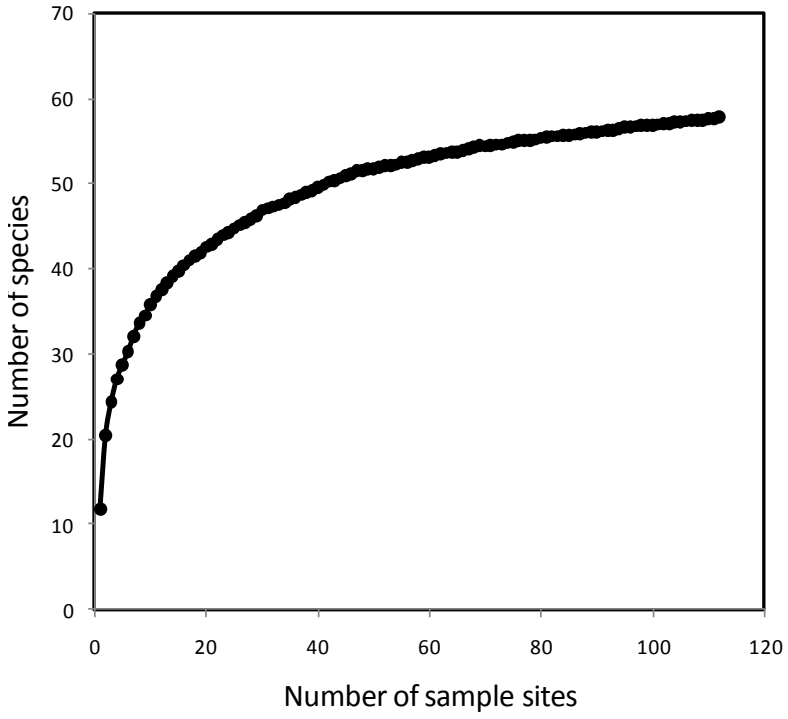



*Figure 4.13 Cumulative curve showing the increase in observed number of macroalgal species with number of samples collected at the 112 sample sites in the summer of 2009.*

Communities with the same number of species can be very different depending on the relative abundance of the species within the community. Ranking the species found during summer 2009 and 2010 according to their relative abundance (measured as the percentages of sample sites where the species was observed) showed a relatively even distribution of species in the area (Figure 4.14). Several species

were found at many sample sites but also a large part of the species (30) was only found at 1–10 sample sites.

The patterns in species rank were similar between sampling years. In 2009 filamentous species (*Polysiphonia fucoides*, *Ceramium virgatum* and *C. tenuicorne,* ranks 1–3) were found at 78 to 93% of the sample sites. The large coarsely branched or sheet-formed species *Coccotylus truncatus* (rank 5), *Furcellaria lumbricalis* (rank 7), *Delesseria sanguinea* (rank 8) and *Phycodrys rubens* (rank 11) were found at 43 to 73% of the sample sites. In 2010 filamentous species (*Polysiphonia fucoides*, *Ectocarpus/Pylaiella* and *Ceramium virgatum,* rank 1-3) were again found at most sample sites. And the large coarsely branched or sheet-formed species *Coccotylus truncatus* (rank 4), *Delesseria sanguinea* (rank 9), *Furcellaria lumbricalis* (rank 11), and *Phycodrys rubens* (rank 14) were found at 47 to 77% of the sample sites.

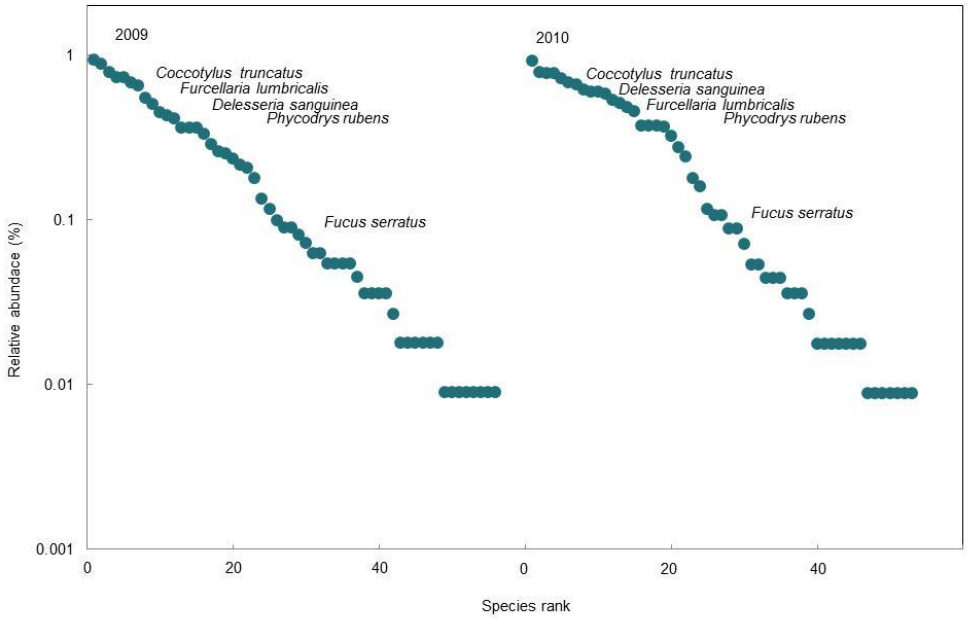



*Figure 4.14 Rank-abundance diagram of macroalgae species in the summers of 2009 and 2010. Log relative abundance of species (number of sites the species was found in %) is shown as a function of falling rank from left to right. The rank number of selected key species is indicated.*

*Table 4.2 Macroalgae species found in Fehmarnbelt in the summer of 2009 and 2010.*

| **Chlorophyceae (Green algae)** | **Phaeophyceae (Brown algae)** | **Rhodophyceae (Red algae)** |
|---|---|---|
| *Bryopsis hypnoides* | *Acrothrix gracilis* | *Acrochaetiales* |
| *Bryopsis plumosa* | *Chorda filum* | *Aglaothamnion/Callithamnion* |
| *Chaetomorpha linum* | *Desmarestia aculeatae* | *Ahnfeltia plicata* |
| *Chaetomorpha melagonium* | *Desmarestia viridis* | *Brongniartella byssoides* |
| *Cladophora glomerata* | *Dictyosiphon foeniculaceus* | *Ceramium tenuicorne* |
| *Cladophora rupestris* | *Ectocarpus siliculosus* | *Ceramium virgatum* |
| *Cladophora* sp. | *Ectocarpus sp.* | *Coccotylus truncatus* |
| *Derbesia marina* | *Elachista fucicola* | *Cystoclonium purpureum* |
| *Derbesia* sp. | *Eudesme virescens* | *Dasya baillouviana* |
| *Rhizoclonium sp.* | *Fucus serratus* | *Delesseria sanguinea* |
| *Ulothrix flacca* | *Fucus sp.* | *Dumontia contorta* |
| *Ulva intestinalis* | *Fucus vesiculosus* | *Furcellaria lumbricalis* |
| *Ulva lactuca* | *Halosiphon tomentosus* | *Membranoptera alata* |
| *Ulva linza* | *Laminaria digitata* | *Membranoptera cf. Pantoneura* |
| *Ulva procera* | *Mesogloia vermiculata* | *Nemalion helminthoides* |
| *Ulva prolifera* | *Petalonia zosterifolia* | *Phycodrys rubens* |
| *Ulva sp.* | *Pylaiella littoralis* | *Phyllophora pseudoceranoides* |
| | *Saccharina latissima* | *Polyides rotundus* |
| | *Scytosiphon lomentaria* | *Polysiphonia elongata* |
| | *Sphacelaria rigidula* | *Polysiphonia fibrillosa* |
| | *Sphacelaria sp.* | *Polysiphonia fucoides* |
| | *Sphaerotrichia divaricata* | *Polysiphonia sp.* |
| | *Stictyosiphon tortilis* | *Polysiphonia stricta* |
| | *Stilophora tuberculosa* | *Pterothamnion plumula* |
| | *Striaria attenuate* | *Rhodochorton purpureum* |
| | | *Rhodomela confervoides* |
| | | *Spermothamnion repens* |

### 4.2.2 *Species number and diversity within key communities*

The species number of benthic macroalgae varied between 5 and 23 at the sampling sites in 2009 (112 sites) and 2010 (113 sites) (Table 4.3). Table 4.4 shows the mean number of species at the sampling sites in key communities in Danish and German areas.

On average the *Phycodrys/Delesseria*-communities had the highest number of species in 2009 (14.2) and a similar diversity (combining species richness and evenness) in the two years; Simpson's index of diversity (1-D) = 0.67 in 2009 and 0.63 in 2010 and a Shannon diversity (H) = 1.4 and 1.2. On average the *Fucus*- and *Furcellaria*-communities had a species number between 12.0 and 17.2. *Fucus* species are large and dominate the biomass in *Fucus*–communities; resulting in the lowest species diversity in both 2009 and 2010 (1-D= 0.20 in 2009 and 0.26 in 2010, H = 0.42 and 0.52). *Saccharina*- and filamentous species-communities had the lowest average number of species in both years. Species diversity was intermediate.

In general, similar patterns in species diversity were found in 2009 and 2010, only the *Furcellaria*-community had a the highest mean species richness (17.2) in 2010.

*Table 4.3* *Mean, median and range in number of species, Shannon-Wiener diversity and Simpson's evenness at sample sites in the key communities in Fehmarnbelt in the summers of 2009 and 2010.*

| **Sites** | **No. Species (S)** Mean/Median (range) | | **Shannon-Wiener (H)** Mean /Median (range) | | **Simpson (1-D)** Mean /Median (range) | |
|---|---|---|---|---|---|---|
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| Total no. species | 11.7/ 11.0 (5-23) | 13.5/ 14.0 (5-21) | 1.1/1.2 (0.1-2.1) | 1.2/1.2 (0.13-2.0) | 0.52/0.58 (0.04-0.85) | 0.56/0.62 (0.04-1.1) |
| *Fucus* | 13.3/ 12.5 (8-19) | 13.7/12.5 (8-21) | 0.42/ 0.40 (0.10-0.93) | 0.52/0.59 (0.12-0.98) | 0.20/ 0.20 (0.02-0.52) | 0.26/0.23 (0.04-0.53) |
| *Furcellaria* | 11.9/ 11 (6-21) | 17.2/18 (13-20) | 1.0/ 1.0 (0.20-2.06) | 1.2/1.3 (0.61-1.8) | 0.49/ 0.49 (0.08-0.83) | 0.55/0.62 (0.24-0.79) |
| *Phycodrys /Delesseria* | 14.2/ 14.5 (7-23) | 11.7/12.5 (5-21) | 1.4/ 1.4 (0.84-1.8) | 1.2/1.2 (0.61-1.9) | 0.67/ 0.71 (0.40-0.78) | 0.63/0.65 (0.36-1.1) |
| *Saccharina* | 10.9/ 10 (5-20) | 11.3/12 (5-15) | 1.1/ 1.2 (0.38-1.7) | 1.2/1.2 (0.74-2.0) | 0.55/ 0.61 (0.20-0.79) | 0.60/0.57 (0.38-0.82) |
| Filamentous algae | 11.0/ 10 (5-20) | 12.5/12.5 (7-17) | 0.96/ 1.03 (0.08-1.8) | 1.2/1.3 (0.38-2.0) | 0.47/ 0.54 (0.02-0.83) | 0.56/0.61 (0.15-0.84) |

*Table 4.4 Median number of species of the key communities at sampling sites in Danish and German areas and in Natura 2000 sites.*

| **Area** | **Filamentous algae** Median (range) | | ***Fucus*** Median (range) | | ***Furcellaria*** Median (range) | | ***Phycodrys/ Delesseria*** Median (range) | | ***Saccharina*** Median (range) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| Overall | 10.8 (5-20) | 12.5 (7-17) | 12.5 (8-19) | 12.5 (8-21) | 11.0 (6-21) | 18.0 (13-18) | 14.5 (7-23) | 12.5 (5-21) | 10.0 (5-20) | 12.0 (5-15) |
| Danish waters | 10.0 (5-15) | 14.0 (10-17) | 17.0 (-) | - | 11.0 (6-21) | 18.0 (13-20) | 16.0 (7-23) | - | 17.0 (17-20) | - |
| German waters | 10.5 (5-20) | 9.5 (7-15) | 12.0 (8-19) | 12.5 (8-21) | 14.0 (13-15) | 17.0 (16-18) | 14.0 (5-18) | 12.5 (5-21) | 8.0 (5-16) | 12.0 (5-15) |
| German coastal zone | 10.5 (5-20) | 9.5 (7-15) | 12.0 (8-19) | 12.5 (8-21) | 14.0 (13-15) | 17.0 (16-18 | 14.5 (11-18) | 14.0 (5-21) | 10.0 (6-13) | 12.0 (9-15) |
| German EEZ | - | - | - | - | - | - | 5.0 (-) | 6.0 (5-9) | 6.5 (5-16) | 7.0 (5-13) |
| DE 1332-301 Fehmarnbelt | - | - | - | - | - | - | 5.0 (-) | 6.0 (5-9) | 6.5 (5-16) | 7.0 (5-13) |
| DE 1533-301 Staberhuk | 10.5 (5-13) | 9.0 (7-10) | - | - | 13.0 (-) | 17.0 (16-18) | 15.5 (13-18) | 11.5 (6-15) | 11.0 (6-13) | 11.5 (9-12) |
| DE 1631-392 Eastern Kiel Bight | 15.0 (9-20) | 11.0 (9-13) | 12.0 (12-13) | 12.0 (8-17) | - | - | 13.0 (11-15) | 16.0 (14-21) | - | 15.0 (-) |
| DE 1632-391 Großenbrode | 10.0 (8-13) | - | 11.0 (-) | - | 15.0 (-) | - | - | - | - | - |
| DE 1733-301 Sagasbank | 14.0 (-) | - | - | - | - | - | 14.5 (11-18) | 13.0 (8-16) | - | - |
| DK00VA200 Langeland | 15.0 (-) | - | 17.0 (-) | - | 16.0 (16-21) | - | 21.5 (20-23) | - | 17.0 (17-20) | - |

### 4.2.3 Depth distribution of species diversity

Species diversity at sample sites showed a bell-shaped pattern with depth. All three measures of species diversity peaked at intermediate depth levels. In 2009 the number of macroalgae species at the sampling sites increased with depth until 10–12 m, and then decreased at deeper water. However, there was a high variability in species number in each depth interval (Figure 4.15) and depth could only explain 24% of the variability in number of species ($S = -0.077*depth^2 + 1.4*depth + 7.9$, $R^2 = 0.24$, $p < 0.01$). Shannon-Wiener diversity and Simpson's index of diversity showed the same weak relationships with depth ($R^2 = 0.32$ and 0.30, respectively). A similar pattern was found in 2010 (Figure 4.15). Analysing species number within depth intervals corresponding to the sampling intervals (0–2 m, 2-5 m, 5-10 m, 10-15 m, 15-20 m) confirm the distribution pattern of species diversity and are illustrated in Appendix 7.

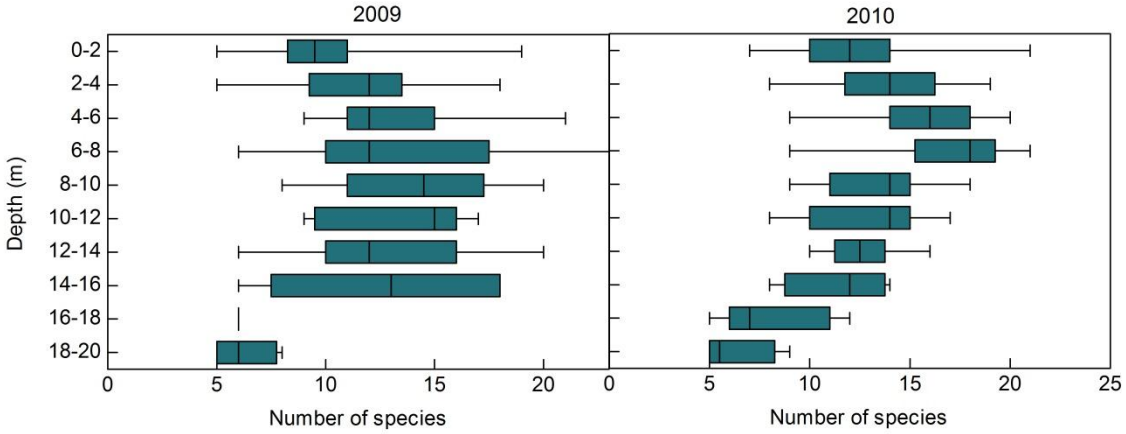



*Figure 4.15 Variation in number of macroalgae species at the sites in 2 m intervals of depth. Perpendicular lines represent the median value in each depth interval, boxes represent 25-75% percentiles, and whiskers represent 10-90% percentiles.*

If we instead used the average number of macroalgal species in each depth intervals for the regression analysis, the percentages of variability accounted for by depth increased, because using mean values (instead of all values) for the intervals deliberately reduced the variability (Table 4.5). Using this method, the average depth in intervals could account for 60-70% of the variability in number of macroalgae species, 43-50% of the variation in Shannon-Weiner diversity and about 35% of the variation between sample sites in Simpson's index of diversity.

*Table 4.5 Determination coefficients ($R^2$) and equations describing the relationships between species richness (S), Shannon-Wiener diversity (H) and Simpson's evenness (1-D) and depth in 0 intervals of depth. The relationships are shown for 2009 and 2010 data and they were all significant ($p < 0.01$).*

| Parameter | Year | Equation | $R^2$ |
|---|---|---|---|
| Species richness (S) | 2009 | $S = -0.096*depth^2 + 1.7*depth + 7.0$ | 0.61 |
| | 2010 | $S = 0.088* depth^2 + 1.3*depth + 10.8$ | 0.72 |
| Shannon-Wiener diversity (H) | 2009 | $H = -0.0075*depth^2 + 0.16*depth + 0.48$ | 0.43 |
| | 2010 | $H = -0.0074*depth^2 + 0.15*depth + 0.62$ | 0.50 |
| Simpson (1-D) | 2009 | $1\text{-}D = -0.0032*depth^2 + 0.071*depth + 0.25$ | 0.36 |
| | 2010 | $1\text{-}D = -0.0015*depth^2 + 0.044*depth + 0.37$ | 0.34 |

The bell-shaped pattern of species diversity with depth can be explained by the intermediate disturbance hypothesis. The rationale for this idea is that at low disturbance (e. g. deep water) strong competitors exclude competitively inferior species and communities are dominated by few species. Intermediate rates of disturbance (e. g. intermediate depths) disrupt competitive hierarchies by increasing rates of mortality and thus making free space available for recruitment of competitively inferior species. At successively higher rates of disturbance recruitment cannot balance the high rates of mortality, and slow recruiting species disappear from the community (shallow water).

The intermediate disturbance hypothesis may contribute to explain the differences in species richness among the key communities. Highest diversity was found in the community that occupies the intermediate depths: *Phycodrys/Delesseria.* The mean species richness was the same or only marginally lower in the *Fucus*- and *Furcellaria*-communities, which occupy the more shallow depths. The lowest number of species was found in the deepest growing community *Saccharina* (Table 4.3). Species diversity was also low in the filamentous species-community, which is characteristic for the very shallow water.

## 4.3 Cover and biomass of macroalgae

### 4.3.1 Cover of macroalgae in key communities

Total macroalgae cover ranged from 0 to 100% at the 25 $m^2$ coverage sampling sites visited in Fehmarnbelt 2009 (357 sites) and 2010 (135 sites) and the mean (± 95% C.L.) was 31.0 (± 2.9) and 41.2 % (± 4.3) in 2009 and 2010, respectively (Table 4.7). Maps with the spatial distribution of diver estimated cover can be seen in Appendix 6.

The mean total cover for all sites was 30% higher and mean substrate specific cover for all sites was 10% higher in 2010 than in 2009, but the pattern of differences between key community was similar the two years. The reason for the difference was that the sampling in 2010 was focused on biomass sampling sites. Biomass sample sites were preferably situated where the vegetation was well established and therefore likely to have relatively high cover. The mean total cover (± 95% C.L.) was 31.0 (± 3.1) in 2009 and 41.2 (± 4.3) in 2010 (Table 4.6, Table 4.8). The mean cover was 40-70% in *Fucus*, *Furcellaria* and *Phycodrys/Delesseria*-communities, 35-50% in *Saccharina*-communities and lower (30-40%) in filamentous communities. Total cover was < 10% at 82 of the 25 $m^2$ coverage sites in 2009; no algae community was assigned to these sites.

Substrate specific cover ranged between 0 and 100% and the mean (± 95% C.L.) was 69.9 (± 3.6) and 77.3% (± 4.5) in 2009 and 2010, respectively (Table 4.7). *Furcellaria*-communities had the highest substrate specific cover of 94-97%, *Fucus*- and the *Phycodrys/Delesseria*- and *Saccharina*-communities had mean substrate specific cover values between 73 and 83%. The mean substrate specific cover in filamentous species communities was 65-74%.

*Table 4.6* *Mean (±95% C.L.) and median values of total cover of key communities in Fehmarnbelt and neighbouring areas in the summers of 2009 and 2010. Ranges are given in brackets. n = number of sample sites.*

| **Key community** | **Total cover (%)** | | | | **N** | |
|---|---|---|---|---|---|---|
| | *Mean (±95% C.L.)* | | *Median (range)* | | | |
| | *2009* | *2010* | *2009* | *2010* | 2009 | 2010 |
| Total cover | 31.0 (±2.9) | 41.2 (±4.3) | 24 (0-100) | 40 (0-95) | 357 | 135 |
| *Fucus* | 51.6 (±12.5) | 69.0 (±14.7) | 56.4 (15-90) | 74.3 (14-90) | 18 | 10 |
| *Furcellaria* | 49.5 (±3.1) | 46.9 (±7.3) | 42.8 (10-95) | 45 (10– 80) | 52 | 29 |
| *Phycodrys/ Delesseria* | 48.7 (±7.5) | 40.9 (±9.2) | 45.5 (0-100) | 38.5 (10-95) | 43 | 29 |
| *Saccharina* | 36.6 (±9.2) | 50.4 (±10.4) | 30 (9-95) | 50 (20-85) | 29 | 13 |
| Filamentous species | 31.0 (±4.2) | 40.0 (±7.7) | 24 (0.9-91) | 39.3 (0-95) | 136 | 36 |

*Table 4.7* *Mean (±95% C.L.) and median values of substrate specific cover of key communities in Fehmarnbelt and neighbouring areas in the summers of 2009 and 2010. Ranges are given in brackets. n = number of sample sites.*

| **Key community** | **Substrate specific cover (%)** | | | | **N** | |
|---|---|---|---|---|---|---|
| | *Mean (±95% C.L.)* | | *Median (range)* | | | |
| | *2009* | 2010 | 2009 | *2010* | 2009 | 2010 |
| Total cover | 69.9 (± 3.4) | 77.3 (±4.5) | 80 (0-100) | 87.5 (0-100) | 357 | 134 |
| *Fucus* | 80.8 (±8.7) | 79.4 (16.8) | 80 (30-100) | 90 (25-100) | 18 | 9 |
| *Furcellaria* | 94.3 (±1.4) | 97.1 (±3.5) | 100 (40-100) | 100 (50-100) | 52 | 29 |
| *Phycodrys/ Delesseria* | 83.4 (±6.4) | 73.6 (8.3) | 95 (0-100) | 75 (35-100) | 45 | 29 |
| *Saccharina* | 86.7 (±6.4) | 86.2 (±7.8) | 90 (50-100) | 90 (65-100) | 29 | 13 |
| Filamentous species | 65.0 (±4.9) | 73.6 (±8.7) | 70 (5-100) | 80 (0-100) | 136 | 36 |

*Table 4.8 Mean and median total cover of key communities in the Danish and German areas. * only 1 site, # only 2 sites*

| **Area** | **Filamentous algae** Mean/Median | | ***Fucus*** Mean/Median | | ***Furcellaria*** Mean/Median | | ***Phycodrys/ Delesseria*** Mean/Median | | ***Saccharina*** Mean/Median | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| Overall | 31.0 | 40.0 | 51.6 | 69.0 | 49.5 | 46.9 | 48.7 | 40.9 | 36.3 | 50.4 |
| | 24.0 | 39.3 | 56.4 | 74.3 | 42.8 | 45.0 | 45.5 | 38.5 | 30.0 | 50.0 |
| Danish waters | 20.8 | 33.2 | 27.8# | - | 44.0 | 45.8 | 37.2 | - | 28.6 | - |
| | 11.6 | 28.5 | 27.8# | | 40.0 | 45.0 | 30.0 | | 23.8 | |
| German waters | 43.1 | 50.6 | 54.6 | 69.0 | 75.6 | 54.0 | 54.9 | 40.9 | 40.2 | 50.4 |
| | 40.0 | 44.6 | 65.9 | 74.3 | 80.0 | 62.5 | 49.3 | 38.5 | 33.0 | 50.0 |
| German coastal zone | 43.1 | 50.6 | 54.6 | 69.0 | 75.6 | 54.0 | 56.5 | 46.1 | 45.3 | 50.7 |
| | 40.0 | 44.6 | 65.9 | 74.3 | 80.0 | 62.5 | 49.5 | 44.0 | 40.0 | 49.4 |
| German EEZ | - | - | - | - | - | - | 10.0* | 16.0 | 25.1 | 49.7 |
| | | | | | | | 10.0* | 15.0 | 19.5 | 50.0 |
| DE 1332-301 Fehmarnbelt | - | - | - | - | - | - | 10.0* | 16.0 | 25.1 | 49.7 |
| | | | | | | | 10.0* | 15.0 | 19.5 | 50.0 |
| DE 1533-301 Staberhuk | 41.2 | 57.3 | - | - | 80.0 | 54.0 | 64.3 | 57.0 | 32.9 | 45.8 |
| | 40.0 | 55.5 | | | 85.0 | 62.5 | 70.0 | 59.0 | 17.5 | 41.5 |
| DE 1631-392 Eastern Kiel Bight | 56.7 | 65.8# | 50.5 | 68.1 | - | - | 49.8 | 40.1 | 85.0# | 48.8* |
| | 59.8 | 65.8# | 49.0 | 74.3 | | | 44.0 | 44.0 | 85.0# | 48.8* |
| DE 1632-392 Großenbrode | 39.3 | - | 51.9 | - | 40.0* | - | - | - | - | - |
| | 30.0 | | 63.8 | | 40.0* | | | | | |
| DE 1733-301 Sagasbank | 63.0# | - | - | - | - | - | 49.1 | 59.8 | - | - |
| | 63.0# | | | | | | 40.0 | 63.8 | | |
| DK00VA200 Langeland | 20.7 | - | 27.8# | - | 27.0 | - | 46.7 | - | 28.6 | - |
| | 20.5 | | 27.8# | | 22.5 | | 30.0 | | 23.8 | |

### 4.3.2 *Biomass of macroalgae in key communities*

Total macroalgal biomass (average of five replicates) ranged between 6.9 and 4426.8 g DW $m^{-2}$ at the sampling stations in Fehmarnbelt and neighbouring areas in the summer of 2009 (112 sites) and between 1.4 and 2573.2 g DW $m^{-2}$ in the summer of 2010 (113 sites, Table 4.9).

The pattern in biomass of key communities was similar in the two sampling years (Table 4.9). The highest mean biomass was found in *Fucus*-communities.The mean biomass of *Fucus*-communities was about 3 times has high as the mean biomass of *Furcellaria*-communities. Mean biomass of *Phycodrys/Delesseria*-communities was only slightly higher than mean biomass of *Saccharina*- and filamentous species-communities. Table 4.10 shows the mean total biomass of key communities in Danish and German areas.

*Table 4.9* *Mean (±95%C.L.) and median (range) total biomass of macroalgal key communities in Fehmarnbelt and neighbouring areas in the summers of 2009 and 2010. Ranges are given in parentheses. N = number of sample sites.*

| **Key community** | **Community biomass (g DW $m^{-2}$)** | | | | | |
|---|---|---|---|---|---|---|
| | *Mean (±95%C.L.)* | | *Median (range)* | | N | |
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| Total biomass | 308.3 (± 90.9) | 346.9 (±93.2) | 166.2 (6.9 - 4426.8) | 163.2 (1.4-2573.2) | 112 | 113 |
| *Fucus* | 1282.6 (±950.4) | 1713.4 (±545.3) | 857.4 (181.9 - 4426.8) | 1873.5 (22.1-2573.2) | 8 | 10 |
| *Furcellaria* | 549.3 (±114.3) | 438.9 (± 62.0) | 541.7 (166.2 - 1107.9) | 489.1 (111.0-1012.5) | 18 | 27 |
| *Phycodrys/ Delesseria* | 295.4 (±112.3) | 166.9 (±45.3) | 228.5 (31.3 – 794.0) | 174.9 (1.4-400.8) | 16 | 26 |
| *Saccharina* | 166.7 (±67.1) | 133.3 (±37.4) | 110.1 (39.1-456.6) | 105.2 (26.7-244.1) | 15 | 13 |
| Filamentous species | 136.9 (±33.4) | 121.3 (±61.0) | 105.3 (6.9 – 745.7) | 90.0 (13.2-1012.5) | 52 | 32 |

*Table 4.10 Mean and median total biomass of macroalgal key communities in Danish and German areas.* * only 1 site, # only 2 sites

| **Area** | **Filamentous algae** Mean/Median | | ***Fucus*** Mean/Median | | ***Furcellaria*** Mean/Median | | ***Phycodrys/ Delesseria*** Mean/Median | | ***Saccharina*** Mean/Median | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| Overall | 136.9 | 121.3 | 1282.6 | 1713.4 | 549.3 | 438.9 | 295.4 | 166.9 | 166.7 | 133.3 |
| | 105.3 | 90.0 | 857.4 | 1873.5 | 541.7 | 489.1 | 228.5 | 174.9 | 110.1 | 105.2 |
| Danish Waters | 113.5 | 146.9 | 4426.8* | - | 594.6 | 461.3 | 445.8 | - | 310.4 | - |
| | 95.5 | 103.1 | 4426.8* | | 559.8 | 495.4 | 478.9 | | 264.1 | |
| German Waters | 174.7 | 65.0 | 833.5 | 1718.4 | 186.5# | 159.4# | 245.2 | 166.9 | 130.7 | 133.3 |
| | 154.1 | 68.7 | 732.7 | 1873.5 | 186.5# | 159.4# | 217.2 | 174.9 | 94.6 | 105.2 |
| German coastal zone | 174.7 | 65.0 | 833.5 | 1718.4 | 186.5# | 159.4# | 245.2 | 203.5 | 141.5 | 117.5 |
| | 154.1 | 68.7 | 732.7 | 1873.5 | 186.5# | 159.4# | 217.2 | 191.0 | 126.5 | 100.9 |
| German EEZ | - | - | - | - | - | - | - | 65.9 | 120.0 | 186.1 |
| | | | | | | | | 98.4 | 61.3 | 228.6 |
| DE 1332-301 Fehmarnbelt | - | - | - | - | - | - | - | 65.9 | 120.0 | 186.1 |
| | | | | | | | | 98.4 | 61.3 | 228.6 |
| DE 1533-301 Staberhuk | 94.7 | 57.2 | - | - | 166.2* | 159.4# | 281.1 | 165.8 | 126.2 | 118.6 |
| | 95.0 | 52.2 | | | 166.2* | 159.4# | 218.8 | 199.5 | 124.3 | 99.9 |
| DE 1631-392 Eastern Kiel Bight | 251.4 | 65.1# | 609.9 | 1718.4 | - | - | 152.1# | 252.0 | - | 96.6* |
| | 234.7 | 65.1# | 665.4 | 1873.5 | | | 152.1# | 243.2 | | 96.6* |
| DE 1632-392 Großenbrode | 100.4 | - | 219.0* | - | 206.9* | - | - | - | - | - |
| | 60.3 | | 219.0* | | 206.9* | | | | | |
| DE 1733-301 Sagasbank | 146.1* | - | - | - | - | - | 226.1 | 235.4 | - | - |
| | 146.1* | | | | | | 203.8 | 213.8 | | |
| DK00VA200 Langeland | 135.5* | - | 4426.8* | - | 535.9 | - | 781.5# | - | 310.4 | - |
| | 135.5* | | 4426.8* | | 424.0 | | 781.5# | | 264.1 | |

The mean biomass of key species followed the same pattern as the key community biomass (Table 4.11). *Fucus* sp. had the highest and *Furcellaria lumbricalis* had the second highest mean biomass. The mean biomass of *Coccotylus*/*Phyllophora* and *Saccharina latissima* was only slightly higher than the mean biomass of *Delesseria sanguinea* and *Phycodrys rubens.* Only sites where species biomass was > 0.5 g DW $m^{-2}$ was included in calculations.

*Table 4.11 Mean (±95%C.L.) and median (range) total biomass of macroalgal species in Fehmarnbelt and neighbouring areas in the summers of 2009 and 2010. Ranges are given in brackets. N = number of sample sites.*

| **Species** | **Species biomass (g DW $m^{-2}$)** | | | | | |
|---|---|---|---|---|---|---|
| | *Mean (±95%C.L.)* | | *Median (range)* | | N | |
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| *Fucus* spp. | 741.1 (±553.5) | 1766.1 (± 756.6) | 483.2 (1.3 – 4329.9) | 1683.7 (40-4738.9) | 15 | 14 |
| *Furcellaria lumbricalis* | 154.9 (±67.8) | 161.4 (±47.6) | 39.4 (0.52 – 1062.4) | 92.9 (0.6-587.2) | 48 | 51 |
| *Coccotylus/ Phyllophora* | 71.1 (±26.5) | 56.2 (±17.9) | 25.1 (0.54 – 546.5) | 22.7 (0.6-387.7) | 63 | 71 |
| *Delesseria sanguine* | 37.7 (±12.0) | 36.2 (±10.6) | 18.0 (0.52-162.2) | 23.0 (0.85-180.3) | 48 | 44 |
| *Phycodrys rubens* | 57.6 (±17.8) | 33.1 (±10.0) | 47.0 (0.7 – 235.3) | 26.2 (1.0-121.9) | 37 | 37 |
| *Saccharina latissima* | 51.2 (± 27.6) | 90.7 (±30.3) | 51.7 (6.1 – 113.3) | 79.6 (0.6-213.6) | 8 | 18 |

### *4.3.3 Depth distribution of cover and biomass*

*General pattern*

If light is limiting the depth distribution of bottom vegetation we would expect vegetation down to a depth where about 1% of the surface light is available for photosynthesis. Based on an average light attenuation coefficient ($K_d$) of 0.24 (average June–August 2009) this would be about 19 m. Growth at this depth was observed at Langeland (26 m), Fehmarnbelt (32 m), some parts of the west coast of Fehmarn (19 m) and along the east coast of Fehmarn (17–19 m). In these areas the depth distribution is probably set by light, but fishery activities (trawling) can have a cumulative effect.

Along the coast of Lolland the vegetation depth limit was 10–14 m, suggesting that light is not the limiting factor for the overall vegetation depth limit. In this area

hard substrate significantly decreased with increasing depth and in the 10–15 m depth interval the coverage of suitable hard substrate was < 10%. Other areas showed similar shallow depth limits of macroalgae: the north-west coast of Fehmarn (8–10 m), Großenbrode (10 m) and Sagasbank (10–16 m). In these areas the lower depth limit is not set by light but by the availability of suitable substrate.

*Depth distribution of cover and biomass*
Perennial macroalgae are generally regarded as stable components of the bottom vegetation, in contrast to annual macroalgae, which exhibit large fluctuations. Results from this study proved a high spatial variability even within the same depth intervals.

Depth distributions of cover and biomass showed similar patterns in 2009 and 2010.

Total cover was highest in shallow water (0-10 m) and decreased from the intermediate depth intervals to the lower depth (most clearly in 2009, Figure 4.16), but cover showed large variations within each depth interval. Total cover is related to the availability of hard substrate, which has been shown to have a similar pattern along the depth gradient (Figure 3.1).

Substrate specific cover describes the vegetation cover taking into account the large difference in suitable substrate at the sites. Total substrate specific cover was high along the whole depth gradient (Figure 4.16). The high substrate specific cover was expected as different species have different depth distribution and there are species able to explore all depths.

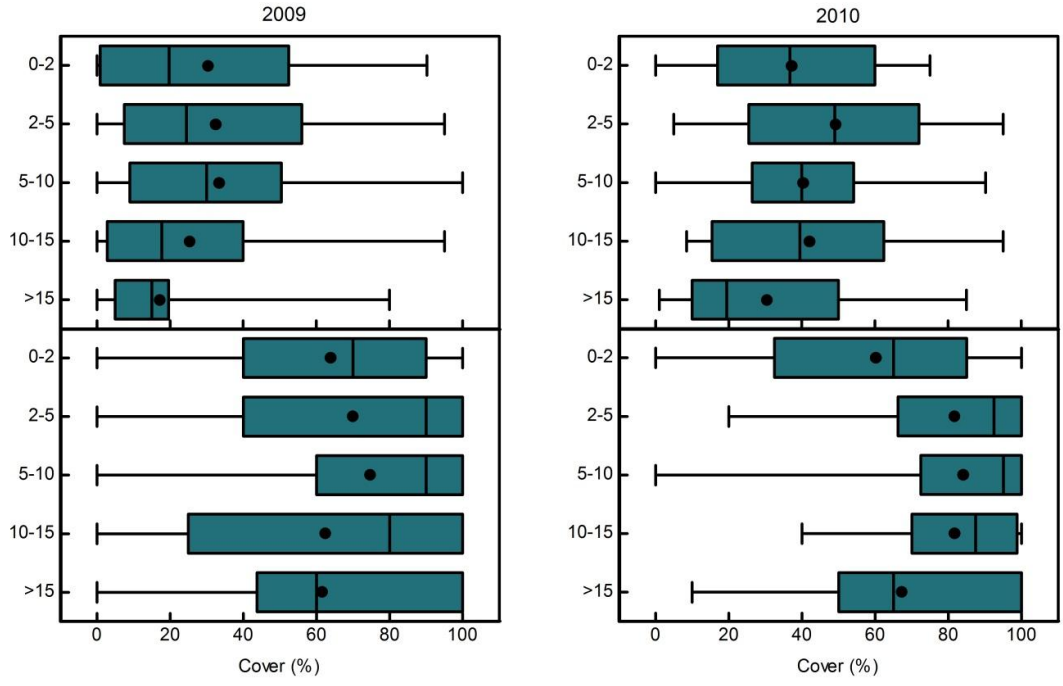



*Figure 4.16 Total cover (upper) and total substrate specific cover (lower) of macroalgae as a function of depth in macroalgae communities of Fehmarnbelt and neighbouring areas in the summers of 2009 and 2010. Circles represent mean values of cover in each depth interval, vertical lines represent medians, boxes represent 25-75% percentiles, and whiskers represent 10-90% percentiles.*

The species are distributed along the depth gradient among others depending on their ability to utilize low light intensities and to resist disturbance. They therefore

occupy different depth zones. *Fucus* species could be found from 0.5 to 7.5 m, *Furcellaria* between 1.3 and 10 m, *Coccotylus/Phyllophora* between 1.6 and 17 m and *Phycodrys/Delesseria* in the depth interval from 2 to 19.7 m (Figure 4.17).

Substrate specific cover ranges between almost 0 and 100% for all species but for *Coccotylus/Phyllophora* it was mostly below 80% and for *Phycodrys/Delesseria* below about 30% However, the cover is not describing the density of the vegetation in the covered area. Therefore, to describe the decrease in abundance with depth, biomass per area is a more adequate measure.

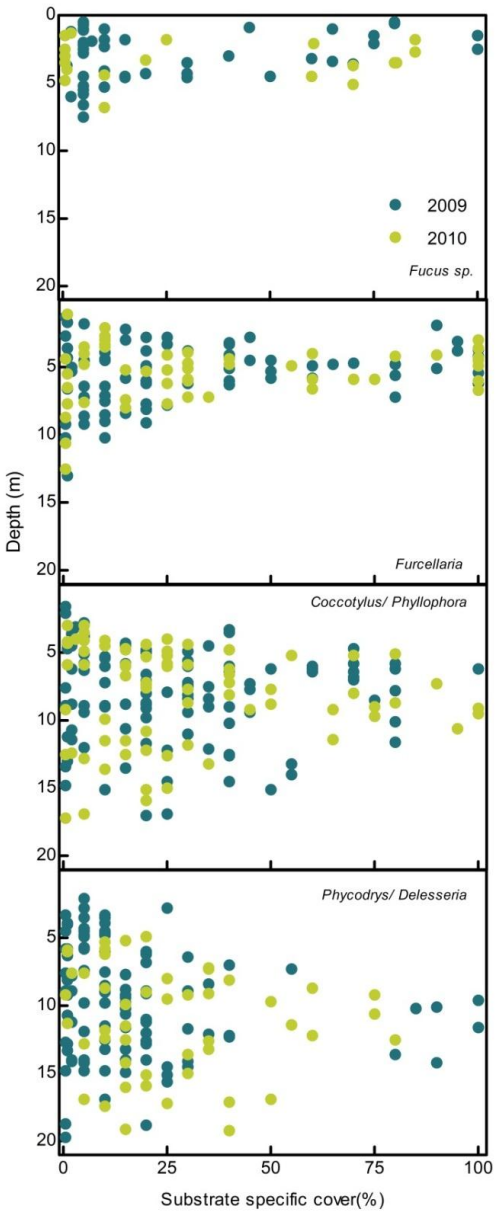



*Figure 4.17 Substrate specific cover of key species as a function of depth in Fehmarnbelt and neighbouring areas in the summers of 2009 (blue dots) and 2010 (green dots).*

*Biomass*

Macroalgal biomass was sampled in the depth range between 1 and 19.7 m in Fehmarnbelt. The biomass varied markedly over the depth gradient, and variations were also large at the specific depths, especially in shallow water (Figure 4.18), where physical disturbances in the form of waves and wind exposure are large. The biomass of subsamples (replicates) had a maximum of approximately 6000 g DW m-2 in Fucus-communites in the 0–5 m interval, and then declined steeply with increasing depth down to the depth limit of about 20 m (Figure 4.19), where about 0.76% of the surface photon flux density (PFD) remained (assuming an average summer light attenuation coefficient (Kd) of 0.24). Total biomass and cover-corrected biomass along the depth gradient confirm the distribution pattern of community biomass and are illustrated in Appendix 7.

Using all subsamples as data we obtained a large dataset that allowed us to describe both average trends of the entire dataset and the bound of the distribution, as expressed by the 90th percentile of the grouped data set. Filamentous species communities in general had much lower biomasses and were not contributing to the upper biomass boundary e. g. always much lower that the highest biomass values at a depth (Figure 4.19). The analyses were therefore also carried out excluding the filamentous communities.

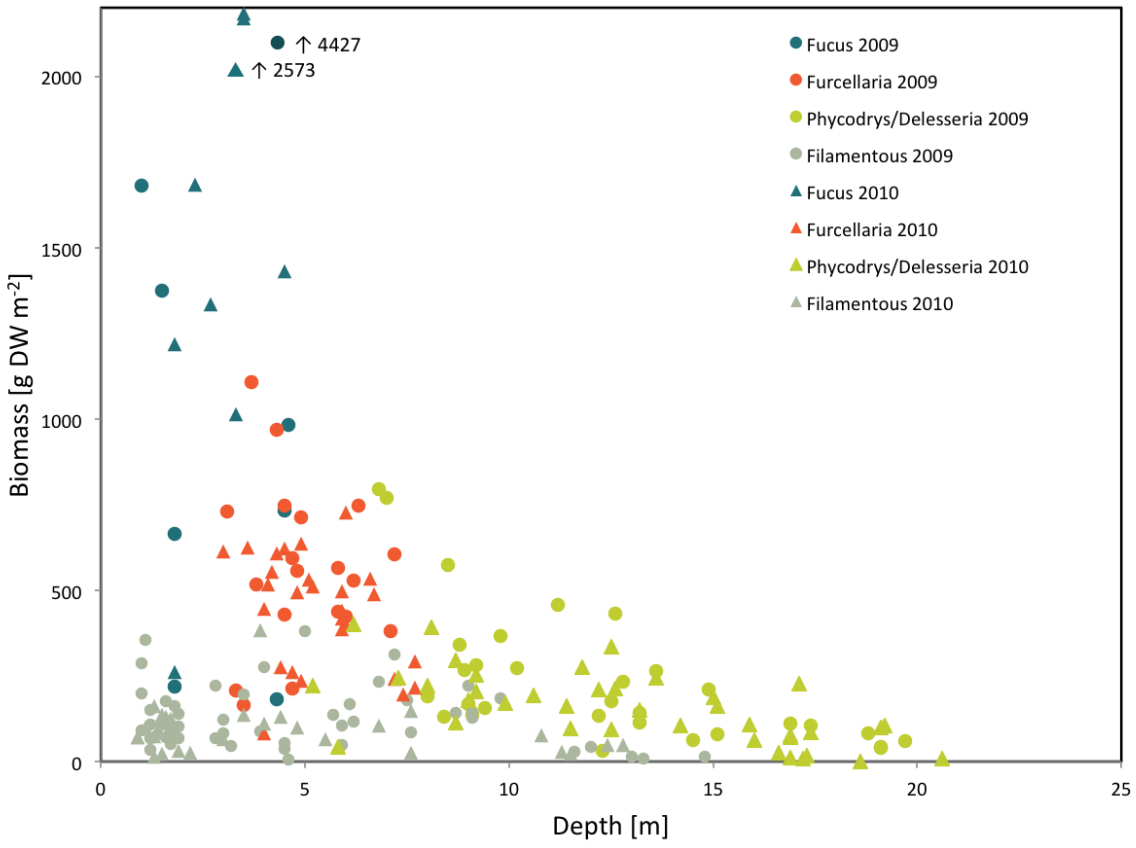



*Figure 4.18 Mean total biomass of key communities at the sample sites in 2009 (112 sites) and 2010 (113 sites) as a function of depth.*

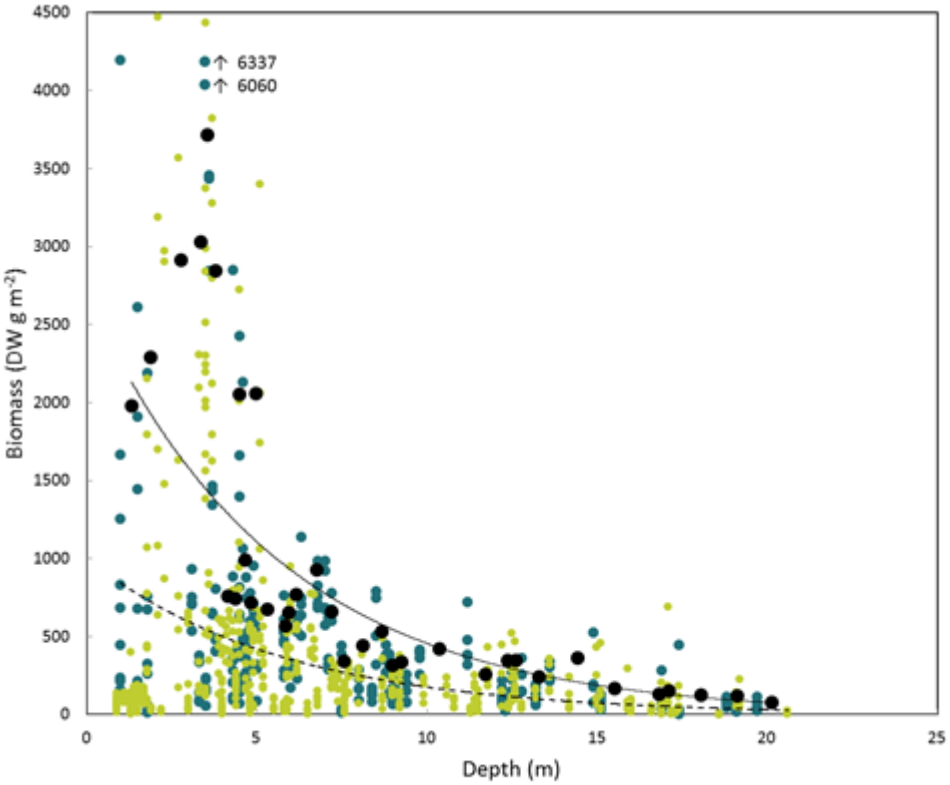



*Figure 4.19* *Total biomass of all subsamples in 2009 (blue dots) and in 2010 (green dots) and 90% percentiles of grouped observations (black dots) as a function of depth. The lines describe the exponential decrease in biomass (dotted line= average trend, solid line= 90% percentile of grouped data) with depth.*

Figure 4.19 and Table 4.12 are based on total biomass of each sample collected (subsample/replicate), i. e. all data were compiled without considering species/communities.

The models of exponential decline described the decrease in macroalgae biomass with depth. Using all data the average trend in biomass showed a highly significant exponential decline due to the large number of data included, but the models only explained 17-41% (with and without filamentous species) of the variation, and thus had little predictive power.

In contrast the model describing the upper biomass boundary of the distribution explained 60-83% of the variations with depth (Figure 4.19 and Table 4.12).

*Table 4.12* *Fitted models of macroalgae biomass (g DW $m^{-2}$) as a function of depth in the summers 2009 and 2010. A model of exponential decrease was fitted to both individual points and to upper bounds ($90^{th}$ percentile) of grouped data set. The depth distribution was fitted for all subsamples and for a data set where filamentous communities were excluded. $R^2$= co-efficient of determination. The relationships were all significant ($p < 0.0001$). N = number of samples sites*

| Data | Exponential model | $R^2$ | N |
|---|---|---|---|
| *All communities* | | | |
| All data | LN(Biomass) =6.0 - 0.11*depth | 0.17 | 865 |
| 90th percentile | LN(Biomass) =7.4 -0.14*depth | 0.60 | 34 |
| *Without filamentous species communities* | | | |
| All data | LN(Biomass) =6.9 - 0.17*depth | 0.41 | 700 |
| 90th percentile | LN(Biomass) =7.9 -0.18*depth | 0.83 | 34 |

Light, nutrients and physical factors play an important role in regulation of macroalgae biomass at a given depth and contribute to a complex regulation of the mean value, which makes it difficult to predict the mean value accurately. In contrast, in deeper water (e.g > 5 m) only one factor, light, governs the upper limit of growth. Therefore, the upper limit is far easier to predict accurately than the mean value, which is why the upper limit conveys more information on the light limiting growth.

The 'biomass attenuation' (reduction of biomass with depth) was 0.18 $m^{-1}$ (without filamentous species, $90^{th}$ percentile model). In single-species communities we would expect that the biomass attenuation should be close to the average light attenuation coefficient (0.24 $m^{-1}$) if photosynthesis is linearly related to light (Krause–Jensen et al. 2000). For multi-species communities, like most macro algae communities, we cannot expect light and biomass to have the same attenuation with depth. As deep growing species utilise light more efficiently than shallow water species and therefore may obtain higher biomass for the same limited light availability. This will result in less reduction in biomass with depth than expected for the biomass attenuation for a single species.

Because light availability sets the maximum biomass at a given depth, the slope of the upper limit of macroalgae biomass vs. depth is expected to change with a general change in light availability.

The depth distribution of key communities/species and the decrease in the upper limit of macroalgae biomass with depth explains the difference in average biomass for the key communities/species. *Fucus*-communities growing in shallow water, where light barely limits photosynthesis and growth, had very high mean biomass. *Furcellaria*-communities - growing in intermediate depths, where light is limiting photosynthesis - had the second highest mean biomass. *Delesseria/Phycodrys*- and *Saccharina*-communities occupy deeper zones, where light further constrains biomass and have the lowest average biomass.

Any changes in the depth distribution of these key communities are therefore expected to have an effect on the average biomass of key communities.

### 4.3.4 *Estimation of Cover-Corrected Biomass in Key Communities*

At the sampling sites cover varied between 0 and 100%. Multiplying the biomass of macroalgae in well established vegetation with the cover at the site provides an estimate of the average biomass at the whole station. In the following this is named cover-corrected biomass. The cover-corrected biomass of macroalgae at the biomass sample sites was highly variable and ranged between 0.01 and 1394 g DW $m^{-2}$ (median: 54 g DW $m^{-2}$, mean 132 (± 41.7) g DW $m^{-2}$) in the summer of 2009 and between 0.14 and 2200 g DW $m^{-2}$ (median: 75.3, mean 208.6 (± 75.9) g DW $m^{-2}$) in the summer of 2010.

The cover-corrected biomass of macroalgae in key communities represents the average biomass at the stations and it increases as a function of cover at the stations. Linear relationships were fitted for the *Furcellaria*-community, the filamentous community, the *Phycodrys/Delesseria*- and the *Saccharina*-community (Table 4.13, Figure 4.20). The relations (based on 2009 data) have been used to produce a map of macroalgae cover-corrected biomass in the area (Figure 6.5). The relationship was not significant for the *Fucus*-community because there were too few data; the average cover-corrected biomass was used for this community. In areas with mixed eelgrass/algae vegetation a linear relationship for the combined algae and eelgrass relationship was used (cover corrected biomass (g DW $m^{-2}$)=1.6* total cover).

The cover-corrected biomass of macroalgae at the 357 sites, where total cover was estimated (25 $m^2$ coverages estimates) was highly variable and ranged between 0 and 627 g DW $m^{-2}$ (median: 42 g DW $m^{-2}$, mean 116 (±16.6) g DW $m^{-2}$) in 2009 and between 0 and 528 g D W $m^{-2}$ (median:83.3 g DW $m^{-2}$, mean 134 (± 22.4) g DW $m^{-2}$) at the 135 sites in 2010.

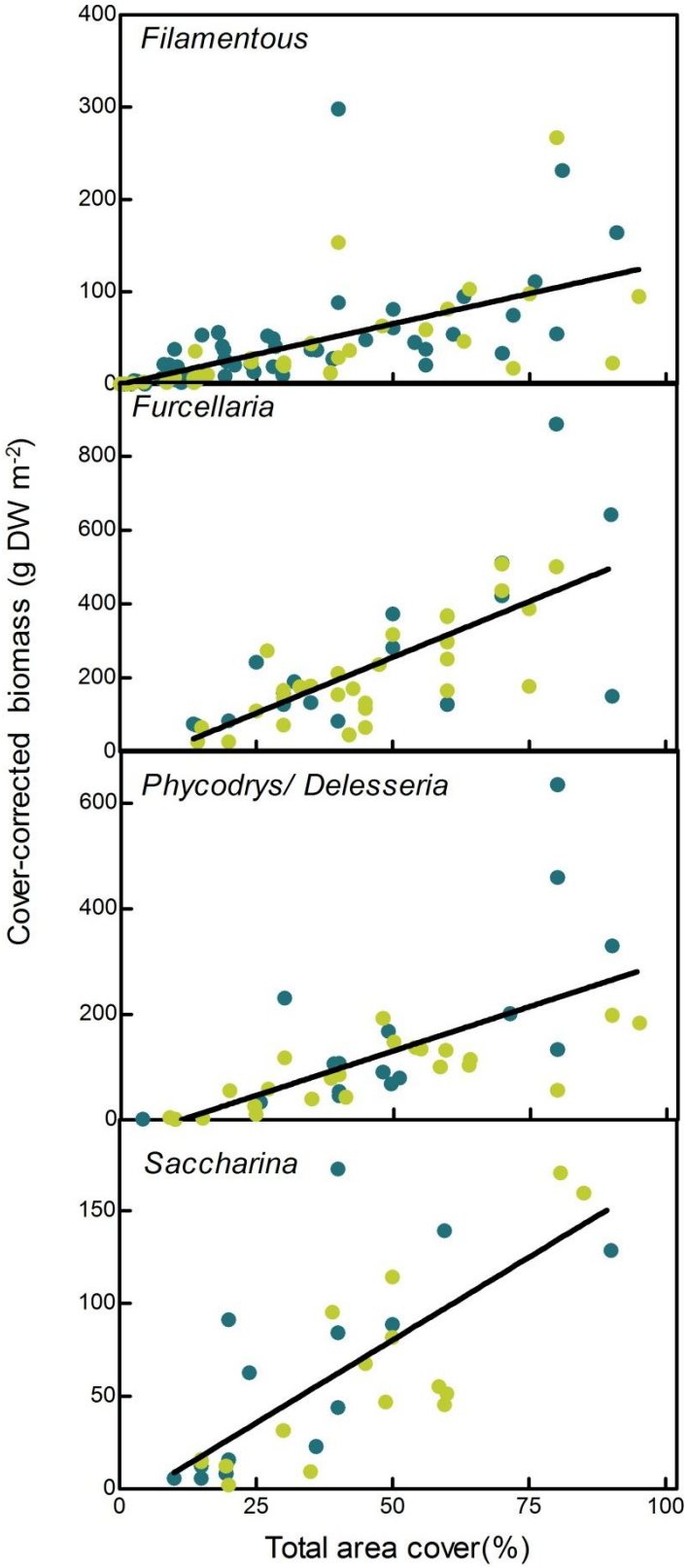



*Figure 4.20 Cover-corrected biomass as a function of total cover at the sites in 2009 (blue circles) and 2010 (green circles). Statistics for the fitted lines can be seen in Table 4.13.*

*Table 4.13 Cover-corrected biomass (g DW $m^{-2}$) as a function of total cover (%) in four key communities in Fehmarnbelt in 2009 and for all data (2009 and 2010). $R^2$= coefficient of determination and p = level of significance.*

| Key-community | Data | Relationship between cover-corrected biomass (Y) and total cover (%) | $R^2$ | P |
|---|---|---|---|---|
| Filamentous-community | 2009 | Y=1.4*total cover | 0.37 | p<0.0001 |
| | all | Y=1.3*total cover | 0.38 | p<0.0001 |
| *Furcellaria* – community | 2009 | Y=6.6*total cover | 0.63 | p<0.0001 |
| | all | Y=6.0*total cover | 0.51 | p<0.0001 |
| *Phycodrys/Delesseria*-community | 2009 | Y=3.6*total cover | 0.44 | p<0.0001 |
| | all | Y=3.4*total cover | 0.42 | p<0.0001 |
| *Saccharina*-community | 2009 | Y=1.8*total cover | 0.52 | p<0.0001 |
| | all | Y=1.8*total cover | 0.55 | p<0.0001 |

Seasonal variability in cover-corrected biomass was expected to show a pattern of low biomasses in winter and increasing biomasses from spring to summer.

*Furcellaria*-communities that are dominated by perennial species with high biomass, showed the expected pattern in cover-corrected biomass with biomasses increasing from March to summer months. *Phycodrys/Delesseria*- and *Saccharina*-communities as well as the filamentous species also showed a tendency of this pattern but with more variability. Biomass samples of key communities dominated by species with relatively low biomasses like filamentous species and *Phycodrys/Delesseria* are more affected by occational occurrence of other larger perennial species, this may cause higher spatial variability. Likewise the different size and occurrence of *Saccharina latissima* in *Saccharina*-communities may contribute to higher variability.

Seasonally, mean cover-corrected biomass varied between 161.8 g DW $m^{-2}$ and 629.8 g DW $m^{-2}$ in *Furcellaria*-communities (Figure 4.21). Mean cover-corrected biomass increased from March to August. The highest biomass was observed in August and the lowest in January.

The mean cover-corrected biomass of *Phycodrys*/*Delesseria* and *Saccharina* was highest in the months from April to July and lowest in November. Mean cover-corrected biomass of filamentous species communities was very variable the mean value was lowest in January and highest in May. Although filamnetious species communities are dominated by filamentous species, larger perennial species also occur with relatively low cover. The perennial species are included in some of the biomass samples and not in others causing a very high variability in the community biomass of filamentous species communities.

*Fucus* species were sampled at one site and showed no really seasonal pattern the cover-corrected biomasses were: 2855.8 g DW $m^{-2}$ in March, 1411.5 g DW $m^{-2}$ and 1523.3 g DW $m^{-2}$ in April, 816.4 g DW $m^{-2}$ in May, 397.8 g DW $m^{-2}$ in June and 2062.9 g DW $m^{-2}$ in November.

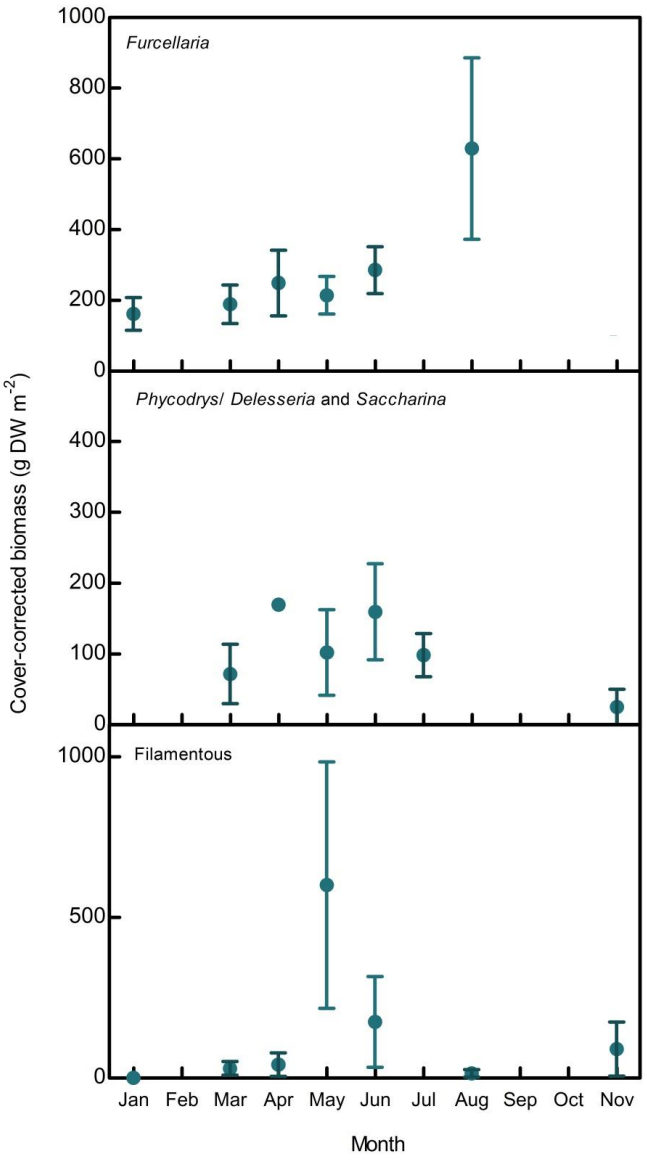



*Figure 4.21 Mean cover-corrected biomass of selected key communities in 2009 and 2010. Vertical lines show standard errors.*

# 5 FLOWERING PLANT (ANGIOSPERM) COMMUNITIES IN FEHMARNBELT AND NEIGHBOURING AREAS

Flowering plant communities were mainly confined to the sheltered, sandy areas in Rødsand Lagoon and Orth Bight. Eelgrass was also found in the more exposed areas at Großenbrode, southwest coast of Fehmarn and along the south coast of Fehmarn. Soft bottom sampling has only been conducted in 2009; therefore all analyses are based on this data set. Soft bottom sampling was conducted in Rødsand, Orth Bight and Großenbrode.

Due to the smaller data set the community analyses was conducted for the whole data set (depth range 0–6 m) and not divided into depth intervals like for the macroalgae samples. The analyses of cover and biomass focus on the most abundant species (mainly eelgrass). Supplementary analyses of cover and biomass for the whole data set are illustrated and described in Appendix 7.

## 5.1 Species Composition and Definition of Key Communities

### 5.1.1 Communities in the 0–6 m Depth Interval

The variability in species composition and biomass was very high between the Rødsand Lagoon, Orth Bight and Großenbrode (ANOSIM, R = 0.029, p = 0.24).

The average similarity was very high between samples within Großenbrode (SIMPER, 80.6%). The average similarity between samples within Orth Bight (42.9%) and within Rødsand (31.0%) was low compared to that in Großenbrode. This is caused by a higher number of soft bottom macrophyte species in the sheltered areas of Orth Bight and Rødsand Lagoon, whereas only one species occurred at the more exposed site Großenbrode.

The samples were firstly grouped (TWINSPAN) into sites where *Zostera marina* was present (+) or absent (-). A further division of samples with *Zostera marina* could be made upon the presence/absence of *Chara spp.* and *Ruppia spp./Zostera noltii.* Where *Zostera marina* was absent a further division of samples could be made upon the presence/absence of *Tolypella nidifica* and *Zannichellia palustris* (Figure 5.1). But the sample number was too low to make a clear division and definition of four evident communites. Furthermore there was an overlap of communities with and without *Zostera marina,* as key species, could be observed in the depth interval between 1.0–2.5 m. Therefore only two angiosperm communities was defined by this community analysis.

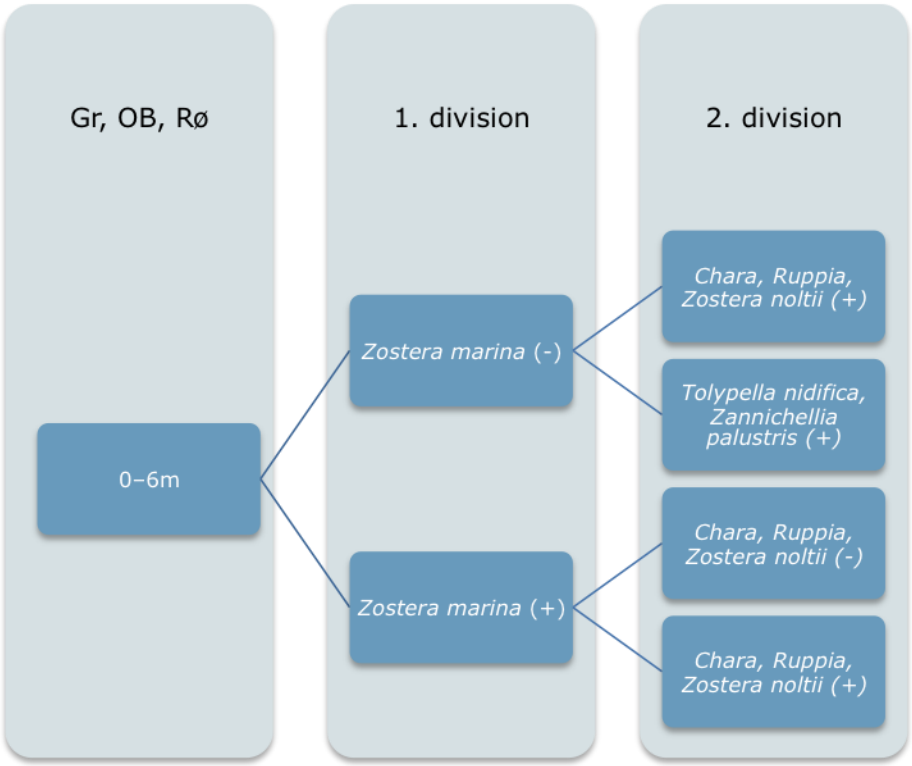



*Figure 5.1 Diagram showing results of the TWINSPAN-analysis off flowering plant species the 0–6 m depth interval of the investigation area. Großenbrode= Gr, Orth Bight = OB, Rødsand Lagoon = Rø.*

### 5.1.2 Key Angiosperm Communities

The multivariate analyses identified two different flowering plant communities within the investigation area: the eelgrass-community and the tasselweed/dwarf eelgrass-community. In the more exposed areas outside of Rødsand Lagoon and Orth Bight the sediment conditions are more variable. In those areas hard substrates (boulders, cobbles and pebbles) and soft sediments are evenly distributed. Therefore a third, mixed vegetation community of flowering plants and macroalgae was observed: eelgras/algae-community (Figure 5.2). But as the multivariate analyses have been made on the data sets for macroalgae and angiosperms separately this specific community could not be defined by those techniques. This community type is described shortly below but the quantitative analyses are based only on the pure soft bottom communities.

The above described results were compared with an analysis of historical observations on soft bottom communities in the Western Baltic (Blümel et al. 2002), before the three different communities were defined. Only perennial flowering plants and charophytes were used, with a steadily occurrence in specific habitats and no ubiquitous occurrence in a variety of different habitats (normally depth or substrate specifications). Some species were abundant in more than one community. In these cases the species are not defined as key species but as accompanying species in the communities.

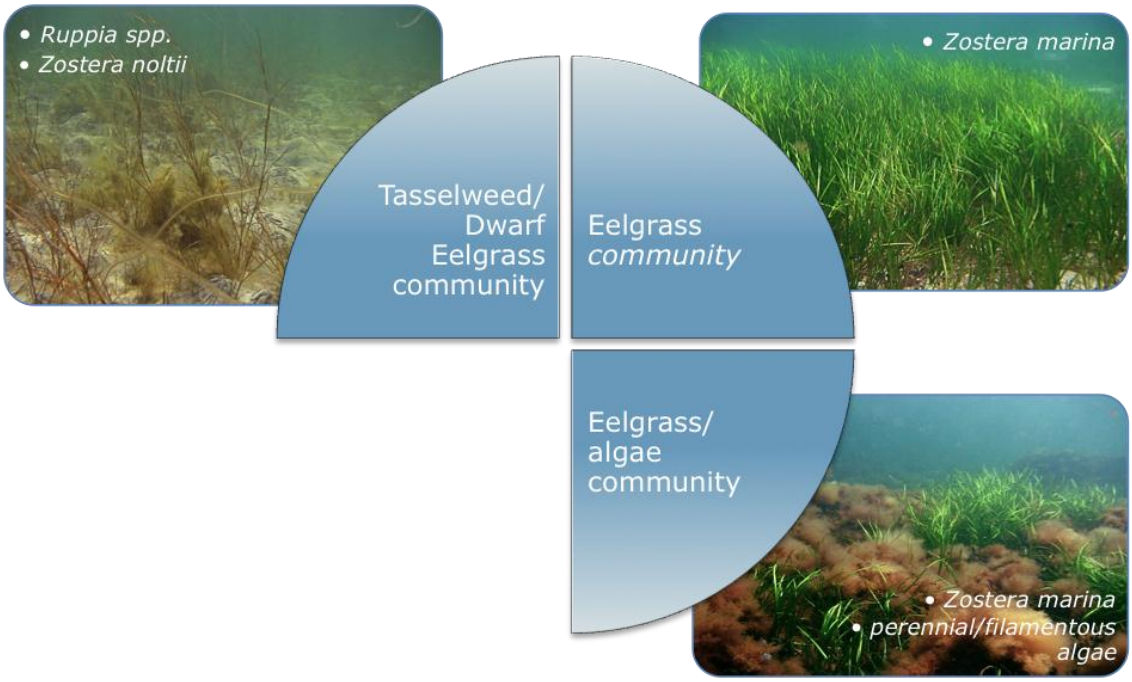



*Figure 5.2 Characteristic soft and mixed bottom angiosperm communities within the investigation area in 2009.*

*Eelgrass-community*

The eelgrass-community is characteristic for sheltered bays or lagoons as well as for semi-exposed areas along the coastline. Soft sediments (sand and clay/silt/mud) are preferred by this community, but eelgrass can also grow on gravel and mixed sediments (Figure 5.3). The depth distribution for this community is from 1 to about 5–6 m.

In sheltered areas eelgrass can build up high biomass because plants can grow very tall, with high shoot densities and coverage up to 100%. At semi-exposed sites, coverage is lower as eelgrass is not forming continuous beds but is growing in scattered spots. Macroalgae can occur as epiphytes in great abundances (e. g. *Pylaiella/Ectocarpus*, *Aglaothamnion/Callithamnion, Ceramium* spp.), increasing the total biomass of benthic vegetation significantly. Eelgrass leaves can also be overgrown by hydrozoans under sheltered conditions (Figure 5.3). Large amounts of drifting algae were present in eelgrass-communities in the 2009 study, especially in Rødsand Lagoon.

The dense, large scale eelgrass beds in sheltered areas have an important structuring role in the coastal ecosystem as they provide habitat for fauna and small fish, while scattered eelgrass stands along the open coastline have less importance.

The key species is eelgrass (*Zostera marina*). Species diversity within the eelgrass community is low. In sheltered bays some flowering plant species like *Ruppia* or *Potamogeton* as well as some charophytes, especially *Tolypella nidifica*, can mix with eelgrass. But eelgrass is the predominant species. Along the outer coastline pure eelgrass beds occur without accompanying flowering plants or charophyte species.

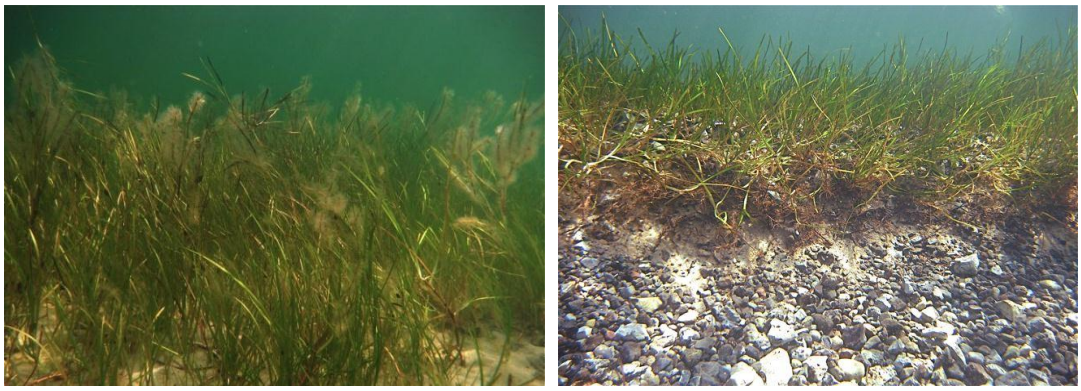


*Figure 5.3 Eelgrass covered with hydrozoans at the tips of the leaves on soft bottom in Orth Bight (left side). Eelgrass on gravel in Großenbrode (right side).*

*Tasselweed/dwarf eelgrass-community*

The tasselweed/dwarf eelgrass-community is characteristic for sheltered bays or lagoons with predominant soft bottoms (sand + clay/silt/mud). This community type was found from the shoreline to about 1.5 m. Some of the characteristic species can grow deeper, but normally they are outcompeted by eelgrass and/or *Potamogeton pectinatus* in deeper areas. As this community is dependent on sheltered conditions, it was spatially restricted to Rødsand and Orth Bight within the investigation area.

Coverage degree, shoot densities and biomass values are low compared to eelgrass beds, as the characteristic species are small growing with tiny, narrow leaves (Figure 5.4). Macroalgae can occur as epiphytes with large abundances (e. g. *Pylaiella/Ectocarpus*, *Aglaothamnion/Callithamnion, Ceramium* spp.). Especially charophytes and *Ruppia* spp. can be overgrown by them (Figure 5.4). Therefore, during spring and summer, the plants in the shallow parts can be completely covered by epiphytic, filamentous algae, which can significantly increase the total biomass.

Due to their small growth form the structuring role of this community and the importance as habitat for fauna and small fish is low compared to other communities. It plays also a minor role as food source for birds as brent geese (*Branta bernicla*), wigeon (*Anas penelope*), mute and whooper swans (*Cygnus olor* and *Cygnus cygnus*) (Tyler-Walters 2005).

Key species for this community are the tasselweeds *Ruppia cirrhosa* and/or *Ruppia maritima* as well as the dwarf eelgrass *Zostera noltii*. These flowering plants are accompanied by different charophytes like *Chara baltic*a and/or *Tolypella nidifica*. *Potamogeton pectinatus* occurs in high abundances and biomass, but it is not used as an indicator of this community as it also occurs as an accompanying species in the eelgrass-community. Compared to the other flowering plant communities the diversity is high.

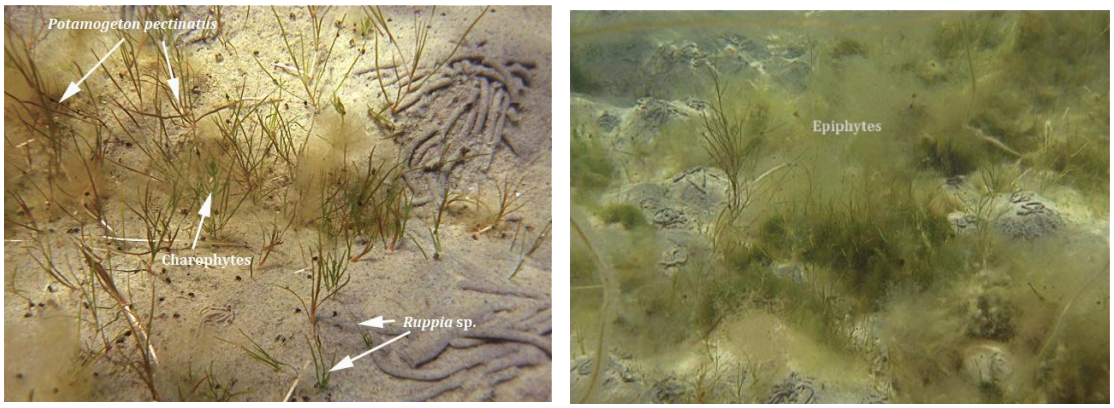



*Figure 5.4 Left: Typical low density of the tasselweed/dwarf eelgrass-community. Right: Epiphytes densely cover flowering plants and charophytes.*

*Eelgrass/algae-community*

The eelgrass/algae-community is characteristic for semi-exposed to exposed areas along the outer coastline and occurs in coarse sediments (a mixture of soft and hard substrates). The depth distribution for this community type corresponds with the pure eelgrass-community (1 to about 5–6 m).

Due to the higher exposure eelgrass is not growing as tall as in sheltered areas, but the shoot density is often higher and ensure anchoring of the eelgrass stands at high exposure. This also leads to high biomass values. Additionally, the algae are contributing to the biomass values of this community, especially if perennial algae are included. The degree of coverage depends of course on the substrate structure, but coverage up to 100 % is possible, if all soft sediments are covered with eelgrass and all hard substrates by algae. But normally the coverage of this community is lower and lies between 25–50%. Macroalgae seldom occur as epiphytes on eelgrass shoots as the exposure level is too high.

Mixed communities are very important in coastal ecosystems as they provide habitat for a combination of different fauna and small fish adapted either on the abundance of eelgrass or the abundance of algae. The number of micro-habitats is usually very high in mixed communities.

Key species for the soft bottom part of this community is the angiosperm *Zostera marina*. Several key species can occur as the hard bottom part of this community. Perennial key macroalgal species growing within the same depth level of *Zostera marina* are *Fucus vesiculosus* and *Furcellaria lumbricalis*. But at most sites *Zostera marina* is socialised with filamentous algae.

*Figure 5.5 Eelgrass in coarse sediments can be socialised with filamentous algae (left side) or with perennial macroalgae like* Fucus vesiculosus *(right side).*

### 5.1.3 Distribution of Key Angiosperm Communities

Figure 5.6 shows the distribution of the defined angiosperm communities within the investigation area and Table 5.1 shows the distribution of sites in Danish and German areas.

*Table 5.1 Number of sites with angiosperm communities in Danish and German areas in 2009, * including fauna investigations.*

| Area | Eelgrass | Tasselweed/ Dwarf eelgrass | Eelgrass/Algae |
|---|---|---|---|
| | 2009 | 2009 | 2009 |
| Overall | 46 | 19 | 22* |
| Danish waters | 30 | 13 | 0 |
| German waters | 16 | 6 | 22* |
| German coastal zone | 16 | 6 | 22* |
| German EEZ | 0 | 0 | 0 |
| DE 1332-01 Fehmarnbelt | 0 | 0 | 0 |
| DE 1533-301 Staberhuk | 0 | 0 | 3 |
| DE 1631-392 Eastern Kiel Bight | 16 | 6 | 2 |
| DE 1632-392 Großenbrode | 0 | 0 | 17* |
| DE 1733-301 Sagasbank | 0 | 0 | 0 |
| DK006X238 Rødsand Lagoon | 30 | 13 | 0 |
| DK00VA200 Langeland | 0 | 0 | 0 |

The area covered with angiosperm vegetation is much smaller than the area covered by macroalgae. This is due to restricted occurrence ofareas shallower than 6 m and with a low degree of exposure. Of course, also the sediment conditions are im-

portant for the distribution pattern of angiosperms, but the shallow sandy areas along the northcoast of Fehmarn and also partly along the coast of Lolland without or only with low cover of angioperms (1–10 %) demonstrate how important the exposure level is for soft bottom vegetation.

Larger areas of the eelgrass-community is almost confined to the Rødsand Lagoon and Orth Bight. The only other area with noteable eelgrasss community is south of Großenbrode. Eelgrass is distributed between 1 and 6 m depth. Overall 46 sites of the 87 sites investigated could be classified into an eelgrass community.

The tasselweed/dwarf eelgrass-community occurs only within the Rødsand Lagoon and Orth Bight. Overall 19 sites of the sites investigated could be classified into a tasselweed/dwarf eelgrass-community.

Larger areas of the eelgrass/algae-community is found north of Großenbrode and at the southwest coast of Fehmarn. Single sites with this community are furthermore observed at the southeastern cape of Fehmarn (Staberhuk) and along the coast south of Großenbrode. Overall 22 sites of the investigation area could be classified as eelgrass/algae-community.

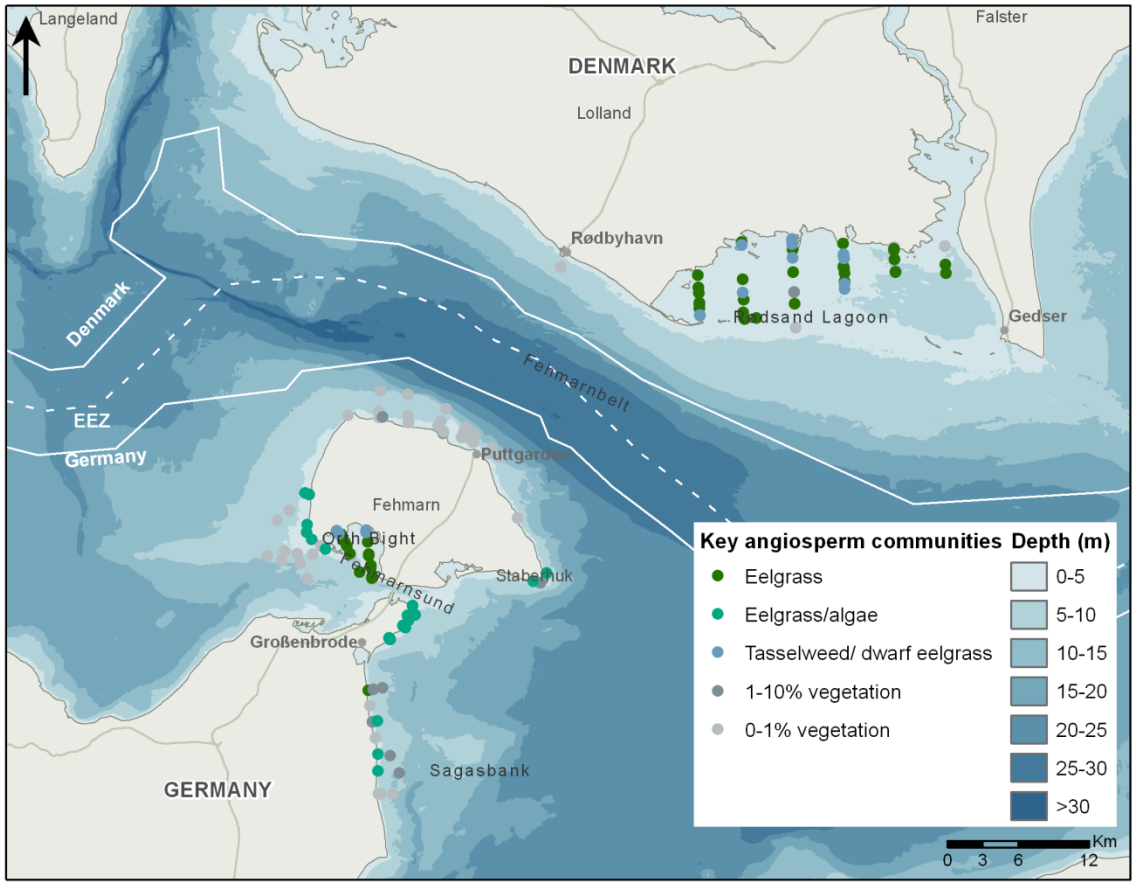



*Figure 5.6 Site distribution of angiosperm communities within the investigation area.*

## 5.2 Species Diversity

As mentioned eelgrass dominated the soft bottom benthic vegetation. Populations of tasselweed and pondweed were also of importance. Other species were only recorded at few sites with low abundances. The following text on specis is therefore focused on eelgrass, tasselweed and pondweed.

Overall six flowering plant species have been recorded together with six charophyte species within the investigation area (Table 5.2). If hard substrate is present, brown algae like *Fucus vesiculosus* and/or *Chorda filum* can occur, but the overall abundance of macroalgae species is low in the floweing plant communities.

*Table 5.2 Species of flowering plants and charophyceae recorded along 8 transects in the Lagoon of Rødsand and Orth bight in the summer of 2009.*

| | Species |
|---|---|
| **Flowering plants** | *Potamogeton pectinatus* |
| | *Ruppia cirrhosa* |
| | *Ruppia maritime* |
| | *Zannichellia palustris* |
| | *Zostera marina* |
| | *Zostera noltii* |
| **Charophyceae** | *Chara aspera* |
| | *Chara baltica* |
| | *Chara canescens* |
| | *Chara* sp. |
| | *Lamprothamnium papulosum* |
| | *Tolypella nidifica* |

## 5.3 Eelgrass

### 5.3.1 Distribution and Cover of Eelgrass

Eelgrass was widely distributed inside the 6 m depth contour in Rødsand Lagoon (Figure 5.8). It occurred in most vegetated areas, often as the predominant species. In areas where the beach slope is very gentle, the potential distribution area is large. Hence, eelgrass occurred extensively in the shallow water areas in the western part of the lagoon while in the deeper east part of the lagoon, the occurrence is limited due to light limitation. The deepest observations (with > 10% cover) were at 5.2 m and the average depth limit (5 observations) was at 4.6 m in the eastern part.

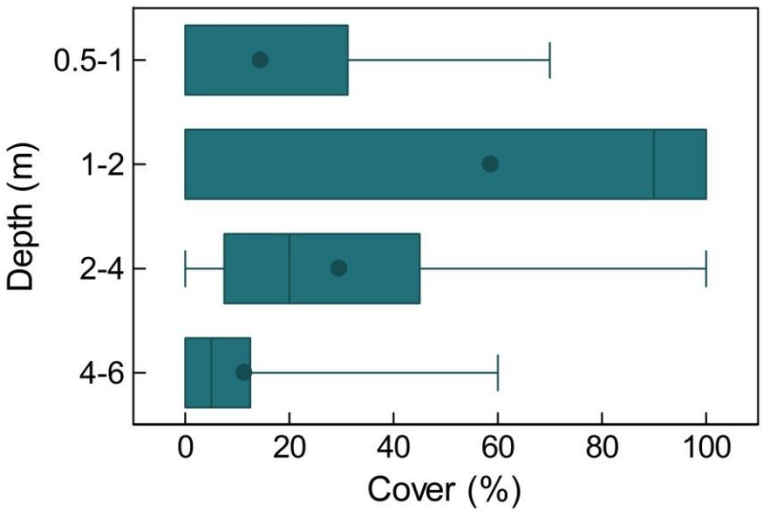



*Figure 5.7* *Vertical distribution of eelgrass in Rødsand Lagoon in the summer of 2009. Circles represent mean values of cover in each depth interval, lines represent medians, boxes represent 25-75% percentiles, and whiskers represent 10-90% percentiles. The analysis was based on 48 diver observations along 6 transects in Rødsand Lagoon.*

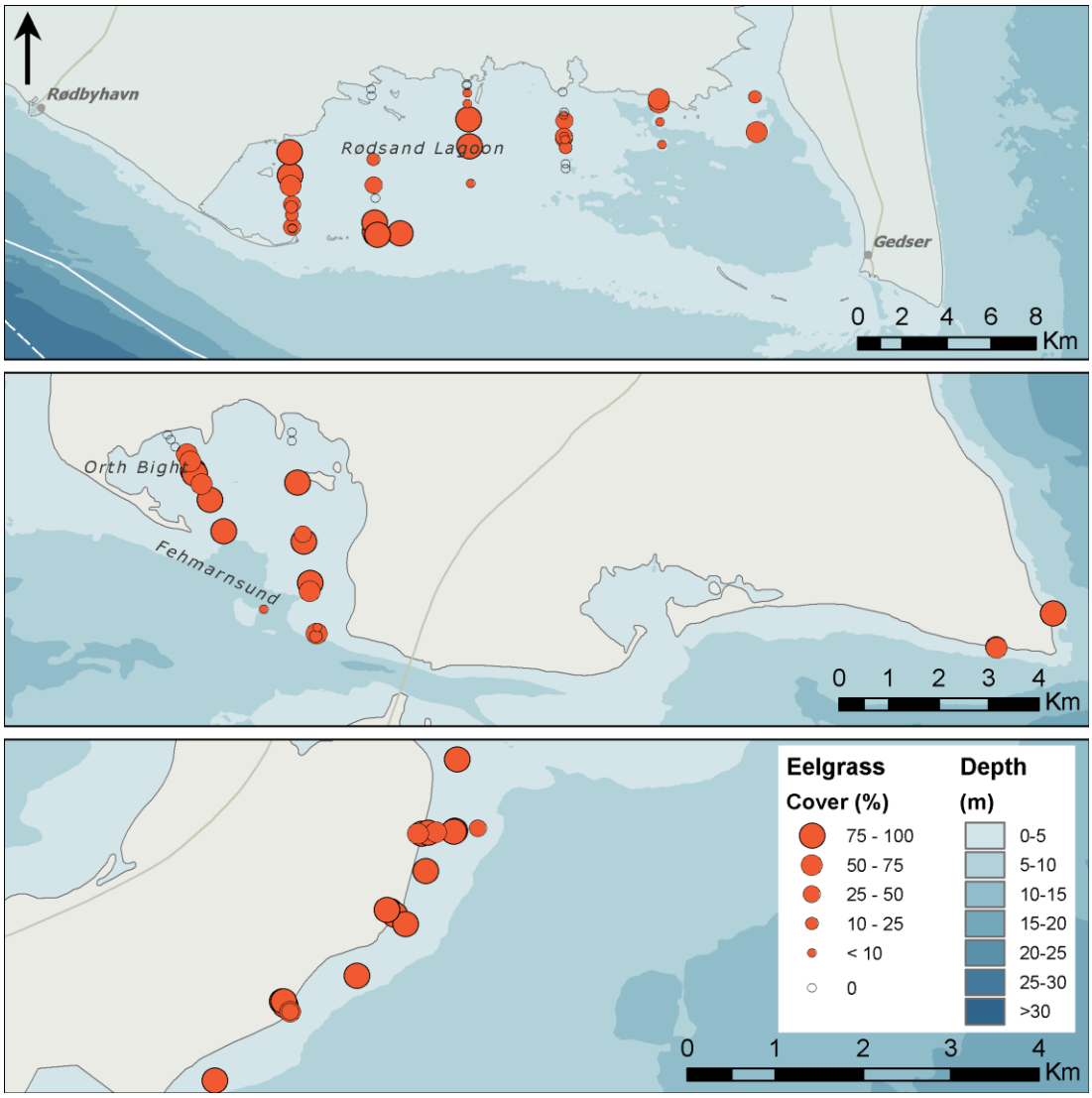



*Figure 5.8* *Cover of eelgrass estimated by divers along transects in the Rødsand lagoon (upper panel), Orth Bight (middle panel) and Grossenboden (lower panel) in the summer of 2009.*

Extensive variation in eelgrass cover was found along the transects, ranging from 0 to 100% cover in the depth range 0.5–6 m (Figure 5.8). Percentage covers had a bell-shaped vertical distribution pattern (Figure 5.7) with low cover between 0.5 and 1 m, maximum cover between 1 and 2 m, intermediate cover between 2 and 4 m and low cover at depths of more than 4 m.

In Orth Bight, eelgrass was also widely distributed (Figure 5.8). The downward slope of the bay is very gentle and the depth in nearly the whole bay is shallower than 4 m. The depth limit of eelgrass was 4.5 and 4.8 m at the two investigated transects. Coverage was highest in the interval 1-4 m

Coverage of *Zostera marina* was high in almost the whole bay in the depth interval between 1 and 4 m and very low deeper than 4 m (Figure 5.9). Nevertheless, the highest biomass was found at the western transect. Eelgrass is more scatterely distributed along the northern coastline. In this area, where water depths are low, other flowering plants (like *Ruppia* spp. or *Zannichellia palustris*) and *Chara* spp. are the dominant components of the vegetation.

In Großenbrode cover of *Zostera marina* ranged between 20 and 75% (Figure 5.8). Mean cover (± 95 CL) was 59.1 (± 16.9). The species showed a continuous distribution along the shoreline between 1 and 4 m depth.

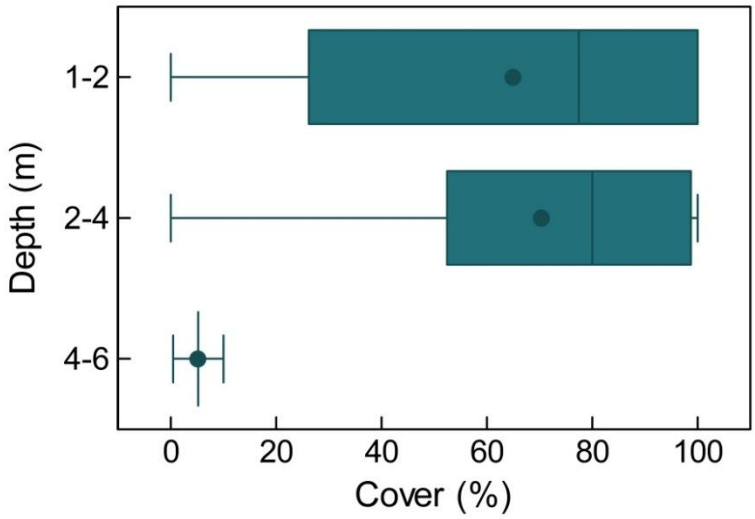



*Figure 5.9* *Vertical distribution of eelgrass in Orth Bight in the summer of 2009. Circles represent mean values of cover in each depth interval, lines represent medians, boxes represent 25-75% percentiles, and whiskers represent 10-90% percentiles. The analysis is based on 28 diver observations along 2 transects in Orth Bight.*

### *5.3.2 Biomass and Shoot Density of Eelgrass*

The total biomass of eelgrass ranged from 0 to 480 g DW $m^{-2}$ at the 17 stations in Rødsand Lagoon (Table 5.3). Mean leaf biomass (± 95% CL) was 61.4 (± 44.0) and mean rhizome biomass (± 95% CL) was 101.3 (± 56.0) g DW $m^{-2}$. Rhizome biomass made up more than 50% of the total biomass at 6 of the 10 sampling stations and the mean below : above ground biomass ratio (± 95% CL) was 2.6 (± 1.2). The mean shoot density (± 95% CL) was 191 (± 81) shoots $m^{-2}$. The maximum shoot density was 447 shoots $m^{-2}$.

In Orth Bight total biomass ranged from 0 to 294.7 g DW $m^{-2}$ (Table 5.3). The mean leaf biomass (± 95% CL) was 133.3 (± 108.2) g DW $m^{-2}$, and mean rhizome biomass (± 95% CL) was 161 (± 69.4) g DW $m^{-2}$. Rhizome biomass constituted more than 50% of total biomass at 3 out of 6 sites and the mean below : above ground biomass ratio (± 95% CL) was 2.0 (± 1.1). The mean shoot density (± 95% CL) was 423 (± 214). The maximum shoot density was 760 shoots $m^{-2}$.

In Großenbrode total biomass ranged from 0 to 413.4 g DW $m^{-2}$ (Table 5.3). The mean leaf biomass (± 95% CL) was 131.2 (± 37.2) g DW $m^{-2}$, and mean rhizome biomass (± 95% CL) was 285.3 (± 123.8) g DW $m^{-2}$. Rhizome biomass constituted more than 50% of total biomass at all sites and the mean leaf : rhizome biomass ration ratio (± 95% CL) was 2.1 (± 1.1). The mean shoot density (± 95% CL) was 700 (± 409). The maximum shoot density was 1665 shoots $m^{-2}$.

*Table 5.3 Mean (± 95% CL) leaf, rhizome and total biomass, rhizome: leaf biomass ratio and shoot density of eelgrass in Rødsand Lagoon, Orth Bight and Großenbrode in summer 2009. Ranges are given in parentheses. N = number of samples.*

| | **Rødsand Lagoon** | | | **Orth Bight** | | | **Großenbrode** | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean (±95%CL) | Median (range) | N | Mean (±95%CL) | Median (range) | N | Mean (±95%CL) | Median (range) | N |
| Leaf biomass (g DW $m^{-2}$) | 61.4 (±44.0) | 31.4 (0-256.4) | 17 | 133.3 (±108.2) | 82.8 (0-407.1) | 8 | 131.2 (±37.3) | 137.9 (47.1-184.9) | 6 |
| Rhizome biomass (g DW $m^{-2}$) | 101.3 (±56.0) | 77.0 (0-298.0) | 17 | 161 (±69.4) | 193.3 (0-250.0) | 8 | 285.3 (±123.8) | 323.3 (55.0-443.3) | 6 |
| Total biomass (g DW $m^{-2}$) | 160.4 (±88.1) | 155.8 (0-479.8) | 17 | 294.7 (±157.5) | 278.3 (0-657.1) | 8 | 413.4 (±162.3) | 462.9 (83.7-628.3) | 6 |
| Rhizome:leaf biomass ratio | 2.6 (±1.2) | 1.4 (0.8-6.5) | 10 | 2.0 (±1.1) | 2.0 (0.5-4.1) | 6 | 2.1 (±0.5) | 2.1 (1.2-2.8) | 6 |
| Shoot density (shoots $m^{-2}$) | 191 (±81) | 118.7 (8-447) | 14 | 423 (±214) | 412 (124-760) | 8 | 700 (±409) | 520 (219-1665) | 6 |

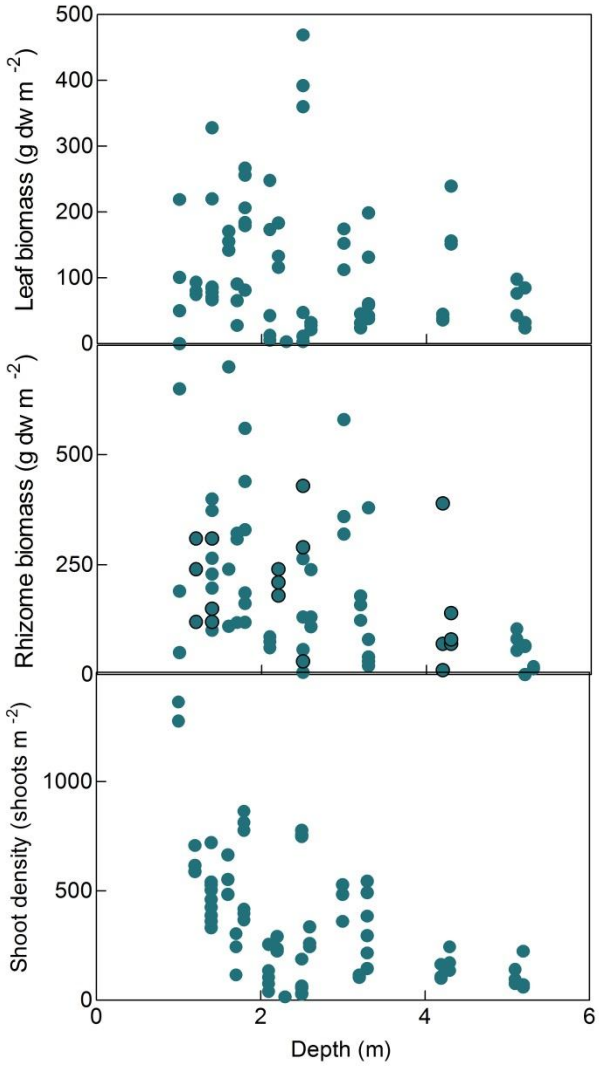



*Figure 5.10 Leaf and rhizome biomass as well as shoot density of eelgrass as a function of depth in Rødsand Lagoon, Orth Bight and Großenbrode in the summer of 2009. Note the different scales.*

The vertical distribution of eelgrass leaf biomass in Rødsand Lagoon, Orht Bight and Großenbrode exhibited no clear pattern (Figure 5.10). High and low biomasses were found between 1 and 4 m, but below 4 m values are generally lower and less variable. Rhizome biomass and shoot density decreased significantly with increasing depth (linear regressions, $R^2$ = 0.18 and 0.25, respectively, $p < 0.01$ for both). Rhizome biomass was highest in shallow water and low and less variable in deeper water. For shoot density there was a tendency of a decreasing upper limit (i. e. maximum reachable value) from 1 m depth to the depth limits.

The total biomass of eelgrass is within the ranges of summer biomasses reported from Europe, USA and Japan (collected in Olesen & Sand-Jensen 1994). Eelgrass biomass for Rødsand Lagoon was lower than for Orth Bight and Großenbrode, but was similar to earlier reports of eelgrass biomass from Rødsand Lagoon (references in Chapter 2).

Biomass and shoot density of eelgrass is highest during the summer season. The mean leaf biomass in this summer investigation was approximately three times higher than the mean biomass found during autumn and winter 2008/2009 (FEMA

2009). Rhizome biomass was approximately four times higher in summer. The mean shoot density was also highest in summer although sites with many small shoots were found in Rødsand in winter, resulting in only a small difference between mean summer and winter shoot density for this area.

Eelgrass biomass was expected to be patchy and to exhibit lower biomasses in shallow, exposed sites than in deeper and more protected waters, as found in other studies (e. g. Fonseca et al. 1983, Krause-Jensen et al. 2000, 2003). However, no clear pattern was found in the depth distribution of eelgrass leaf biomass.

Seagrasses acclimate to low light in deep water by reducing shoot density but increasing shoot size. Reduction of shoot density along the depth gradient enhances the relative amount of light available for absorption per shoot (Krause-Jensen et al. 2000, Olesen et al. 2002). Another response to shading is that below-ground biomass decreases relatively to above-ground biomass (Olesen et al. 2002). In this study shoot density and rhizome biomass showed a tendency to decrease with depth.

### 5.3.3 *Estimation of Cover-Corrected Biomass of Eelgrass*

At the sampling stations in Rødsand Lagoon, Orth Bight and Großenbrode percentage covers varied between 0 and 100%. Multiplying the biomass of macroalgae in well established vegetation with the cover at the site provides an estimate of the average biomass at the whole station. In the following this is called cover-corrected biomass. The cover-corrected leaf biomass of eelgrass at the different sites was highly variable and ranged between 0 and 407.1 g DW $m^{-2}$ (mean 87.2 ± 34.4 g DW $m^{-2}$).

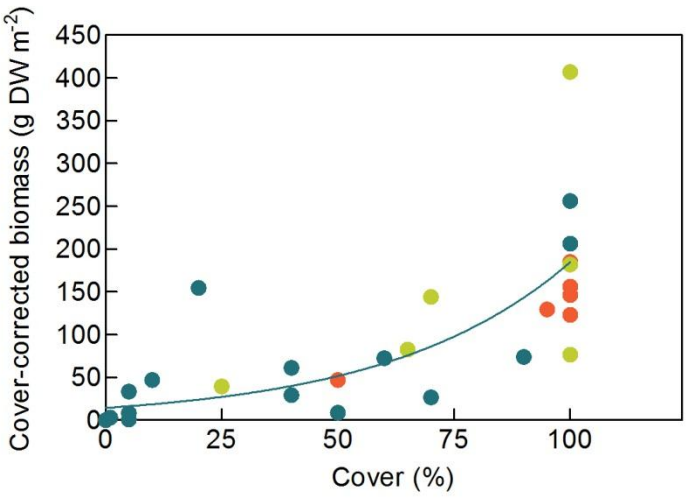



*Figure 5.11 Cover corrected leaf biomass of eelgrass versus cover at sampling sites in Rødsand Lagoon (blue circles) and Orth Bight (red circles) and Großenbrode (green circles) in the summer of 2009. $Y=14.5 * e^{(Cover\ (\%)*0.025)}$, $r^2 = 0.60$).*

The cover-corrected biomass of eelgrass increases as a function of cover at the stations. Data from all three areas were used and an exponential relationship was fitted ($Y=14.5 * e^{(Cover\ (\%)*0.025)}$, $R^2 = 0.60$, $p < 0.001$, Figure 5.11). Thus, a cover of 50% corresponds to a cover-corrected biomass of 59.6 g DW $m^{-2}$. This relation has been used to produce a map of eelgrass cover-corrected leaf biomass from cover data in Rødsand Lagoon, Orth Bight and Großenbrode (Figure 5.12).

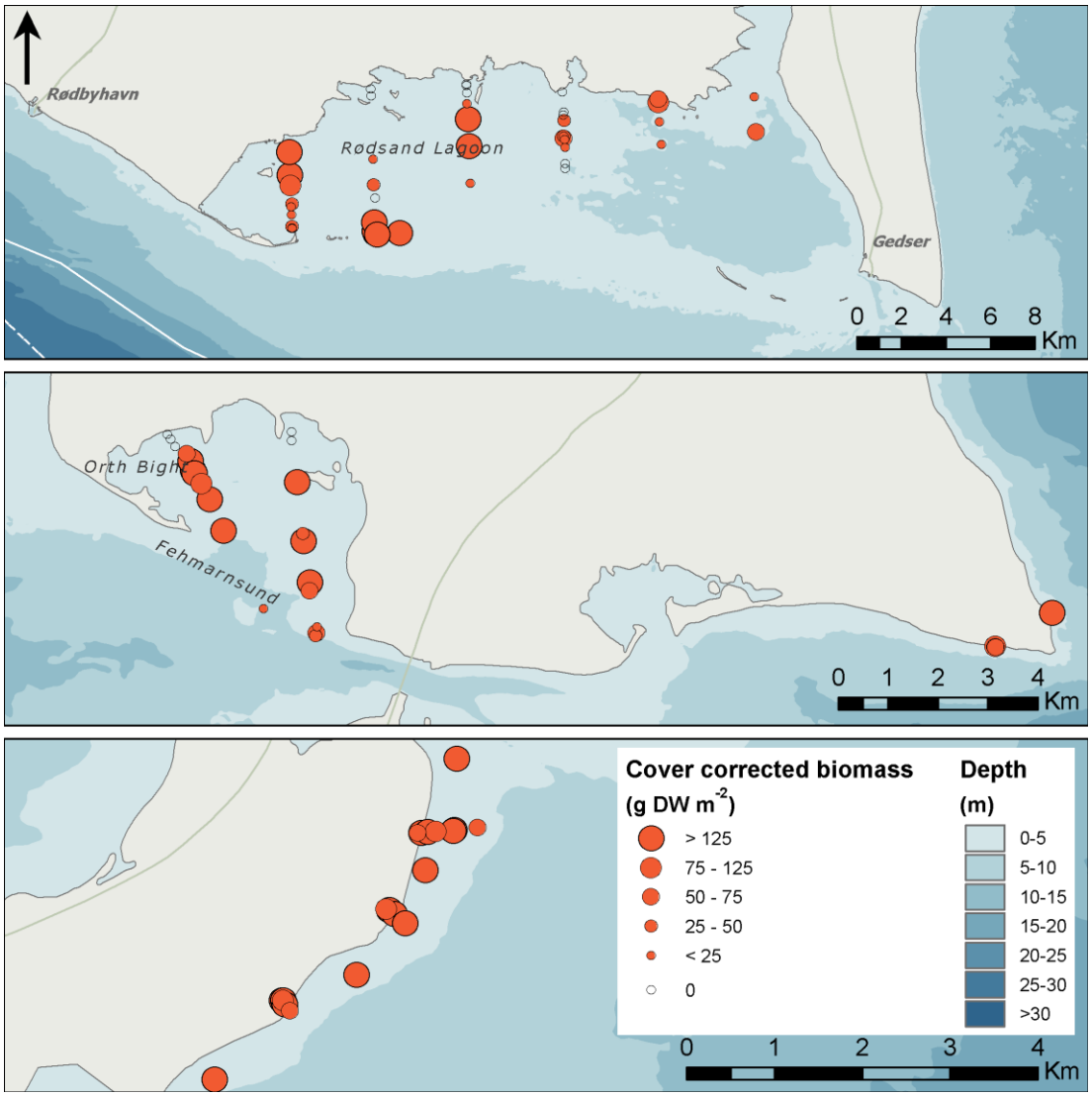



*Figure 5.12 Cover-corrected biomass of eelsgrass in Rødsand Lagoon (upper panel), Orth Bight (middle panel) and Großenbrode (lower panel) observed in summer 2009.*

Cover-corrected leaf biomass of eelgrass in the 1-2, 2-4 and 4-6 m intervals increased during spring and peaked in the summer months (Figure 5.13). Mean cover-corrected biomass was similar in the 1-2 and 2-4 m interval. The biomass increased from 22.9 6 g DW $m^{-2}$ in March and 126.1 6 g DW $m^{-2}$ in June in the 1-2 m interval and increased from 25.2 6 g DW $m^{-2}$ in March to 108.36 g DW $m^{-2}$ in July in the 2-4 m interval. November was represented with one sample site with a high value in the 1-2 m interval (172.4 g DW $m^{-2}$) and lower in the 2-4 m interval (93.8 g DW $m^{-2}$).

In the 4-6 m depth interval cover-corrected biomass was in general below 8 g DW $m^{-2}$ except for one sampling occation in august where mean cover-corrected biomass exceeded 20 g DW $m^{-2}$. The lowest mean cover-corrected biomass was observed in November (1.2 g DW $m^{-2}$), and the highest in August (24.1 g DW $m^{-2}$).

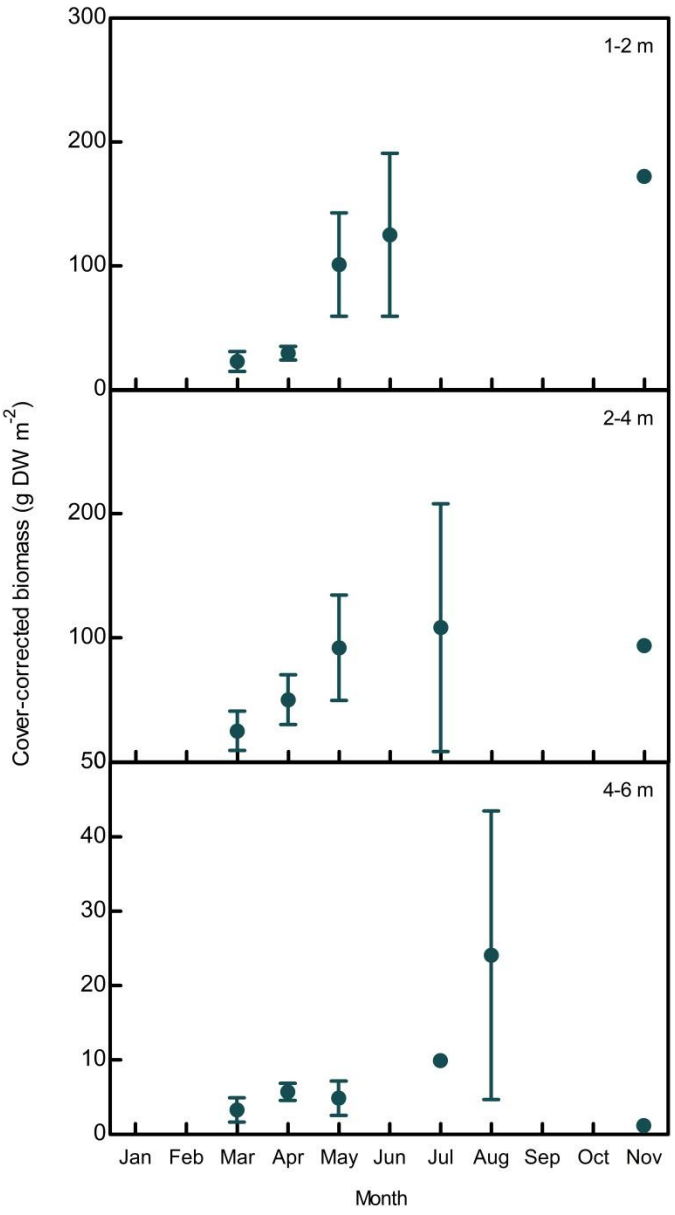



*Figure 5.13 Mean cover-corrected leaf biomass of eelgrass in Orth bight and Rødsand Lagoon in summer and autumn 2009 and spring 2010.*

## 5.4 Tasselweed and Pondweed

### 5.4.1 Distribution, Cover and Biomass of Tasselweed and Pondweed

*Tasselweed (Ruppia)*
Tasselweed occurred mainly in shallow-water areas between 0.5 and 5.3 m depth in Rødsand Lagoon (Figure 5.14). The distribution was scattered, and cover at the sites, where tasselweed occurred, varied between 1 and 100%. Mean cover (± 95% CL) was 30.1 (± 13.7)%. The coverage was highest between 0.5 and 1 m depth (Figure 5.15). Below 2 m only low cover was recorded.

In Orth Bight tasselweed occurred between 0.5 and 2.2 m depth. The maximum coverage at these sites was 65%.

Two species of tasselweed were identified during this study. *Ruppia cirrhosa* was found at 9 of the sampling stations in Rødsand Lagoon and at 3 of the sampling stations in Orth Bight. Leaf biomass ranged between 0.05 and 16.3 g DW $m^{-2}$. *Ruppia maritima* was only found at one site in Orth Bight with low biomass of < 1 g DW $m^{-2}$.

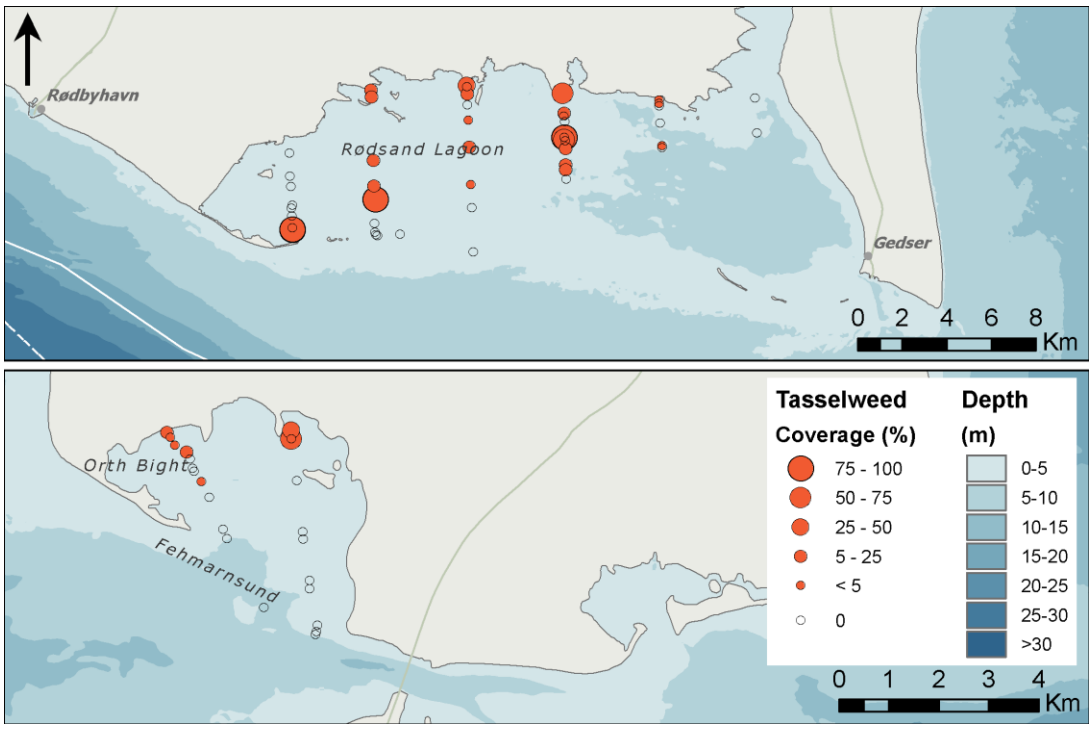



*Figure 5.14 Diver estimated cover of tasselweeds and pondweed in Rødsand Lagoon (upper panel) and Orth Bight (lower panel) in the summer of 2009.*

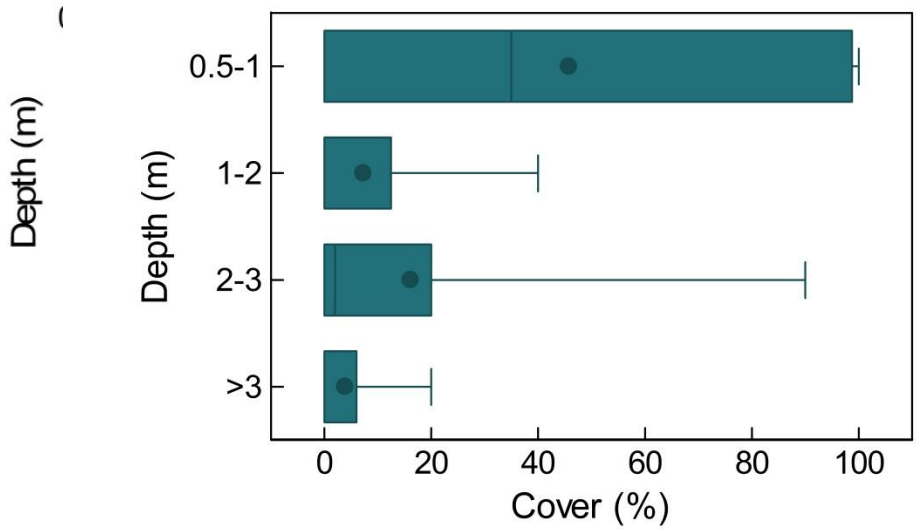



*Figure 5.15 Vertical distribution of tasselweed in Rødsand Lagoon in the summer of 2009. Circles represent mean values of cover in each depth interval, lines represent medians, boxes represent 25-75% percentile es, and whiskers represent 10-90% percentiles. The analysis is based on 24 diver observations along 6 transects in Rødsand Lagoon.*

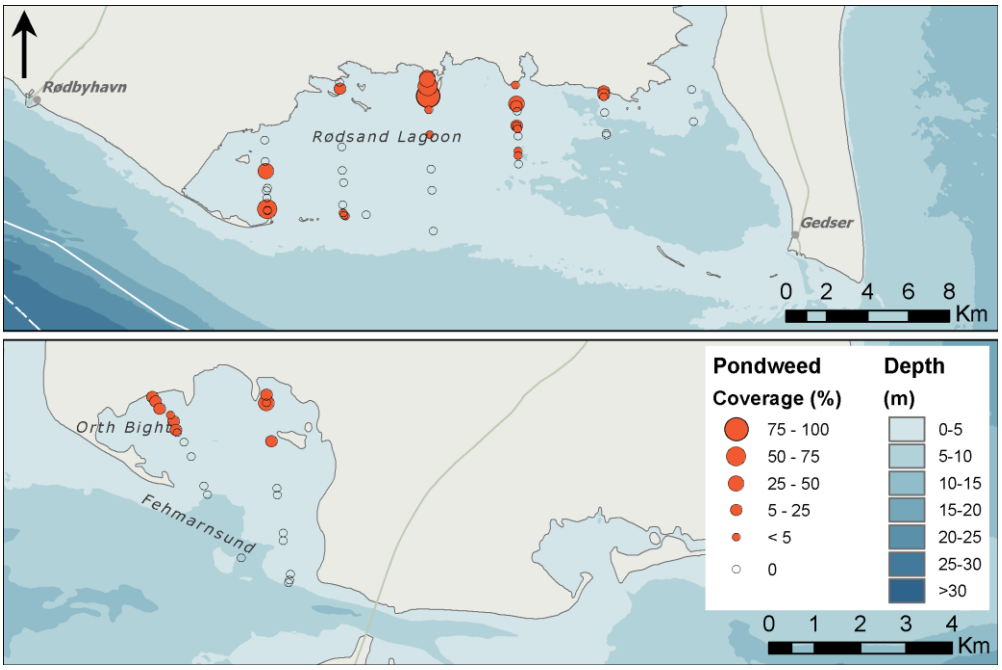



*Figure 5.16 Diver estimated cover of pondweed in Rødsand Lagoon (upper panel) and Orth Bight (lower panel) in summer 2009.*

*Pondweed (*Potamogeton*)*
Pondweed was present in the Rødsand Lagoon in the depth interval between 0.6 and 3 m (Figure 5.17). The distribution was scattered and cover was between 5 and 100% (Figure 5.16). - In Orth Bight pondweed was present in the inner shallow waters with up to 45% cover in the depth interval 0.5 to 1.8 m (Figure 5.16).

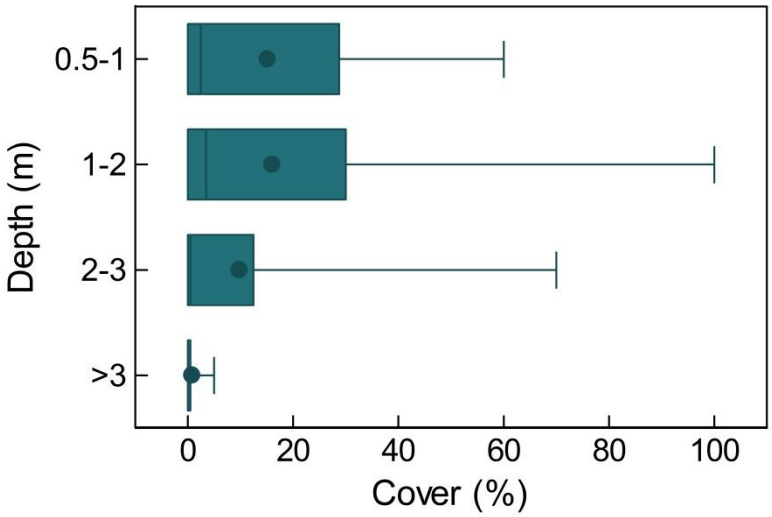



*Figure 5.17 Vertical distribution of pondweed in Rødsand Lagoon in the summer of 2009. Circles represent mean values of cover in each depth interval, lines represent medians, boxes represent 25-75% percentiles, and whiskers represent 10-90% percentiles. The analysis was based on 23 diver observations along 6 transects in Rødsand Lagoon.*

One species of pondweed was identified during this study. *Potamogeton pectinatus* was found at nine of the sampling stations in Rødsand Lagoon and at five of the sampling stations in Orth Bight. Leaf biomass ranged between 0.7 and 75.3 g DW $m^{-2}$ in Rødsand Lagoon and between 3.9 and 20.4 g DW $m^{-2}$ in Orth Bight.

## 5.5 Other Observations

*Zostera noltii* occurred at four stations in Rødsand Lagoon and two stations in Orth Bight. The biomass was between 0.05 and 54.4 g DW $m^{-2}$.

*Zannichellia palustris* was present at one station in Orth Bight and 11 stations in Rødsand Lagoon with biomass values between 0.3 and 85.5 g DW $m^{-2}$.

Species of the stonewort family Characeae are typically found in soft bottom habitats. *Chara* sp. occurred at eight stations in Rødsand Lagoon and three stations in Orth Bight with biomasses between 0.1 and 101.4 g DW $m^{-2}$. The species were identified to *Chara baltica* and *Chara aspera*. *Chara canescens* was found with low biomass (< 1 g DW $m^{-2}$) at one sampling site in Rødsand.

*Tolypella nidifica* occurred at seven stations in Rødsand Lagoon and one station in Orth Bight with biomasses between 0.05 and 17.2 g DW $m^{-2}$. *Lamprothamnium papulosum* occurred with low biomass (0.05 and 1.1 g DW $m^{-2}$) at two stations in Rødsand Lagoon.

Other macroalgae that occurred in the lagoon and bight were mainly free-floating or epiphytic. Macroalgae coverage varied between 0 and 100%.

# 6 BENTHIC VEGETATION MAPPING

## 6.1 Distribution and cover

### 6.1.1 Macroalgae

The individual physico-chemical factors explained between 5 and 35% of the variability in macroalgae cover in 2009 (Table 6.1). Hard substrate is essential for colonisation of macroalgae and accordingly hard substrate was the single factor that could explain most of the variation in algal cover (35%). Depth, slope and Secchi depth could individually explain about 11% of the variation in total macroalgae cover. Depth combines the effect of reduced light availability and exposure. Hard substrate, depth, shear stress, slope, mean current speed and Secchi depth could together explain 54.7% of the variability in macroalgae cover (deviance explained, GAM model, $p < 0.001$, statistical details in Appendix 8).

*Table 6.1 Deviation explained in single factor general additive models (GAM analysis) describing the relationships between total macroalgae cover and environmental factors.*

| Environmental factor | Unit | Deviation explained (%) |
|---|---|---|
| Hard substrate | % cover | 34.6 |
| Depth | m | 11.0 |
| Slope | Degrees | 11.1 |
| Secchi depth | M | 11.0 |
| Irradiance at bottom | % of surface irradiance | 7.3 |
| Bed shear stress current and wave | N $m^{-2}$ | 5.9 |
| Current speed max | cm $s^{-1}$ | 3.7 |
| Current speed mean | cm $s^{-1}$ | 4.8 |
| Salinity | psu | 9.0 |
| Temperature, mean summer | °C | 7.3 |
| Total N | µmol $L^{-1}$ | 7.6 |
| Total P | µmol $L^{-}$ | 10.3 |

The environmental factors included in the final GAM model were used to predict the total cover of macroalgae in the whole Fehmarnbelt area. This habitat mapping predicts the potential area of macroalgae occurrence.

The mapping was refined by incorporating mapped habitats from interpretations of aerial photography and integrating expert knowledge of distribution of species and habitats (Ferrier et al. 2002). The predictive map of total macroalgae cover was combined with results from the aerial photography mapping to improve the ground-truthing of the results in shallow areas. In the deep areas not covered by aerial photos the statistical mapping is our best prediction of distribution and cover.

There was a good agreement between observed and predicted data. The agreement was assessed using Pearson's correlation, Spearman rank correlation and linear regressions. 2/3 of the data were used for modelling and 1/3 of the data for validation. Pearson's correlation was 0.69 and Spearman rank correlation was 0.54. A 'perfect model' would result in a a linear regression with a slope near 1 and an intercept near 0.0. The relationship between observed and predicted data from Feh-

marnbelt was highly significant and had a slope of 0.89 and an intercept of 0.0055 ($R^2$ = 0.45).

Comparing the 2010 data with the predicted model based on 2009 data showed a relatively good relationship (Pearson's correlation = 0.37, Spearman rank correlation = 0.42), suggesting that the pattern of macroalgal cover is consistent between years although the actual values show some year to year variability.

The model was best at predicting cover at locations where macroalgae cover large areas in dense populations. This is in areas like along the Lolland coast and at Staberhuk. The areas where the model has most difficulties in the predicting macroalgae cover was in areas with mixed substrate where eelgrass and macroalgae occur together and where the distribution is very scattered. The mixed areas occur for example south-west and south-east of Fehmarn. The scattered distribution is found in the deeper waters west of Fehmarn and south of Rødsand, where the predictions can rather be used to describe the pattern of a patchy distribution but not the detailed occurence.

Macroalgae are widely distributed along the coastline of Lolland and Langeland with partly high coverage values (Figure 6.1, larger map available in Appendix 6). Within the soft bottom dominated area of Rødsand Lagoon and areas off the lagoon macroalgae are distributed in a scattered way with low coverage. Nearly all of the macroalgae locations occur lower than 10 m depth.

The resulting mappings are in agreement with the observed pattern in macroalgal distribution. Around Fehmarn macroalgae are widely distributed along the east coast of Fehmarn with high coverage values, especially at the south-east cape of Fehmarn (Staberhuk). Along the west coast of Fehmarn macroalgae show a more scattered distribution with higher coverage values within the near coast stripe. At the soft bottom dominated areas in the north and south of Fehmarn and in Orth Bight macroalgae are absent or only occur in very small, scattered areas. Around Fehmarn most of the macroalgae are distributed above the 10 m depth contour, but especially at the east coast of Fehmarn macroalgae can also be found deeper than 10 m.

Along the coastline of Wagrien macroalgae occur in higher coverage values north of Großenbrode (east coast of Wagrien) and to a lesser extent also along the west coast of Wagrien.

Within Kiel Bight (below 10 m) and Fehmarnbelt (below 10 m) macroalgae are scarcely distributed due to a lower extent of suitable hard substrates. Coverage values are below 25%.

Within the Mecklenburg Bight the area Sagasbank offers a higher coverage with suitable substrate. Therefore macroalgae are distributed all over Sagasbank but coverage values are low outside the centre area with depth around the 10 m depth contour.

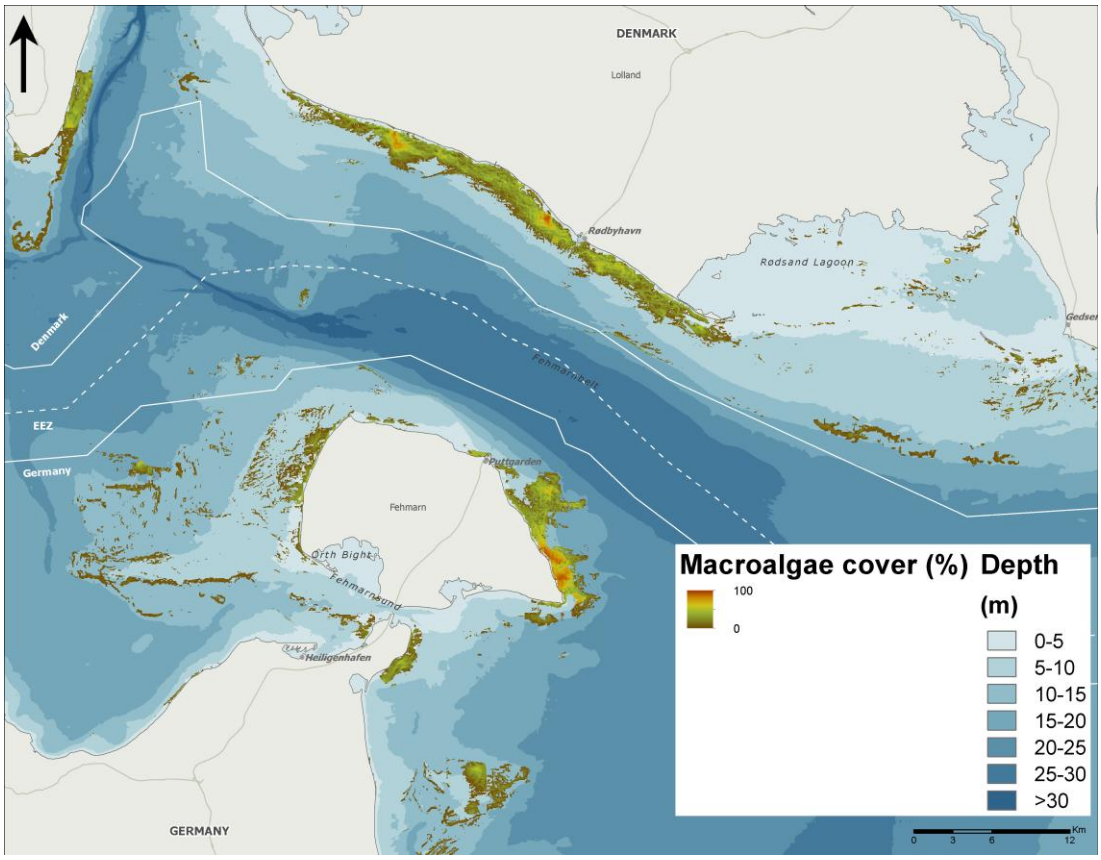



*Figure 6.1 Predicted distribution and cover of macroalgae within the investigation area in the summer of 2009 (a larger version of the map is available in App. 6). Prediction prepared using the GAM model.*

### *6.1.2 Eelgrass*

The individual physico-chemical factors explained between 2 and 54% of the variability in eelgrass cover (Table 6.2). Depth, shear stress, slope and mean current speed was included in the model. To account for some of the spatial variation that could not be explained by the environmental variables, longitude and latitude were included as variables, and both were significant.

Together the variables could explain 63.3% of the variability in eelgrass cover (deviance explained, GAM model, $p < 0.001$, statistical details in Appendix 8). There was no spatial auto-correlation in the model residuals.

*Table 6.2 Deviation explained in single factor general additive models (GAM analysis) describing the relationships between total eelgrass cover and environmental factors.*

| Environmental factor | Deviation explained (%) |
|---|---|
| Depth (m) | 54.1 |
| Slope | 2.3 |
| Secchi depth | 53.3 |
| Bed shear stress current and wave | 17.2 |
| Current speed max | 34.8 |
| Current speed mean | 30.5 |
| Salinity | 31.7 |
| Temperature, mean summer | 36.9 |
| Total N | 16.3 |
| Total P | 24.3 |

The environmental factors included in the final GAM model were used to predict the total cover of eelgrass in the whole Fehmarnbelt area. This habitat mapping predicts the potential area of eelgrass occurrence. The predictive map of total eelgrass cover was combined with results from the aerial photo mapping to improve the ground-truthing of the results in shallow areas. In areas not covered by aerial photo mapping expert knowledge about eelgrass occurrence was used as ground-thruthing.

There was high agreement between observed and predicted cover values using 1/3 of the data for validation and 2/3 of the data for modelling (Pearson's correlation = 0.66, Spearman rank correlation = 0.66). The linear regression was highly significant with a slope of 0.99 and an intercept of 0.003 ($R^2$ = 0.44).

The mapping was refined by incorporating mapped habitats from interpretations of aerial photography and integrating expert knowledge of distribution of species and habitats (as also suggested in Ferrier et al. 2002). The predictive map of total eelgrass cover was combined with results from the aerial photo mapping to improve the ground-truthing of the results in shallow areas. In areas not covered by aerial photo mapping expert knowledge about eelgrass occurrence was used as ground-thruthing.

Figure 6.2 shows the distribution and coverage of eelgrass in the whole investigation area.

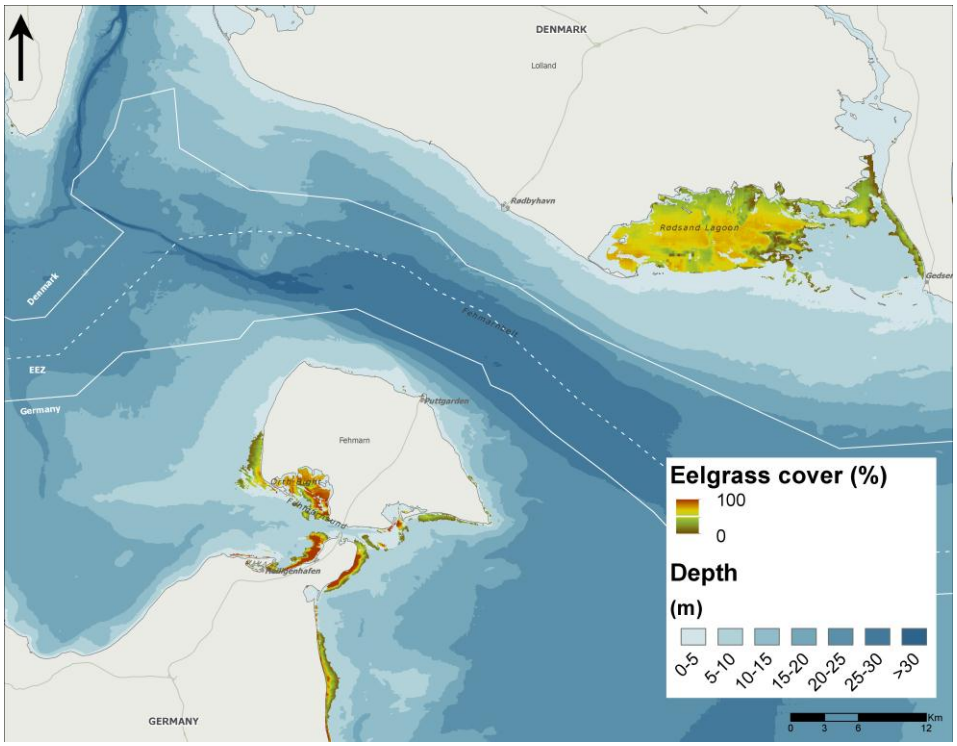



*Figure 6.2 Cover of eelgrass predicted by the GAM model in the Fehmarnbelt area in the summer of 2009.*

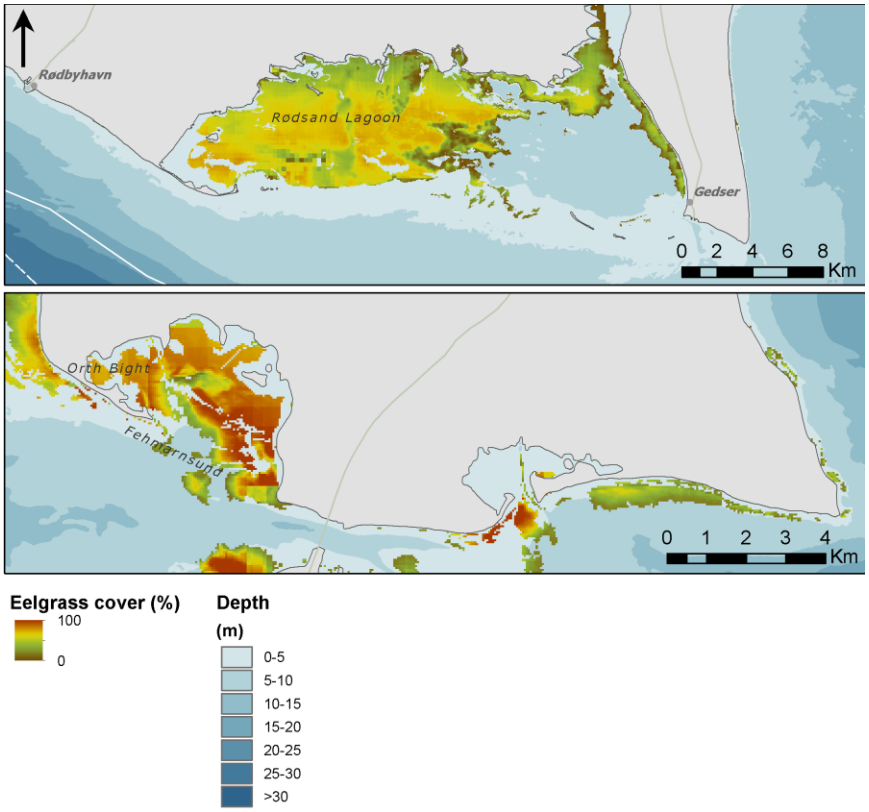



*Figure 6.3 Cover of eelgrass predicted by the GAM model in the Rødsand Lagoon and Orth Bight in the summer of 2009.*

Figure 6.3 shows the predicted distribution and coverage of eelgrass within the investigation area. Highest eelgrass coverages occur as expected in the sheltered and soft bottom dominated lagoons.

Within the Rødsand Lagoon eelgrass occurs in the western part of the lagoon more steadily, whereas within the eastern part it is completely absent within a larger area. Here water depth is too high (> 5 m) for eelgrass growth.

Eelgrass is distributed within the whole area of Orth Bight with very high coverages, especially in the eastern part of the bight. But in this case the prediction does not reflect the real distribution of eelgrass, because the intensive monitoring investigations during the last years proved higher densities in the western area.

Eelgrass occurs also outside of these soft bottom dominated areas and some places with high coverage. Along the south-west coast and south coast of Fehmarn eelgrass is widely distributed due to the mixed sediment conditions there (sandy bottoms with scattered stones). Even within small, sandy spots at Staberhuk eelgrass occurs in coverage degrees up to 25–50%.

## *6.2 Distribution of key-communities*

Areas covered by the key communities were estimated combining the predicted map of benthic vegetation distribution (GAM modeling for macroalgae and angiosperms) with the identification of key communities determined at all sampling sites in 2009. As the 2010 data confirmed the distribution of those communities, the community map was not updated. Key communities have only been assigned to areas with benthic vegetation cover > 10%. In some areas macroalgae and angiosperms were predicted in the same area due to occurrence of mixed sediment. In such areas an eelgrass/algae-community was assigned.

For some areas in the very shallow parts of Rødsand Lagoon and Orth Bight (< 1.0 m) no coverage predictions could be made by GAM modeling. In this specific case the aerial survey data (which also comprise spatial information about vegetation classes) have been combined with the key communities determined at shallow sites to enable a spatial illustration of vegetation also in such shallow areas.

For other specific areas (normally outside or at the edge of the investigation area like southeast of Falster, southwest of Sagasbank or east of Heiligenhafen) predictions for benthic vegetation distribution were available, but no information about vegetation communities as no sampling sites exist in those areas. In such cases vegetation communities were assigned based on information from national monitoring programmes.

Figure 6.4 shows the distribution and coverage of the benthic vegetation communities within the investigation area.

Pure angiosperm communities (eelgrass, tasselweed/dwarf eelgrass) were widely distributed within in the soft bottom dominated areas of western Rødsand Lagoon and Orth Bight. Due to the soft bottom and sheltered conditions in these areas both communities occurred with high coverages (> 50%).

The eelgrass-community was also located outside of the sheltered bays: along the south coast and south-west coast of Fehmarn, east and west of Wagrien and south of Großenbrode with coverage was 25–50%. In these areas the eelgrass-community was associated with different macroalgae communities, typically filamentous algae forming the eelgrass/algae-community. These areas are partly

included in different Natura 2000 areas. Low densities of this community were also located along the western part of the Lolland coast and with some very small spots along the north coast of Fehmarn. Higher exposure and mixed sediments prevent higher coverages of this community type.

Along the coast of Lolland, including the vicinity of the proposed alignment area (e. g. ± 10 km), the dominating benthic vegetation was the *Furcellaria*-community and filamentous algae-community. The total cover of these two communities rangede between 15–50%. Only in small areas the cover was > 50%. The *Furcellaria*- and the *Phycodrys/Delesseria*-community are the dominant vegetation forms along the coastline of Langeland. At the lower depth limit the *Saccharina*-community occurred within a small stripe. The algae cover was between 25 and 50%. This area is part of the Natura 2000 area Langeland.

Along the east coast of Fehmarn hard substrate is widely distributed with increasing densities as distance to the the proposed alignments increase. All five macroalgae communities could be found here. In shallow waters the filamentous algae-community was dominant and the *Fucus*-community occurred in small, single spots. The *Furcellaria*-community was found at intermediate water depths. The *Phycodrys/Delesseria*- and *Saccharina*-community was found in very high densities especially at the south-eastern part of the coastline (approximately 4 km away from the alignment). This area is part of the Natura 2000 area Staberhuk.

Along the north coast of Fehmarn, west of the proposed alignments (e. g. ± 10 km), the cover of benthic vegetation is low due to lack of hard substrate. Only in a small area directly west of Puttgarden harbour (approximately 0.5 km away from the proposed alignment area) high densities of hard substrate covered by *Fucus* occurred. Hard substrates are very rarely distributed along the west coast of Fehmarn. Only within a narrow stripe near the coastline higher densities occur. These stones were covered with a *Fucus*-community (approximately ± 10 km from the proposed alignment area). In deeper areas a high dominance of blue mussels occurred and only filamentous algae were located there. Below 8–10 m water depth the *Phycodrys/Delesseria*- and the *Saccharina*-community covered the scattered stones. The *Fucus*-community had the highest cover (with 25-50% coverage). Within the deeper part of Fehmarnbelt most areas are unsuitable for vegetation (sand and silt bottom). Only within the western part an area with scattered hard substrates is located. These stones were covered with the *Phycodrys/Delesseria*- and *Saccharina*-community down to about 20–21 m. But coverage did not exceed 25% due to the lack of suitable substrate. The area is part of the Natura 2000 area Fehmarnbelt.

At Sagasbank (10 km south of Fehmarn) the *Phycodrys/Delesseria*- and the filamentous algae-community occurred with up to 50% coverage in the central part. This area is part of the Natura 2000 area Sagasbank.

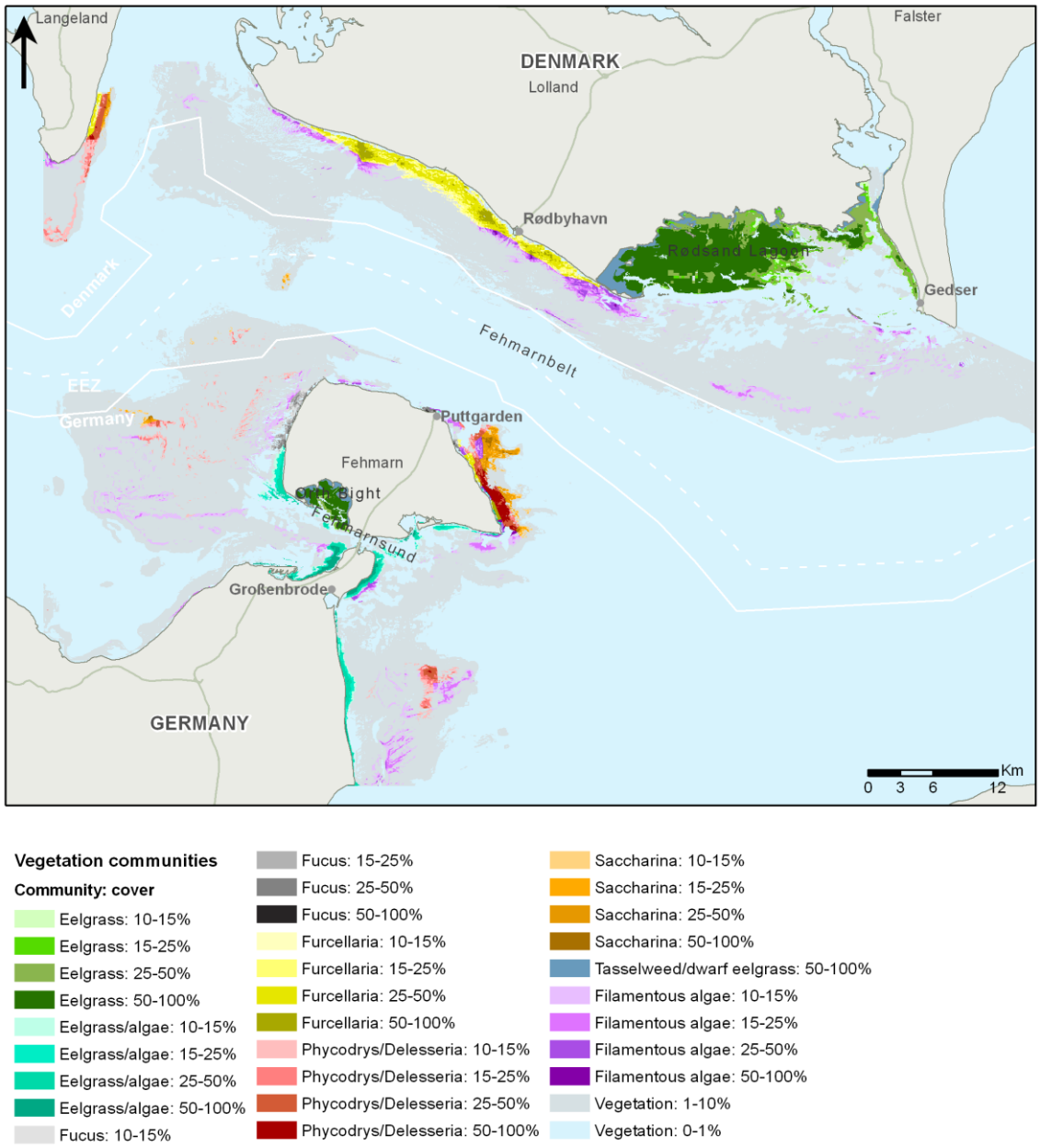



*Figure 6.4 Distribution and coverage of the different vegetation communities within the investigation area (a larger version of the map is available in App. 6). Based on predicted mapping of macroalgae and eelgrass and the distribution of key-communities in the area.*

## 6.3 Biomass of benthic vegetation

Key community specific relationships between cover and cover-corrected biomass were used to produce a map of cover-corrected biomass of benthic vegetation (Figure 6.5).

Highest biomass values are found in areas where the *Fucus*-community occurs. *Fucus* show the highest biomassof all vegetation components. Therefore high biomasses are located along the west coast of Fehmarn, in a small area directly west of Puttgarden and some small spots east of the proposed alignment.

In areas where the *Furcellaria*-community occurs in very high densities, the biomass values can also be very high. Therefore two areas along the coastline of Lolland show as high biomass values as areas with *Fucus*-community.

Lower densities of *Furcellaria* as well as high densities of the *Phycodrys/Delesseria*- and the *Saccharina*-community are responsible for intermediate biomass values. Intermediate biomasses are therefore found along the Lolland coast, the Langeland coast, the east coast of Fehmarn and Sagasbank.

Biomass values for vegetation below the 10 m depth contour are generally low within the whole investigation area. Only along the south-east coast of Fehmarn slightly higher biomass values can be reached also below 10 m due to the high densities of red algae (*Phycodrys/Delesseria*).

All areas with a dominance of filamentous algae show low biomass values.

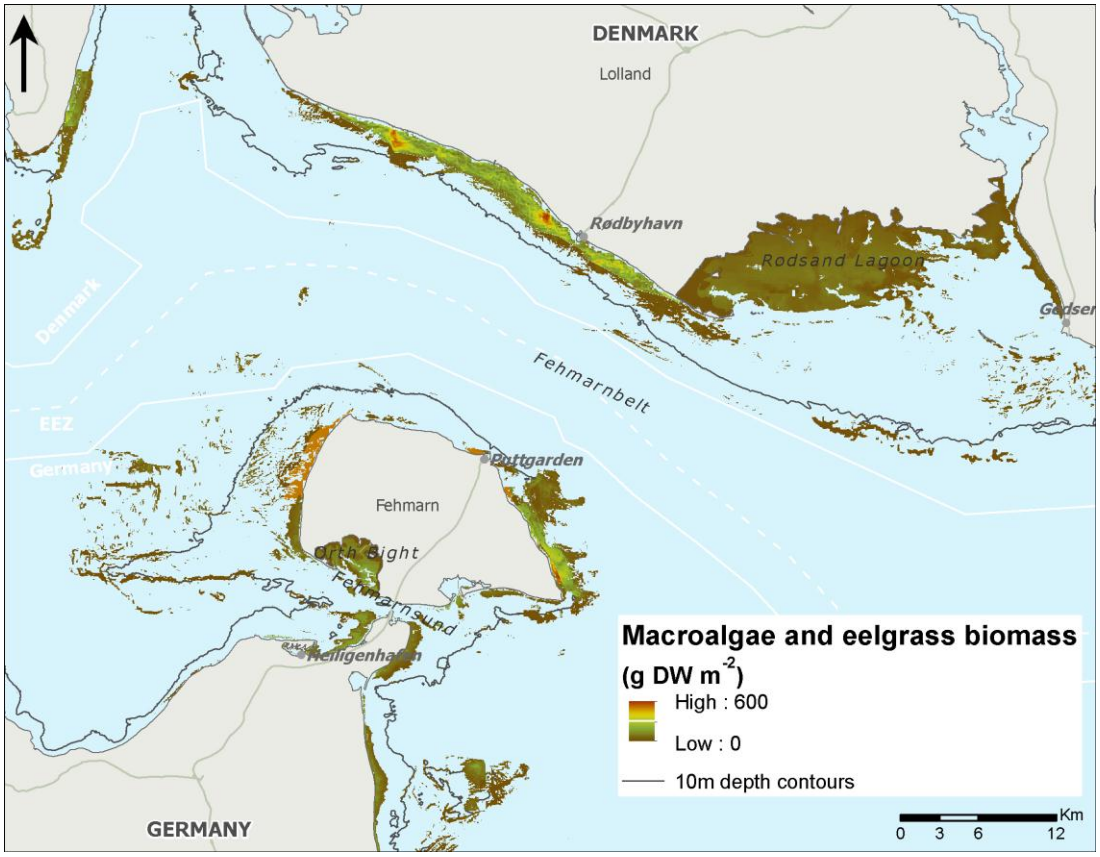



*Figure 6.5 Cover-corrected biomass (g DW $m^{-2}$) of macroalgae and eelgrass in Fehmarnbelt area in the summer of 2009 (a larger version of the map is available in App. 6). Based on the data of predicted cover (Figure 6.1 and Figure 6.2) and converted to cover-corrected biomass using the relationships from Table 4.13 (2009 data) and Figure 5.11.*

# 7 TEMPORAL VARIABILITY AND TRENDS

Historical data and long time series are nessesary to be able to determine long-term changes in natural biological communities. As long dataseries on benthic vegetation in the Fehmarnbelt area are very rare to not existing the available data can only provide trends of year to year variability. In this chapter the trends in year-to-year variability and possible long-term changes are discussed using results from this baseline study and from earlier studies of the area.

The total number of macroalgae and flowering plant species found in this study was 67. The number of species is twice as high as the 33 species reported from the feasibility study (COWI-Lahmeyer 1998), probably due to a higher sampling intensity in this study.

## 7.1 Year to year variability

In general, although sampling sites were not exactly the same in 2009 and 2010, the patterns of species diversity, key community coverage and biomass was quite similar in 2009 and 2010.

The overall ranking of abundance and the rank of the key-species based on number of observation sites were very similar in the two years, suggesting that the distribution of species are stable. The levels of species richness was also similar in the two years; although *Phycodrys/ Delesseria* had the highest mean number of speices in 2009 while *Furcellaria* was the most species rich key-community in 2010. In both years species richness and diversity peaked at intermediate depths.

Mean total cover of macroalgae for all sites was 30% higher and mean substrate specific cover for all sites were 10% higher in 2010 than in 2009, but the pattern of differences in cover between key-communities was consistent. The depth distribution of cover, community biomass and depth distribution of species and biomass all showed similar patterns in 2009 and 2010. Biomass of key species also followed the same pattern but biomass for *Fucus* and *Saccharina* were much higher in 2010 than in 2009. This could be due to higher growth rates of *Saccharina* in years with low winter temperatures. In this study it was for example observed that the thallus of *Saccharina* was much longer in 2010 than in 2009. Another possible explanation is that thalli of the large brown algae may be very different in size resulting in large variabilty in biomass samples of an equal area. A relatively large number of samples is therefore nessesary to account for the large spatial variability and to be able to make reliable estimates of temporal variability.

Two years of sampling are, however, not enough to determine year to year variability. Unfortunately no long time series of data exist from the area that could allow a thorough analysis of the year to year variability. However, at 14 sites biomass was measured 3 or 4 years. These data were used to get a hint of the year to year variability. The data originate from EIA work in connection with establishment of the wind farm in Rødsand and from German national monitoring. As not all sampling designs included area cover, the biomass in dense vegetation at the sites were used. The data include both macroalgae and eelgrass data. The yearly deviations from the mean (of the same site) calculated from these data are shown in Figure 7.1. The yearly deviation was on average ± 22%. The pattern was not totally random suggesting that the differences could be a consequence of variable conditions for growth between years, although the dataset is too small to make statistics with this.

Natural variability depends on the species and the depth of the vegetation. Biomass of long-lived perennial species with a long-lived thallus like *Furcellaria* should be less variable than ephemeral species with a high growth rate. Moreover deep populations should be less variable due to less stress from physical disturbances. However, due to the small number of sample sites with a longer time series ( more than two years sampling), these aspects could not be accounted for in the analysis. Natural variability will also be driven by varitions in radiation. Year to year variations in the weather has effects on light available and will also impact the depth limit of the eelgras

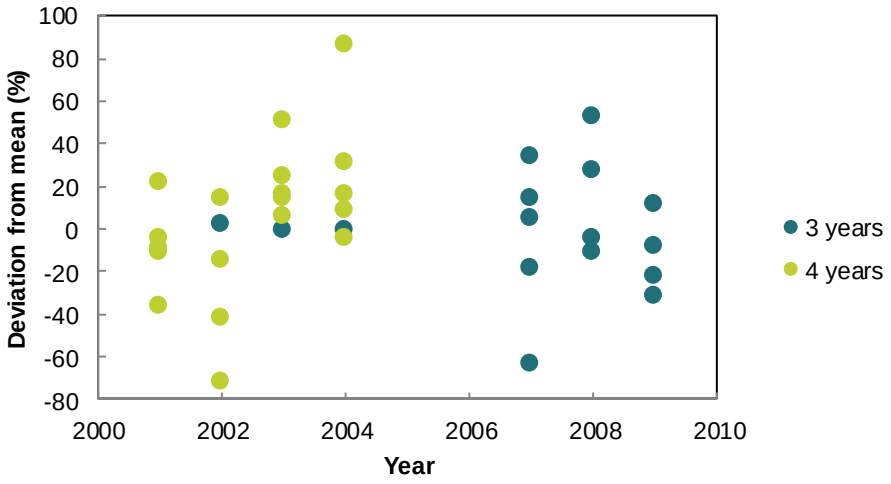



*Figure 7.1 Mean deviation from the average of 2-4 years of benthic flora biomass at sites in different years.*

Analyses of year-to-year variability of eelgrass depth limit in the area, is also hindered by lack of recent historical data. Some variability can be seen, but not concluded on, from the few recent historical data form the area. In Rødsand Lagoon the depth limit was determined to 5 m in 1995 and 3,6 m in 2007. South-east of Femern (Burg) depth limit was 6.2 m and west of Femern (Wallnau) 4.9 m in 2006. Moreover, just outside the study area, in Nakskov Fjord, the depth limit varied between 3,1 and 5,6 in the years 1989 to 1997 (Figure 7.2), supporting the suggestion that relatively large natural year-to-year variations should be expected.

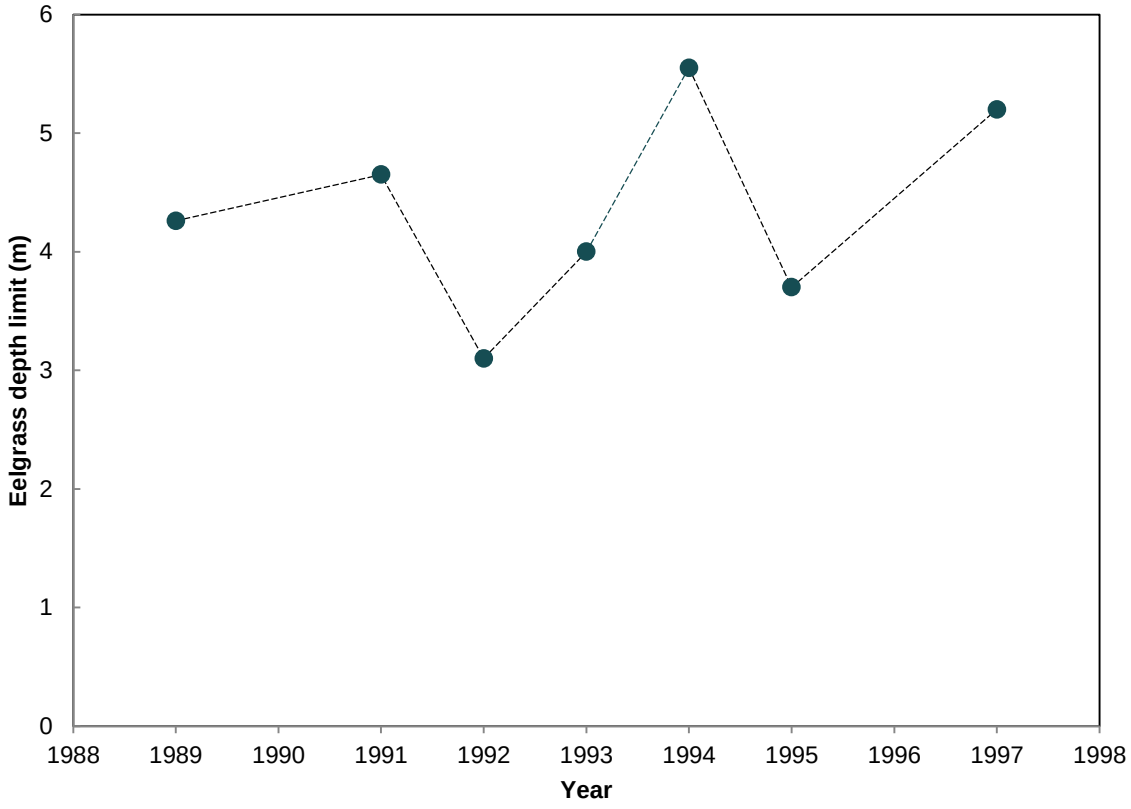



*Figure 7.2 Eelgrass depth limits in Nakskov Fjord 1989 to 1997.*

## 7.2 Historical perspective

### 7.2.1 Macroalgae

Five macroalgae communities were identified in the present field study: *Fucus*, *Furcellaria*, *Phycodrys/Delesseria*, *Saccharina* and a filamentous species community. The identified communities have been important parts of the coastal ecosystem in the Western Baltic for decades (Hoffmann 1952, Schwenke 1964).

*Fucus*
*Fucus* communities were found between 1–5 m depths, but single plants of *Fucus* occurred down to about 6–7 m. In other areas of the Kattegat-Baltic Sea (e. g. Swedish West coast), where hard substrate is more abundant, this community forms dense belts down to 12 m (Kautsky 2007).

*Fucus* species form a big canopy-like thallus, which plays an important structuring role in marine coastal habitats. *Fucus* habitats offer protection and serve as food and nursery grounds for invertebrates and small fish species (Crothers 1985) as well as substrate for other algae species. *Fucus serratus* supports a wide variety of epiphytes with over 90 species having been recorded (Boaden et al. 1975), which can sometimes cover over 75% of the algal host's surface area (Williams & Seed 1992). Even if the coverage degree is low due to lack of hard substrate, biomass can nevertheless be extremely high compared to all other plant communities.

Until the 1960s *Fucus vesiculosus* was distributed down to 10 m depth, *Fucus serratus* even to 13 m depth (Hoffmann 1952, Schwenke 1964). Today *Fucus* is rarely growing deeper than 4–5 m (Fürhaupter et al. 2007). The mapping of Hoffmann in the 1950s showed large areas with *Fucus* along the north-west coast,

along the whole east coast and the south-eastern coast of Fehmarn with partly high densities (Figure 7.3). The mapping of Schwenke in the 1960s confirmed these results and showed additional *Fucus* areas northwest of Puttgarden. This mapping unfortunately gave no information about densities. *Fucus* can still be found in the same areas today, but the overall occupied area has been strongly reduced as well as the coverage. Especially along the east and south coast of Fehmarn *Fucus* areas have been reduced. The reduction in these areas may be due to stone fishery as in these areas the most intensive stone fishery activity took place. Isolated *Fucus* stands seem to have a very low recovery potential due to a restricted ability of dispersal (Eriksson & Johansson 2005a).

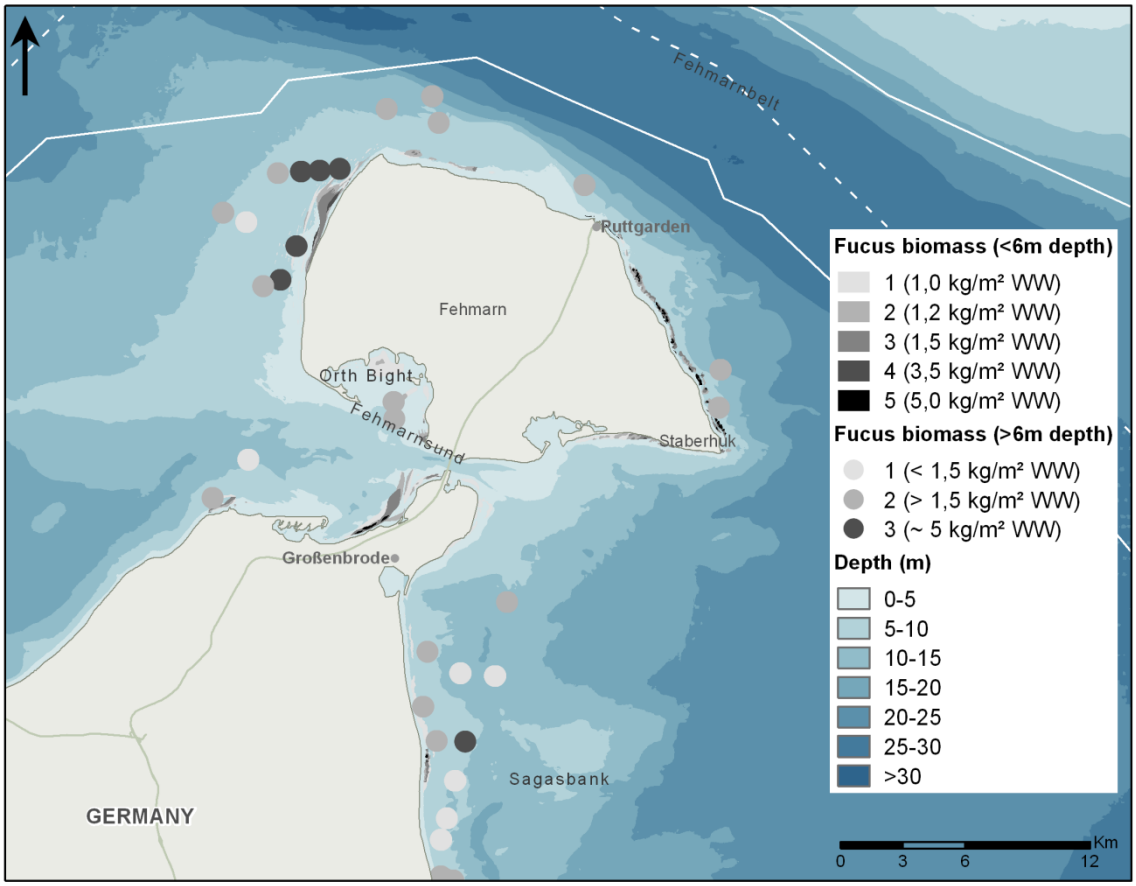



*Figure 7.3 Distribution and cover of Fucus around Fehmarn in the 1950s (based on Hoffmann 1952).*

Physiological investigations showed that the available light should enable a positive photosynthesis also in greater depths than *Fucus* is currently distributed (King & Schramm 1976, Johansson & Snoeijs 2002, Pehlke et al. 2008). Hard substrate is also available. Nevertheless, the remains of the former dense population have not been able to colonize available hard substrate areas again. Possible reasons could be abiotic factors like sedimentation or wave impact as well as biotic factors like predation by the isopod *Idotea balthica* as well as competition for settling space with other algae (e. g. *Furcellaria lumbricalis* or *Coccotylus truncatus*) and mussels (Kangas et al. 1982, Haahtela 1984, Torn et al. 2006, Pehlke et al. 2008).

*Furcellaria*

*Furcellaria*-communities were growing in depths between 2–8 m. Single plants of this species occurred down to about 10 m. At its upper depth limit *Furcellaria* is competing with *Fucus* for settling space. In mixed stands *Furcellaria* often grows beneath the tall growing *Fucus* canopies. A mixing between the *Fucus*- and *Furcellaria*-community around the 3–5 m depth level was observed within the investigation area. Although *Furcellaria* thalli are small and not as important as habitat forming species as *Fucus*, it has, nevertheless, a structuring role for the habitat. At sites with high densities of biomass values can nearly reach the values of the *Fucus*-community.

Historically *Furcellaria lumbricalis* was distributed between 5 and 25 m depth but dominating in the depth interval 8–12 m (Schwenke 1964). Compared to the current investigations the growth zone of *Furcellaria* has therefore conspicuously changed at the upper and lower limit.

Information about the historical distribution of *Furcellaria* is scarce but like the *Fucus*-community, this community formed dense beds down to about 10 m in the Baltic Sea area in former times (Hoffmann 1952, Schwenke 1964). The density of these "*Furcellaria* beds" was so high in the past that *Furcellaria* was used for industrial carrageen production (Hoffmann 1952). According to Schwenke (1964) this community was distributed along the northwest coast and the whole east coast of Fehmarn (Figure 7.4). Compared to the current findings the distribution of *Furcellaria* has been reduced as considerably as the *Fucus*-community. Today the *Furcellaria*-community only exists at some locally restricted spots along the east coast of Fehmarn. In the north-western area of Fehmarn this community type has completely disappeared. But along the southern coast of Lolland large areas with a dominance of *Furcellaria lumbricalis* still exist.

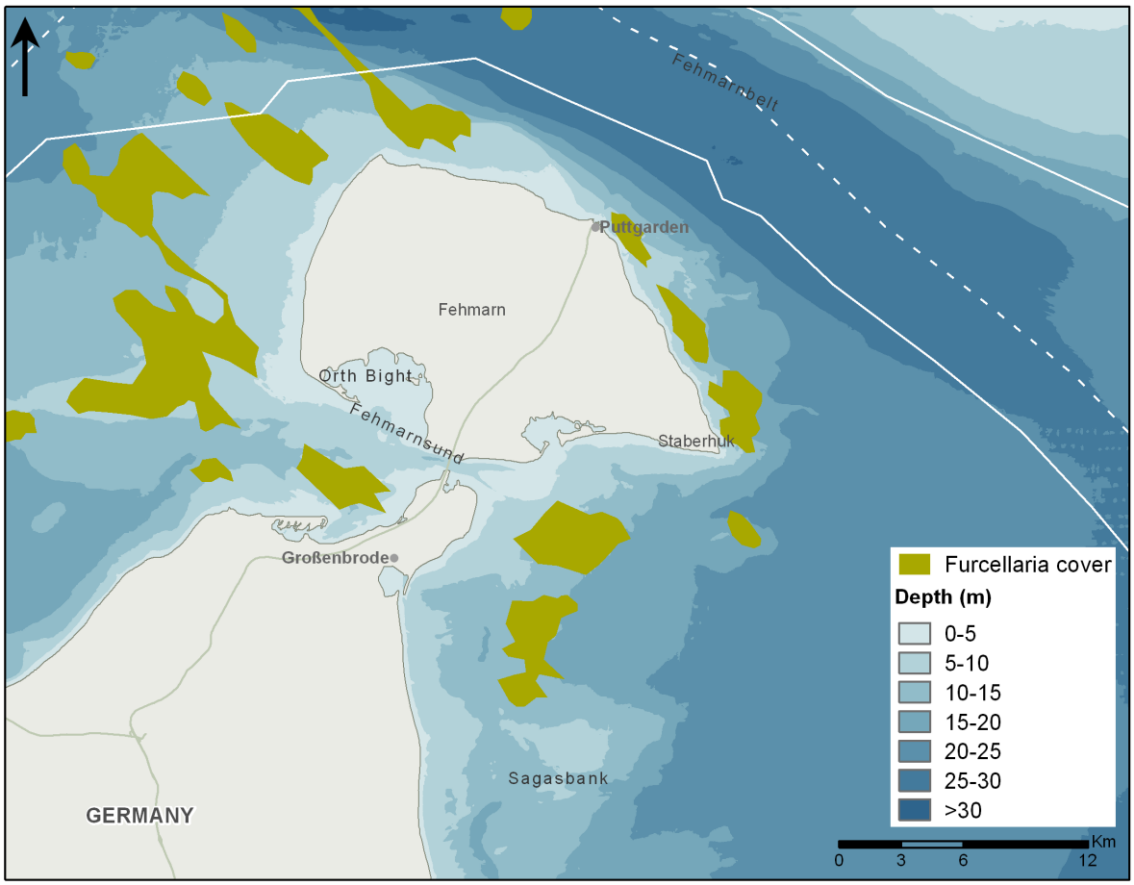



*Figure 7.4 Distribution of Furcellaria around Fehmarn in the 1960s (based on Schwenke 1964).*

Although no scientific studies of the possible recovery potential of *Furcellaria lumbricalis* exist, its slow growth rate (3.3% fresh weight per day, Bird et al. 1979) and the long time needed to reach maturity (Austin 1960) suggest a slow recovery rate. Hiscock et al. (1999) suggest partial recovery within 5 years and full recovery taking up to 10 years.

*Phycodrys*/*Delesseria*

The *Phycodrys*/*Delesseria*-community was found in depths between 8 and 19 m, but single plants of *Phycodrys rubens* or *Delesseria sanguinea* occurred down to about 21 m, with up to 100 % total cover where suitable hard substrate was present. But even with high densities biomass was low compared to the other key communities. Both *Delesseria sanguinea* and *Phycodrys rubens* are small growing algae with thin phylloids (= leaves) and various branching types. Many different perennial and annual algae accompany this community and form a dense network of different red algae in which nearly every species can grow upon each other. The sheet-like growth form has a high surface area and the *Phycodrys/Delesseria*-community offers protection for various invertebrates and small fishes and serves as food and nursery ground. This has a positive effect on the overall biodiversity of the deeper benthic areas (Lüthje 1978).

Historically the perennial red algae species *Phycodrys rubens* and *Delesseria sanguinea* are known to grow down to about 20–30 m depending on the availability of suitable hard substrate. Together with *Saccharina latissima* and *Furcellaria lumbricalis* (only historically) these two species established the lower distribution limit of vegetation (Schwenke 1964). Unfortunately Hoffmann (1952) and Schwenke (1964) only had the category "red algae" or "total vegetation cover" in their mapping surveys to compare with. But at least for all deeper areas these

maps can give information about the historical growth area of *Phycodrys/Delesseria*. Both surveys showed high densities in the north-west area of Fehmarn, along the whole east coast of Fehmarn and at Sagasbank (Figure 7.5); this is in agreement with the findings of the baseline survey. It seems that the lower depth limit of this community has not been changed significantly compared to the historical limits. But it has to be kept in mind that the historical depth limit was set by a lack of suitable substrate and not by light availability (Reinke 1889, Schwenke 1964).

The upper distribution limit for the *Phycodrys/Delesseria*-community has shifted upwards from 8–10 m to about 5–6 m depth. At this depth level they are competing with *Furcellaria lumbricalis* and to a lesser extent with *Fucus* spp. for settling space. But overall the shift of the upper limit with no detectable reduction of the lower depth limit indicates that, in contrast to the before mentioned communities, no drastic reduction of the spatial extent has occurred. But as more or less precise historical density or biomass values are lacking, no conclusion about a reduction of the overall abundance can be made.

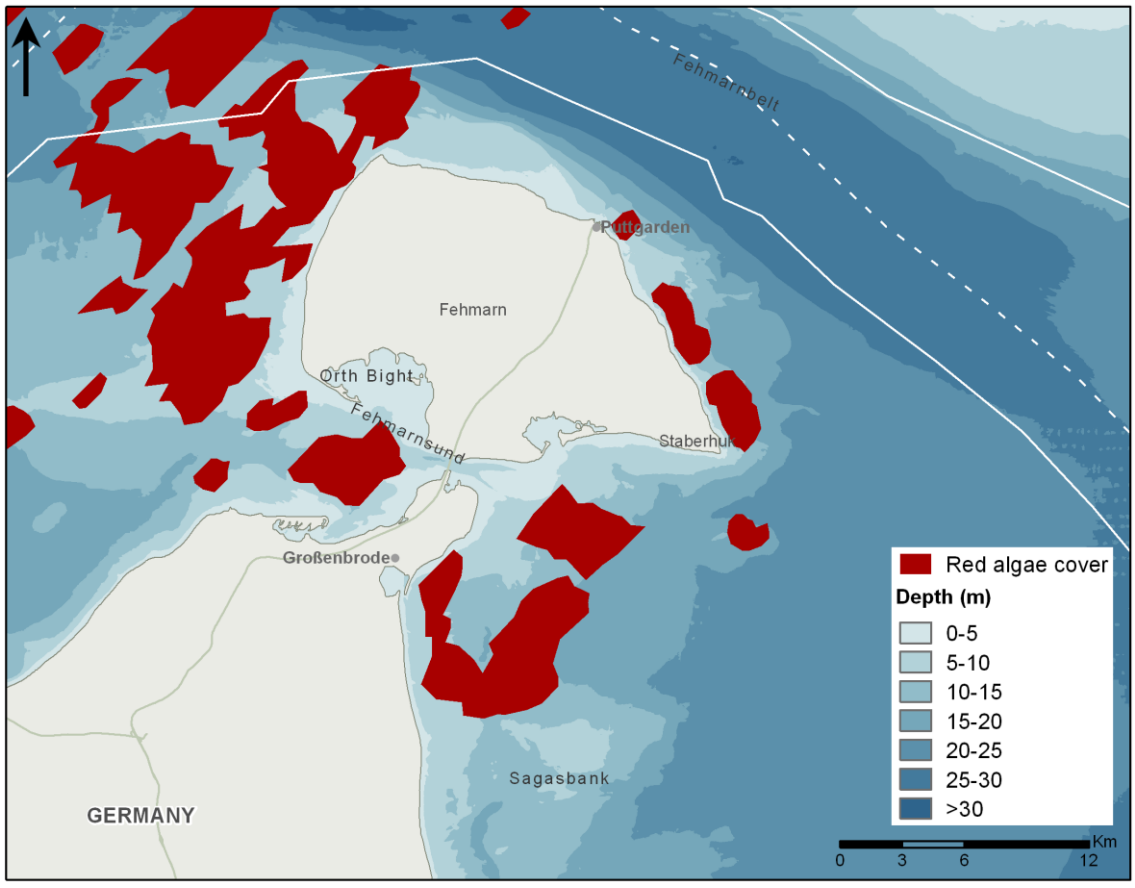



*Figure 7.5 Distribution of "red algae" around Fehmarn in the 1960s (based on Schwenke 1964).*

*Saccharina*

The *Saccharina*-community was present in depths between 12–19 m. Single plants of *Saccharina latissima* occurred down to about 22–25 m and 32 m once. Coverage degrees were very low throughout the investigation area (< 10%) and only very few locations showed coverages about 25%. But even if the coverage degree is low, biomass can be high compared to the *Phycodrys/Delesseria*-community, because of the high biomass of single *Saccharina* thalli. On the more or less slippery surface of *Saccharina* epiphytes rarely occur. If other algae are socialised with *Saccharina latissima* they grow around the stem or the holdfast. Therefore the *Saccharina*-community plays only a minor role as habitat structuring species.

Compared to the historical depth limit of vegetation around 22–23 m (Schwenke 1964) or 30 m (Reinke 1889), a shift in the lower distribution limit is, like for the *Phycodrys/Delesseria*-community, less evident. In this first survey year the deepest occurrence of *Saccharina latissima* was around 30 m (video recording as well as data from dredge samples of the benthic fauna group). From other investigations within the Western Baltic findings down to 25 to 30 m are known (Meyer 2004). As *Saccharina latissima* is less dependent on hard substrates with greater grain sizes for settling, it has a large scale-distribution and is not restricted to single spots. This large-scale distribution combined with very low densities makes it quite difficult to determine the exact distribution range and the lower depth limit of this community.

Whereas the lower depth distribution limit shows no clear variation compared to the past, the upper distribution limit for the *Saccharina*-community has shifted. In historical data *Saccharina latissima* was rarely found shallower than 15 m (Schwenke 1964). Currently specimens of *Saccharina latissima* can be found up to about 8 m. But these are normally young, small specimens. In contrast to other algae communities the upper distribution limit is set to a lower degree by competition for space with other algae or invertebrates. Abiotic factors like salinity or temperature are more important for this upper limit.

### *7.2.2 Flowering plant communities*

Three flowering plant communities were identified in the study: Eelgrass, tasselweed/dwarf eelgrass- and a mixed eelgrass/algae-community. The identified communities have been important parts of the coastal ecosystem in the Western Baltic for decades (Blümel et al. 2002).

Historically eelgrass beds were distributed down to about 10 m depth also in the Fehmarnbelt area (Schories et al., 2009 and citations therein). In this baseline study the depth limit of eelgrass was estimated to 4.6 m in Rødsand Lagoon and 4.5-4.8 m in Orth Bight and in general eelgrass rarely grows deeper than 5 m (Fürhaupter et al. 2009). The reduced light penetration in the water and shading by epiphytic algae caused by nutrient enrichment are believed to be the primary causes of reduced depth distribution of eelgrass compared with historical observations (e. g. Krause-Jensen & Rasmussen 2009).

Increased nutrient loadings also cause increased sedimentation of organic materials on the seabed, making the seabed less suitable for eelgrass growth (Wicks et al. 2009), and at the same time it increases the risk of anoxia and sulphide release, which are also damaging for eelgrass (Holmer & Bondgaard 2001, Borum et al. 2005).

Within the Western Baltic charophytes are often found together with tasselweed or eelgrass. In the past charophytes have been known to occur in dense populations down to 8 m depth in lagoons and bays (Holtz 1892, 1899, Hoppe & Pankow 1968). Today charophytes rarely grow deeper than 2 m (Fürhaupter et al. 2009). Only the species *Tolypella nidifica* can be found down to 5 m (Fürhaupter et al. 2009). Unfortunately, there have not been any investigations about the light requirements of *Tolypella nidifica* so far, but it is assumed that the lower depth distribution limit is due to a lower light requirement of this alga. Also in the past this species had greater depth distributions (down to 14–15 m) than other charophytes (Reinke 1889; Blindow 2000).

# 8 WATER FRAMEWORK DIRECTIVE ASSESSMENT

The European Water Framework Directive (WFD) aims at establishing a good ecological status for European surface waters. Member states developed appropriate assessment methods for the classification of their coastal waters with five ecological quality classes (high, good, moderate, poor, bad). Benthic vegetation is one of the main biological quality components of the WFD. The classification schemes for the biological component should be based mainly on species composition, abundance and the presence/absence of sensitive and tolerant species. The ecological status is expressed as Ecological Quality Ratio (EQR).

The coastline of each member state has been divided into different water bodies according to abiotic factors and geographical borders (Figure 8.1). The assessment of the ecological status has to be carried out for each water body, if vegetation is present.

Each member state has developed different assessment systems; classification schemes can differ significantly between member states.

The German assessment has been used along the German coast and the Danish assessment has been used along the Danish coast.

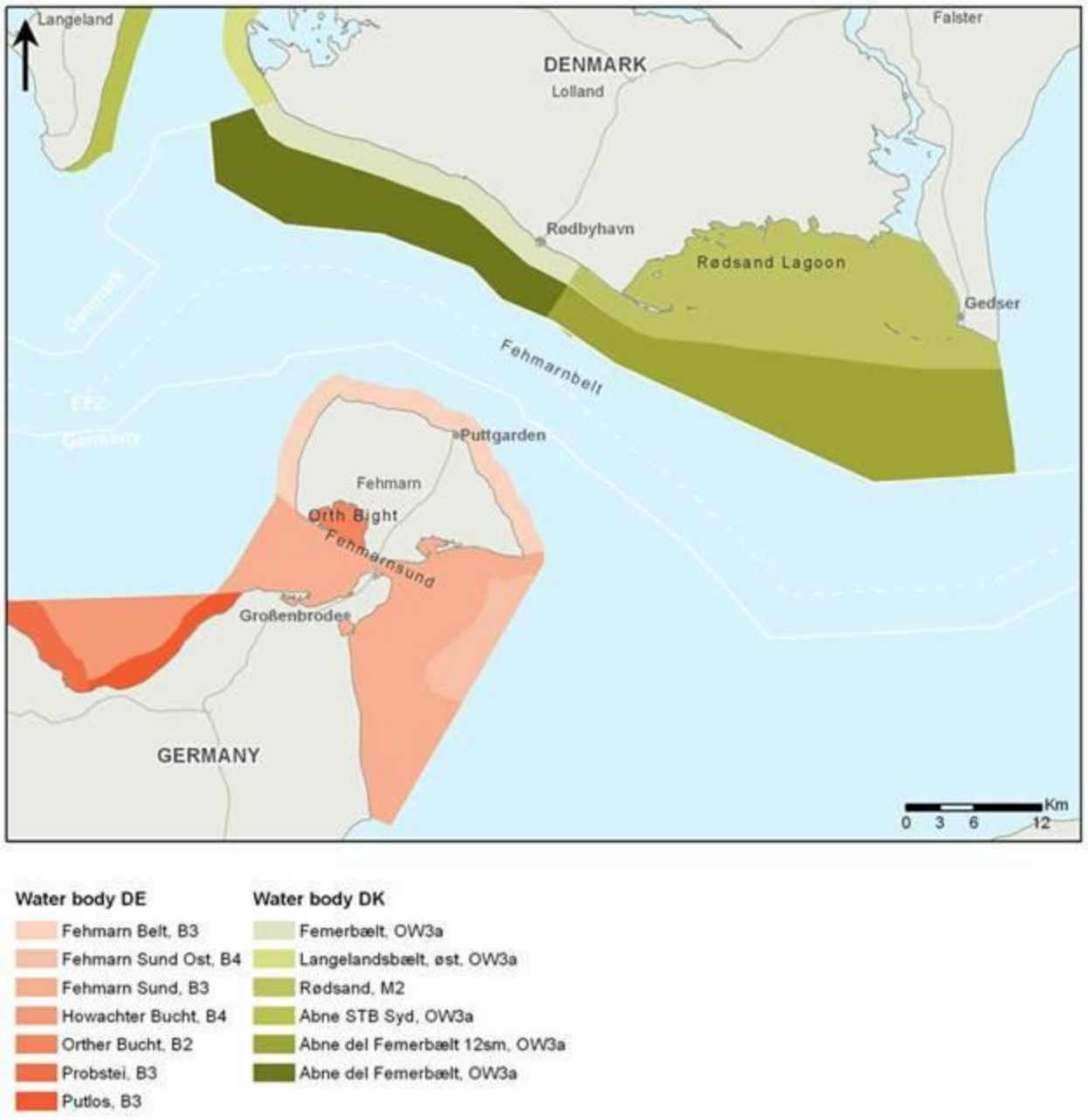



*Figure 8.1 Distribution of specific WFD water bodies within the area.*

## 8.1 Water Framework Directive Assessment DE

In Germany two different assessment systems for macrophytes are accepted for the WFD. The ELBO-System (Schubert et al. 2003, Selig et al. 2007) is valid for shallow inner bays and lagoons and focuses mainly on soft bottom vegetation (higher plants and charophytes). Species composition is measured in different depth steps until the lower vegetation limit is reached. The metrics for the determination of the ecological status are:

- the occurrence of specific plant communities
- the depth limit of flowering plants (angiosperms)
- the depth limit of charophytes

The final index is the median value of these three metrics.

The occurrence of Charophytes are decisive to the classification. The more charophyte species occuring in specific depth levels the higher the ecological value of the plant community. When no charophytes are present the ecological status cannot be better than poor.

In the shallow lagoon Orth Bight the depth distribution of charophytes is assessed as moderate. The depth limit of angiosperms is generally assessed as good, but as Orth Bight itself is too shallow to define the depth limit of angiosperms this was surveyed in Fehmarnsund. Thus, the water body Orth Bight is classified as having a good ecological status at the boundary to moderate (Table 8.1). Orth Bight was surveyed only in 2009 but the national WFD-programme of 2009 and 2010 confirms the results of the 2009 assessment (Fürhaupter et al. 2009, 2010).

*Table 8.1 Ecological quality assessment of benthic vegetation of Orth Bight, according to the ELBO-System. ChRuci = Chara/Ruppia cirrhosa*

| Transect | Plant community | Ecologi-cal status | Depth limit charo-phytes | Ecological status | Depth limit angio-sperms | Ecological status | Final Index (EQR) |
|---|---|---|---|---|---|---|---|
| **2009** | | | | | | | |
| OB-S-W01 | ChRuci | 0.6/good | 1.25 m | 0.48/ moderate | 4.5 m | 0.6/good | 0.6/good |
| OB-S-W02 | ChRuci | 0.6/good | 1.0 m | 0.46/ moderate | 4.5 m | 0.6/good | 0.6/good |
| **2010** | | | | | | | |
| OB-S-W01 | ChRuci | 0.6/good | 1.0 m | 0.46/ moderate | 4.5 m | 0.6/good | 0.6/good |
| OB-S-W02 | ChRuci | 0.6/good | 0.75 m | 0.43/ moderate | 4.3 m | 0.6/good | 0.6/good |

The second assessment system, BALCOSIS (Baltic ALgae COmmunity AnalySIS System; Fürhaupter & Meyer, 2009) is valid for the outer coastal areas. It focuses on soft and hard bottom benthic vegetation (angiosperms and macroalgae). A set of seven metrics are established for the assessment of the ecological quality ratio. Primary metrics are depth distribution limits of Zostera and Fucus. Secondary parameters are biomass ratios of opportunists (within the eelgrass- and red algae-communities), Fucus abundance measured by vegetation cover in the upper sublittoral zone, species reduction compared to a reference species list and Furcellaria-biomass (Figure 8.2). For each parameter a five-step assessment system is developed. Depth distribution limits are surveyed by underwater video, whereas the secondary parameters are measured by quantitative sampling in specific depth intervals (diver supported). For the summary assessment all parameters are merged, weighting primary parameters (depth distributions) higher than secondary parameters. The final index is the median value of the weighted parameters (Figure 8.2).

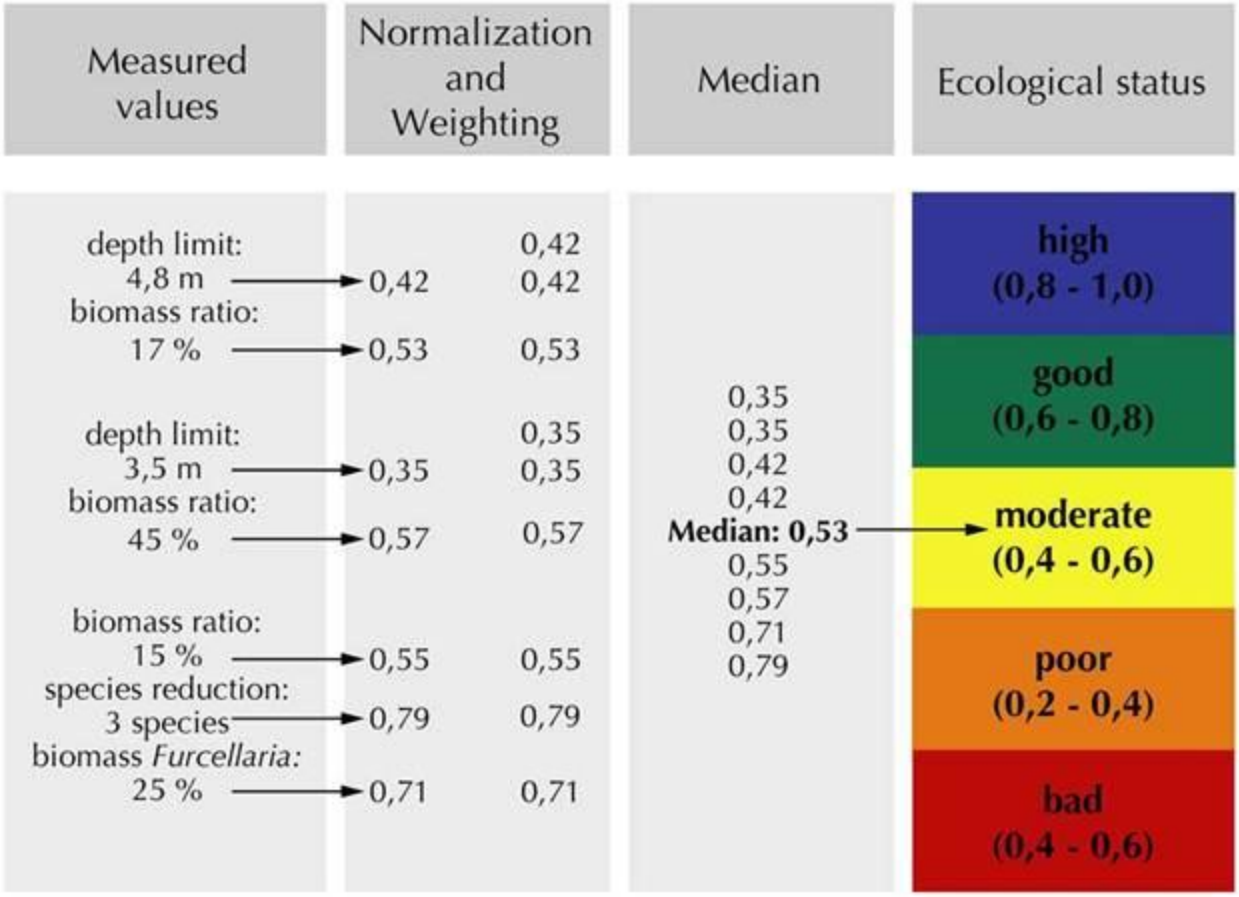



*Figure 8.2 Overview of assessment parameters (left side) and the summary assessment scheme for BALCOSIS (right side).*

The water body Fehmarnbelt (B3) has been assessed using the BALCOSIS-System. As the depth distribution of *Fucus* can only be interpreted at transects, where sufficient hard substrates are present from shoreline to about 10 m, only one transect and depth limit value was used for the assessment of this factor.

The ecological status of the depth distribution limit of *Fucus* is assessed as moderate (Table 8.2). The respective depth intervals are dominated by filamentous algae and/or mussel beds or by the *Furcellaria*-community. Equivalent to the depth distribution value the ecological status for *Fucus* dominance was low along the east coast of Fehmarn, as *Fucus* has been outcompeted there in deeper and shallow waters. Only at the west coast of Fehmarn (transects Fe-S-W01, -W06, -W08) *Fucus* is still the dominant vegetation parameter in shallow waters and has therefore a high to good ecological status.

Species reduction (compared to a reference species list) within the red algae zone is evaluated as moderate and good.

The evaluation of the opportunist biomass compared to perennial algae resulted in a high variability of this factor. Three transects along the Fehmarn coast are dominated by filamentous algae up to 100 % and are therefore classified as bad. In contrast transects dominated by perennial macroalgae like *Furcellaria*, *Coccotylus/Phyllophora* and/or *Phycodrys/Delesseria* are classified as high or good.

The assessment factor *Furcellaria*-biomass showed bad to moderate results for Fehmarn, as a *Furcellaria*-community has only a minor importance here.

The assessed values of the water body Fehmarnbelt (B3) fits to the results of the national WFD-monitoring programme in Germany. Here this water body is classified at the borderline between good and moderate. If eelgrass beds are included in the classification this water body is classified as good (at the boundary to moderate).

The ecological status of the water bodies Fehmarnbelt and Orth Bight is illustrated in Figure 8.3.

*Table 8.2 Ecological quality assessment of the German water body in Fehmarnbelt (DE) according to the BALCOSIS-System.*

| **Transect** | ***Fucus*-Phytal** | | **Red Algae-Phytal** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Domi-nance [%]** | **Status class (EQR)** | **Species reduc-tion [%]** | **Status class (EQR)** | **Oppor-tunist biomass [%]** | **Status class (EQR)** | ***Furcel-laria* Bio-mass [%]** | **Status class (EQR)** |
| **2009** | | | | | | | | |
| Fe-S-E01 | <1 | 0.2/poor | 50 | 0.47/mode rate | 15 | 0.56/mode rate | 0 | 0.0/bad |
| Fe-S-E02 | 45 | 0.54/mode rate | 30 | 0.6/good | 3 | 0.78/good | <1 | 0.2/poor |
| Fe-S-E03 | 0 | 0.0/bad | 30 | 0.6/good | 4 | 0.75/good | <1 | 0.2/poor |
| Fe-S-E04 | 0 | 0.0/bad | 30 | 0.6/good | 1 | 0.8/high | 30 | 0.41/mode rate |
| Fe-S-E06 | 0 | 0.0/bad | 50 | 0.47/mode rate | 15 | 0.56/mode rate | <1 | 0.2/poor |
| Fe-S-E09 | 0 | 0.0/bad | 40 | 0.54/mode rate | 100 | 0.0/bad | <1 | 0.2/poor |
| Fe-S-W01 | 100 | 1.0/high | no red algae phytal | | | | | |
| Fe-S-W05 | <1 | 0.2/poor | 50 | 0.47/mode rate | 0 | 1.0/high | <1 | 0.2/poor |
| Fe-S-W06 | 65 | 0.72/good | 50 | 0.47/mode rate | 0 | 1.0/high | <1 | 0.2/poor |
| Fe-S-W08 | 60 | 0.68/good | 40 | 0.54/mode rate | 2 | 0.79/good | <1 | 0.2/poor |
| *Fucus* depth limit: | | 5.1 m | 0.47/moderate | | | | | |
| Eelgrass depth limit: | | 4.8 m | 0.42/moderate | | | | | |
| **Final index (EQR):** | | **0.60/good-moderate boundary** | | | | | | |
| **2010** | | | | | | | | |
| Fe-S-E01 | 0 | 0.0/bad | 40 | 0.54/mode rate | 45 | 0.34/poor | 0 | 0.0/bad |
| Fe-S-E02 | <1 | 0.22/poor | 60 | 0.4/moder ate | 0 | 1.0/high | 0 | 0.0/bad |
| Fe-S-E03 | 0 | 0.0/bad | 40 | 0.54/mode rate | 0 | 1.0/high | <1 | 0.2/poor |
| Fe-S-E04 | 0 | 0.0/bad | 40 | 0.54/mode rate | 4 | 0.75/good | 10 | 0.41/mod erate |
| Fe-S-E06 | 0 | 0.0/bad | 50 | 0.47/mode rate | 1 | 0.8/high | <1 | 0.2/poor |
| Fe-S-E09 | 0 | 0.0/bad | 50 | 0.47/mode rate | 97 | 0.02/bad | <1 | 0.2/poor |
| Fe-S-W01 | 100 | 1.0/high | no red algae phytal | | | | | |
| Fe-S-W05 | 0 | 0.0/bad | 50 | 0.47/mode rate | 100 | 0.0/bad | <1 | 0.2/poor |
| Fe-S-W06 | 70 | 0.77/good | 50 | 0.47/mode rate | 0 | 1.0/high | <1 | 0.2/poor |
| Fe-S-W08 | 30 | 0.5/moder ate | 80 | 0.27/poor | 100 | 0.0/bad | <1 | 0.2/poor |
| *Fucus* depth limit: | | 5.0 m | 0.47/moderate | | | | | |
| Eelgrass depth limit: | | 4.8 m | 0.42/moderate | | | | | |
| **Final index (EQR):** | | **0.60/good-moderate boundary** | | | | | | |

## 8.2 Water Framework Directive Assessment DK

In Denmark, the Danish Nature Agency is responsible for preparing WFD assessments. The Danish WFD territory is divided into 4 water basin districts which each comprise a number of main catchment areas, in all 23 catchment areas. The area of Fehmarnbelt is a part of the water basin district 2 Sjælland and within this the main catchment area '2.6 Østersøen' (Miljøministeriet 2011). The coastal area located at/near the alignment of the Fixed Link is further divided into two coastal water bodies: Femerbælt and Rødsand. Presently the only marine WFD indicator used in Denmark is the depth limit of eelgrass.

For the benthic vegetation along the Danish coast the environmental authorities have in December 2011 published their assessment of the reference conditions, the environmental goals and the present status (Miljøministeriet (2011). A résumé of the assessment for Fehmarnbelt is given below.

In 'Femerbælt' the reference conditions state a depth limit of 10.9 m for eelgrass, and a good ecological status is achieved when eelgrass has a depth limit of 8.1 m. In 'Rødsand Lagoon' the reference condition is 5.6 m, and a good ecological status is achieved when the depth limit is 4.1 m.

With regard to the present status the Vandplan does not classify the 'Femerbælt' and the 'Rødsand' areas. For the 'Femerbælt' no data are available on depth limits for eelgrass . In 'Rødsand' data is available for only one year, and this is considered as insufficient for a classification.

In general, nutrient concentrations are identified as the primary factor determining the depth limit of eelgrass.

In the present study the depth limit of eelgrass was 4.6 (average of 5 observations) in the eastern light limited part of Rødsand Lagoon. This depth limit corresponds to a good ecological status (Table 8.3).

Along the coast of Lolland ('Femerbælt') only few tufts of eelgrass were found in this study. Thus, it was not possible to define a depth limit.

*Table 8.3 Reference conditions, goals for achieving a good environmental status and the national classification at Femernbelt and Rødsand. Data from 'Udkast til Vandplan Hovedvandopland 2.6 Østersøen'.*

| **Area** | **Reference condition Eelgrass depth limit** (m) | **Good ecological status** (m) |
|---|---|---|
| Femerbælt | 10.9 | 8.1 |
| Rødsand | 5.6 | 4.1 |

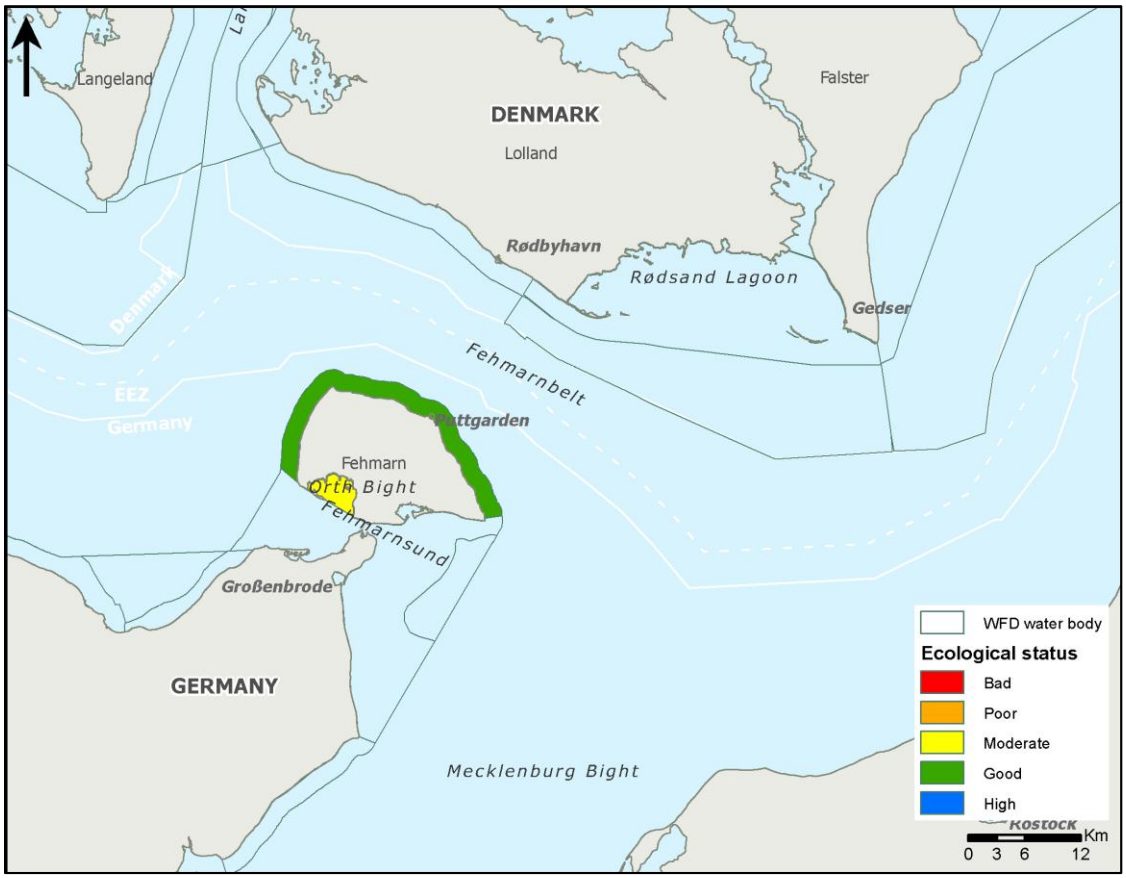



*Figure 8.3 Ecological status of different water bodies within the investigation area.*

## 8.3 Other assessments based on the Water Framework Directive

The Marine Strategy Framework Directive (MSFD) is based on the WFD and aims at extending its objectives into the offshore waters including the EEZ. It uses an ecosystem approach with an integrative assessment to brace all major living components. The assessment criteria for the MSFD are much more detailed than for the WFD, comprising a specific list of 11 descriptors in which indicator and indicator thresholds for good environmental status (GES) will be identified. A corresponding list of 8 pressures with several impacts each has been identified and must be incorporated into the assessment. The result is an evaluation whether a given water body (on a larger scale than WFD water bodies) reaches the GES or not.

Currently, there exists no assessment system for the MSFD that covers all these aspects. The exact interpretation of the assessment criteria and a definition of the indices is currently starting. For the Baltic Sea, the HELCOM HOLAS assessment (HELCOM 2010) is one step in this process, trying to define and assess the environmental status using an integrative approach. As such, it is not possible yet to give a comprehensive assessment of the status of the investigation area with respect to the MSFD.

# 9 LAW PROTECTED BENTHIC VEGETATION

## 9.1 Red-Listed Species

None of the macroalgae and flowering plant species observed during the baseline study are red-listed in Denmark. 23 of the species found within the investigation area in 2009 and 2010 are red-listed in Germany (for red-list see: Hamann & Garniel 2002, Korneck et al. 1996, Merck and von Nordheim 1996, Schories et al. 2010, Schmidt et al. 1996:). Some have a different conservation status for the whole German Baltic coast compared to the Baltic coast of Schleswig-Holstein. Table 9.1 gives an overview of the respective species, their threat category (German Baltic/Schleswig-Holstein) and their occurrence within the investigation area (DE/DK).

Several of these protected species are key species (K) or accompanying species (AP) of the communities defined in the present baseline study.

- Tasselweed/dwarf eelgrass-community: *Ruppia* spp. (K), *Zostera noltii* (K), *Chara* spp. (AP), *Lamprothamnion papulosum* (AP), *Tolypella nidifica* (AP)
- *Fucus*-community: *Fucus serratus* (K), *Fucus vesiculosus* (K), *Ahnfeltia plicata* (AP)
- *Furcellaria*-community: *Ahnfeltia plicata* (AP),
- *Phycodrys/Delesseria*-community: *Brongniartella byssoides* (AP), *Membranoptera alata* (AP)

The causes for the decline of several of the communities have been described in chapter 0.

*Table 9.1 The 23 red-listed species occurring within the investigation area with threat status in German Baltic and Schleswig-Holstein as well as the occurrence in Germany (DE) and Denmark (DK). Threat categories: 0: extinct or missing, 1: critically endangered, 2: endangered, 3: vulnerable, G: indeterminate, R: extremely rare, V: near threatened, D: data deficient, *: established in area.*

| Species | Threat category German Baltic | Threat category Schleswig-Holstein | Occurrence |
|---|---|---|---|
| **Spermatophytes** | | | |
| *Ruppia cirrhosa* | 3 | 3 | DE, DK |
| *Ruppia maritima* | 2 | 2 | DE, DK |
| *Zostera noltii* | 3 | 1 | DE, DK |
| **Charophytes** | | | |
| *Chara aspera* | 2 | 3 | DE, DK |
| *Chara baltica* | 2 | 1 | DE, DK |
| *Chara canescens* | 2 | 1 | DE, DK |
| *Lamprothamnion papulosum* | 1 | 1 | DE, DK |
| *Tolypella nidifica* | 1 | 1 | DE, DK |
| **Paeophytes** | | | |
| *Dictyosiphon foeniculaceus* | 2 | * | DK |
| *Elachistra fucicola* | V | * | DE, DK |
| *Eudesme virescens* | 3 | * | DK |
| *Fucus serratus* | G | * | DE, DK |
| *Fucus vesiculosus* | V | * | DE, DK |
| *Sphacelaria rigidula* | D | | DE |
| *Sphaerotrichia divaricata* | G | * | DE, DK |
| *Striaria attenuata* | 1 | 0 | DK |
| **Rhodophytes** | | | |
| *Ahnfeltia plicata* | G | * | DE, DK |
| *Brongniartella byssoides* | G | 0 | DE, DK |
| *Membranoptera alata* | G | * | DE, DK |
| *Nemalion helminthoides* | 0 | 0 | DK |
| *Rhodochorton purpureum* | D | * | DE |
| *Pterothamnion plumula* | R | 0 | DK |
| *Spermothamnion repens* | G | * | DE, DK |

## 9.2 Protected Habitats

### 9.2.1 Habitat Directive

A network of protected areas (Natura 2000) has been established to ensure the survival of most threatened species and habitats. Several Natura 2000 areas occur within the investigation area (Figure 2.1).

The Habitat Directive is the most important instrument for species conservation in Europe. The Directive lists about 1000 protected animal and plant species and more than 200 protected habitat types (Annexes I, II, IV and V of the Habitat Directive). None of the marine macrophyte species observed in the baseline study is included. Some macrophytes are, however, characteristic parts of the protected habitat types and have therefore a conservation status.

In addition to the protection of species the Habitat Directive also focuses on the protection of specific habitat types, which have an outstanding importance for the conservation of biodiversity. These habitat types are listed in Annex I of the Directive. For each Natura 2000 area baseline descriptions are included in Natura 2000 reports.

Annex I (Directive) listed habitat types are not only protected within the Natura 2000 areas. Basically those habitats have a conservation status also according to the MFD (Marine Framework Strategy Directive). Several of the protected habitat types host specific vegetation communities and three of those occur within the investigation area. The definition of these three habitat types (according to the "Interpretation Manual of European Union Habitats" (EUR 2007)), the associated characteristic benthic vegetation species/ communities and the spatial distribution of the habitat types in the Fehmarnbelt area are shortly presented below:

**1110 Sandbanks, which are slightly covered by sea water all the time**

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

"Slightly covered by sea water all the time" means that - above a sandbank - the water depth is seldom more than 20 m below chart datum. Sandbanks can, however, extend beneath 20 m below chart datum. It can therefore be appropriate to include in designations such areas where they are part of the feature and host its biological assemblages.

Characteristic species: *Zostera* sp., *Potamogeton* spp., *Ruppia* spp., *Tolypella nidifica, Zannichellia* spp., charophytes (eelgrass-community, tasselweed/dwarf-eelgrass community)

Spatial distribution: North of Fehmarn, about 5 km west of the proposed alignment, sand banks are occurring. They show a scattered vegetation of eelgrass in very low coverage. This area is part of the Natura 2000 area DE 1631-392 Eastern Kiel Bight.

Large areas in Natura 2000 area DK006X238 Rødsand Lagoon has been classified as 1110 Sandbanks. However, the categorization does not seem to fit with the actual habitats and morphological elements present in the area. The more correct classification is 1160 Large shallow inlets and bays.

**1160 Large shallow inlets and bays**

Definition: Large coastal indentations where, in contrast to estuaries, the influence of freshwater is generally limited. These shallow indentations are generally sheltered from wave action and contain a great diversity of sediments and substrates with a well-developed zonation of benthic communities. Generally these communities have a high biodiversity. The limit of shallow water is sometimes defined by the distribution of the Zosteretea and Potametea associations.

Several physiographic types may be included in this category providing the water is shallow over a major part of the area: embayments, fjords, rias and voes.

Characteristic species: *Zostera* spp., *Ruppia maritima*, *Potamogeton* spp. (e. g. *P. pectinatus, P. praelongus*), benthic algae (eelgrass-community, tasselweed/dwarf eelgrass-community)

Spatial distribution: Orth Bight and Rødsand Lagoon represent this habitat type. In Orth Bight both communities occur in dense stands and are distributed nearly over the whole area of the bight. Also in Rødsand Lagoon both soft bottom communities occur, but due to mainly hydrographical parameters they are not evenly distributed over the whole lagoon, but are concentrated in the western part of the lagoon. Orth Bight is part of the Natura 2000 area DE 1631-392 Eastern Kiel Bight.

**1170 Reefs**

Definition: Reefs are either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone. Reefs may support a zonation of benthic communities of algae and animal species as well as concretions and corallogenic concretions.

Clarifications:
- "Hard compact substrata" are: rocks (including soft rock, e. g. chalk), boulders and cobbles (generally > 64 mm in diameter).

- "Biogenic concretions" are defined as: concretions, encrustations, corallogenic concretions and bivalve mussel beds originating from dead or living animals, i. e. biogenic hard bottoms which supply habitats for epibiotic species.

- "Geogenic origin" means: reefs formed by non biogenic substrata.

- "Arise from the sea floor" means: the reef is topographically distinct from the surrounding seafloor.

- "Sublittoral and littoral zone" means: the reefs may extend from the sublittoral uninterrupted into the intertidal (littoral) zone or may only occur in the sublittoral zone, including deep water areas such as the bathyal.

- Such hard substrata which are covered by a thin and mobile veneer of sediment are classified as reefs if the associated biota is dependent on the hard substratum rather than the overlying sediment.

- Where an uninterrupted zonation of sublittoral and littoral communities exists, the integrity of the ecological unit should be respected in the selection of sites.

- A variety of subtidal topographic features is included in this habitat complex such as: Hydrothermal vent habitats, sea mounts, vertical rock walls, horizontal ledges, overhangs, pinnacles, gullies, ridges, sloping or flat bed rock, broken rock and boulder and cobble fields.

Characteristic species: a great variety of different green, brown and red algae, some of them are growing epiphytic on other algae.

Spatial distribution: Dense boulder and cobble reefs are distributed on large scale all along the eastern coast of Fehmarn and Langeland. They occur down to about 20 m at Fehmarn and to about 15 m at Langeland. In both areas hard substrate is covered by a red algae zone, mainly the *Furcellaria*-community and the *Phycodrys/Delesseria*-community. Also the *Saccharina*-community occurs in both areas. Filamentous algae and the *Fucus*-community are of less spread in both areas. Langeland is part of the Natura 2000 area DK00VA200 Stone reefs southeast of Langeland. Part of the boulder reefs on the east coast of Fehmarn is included in the Natura 2000 area DE 1533-301 Staberhuk. East of the harbour Puttgarden a 3 $km^2$ boulder reef is located; it is not part of any Natura 2000 area.

Less dense cobble and pebble reefs are scatteredly distributed in the shallow water around the north western cape of Fehmarn (Westermarkelsdorf), along the west coast of Fehmarn, directly west of the harbour Puttgarden, and along the south coast of Lolland. They occur down to about 5–6 m at Fehmarn and to about 10 m at Lolland. The hard substrates are covered with a *Fucus*-community at Fehmarn and with a *Furcellaria*-community in Lolland. Filamentous algae dominate some depth intervals in both areas. In addition to the *Fucus*-community directly west of Puttgarden with an extent of 0.5 $km^2$, the other hard substrate areas are part of the Natura 2000 area DE 1631-392 Eastern Kiel Bight. The hard substrate areas of Lolland are not part of any Natura 2000 area.

Less dense cobble and pebble reefs are also scatteredly distributed in the deep areas of the Fehmarnbelt. They occur down to about 35 m and are covered by vegetation down to 18-19 m. The *Phycodrys/Delesseria*- and the *Saccharina*-community occur in this area, which is part of the Natura 2000 area DE 1332-301 Fehmarnbelt.

Dense mussel beds are distributed around the south east cape of Fehmarn, along the east coast of Großenbrode, along the south coast of Lolland and to a lesser extent along the west coast of Fehmarn. They occur from 2–3 m down to about 10 m and cover the hard substrate structures in these areas. Additionally, they form agglomerations on sandy substrates. Mussel beds have only a low value as suitable substrate for algae; they are strong competitors regarding settling space in areas, where blue mussels cover the hard substrate structures. Therefore these mussel beds are only sparcely covered by vegetation. Filamentous algae dominate vegetation nearly completely, whereas perennial vegetation is scarce. The mussel beds of the Fehmarn coast are part of the Natura 2000 areas DE 1631-392 Eastern Kiel Bight, DE 1533-301 Staberhuk and DE 1632-392 Großenbrode.

At the south west cape of Fehmarn clay reefs occur locally in a restricted area called Krummsteert and to a yet smaller extent along the east coast of Großenbrode. Both areas are part of Natura 2000 areas; DE 1631-392 Eastern Kiel Bight and DE 1632-392 Großenbrode. These clay reefs are distributed in the shallow water from 2 down to 4 m. They are normally not covered by vegetation. Eelgrass beds grow on the sandy or gravel substrate located between the clay reefs. Single *Fucus* plants and filamentous algae grow in low coverages on pebbles and/or mussels incorporated within the clay structure. But overall clay reefs are of minor importance as substrate for plants.

### *9.2.2 Nature Conservation in Germany (§ 30 BNatSchG) and Schleswig-Holstein (§ 21 LNatSchG)*

Habitats with vegetation are additionally protected by the national law for nature conservation of Germany (§30 BNatSchG, Bundesnaturschutzgesetz - Gesetz über Naturschutz und Landschaftspflege) and the state law of Schleswig-Holstein (§21 LNatSchG, Landesnaturschutzgesetz - Gesetz zum Schutz der Natur - Schleswig-Holstein). Definitions are identical between both laws but are quite vague:

§30 (1,2) The following biotopes have a special conservation status:
"..., seagrass meadows and all other marine vegetation stands, reefs, sublittoral sand banks of the Baltic and species rich gravel, coarse sand and shell areas of the coastal and marine regions".

This corresponds to the habitats already protected according to the Habitat Directive and includes all perennial vegetation forms as these are the most valuable parts of sublittoral vegetation and are most endangered due to habitat loss and eutrophication.

# 10 IMPORTANCE

The importance of benthic vegetation is defined by their functional value for the ecosystem. Benthic vegetation is a valuable part of the coastal ecosystem due to its function as a three-dimensional habitat as well as nursery, breeding or feeding ground for invertebrates and fish (to a less extent to birds and marine mammals).

The importance of macrophytes species as habitat building organisms can be described by different parameters:

- Habitat complexity (plant shape): size, growth form (erect versus lying and leaf-shaped versus filamentous) and the degree of branching affects the possible number of niches. Large species with upright-growth offer better protection and more niches. Looking to the degree of branching unbranched and strongly branched species offer fewer niches (Hansen et al. 2008).
- Habitat fragmentation (minimum density): To function as a habitat the structuring species need to have a relatively high density (Hovel et al. 2002, 2003). If the habitat is fragmented the single specimens/patches are too far away of each other to have a protection value especially for the highly mobile inhabiting species (Hovel et al. 2002, Hovel & Lipcius 2001, 2002, Hovel und Fonseca 2005). Exact values for the fragmentation degree are not available, normally it is only mentioned that the structuring species should be dominant. In this case dominant for most species is defined as > 50% cover. As for all these criterias, the density aspect is a generalisation, that ensures that larger dense populations are given higher importance than a few straw. There may however also exist areas with low cover that are very important for a positive development of the vegetation and act as source for seed dispersal in an area.
- Habitat size (minimum area of occupancy): To have significant effects on species diversity and abundance of associated invertebrates, fish and macrophytes itself, the total area of the habitat must have a sufficient size. The larger and the more mobile the associated fauna is, the larger the minimum area of the habitat must be. Exact values for a minimum habitat size are therefore not possible to estimate.
- Seasonal biomass/coverage variability: Long living species offer a more stable habitat than short-lived species. Macrophyte key species with a high longevity and a low variation in biomass variation during the year are regarded to be most important as habitat forming species (Schramm 1999).

These parameters have been the basis for the classification of the importance of the benthic vegetation communities. For the German water, national legislation has added a regulatory dimension as the German Nature conversation act (Bundesnaturschutzgesetz, *BNatSchG §30*) lists specific macrophytes., Consequnetly the functionally based classification criteria have been adjusted for German waters to fulfil the regulatory conditions.

The degree of importance has been determined for the different key communities (Table 10.1) and illustrated in a map of importance (Figure 10.1).

*Table 10.1 Importance matrix for benthic vegetation in the investigation area.*

| Importance level | DE | | DK | |
|---|---|---|---|---|
| | **Community** | **Coverage** | **Community** | **Coverage** |
| **Very high** | All (beside filamentous algae) | ≥ 50 % | Eelgrass<br>Eelgrass/ algae<br>Tasselweed/ dwarf eelgrass<br>*Fucus* | ≥ 50 % |
| **High** | All (beside filamentous algae) | 25–50 % | *Furcellaria*<br>*Phycodrys/ Delesseria*<br>*Saccharina* | ≥ 50 % |
| | | | Communities listed in very high | 25–50 % |
| **Medium** | All (beside filamentous algae) | 10–25 %, | Communities listed in very high | 10–25 % |
| | | | Communities listed in high | 10–50 % |
| **Minor** | Filamentous algae | Independent of density | Filamentous algae | Independent of density |
| | Vegetation stands | 1–10 % | Vegetation stands | 1–10 % |

*Very high importance*
*Fucus*-, *Zostera*-, tasselweed/dwarf eelgrass- and the eelgrass/algae-community have a very high importance. The key species of these communities are large species with upright growth and sparsely branched. The species are perennial and thus creating high habitat stability. *Fucus* e. g. has a life span of several years (Lüning 1985). The biomass variation during the season is low for *Fucus* and a high proportion of the biomass is persistent during the winter. For *Zostera* or tasselweed/dwarf eelgrass the seasonal biomass variation is higher, but a significant proportion is also persistent during winter (Hemminga & Duarte 2000).

The importance of the communities for the Baltic Sea region is reflected in different international and national guidelines and legislations. HELCOM has red listed the key species of these communities as well as the habitats they are forming (HELCOM 2007). The Habitat Directive lists eelgrass, tassleweed and dwarf eelgrass as characteristic species for different habitat types (see chapter 9.2.1). A high proportion of key species and associated macrophyte and fauna species are red listed in Germany (Merck & von Nordheim 1996) and seagrass meadows as well as vegetation stands of perennials are law protected in Germany (§30 BNatSchG). Therefore, all perennial macrophytes communities of > 50% cover have "very high" importance in Germany.

If *Fucus*-, *Zostera*- and tasselweed/dwarf eelgrass-community stands and perennial macrophyte communities in German waters cannot fulfil the coverage value (habitat density) of > 50% they will be downgraded one importance class.

*High importance*
The perennial red algae communities (*Furcellaria*, *Phycodrys/Delesseria)* and the *Saccharina*-community have a high importance value. The perennial red algae key species like *Coccotylus truncatus, Furcellaria lumbricalis, Delessseria sanguinea* or *Phycodrys rubens* are medium branched and have an upright growth, but have also relatively small thalli. *Saccharina latissima*, although having a large thalli, is lying

on the ground and is unbranched. The habitat stability of the *Phycodrys/Delesseria*-community is lower than for *Fucus* and/or *Zostera,* as the thallus and density is reduced during winter. *Furcellaria* and *Saccharina latissima* have a life span comparable to *Fucus* (2-5 years, Lüning 1985) and a high proportion of the biomass is persistent during winter.

The Habitat Directive lists no specific species for the habitat type reef (see chapter 9.2.1) as the species composition depends on the climatic region. It is only mentioning a "variety of green, brown and red algae" for this habitat type. Only a few key species of these communities are directly red listed in Germany but a high proportion of associated macrophyte and fauna species are red listed (Merck & von Nordheim 1996).

If *Furcellaria*-, *Phycodrys/Delesseria*- and the *Saccharina*-community stands cannot fulfil the coverage value (habitat density) of > 50%, they will be downgraded for one importance class.

*Medium importance*
All perennial vegetation communities with a density > 10%, but not fulfilling the above-mentioned boundaries, have a medium importance level. Although their contribution to habitat forming is reduced for fish due to a lower habitat density and area of occupancy, they are still important for invertebrate species. As hard substrates areas with high densities > 50% are rare and locally restricted, areas with lower densities can serve as stepping-stones for the associated fauna and flora.

*Minor importance*
Filamentous, opportunistic macrophyte communities and all perennial benthic vegetation communities with less than 10% cover are of minor importance. Key species of filamentous communities are small in size and highly branched. The habitat stability is low as key species are often annual forms with high biomass variability during the year. During winter season these species have a biomass close to zero. Perennial species with cover < 10% are not regarded as a plant community in an ecological sense.

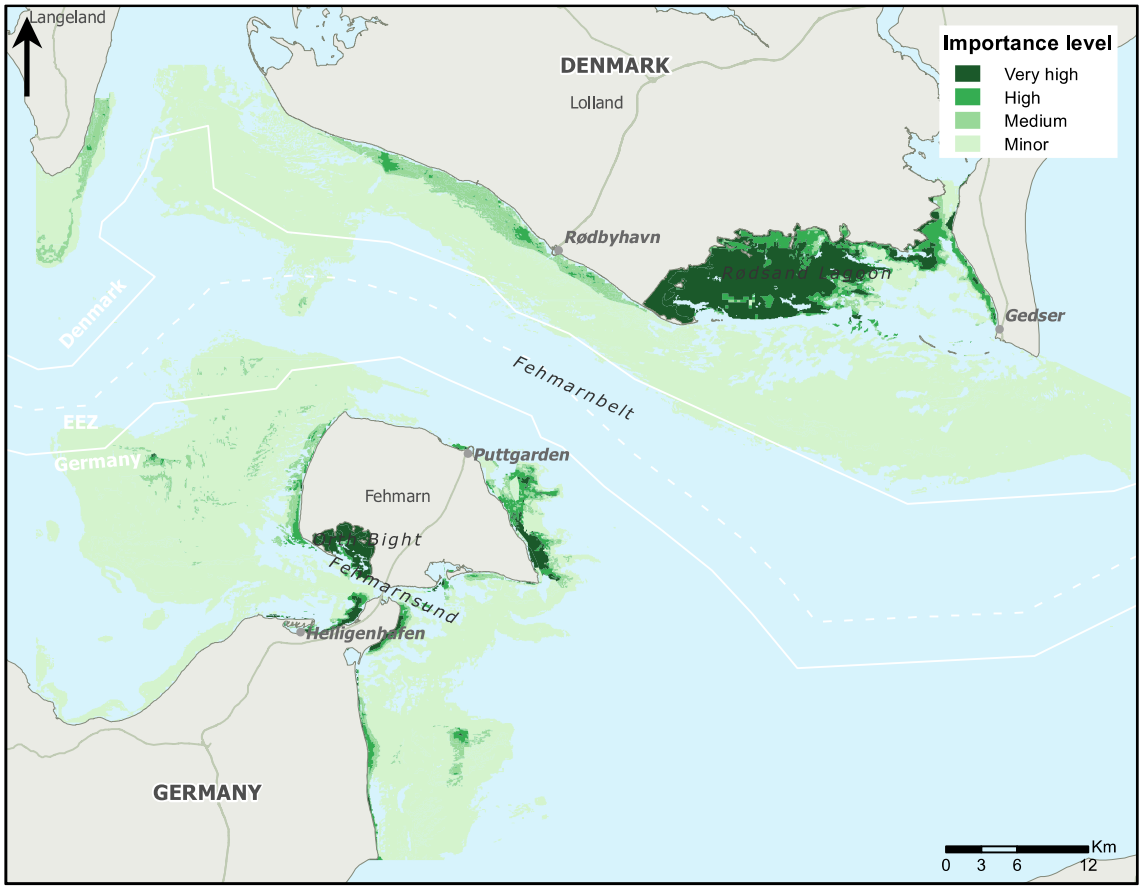



*Figure 10.1 Map of importance for benthic vegetation in the investigation area.*

Large areas of "very high" importance are located within Rødsand Lagoon and Orth Bight. In both areas this classification is based on the large-scale occurrence of eelgrass- and tasselweed/dwarf eelgrass-communities with high coverages (densities). The significance of both areas as a specific and valuable part of the marine environment has led to the allocation as Natura 2000 areas (DK006X238, DE 1631-392); soft bottom vegetation forms a dominant and characteristic component of the habitat type 1160 Shallow bays and inlets, which is assigned at least partly to Rødsand Lagoon and Orth Bight (see chapter 9.2.1). Additionally Orth Bight or parts of Orth Bight have a long nature conservation tradition in Germany (as NSG – National Nature Conversation Area and BSPA – Baltic Sea Protected Area), which verifies the very high importance of the communities occurring in this area.

"Very high" importance areas also occur along the east coast of Fehmarn, with *Furcellaria*-, *Phycodrys/Delesseria*- and *Saccharina*-communities with coverages of more than 50%. Some of the areas are included in the Natura 2000 area Staberhuk. In Germany, these areas are protected by the nature conservation law (§30 BNatschG).

Besides these large areas some smaller areas of "very high" importance exist around Wagrien (mainland south of Fehmarn). This classification is based on the occurrence of the mixed eelgrass/algae-community with a coverage of more than 50%. Especially the mixing of these communities is of ecological importance as different associating species are favoured resulting in a higher overall diversity. These areas are included in different Natura 2000 areas (DE 1631-392, DE 1632-392). Additionally spots of "very high" importance exist around Fehmarn: Directly west of

Puttgarden and in a narrow stretch along the west coast of Fehmarn, dense *Fucus* belts are situated. In addition there is a small area of "very high" importance in the deeper water west of Fehmarn.

"High" importance areas are more or less located around the "very high" importance areas. In these areas the *Fucus*-, eelgrass-, eelgrass/algae- and tasselweed/dwarf eelgrass-communities have a coverage of less than 50% and are therefore downgraded one class. Within the large-scale "high" importance areas around Wagrien the mixed eelgrass/algae-community is occurring, but neither eelgrass nor algae occur with high coverages. "High" importance areas also occur along the coastline of Lolland, Langeland with *Furcellaria*-, *Phycodrys/Delesseria*- and *Saccharina*-communities with coverages of more than 50% and along the east coast of Fehmarn where coverage are lower than 50%. "High" importance areas are also located in other areas around Fehmarn, in deep water areas of Sagasbank, Fehmarnbelt and scattered in Eastern Kiel Bight.

Large "medium" importance areas are located along the coastline of Lolland, Langeland where perennial macroalgae occur with coverages of 10-50%. "Medium" importance areas are also located around Fehmarn, at Sagasbank, Fehmarnbelt and scattered in Eastern Kiel Bight. Within these "medium" classified areas perennial macroalgae communities (*Furcellaria*, *Phycodrys/Delesseria, Saccharina)* occur with low coverages (< 10–25%), as suitable substrate is the limiting factor.

"Minor" importance areas are distributed all over the investigation area, as filamentous algae and perennial vegetation stands with coverages < 10% are widely distributed.

# 11 EXISTING PRESSURES

The baseline pressure analysis, based on expert judgement, attempts to assess the existing anthropogenic pressure drivers and the pressures deriving from them.

The aim of this section is to outline major existing pressure drivers with potential impact on the Baltic Sea ecosystems, and to discuss some of the documented effects of the resulting pressures. This forms the basis for the assessment of existing anthropogenic pressure drivers with respect to their influence on the benthic vegetation in the area of interest, and how they may interact with pressures from the planned project.

## 11.1 Overall Pressures in the Baltic Sea

In a recent peer-reviewed publication (HELCOM 2010), the Helsinki Commission (HELCOM) has established no less than 52 anthropogenic pressure drivers and derived the so-called Baltic Sea Pressure Index (BSPI). The BSPI brings together all available data layers relevant to human uses and pressures acting on the Baltic Sea and evaluates the spatial distribution of the cumulative impact of these pressures.

The Baltic Sea Impact Index (BSII) is a tool to estimate the potential anthropogenic impacts on the marine ecosystem, taking into account areas of the Baltic Sea that are sensitive to human-induced pressures. The concentration of anthropogenic pressures (=BSPI) is combined with the spatial distribution of species, biotopes and biotope complexes to yield the potential anthropogenic impacts (=BSII).

The BSII has been established for the entire Baltic Sea on a grid of 5 km × 5 km (HELCOM 2010). It was found that only the open sea areas of the Gulf of Bothnia are considered to be relatively free of human impact, whereas almost all coastal areas of the Baltic Sea are impaired. Among the most notorious and widespread of anthropogenic stressors are: eutrophication, commercial fisheries, input of hazardous substances and land/seascape modification. The Belt Sea and Arkona Basin are under relatively high pressure and focussing on the basins of the Kiel Bight and the Mecklenburg Bight (of which the Fehmarnbelt is the connecting sea strait) a number of area-specific pressures could be identified. The area-specific anthropogenic pressures that ranked highest within these basins were:

- Extraction of species by bottom trawling, gillnet fishing, surface and mid-water trawling and fishing with coastal stationary gear (standing nets, fykes)
- Input of nutrients and heavy metals (lead and cadmium)
- Abrasion of the seabed by bottom trawling
- Underwater noise by shipping activities (coastal and offshore)

The BSPI, the sum of the anthropogenic pressures within the study area in the Fehmarnbelt has a range between 47 and 90 (Figure 11.1). The areas with the highest index values are notably both ferry harbour entrances at Puttgarden and Rødby havn, the coastal waters around Gedser and the Fehmarnsund between the island of Fehmarn and the German mainland. Also, southeast offshore Langeland and areas in the central Fehmarnbelt are under noticeable pressure. Areas with notably low BSPI values are the Lagoon of Rødsand, the central Lolland coast and the eastern part of the Kiel Bight, west offshore Heiligenhafen.

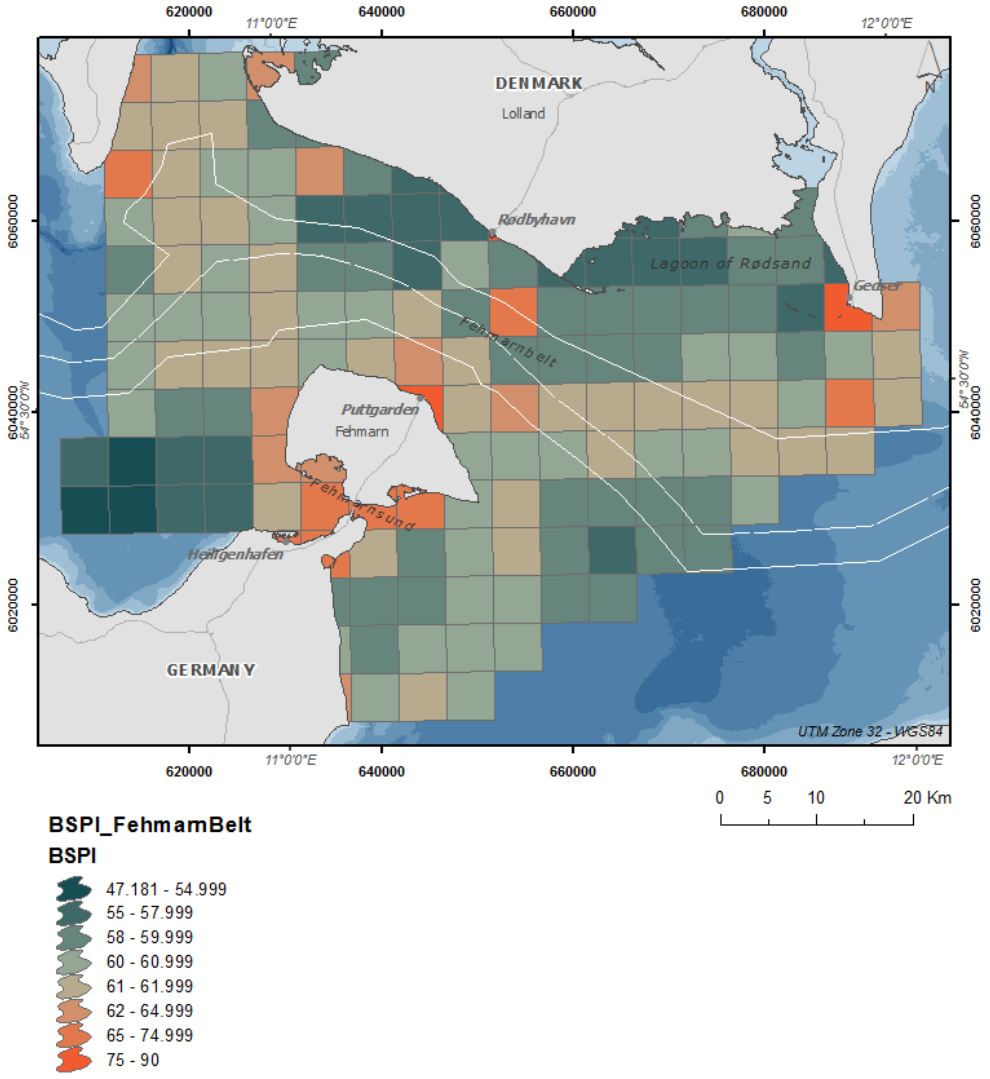



*Figure 11.1 The Baltic Sea Pressure Index (BSPI), for the Fehmarnbelt area.*

## 11.2 Eutrophication

Eutrophication is one of the most serious threats to species diversity and stability of marine ecosystems worldwide (Kotta & Witman 2009). The Baltic Sea has been exposed to very high amounts of nutrients throughout the last 50–80 years. According to the HELCOM Holistic Assessment (HELCOM 2010) the eutrophication status of the Fehmarnbelt region is poor to bad.

## 11.3 Macrophyte communities are affected by eutrophication in different ways:

Firstly, increased nutrient richness stimulates the growth of planktonic algae and thereby reduces water clarity and shades the vegetation (e. g. Nielsen et al. 2002). As nutrients are available more or less throughout the year, phytoplankton blooms can take place more often and last longer during the season. Clearwater periods are therefore shortened and occur more seldom within the growth period of macrophytes (De Vries et al. 1996). The reduction of light penetration has been

suggested to be one of the main causes of the decline in vertical distribution of characteristic vegetation communities (soft and hard bottom) of the Baltic that has been observed in long-term studies (Rönnberg & Mathiesen 1998; Eriksson et al. 2002). Not only lower depth distribution but also the upper depth limit of specific macrophytes has been affected, as species adapted to lower light intensities will move upwards on the coast, where they had been outcompeted before (Breuer & Schramm 1988). Furthermore the overall vegetation abundance in deeper, light limited waters (Duarte 1991, Schramm 1999, Dahl & Carstensen 2008) is reduced and also the relative abundance of perennial species (Breuer & Schramm 1988). The number of species also tends to decrease along a nutrient gradient (Middelboe et al. 1997).

Secondly, higher nutrient levels increase the growth of opportunistic macroalgae species. Opportunistic species are able to respond relatively fast to changes in nutrient condition (Schramm 1999). They have high growth- and turnover-rates (Wallentinus 1979, 1984), a short lifespan and are often annual species. The small size with fine, filamentous phylloids give a high surface: volume ratio and therefore a high rate of nutrient uptake. Growth of these opportunistic species is favoured in areas or periods with high nutrient concentrations. Moreover, the potential for spreading of opportunistic species is high. Many species are able to reproduce vegetatively in form of fragmentation and this is sufficient to built up new populations. This growth characteristic is in contrast to most of the species that are regarded as key species in the Western Baltic. These species are perennials with low growth- and turnover-rates. They are big in size and/or have a broad thallus. They are favoured in areas or periods with low nutrient concentrations. Their potential for spreading is often smaller than the opportunistic species. The abundance of the opportunistic species is increasing with increasing nutrient input (Borum 1985), and may result in changed species composition and dominance structure of the communities (Schramm 1999).

Especially in spring opportunistic algae can build up high coverage. Within short time whole areas of the sea bottom can be covered 100% by opportunistic species. Thick mats of opportunistic algae may reduce water exchange to the underlying substrate. Decomposition of the biomass may result in oxygen deficiency and sometimes $H_2S$ release, which may lead to a die off of the bottom organisms (Rosenberg 1985, Norkko & Bonsdorff 1996). Perennial algae or eelgrass can be overgrown by opportunistic algae reducing light availability (Schramm 1999). Such extreme mass occurrences of filamentous algae normally occur in shallow waters (< 5 m) with high light availability, but the algae mats can be transported to deeper water and increase the oxygen deficiency of these areas.

Increased nutrient loadings also cause increased sedimentation of organic materials on the seabed (siltation), as the growth of phytoplankton is too intensive to be consumed totally by the planktonic (zooplankton, fish) or the benthic (bivalves, polychaetes) food web. Siltation makes the seabed less suitable for vegetation growth. When the hard substrates in deep water are covered by the material it may prevent attachment of the algae spores that are necessary for maintaining the populations. The organic material also covers the leaves of *Saccharina latissima* and deep growing red algae, which probably result in reduced photosynthesis and growth. These effects can of course also be listed underneath "sedimentation", but the causing pressure is eutrophication.

## *11.4 Marine constructions*

Constructions of marine infrastuctures at sea such as harbours, offshore wind farms (OWFs) or deepening of waterways result in loss of substrates in the direct impact

area and sediment spill during construction. No harbours have been built around Fehmarn within the last decades. The building of Puttgarden (ferry) harbour and the Fehmarnsund Bridge in the 1960s were the last marine construction projects on a greater scale along the German coastline of the investigation area.

On the Danish coastline, just offshore the Rødsand lagoon, the Nysted OWF and the larger Rødsand II OWF are located. Although the construction phase of each has not been found to cause significant impairments of the benthic ecosystem, each of the windfarms may have local effects on the environment. Based on the EIA for Rødsand II impacts during the operation phase of the wind farm is associated with changes in waves, long-shore sediment transport and the permanent loss of soft bottom habitats affecting a very small area. The resulting impact on the structure and function of the benthic communities is assessed to be insignificant.

## 11.5 Hard substrate mining

The amount of suitable hard substrates had been reduced along the German coast. From 1800 to 1974 (Bock 2003) intensive "stone fisheries" took place along the whole German Baltic coastline. More than 3.5 million tons of stones were used to build up spur dykes, harbours or different buildings on land. Some of the most effective "fishing grounds" for stones were situated around Fehmarn – east coast of Fehmarn between Marienleuchte and Staberhuk and Sagasbank. Interviews with former stone fishermen indicated that some of these grounds have been fished completely blank of stones during the 1960s and 1970s (Bock 2003). Today stone fishery is forbidden in Germany.

In Denmark it is estimated that about 40 $km^2$ of stone reef have been removed from the coastal areas due to stone fishery within the last 50 years (Dahl et al. 2003). Two reclamation areas have been used for stones along the Lolland coast. Although one is still active, it has not been used since 1990, the other reclamation site has been closed since 1990. As stone fishery took place down to 10-20 m depths, not only the depth distribution may have been reduced but also the cover and biomass of key-communities within the characteristic growth zones. The occurrence of macroalgae in several parts of the study area is limited due to the lack of suitable hard substrate, and any further reduction in hard substrate will strongly affect the distribution and abundance of macroalgae.

## 11.6 Sediment dredging and dumping

Hard substrates are also lost when they are buried by sand- or silt/clay-layers. Such sedimentation occurs due to sediment dumping but also during sand and gravel extraction (reclamation) as up to $^2/_3$ of the extracted material may be returned immediately after fractionation (Gajewski & Uscinowicz 1993). Four sand and gravel extraction sites are located along the Lolland coast, and sediment dumping sites are located near Rødby and Gedser habours. On the German side no sand and gravel extraction sites and no sediment dumping sites are allocated in the investigation area. The nearest site for sediment dumping in German waters is situated near the Walkyriengrund within the Lübeck Bight. The Walkyriengrund is now part of a Natura 2000 area and thus probably not active as sediment dumping area any longer.

Increases in sedimentation from anthropogenic activities have disturbed marine communities worldwide (Schiel 2009). The most sensitive part of the life cycle is spore settlement as sedimentation can inhibit attachment of spores on the hard substrates. Early life stages of large algae seem to be particularly vulnerable (Schiel et al. 2006). A study showed that *Fucus vesiculosus* only recruited, where sediment

was removed, while ephemeral (opportunistic) algae were more tolerant to sedimentation (Eriksson & Johansson 2005b). The sensitivity of 'adult' thallus to sedimentation depends on the respective growth form. Macrophytes with broad leaves or fine, small thalli can be completely buried even if the sedimentation amount is less than 2–5 cm. Plants do not receive sufficient light and will die, if they are not swept free of sediment within a short time. Cartilaginous species (e. g. *Furcellaria lumbricalis*) or species which are held in the water column by air filled bladders (e. g. *Fucus vesiculosus*) are more resistant to sedimentation as they are not buried immediately. However, if the rate of sedimentation is too high or lasts too long, these species will also die. Sediment spills also increases the turbidity of the water and may result in reduced depth limits as already described in the section on eutrophication (changing vertical growth zones and depth limits).

## 11.7 Fishery activity

Commercial trawl fishery has a large impact on benthic vegetation. Macrophytes can be cut loose from the hard substrate or get damaged by the heavy shear trawl doors and tickler chains. As trawl fishery is restricted to depths over 20 m in Germany this pressure affects only the deeper growing *Phycodrys/Delesseria*- and *Saccharina*-community. This physical disturbance, combined with the low growth rates of macrophyte communities in deeper areas, may prevent the development of higher biomasses in these depth ranges. According to the HELCOM Holistic Assessment (HELCOM 2010) bottom trawling has the highest rank of all pressures for Kiel and Mecklenburg Bight, whereas input of fertilisers only inhabits the second rank of pressures for this region. In shallow water gillnet and fyke net fishery is carried out. Both types have only an insignificant impact on macrophytes, as these nets are stationary and do not have any heavy anchors.

## 11.8 Tourism

Tourism may have a direct effect on macrophyte communities in shallow waters (< 10 m). Different kinds of aquatic sports like wind- or kite-surfing as well as swimming cause footfalls and trampling damage to vegetation. Looking to the investigation area these activities are concentrated along the south coast of Fehmarn and in Orth Bight, where the main tourism centres are located. The same activities may be seen in the Rødsand area. Anchoring of boats can impact especially eelgrass beds if rhizomes are teared out of the sediment. Such unvegetated holes within the eelgrass stands results in high physical exposure of the surrounding shoots, that may lead to further instability of the eelgrass bed. Indirect impacts of tourism can be seen in an increase of eutrophication, if wastewater is not sewage-treated adequately.

## 11.9 Invasive Species

During the last 10-20 years different neophytes (invasive species: *Dasya baillouviana, Fucus evanescens* or *Gracilaria vermiculophylla)* have been be observed within the investigation area. Furthermore neophytic species (e. g. *Codium fragile* or *Sargassum muticum*) are known in Kattegat and Skagerrak (Buschbaum 2010). The species that can tolerate low salinity will also be spread into the Baltic Sea. Up to now these introduced species have their main distribution within highly anthropogenic influenced areas like harbours. At least for *Gracilaria vermiculophylla* high biomasses have already been observed recently within the Kiel Fjord (Weinberger et al. 2008). Replacement or disappearance of native species, caused by neophytes, has not been observed.

# 12 REFERENCES


Austin, AP (1960). Observations on the growth, fruiting and longevity of *Furcellaria fastigiata* (L.) Lamouroux. Hydrobiologia, 15, 193-207.

Berger, R, E Henriksson, L Kautsky and T Malm (2003). Effects of filamentous algae and deposited matter on the survival of *Fucus vesiculosus* L. germlings in the Baltic Sea. Aquatic Ecology, 37, 1-11.

Bird NL, Chen LCM & J MacLachlan (1979). Effects of Temperature, Light and Salinity on Growth in Culture of *Chondrus crispus*, *Furcellaria lumbricalis*, *Gracilaria tikvahiae* (Gigartinales, Rhodophyta), and *Fucus serratus* (Fucales, Phaeophyta). Botanica Marina, 22, 521-528

Blackburn, T.M, J.H Lawton, J.N. Perry (1992). A method of estimating the slope of the upper bounds of plots of body size and abundance in natural animal assemblages. Oikos, 65, 107-112

Blindow, I (2000). Distribution of Charophytes along the Swedish Coast in Relation to Salinity and Eutrophication. Internat. Rev. Hydrobiol., 85 (5–6), 707–717.

BLMP (2008). Makrophytobenthos-Untersuchungen auf marinen Substraten: Rahmenbeprobung im Sublitoral. ): Prüfverfahren SOP – Draftversion, 42 pp.

Blümel, C, A Domin, JC Krause, M Schubert, U Schiewer and H Schubert (2002). Der historische Makrophytenbewuchs der inneren Gewässer der deutschen Ostseeküste. Sind historische Daten zur Bestimmung der typspezifischen ökologischen Referenzbedingungen gemäß den Vorgaben der Wasserrahmenrichtlinie der Europäischen Gemeinschaft geeignet? Rostocker Meeresbiologische Beiträge, 10, 5-111.

Boaden, PJS, RJ O'Connor & Seed R (1975). The composition and zonation of a *Fucus serratus* community in Strangford Lough, Co. Down. Journal of Experimental Marine Biology and Ecology, 17, 111-136.

Bock, GM (2003). Quantifizierung und Lokalisation der entnommenen Hartsubstrate vor der Ostseeküste Schleswig-Holsteins. Eine historische Aufarbeitung der Steinfischerei. Studie im Auftrag des LANU, 52 pp.

Borum, J (1985). Development of epiphytic communities on eelgrass (*Zostera marina*) along a nutrient gradient in a Danish estuary. Marine Biology, 87, 211-218.

Borum, J., O. Pedersen, T.M. Greve, T.A. Frankovich, J.C. Zieman, J.W. Fourqurean and C. Madden. (2005). The potential role of plant oxygen and sulfide dynamics for die-off events of the tropical seagrass, *Thalassia testudinum*, in Florida Bay. Journal of Ecology, 93, 148-158

Braun-Blanquet, J (1951). Pflanzensoziologie. Grundzüge der Vegetations-kunde. 2. Aufl. Springer Verlag, Wien, 631 pp.

Bray, JR and JT Curtis (1957). An ordination of the upland forest communities of Southern Wisconsin, Ecological Monographs, 27, 325-349.

Breuer, G and Schramm, W (1988). Changes in macroalgal vegetation of Kiel bight (Western Baltic Sea) during the past 20 years. Kieler Meeresforschungen, Sonderh. 6, 241-255.

Buschbaum C & K Reise (2010) Neues Leben im Weltnaturerbe Wattenmeer. Globalisierung unter Wasser. Biologie in unserer Zeit, 40, 202-210

Chapman, MG and Underwood, AJ (1999). Ecological patterns in multivariate assemblages: information and interpretation of negative values in ANOSIM tests, Marine Ecology Progress Series, 180, 257-265.

COWI-Lahmeyer (1998). Fehmarn Belt Feasibility Study. Coast-to-coast Investigations of Environmental Impact. Benthic vegetation Baseline Investigation. Technical note, Phase 2.

Crothers, JH (1985). Dog-whelks: an introduction to the biology of *Nucella lapillus* (L.). Field Studies, 6, 291-360.

Dahl, K. and J. Carstensen (2008). Tools to assess conservation status on open water reefs in Nature-2000 habitats. National Environmental Research Institute , University of Aarhus. 25 pp. NERI technical report No. 663.

Dahl, K., Lundsteen, S. and Helmig, S.A. (2003). Stenrev – havbundens oaser. G.E.C. Gads Forlag, Copehagen, 98pp

De Vries, I., Philippart, C.J.M., DeGroodt, E.G., Van der Tol, M.W.M. (1996). Coastal eutrophication and marine vegetation: a model analysis. In Schramm, W., Nienhuis, P.H. (eds), Marine Benthic Vegetation: Recent Changes and the Effects of Eutrophication. Springer, Heidelberg, Berlin: 79–113.

Duarte, C.M. (1991) Seagrass depth limits. Aquatic Botany, 40, 363-377

EN ISO 14688-1 (2003). Benennung, Beschreibung und Klassifizierung von Boden. Deutsches Institut für Normung e.V., 15 pp.

Eriksson, B.K., Johansson, G. and Snoeijs, P. (1998). Long-term changes in the sublittoral zonation of brown algae in the southern Bothnian Sea. European Journal of Phycology, 33, 241-249

Eriksson, B.K., G. Johansson and P. Snoeijs (2002) Long-term changes in the macroalgal vegetation of the inner Gullmar fjord, Swedish Skagerrak coast. Journal of Phycology, 38, 284-296.

Eriksson, B.K. and G. Johansson (2005a). Sedimentation reduces recruitment success of Fucus vesiculosus (Phaeophyceae) in the Baltic Sea. European Journal of Phycology, 38, 217–222.

Eriksson, B.K. and G. Johansson (2005b). Effects of sedimentation on macroalgae: species-specific responses are related to reproductive traits. Oecologia, 143, 438-448

EUR 27 (2007). Interpretation Manual of European Union Habitats. European Commission DG Environment. Nature and Biodiversity. 142 pp.

FEHY (2013). Fehmarnbelt Fixed Link EIA. Marine Water Baseline. Volume I. Hydrography of the Fehmarnbelt. Report no. E1TR0057.

FEMA (2009). Urgent investigation. Benthic vegetation

FEMA (2013). Fehmarnbelt Fixed Link EIA. Fauna and Flora – Benthic Marine Biology. Volume III. Habitat Mapping of the Fehmarnbelt Area - Baseline. Report No. E2TR0020.

Ferrier, S, G. Watson, J. Pearce & M Drielsma (2002). Extended statistical approaches to modeling spatial pattern in biodiversity in northeast New South Wales. I. Species-level modeling. Biodiversity and Conservation, 11, 2275-2307.

Fonseca, MS, JC Zieman, GW Thayer and JS Fisher (1983). The role of current velocity in structuring eelgrass *(Zostera marina L.*) meadows, Estuarine, Coastal and Shelf Science, 17, 367-380.

Fürhaupter, K and Th. Meyer (2009). Handlungsanweisung zum Monitoring in den äußeren Küstengewässern der Ostsee nach den Vorgaben der EU-Wasserrahmenrichtlinie. Qualitätskomponente Makrophyten – BALCOSIS-Verfahren. MariLim GmbH, Abschlussbericht für das LLUR-SH, Flintbek und das LUNG-MV, Güstrow. (unpublished)

Fürhaupter, K, C Pehlke, H Wilken and Th. Meyer (2009). WRRL-Makrophytenmonitoring in den äußeren Küstengewässern Schleswig-Holsteins (2009). Abschlußbericht für das LLUR-SH, Flintbek (unpublished)

Fürhaupter, K, Wilken H. and Th. Meyer (2007). WRRL-Makrophyten-monitoring in den äußeren Küstengewässern Schleswig-Holsteins (2007). Abschlussbericht für das LLUR-SH, Flintbek (unpublished)

Fürhaupter, K, Wilken H. and Th. Meyer (2008a). WRRL-Makrophyten-monitoring in den äußeren Küstengewässern Schleswig-Holsteins (2008). Abschlussbericht für das LLUR-SH, Flintbek (unpublished)

Fürhaupter, K, Wilken, H. and T. Meyer (2008b). Kartierung mariner Pflanzenbestände im Flachwasser der Ostseeküste – Schwerpunkt *Fucus* und *Zostera*. Schriftenreihe LANU-SH – Gewässer, D22: 310 pp.

Gajewski, L.S and S. Uscinowicz (1993). Hydrologic and sdimentologic aspects of mining marine aggregate from Slupsk Bank (Baltic Sea). Mar. Geores. Geotech. 11: 229–244

GEUS Havbundstyper. Digital map of the seabed. www.geus.dk/departments/quaternary-marine-geol/gis/havbundstyper-dk.html

Haahtela I (1984). A hypothesis of the decline of the Bladder Wrack (*Fucus vesiculosus* L.) in SW Finland in 1975-1981. Limnologica, 15 (2), 345-350.

Hansen, J.P, Sagermann, J., Axemar, H. Wikström, S.A. (2008). Habitat preferences and distributions of macroinvertebrates in relation to plant habitat complexity on soft bottoms in the Baltic Sea. 43. European Marine Biology Symposium, Ponta Delgada, Azores

Hamann U and A Garniel (2002). Die Armleuchteralgen Schleswig-Holsteins – Rote Liste. Veröffentlichungen des Landesamtes für Natur und Umwelt des Landes Schleswig-Holstein.

HELCOM (1998). Red list of marine and coastal biotopes and biotope complexes of the Baltic Sea, Belt Sea and Kattegat. Baltic Sea Environment Proceedings No. 75.

HELCOM (1999). Guidelines for monitoring of phytobenthic plant and animal communities. Annex C-9 for HELCOM Combine program.

HELCOM (2007). HELCOM lists of threatened and/or declining species and biotopes/habitats in the Baltic Sea area. Baltic Sea Environment Proceedings No. 113.

HELCOM (2010). Ecosystem Health of the Baltic Sea 2003–2007: HELCOM InitialHolistic Assessment. Baltic Sea Environment Proceedings No. 122.

Hemminga, M.A. and C.M. Duarte (2000). Seagrass ecology. Cambridge University Press, Cambridge.

Hiscock K, A Jackson & D Lear (1999). Assessing seabed species and ecosystem sensitivities: existing approaches and development, October 1999 edition. Report to the Department of Environment, Transport and the Regions form the Marine Life Information Network (MarLIN), Marine Biological Association of the United Kingdom, Plymouth.

Hoffmann, C (1952). Über das Vorkommen und die Menge industriell verwertbarer Algen an der Ostküste Schleswig-Holsteins. Kieler Meeresforschungen, 9, 5-14.

Holmer, M. and Bondgaard, E.J (2001). Photosynthetic and growth response of eelgrass to low oxygen and high sulfide concentrations during hypoxic events. Aquatic Botany, 70, 29-38

Holtz, L (1892). Die Characeen Neu-Vorpommerns mit der Insel Rügen und der Insel Usedom. Mitteilungen des Naturwissenschaftlichen Vereins für Neuvorpommern und Rügen, 23, 99-156.

Holtz, L (1899). Die Characeen der Regierungsbezirke Stettin und Kröslin. Mitteilungen des Naturwissenschaftlichen Vereins für Neuvorpommern und Rügen, 31, 101-187.

Hoppe, E and Pankow, H (1968). Ein Beitrag zur Kenntnis der Vegetation der Boddengewässer südlich der Halbinsel Zingst und der Insel Bock (südliche Ostsee). Natur und Naturschutz Mecklenburg, 6, 139-151.

Hovel, K.A. and R.N. Lipcius (2001). Habitat fragmentation in a seagrass landscape: patch size and complexity control blue crab survival. Ecology, 82, 1814-1829.

Hovel, K.A. and R.N. Lipcius. (2002). Effects of seagrass habitat fragmentation on juvenile blue crab survival and abundance. Journal of Experimental Marine Biology and Ecology, 271, 75-98.

Hovel, K.A., Fonseca M.S., Meyer, D.L., Kenworthy W.J. and P.G. Whitfield (2002). Effects of seagrass landscape structure, structural complexity and hydrodynamic regime on macrofaunal densities in North Carolina seagrass beds. Marine Ecology Progress Series, 243, 11-24.

Hovel, K.A. (2003). Habitat fragmentation in marine landscapes: relative effects of seagrass cover and configuration on juvenile crab survival in California and North Carolina seagrass beds. Biological Conservation 110: 401-412

Hovel, K.A. and M.S. Fonseca (2005). Influence of seagrass landscape structure on the juvenile blue crab habitat-survival function. Marine Ecology Progress Series, 300, 179-191.

Johansson G & P Snoeijs (2002). Macroalgal photosynthetic responses to light in relation to thallus morphology and depth zonation. Marine Ecology Progress Series 244, 63-72.

Kangas, P, H Autio, G Haellfors, H Luther, A Niemi and H Salemaa (1982). A General Model of the Decline of *Fucus vesiculosus* at Tvaerminne, South Coast of Finland in 1977-81. Acta Botanica Fennica, 118, 1-27.

Kautsky H. (2007). Recovery of the Baltic Sea phytobenthic system - indications of long term change of environmental conditions. Baltic Sea Science Congress Rostock.

Kautsky, H., L. Kautsky, N. Kautsky, U. Kautsky and C. Lindblad (1992). Studies of the Fucus vesiculosus community in the Baltic Sea. Acta Phytogeogr. Suec 78, 33–48.

Kautsky, N., H. Kautsky, U. Kautsky and M. Waern (1986). Decreased depth penetration of *Fucus vesiculosus* (L.) since the 1940s indicates eutrophication of the Baltic Sea. Marine Ecology Progress Series, 28, 1-8.

Korneck D, M Schnittler and Vollmer (1996). Rote Liste der Farn- und Blütenpflanzen (Pteridophyta et Spermatophyta) Deutschlands. Schriftenreihe für Vegetations-kunde 28, 21-187.

Kotta, J. and J.D. Witman (2009). Regional-scale patterns. In M. Wahl (ed): Marine Hard Bottom Communities. Ecological Studies, 206, p 89-99

Krause-Jensen, D, O H Manscher, J S Laursen, A L Middelboe and M Stjernholm (2004). Teknisk anvisning for marin overvågning. 3.1 Bundvegetation m.v. NOVANA. Danmarks Miljøundersøgelser. Teknisk anvisning fra DMU's Marine Fagdatacenter. 47 pp

Krause-Jensen, D, MF Pedersen and C Jensen (2003). Regulation of Eelgrass *(Zostera marina*) cover along depth gradients in Danish coastal waters, Estuaries, 26, 866-877.

Krause-Jensen, D. and B. Rasmussen (2009). Historisk udbredelse af ålegræs i danske kystområder. Danmarks Miiljøundersøgelser, Aarhus Universitet. 38 s. Faglig Rapport fra DMU nr. 755.

Krause–Jensen, D., Middelboe, A.L., Sand–Jensen, K. and P.B. Christensen (2000). Eelgrass, Zostera marina, growth along depth gradients: upper boundaries of the variation as a powerful predictive tool. Oikos, 91, 233–244.

Lüning, K (1985). Meeresbotanik. Verbreitung, Ökophysiologie und Nutzung der marinen Makroalgen. Thieme Verlag Stuttgart, 375 pp.

Lüthje H (1978). The macrobenthos in the red algal zone of Kiel Bay (Western Baltic). Kieler Meeresforschungen, Sonderheft 4, 108-114.

Mann, K.H. (1973). Seaweeds: their productivity and strategy for growth. Science, 182, 975-981.

Markager, S. and K. Sand-Jensen (1992). Light requirements and depth zonation of marine macroalgae. Marine Ecology Progress Series, 88, 83-92.

Merck, T and H von Nordheim (1996). Rote Listen und Artenlisten der Tiere und Pflanzen des deutschen Meeres- und Küstenbereichs der Ostsee. Schriftenreihe für Landschaftspflege und Naturschutz, 48. Bundesamt für Naturschutz (BfN): Bonn, Germany. ISBN 3-89624-104-4. 108 pp.

Meyer Th., Reincke, T., Wilken H., Fürhaupter K., Krause, S. und A. Linke (2005). Historische Kartierungen mehrjähriger mariner Pflanzen der schleswig-holsteinischen Ostseeküste. Abschlussbericht für das LLUR-SH, Flintbek. (unpublished)

Meyer, Th. (2004). FFH-Vorprüfung und Eingriffsbewertung der Kabel-einspülung des Baltic Cable. Bericht für die Baltic Cable AP: 50 pp.

Middelboe, A.L. and T. Binzer (2007). Importance of canopy structure on photosynthesis in single- and multi-species assemblages of marine macroalgae. Oikos, 107, 422-432

Middelboe, A.L., K. Sand-Jensen and K. Brodersen (1997). Patterns pf macroalgal distribution in the Kattegat-Baltic region. Phycologia, 36, 208-219

Miljøministeriet (2011). Vandplan 2010-2015. Østersøen. Hovedvandsopland 2.6. Vanddistrikt: Sjælland. Miljøministeriet, Naturstyrelsen. 282 pp

Nielsen, S.L., K. Sand-Jensen, J. Borum and O. Geertz-Hansen (2002). Depth colonisation of eelgrass (*Zostera marina*) and macroalgae as determined by water transparency in Danish coastal waters. Estuaries and Coasts, 25, 1025-1032

Norkko A., Bonsdorff, E. (1996). Rapid zoobenthic community response to accumulations of drifting algae. Mar Ecol Prog Ser 131: 143–157.

Olesen, B. and K. Sand-Jensen (1994). Biomass-density patterns in the temperate seagrass *Zostera marina*, Marine Ecology Progress Series, 101, 283-291.

Olesen, B, S Enriquez, CM Duarte and K Sand-Jensen (2002). Depth-acclimation of photosynthesis, morphology and demography of Posidonia oceanica and Cymodoscea nodosa in the Spanish Mediterranean Sea, Marine Ecology Progress Series, 236, 89-97.

Pehlke, C, U Selig and H Schubert (2008). Distribution and ecophysiology of bladder wrack (*Fucus vesiculosus*) in the Mecklenburg Bight (southern Baltic Sea). Rostocker Meeresbiologische Beiträge, 20, 123-143

Reimers H-C (2010). Sea Bottom Sediment Map of the Western Baltic, State Agency for Agriculture, Environment and Rural Areas Schleswig-Holstein; based on Hermansen & Jensen (2000): Digital Sea Bottom Sediment Map around Denmark and data of the Federal Maritime and Hydrographic Agency, Germany (BSH) and the Christian-Albrechts-University of Kiel; compiled by A. Sekinger (2002).

Reinke, J (1889). Algenflora der westlichen Ostsee deutschen Antheils. Eine systematisch-pflanzengeographische Studie. Schmidt & Klaunig, Kiel. 101 pp.

Rönnberg, O. and L. Mathiesen (1998). Long-term changes in the marine macroalgae of Långskär, Åland Sea (N Baltic). Nordic Journal of Botany, 18, 379-384.

Rosenberg, R. (1985). Eutrophication – the future marine coastal nuisance? Mar Poll Bull, 16, 227–231.

Schiel, D.R. (2009). Multiple stressors and disturbances: When changes is not in the nature of things. In M. Wahl (ed): Marine Hard Bottom Communities. Ecological Studies 206, p 281-295.

Schiel, D.R., S.A. Wood, R.A. Dunmore and D.I. Taylor (2006). Sediment on rocky intertidal reefs: effects on early post-settlement stages of habitat-forming seaweeds. Journal of Experimental Marine Biology and Ecology, 331, 158-172.

Schmidt, D, K van de Weyer, W Krause, L Kies, A Garniel, U Geissler, A Gutowski, R Samietz, W Schütz, HCh Vahle, M Vöge, P Wolff and A Melzer (1996). Rote Liste der Armleuchteralgen (Charophyceae) Deutschlands. Schriftenreihe für Vegetationskunde 28, 547-576.

Schories D, R Kuhlenkamp, H Schubert and U Selig (2010). Rote Liste und Gesamtartenliste der marinen Makroalgen (Chlorophyta, Phaeophyceae et Rhodophyta) Deutschlands (Vorabversion vom Juni 2010).

Schories, D, C Pehlke and U Selig (2008). Depth distributions of *Fucus vesiculosus* L. and *Zostera marina* L. as classification parameters for implementing the European Water Framework Directive on the German Baltic coast. Ecological Indicators, 9, 670-680.

Schramm W and H Vogt (1988) Eutrophierung der Nord- und Ostsee (UBA-Projekt). Unpublished data and maps.

Schramm, W. (1999). Factors influencing seaweed responses to eutrophication: some results from EU-project EUMAC. Schmidt & Klaunig, Kiel. 101 pp. Journal of Applied Phycology 11, 69-78.

Schubert H, C Bluemel, A Eggert, T Rieling, M Schubert and U Selig (2003). Entwicklung von leitbildorientierten Bewertungsgrundlagen für innere Küstengewässer der deutschen Ostseeküste nach der EU-WRRL. Forschungsbericht zum BMBF Projekt ELBO. Förderkennzeichen 0330014: 1-109.

Schwenke H (1966). Untersuchungen zur marinen Vegetationskunde. - I. Über den Aufbau der marinen Benthosvegetation im Westteil der Kieler Bucht (westliche Ostsee). Kieler Meeresforschungen, 22, 163-170.

Schwenke H (1969). Meeresbotanische Untersuchungen in der westlichen Ostsee als Beitrag zu einer marinen Vegetationskunde. Internationale Revue der gesamten Hydrobiologie, 54, 35-94

Schwenke H (1964). Vegetation u. Vegetationsbedingungen in der westl. Ostsee (Kieler Bucht), Kieler Meeresforschungen, 20, 157-168.

Seaby R and P Henderson (2007). Community Analysis Package 4.0 - Searching for structure in community data. PISCES Conservation Ltd., Lymington, UK. 155 pp.

Selig, U, A Eggert, D Schories, M Schubert, C Blümel and H Schubert (2007). Ecological classification of macroalgae and angiosperm communities of inner coastal waters in the Southern Baltic Sea. Ecological Indicators, 7, 665-678.

Sommer, U (1998). Biologische Meereskunde.Springer-Verlag Berlin Heidelberg, 475 pp.

Torn K, D Krause-Jensen and G Martin (2006). Present and past depth distribution of bladderwarck (*Fucus vesiculosus*) in the Baltic Sea. Aquatic Botany 84 (1), 53-62.

Tyler-Walters, H (2005). *Zostera noltii*. Dwarf eelgrass. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [online]. Plymouth: Marine Biological Association of the United Kingdom. [cited 14/04/2010]. Available from: http://www.marlin.ac.uk/ speciesimportance.php?speciesID=4601.

Wallentinus, I (1979). Environmental influences on benthic macrovegetation in the Trosa – Askö area, northern Baltic Proper. II. The ecology of macroalgae and submerged phanerogams. Contrib. Askö Lab. 25, 210 pp.

Wallentinus, I (1984). Comparisons of nutrient uptake rates for Baltic macroalgae with different thallus morphologies. Mar. Biol., 80, 215–225.

Ward, L.G., Kemp, M. and Borum, J. (1984). The influence of waves and seagrass communities on suspended particulates in an estuarine embayment. Marine Geology, 59, 85-103.

Weinberger F, Buchholz B, Karez R & M Wahl (2008). The invasive red alga *Gracilaria vermiculophylla* in the Baltic Sea: adaptation to brackish water may compensate for light limitation. Aquatic Botany, 3, 251-264.

Wicks, C.E., Koch, E.W., O'Neil, K. Elliston (2009). Effects of sediment organic content and hydrodynamic conditions on the growth and distribution of *Zostera marina*. Marine Ecology Progress Series, 378, 71-80.

Williams GA & R Seed (1992). Interactions between macrofaunal epiphytes and their host algae. In John DM, Hawkins SJ, Price JH, (eds): Plant-Animal

Interactions in the Marine Benthos. Systematics Association Special Volume 46, GB-Oxford: Clarendon Press, 189-211.

Wood SN (2006). Generalized Additive Models: An Introduction with R. Chapman and Hall, London.

Zuur AF, Ieno EN, Walker NJ, Saveliev AA & Smith GM (2009). Mixed effect models and extensions in ecology. Springer, New York.

## Table of figures

## List of tables